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National Rivers Authority

(South Western Region)

South Crofty Minewater Study

Final Report

Knight Piésold
CONSULTING ENGINEERS

NATIONAL RIVERS AUTHORITY
SOUTH WESTERN REGION

SOUTH CROFTY MINEWATER STUDY
FINAL REPORT

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1. INTRODUCTION

The South Crofty mine is the last operational underground mine in Cornwall. The current mine is worked and dewatered to a depth of some 900 m below ground surface. In the event of closure of the mine, dewatering will cease and water levels will rise within the existing workings. Concern has been expressed that a pollution incident, similar to that arising from the outflow from Wheal Jane, might occur when the rising water reaches natural discharge level.

Therefore, in January 1994, NRA South West (NRA), commissioned Knight Piésold & Partners (KPP) to undertake a study to assess the consequences of mine closure and abandonment. The study was to include four main elements:

- assessment of the existing operations with respect to mine workings, surface and groundwater hydrology and water quality;
- predictions of the impact of mine closure on water levels, water quality and the environment;
- recommendations for monitoring prior to and following closure;
- provision of preventive and remediation measures for use in the event of mine closure.

Preliminary results were presented in an interim report in May 1994. Further studies have since been undertaken, including an adit survey and rock sampling for acid producing potential. This report summarises the findings and proposes recommendations for monitoring and for remedial work should mine closure occur.

2.0 CURRENT MINE OPERATION

An assessment of the existing mine operation has been undertaken from data supplied by the NRA, South Crofty plc (SC) (formerly Carnon Consolidated Limited) and from other sources. This data has been supplemented by site visits, local monitoring, the installation of additional adit flow gauging stations, and observation of conditions within the mine and adits.

The South Crofty mine is currently dewatered at an average rate of 6500 m^3/d to enable mining operations to be carried out to a depth of some 900 m. The area of dewatering at depth extends to approximately 3 km^2, and is surrounded by adjacent flooded mines.

Under current operating conditions it has been estimated that inflow to the mine is derived mainly from adjacent flooded workings (60%) and from the local catchment (40%). Additional infiltration is intercepted by adits which discharge to the Red River and Portreath stream.

Water quality has been monitored in the rivers, adits and mine and indicates average metal loadings of between 1 and 5 mg/l. In places the river Environmental Quality Standard (EQS) is currently exceeded for copper, iron, zinc, cadmium and lead. A significant contribution of these metals is derived from the Dolcoath adit and pumped mine discharge, but there are also indications of other sources of contamination within the river catchment.

3. EFFECT OF MINE CLOSURE

Once the mine pumps cease operation water levels will rise until they reach the lowest adit level. The Dolcoath adit, at 60 m below ground level, is the lowest known outlet and mine discharge will start to flow into the Red River from this adit once the void space has been saturated. It is estimated that the quantity of discharge will not be significantly greater than the current discharge to the Red River from the mine and therefore there will not be a significant impact on flow magnitudes. However the point of discharge will be further downstream than at present.

Should the Dolcoath adit be or become blocked during mine refilling then discharge could occur from a higher level adit (30 m bgl) namely the Barncoose adit, and discharge would take place into the Portreath Stream at Tolskithy. The functioning and state of repair of the adits is thus fundamental to the continued free drainage of the upper sections of the mine workings both during recovery and in the long term. Recommendations have thus been made to ensure that they are, as practicable, inspected and kept in good repair.

The quality of the water discharging from the mine following recovery of water levels has been tentatively predicted. The results of acid producing tests on samples from the Dolcoath adit indicated that there is the *potential* for acid generation in the upper levels of the mine. The extent to which acid mine drainage would be formed cannot be predicted however, but, taking into account the lower percentage of sulphides at South Crofty, it is unlikely to be at anything like the scale experienced at Wheal Jane.

Mixing models and a range of possible metal concentrations have been used to predict the quality of the discharge water and hence the Red River water. The quality of the resulting flow could be similar to that currently in the Red River or, if acidic conditions form, the level of metal concentration would increase. More data are required before the potential impact of discharge into the Portreath stream, should the Dolcoath adit become blocked, can be predicted.

The study has reviewed areas of a potentially sensitive nature in order to assess the likely impact of mine closure and dewatering. The sites studied included licensed abstractions, waste disposal sites, conservation areas and the aquatic ecology. The study indicated that the impact of rising water levels on these sites cannot be predicted with any accuracy but the likelihood of a significant effect is considered to be small.

4.0 MONITORING

On the basis of the study results, recommendations for continued monitoring of water levels, quality and flows in and around the mine have been made. Such monitoring will provide more detailed information on the present inflow regime, baseline information prior to closure, and enable changes in groundwater levels and quality following closure to be observed.

The operation of the Dolcoath and Barncoose adits is considered central to existing and future drainage and therefore weirs and data loggers have been installed at the portals to provide continuous baseline data. In addition a full survey of the adits has been undertaken. The results are included as an Appendix and describe the adit system, its condition and capacity. Although further work has been recommended by SC to reduce inflow to the mine workings, these works are unlikely to be necessary in the event of closure. A continuing programme of adit inspection and maintenance has however been recommended.

In the event of mine closure and cessation of pumping it is recommended that the recovering water level is monitored and that an increased frequency of water quality sampling is started which includes samples from within the mine.

Estimates for the time taken for the mine to flood have been made, based on a steady state flow balance approach and estimates of mine voidage from mining records and tonnage of ore extracted. A time of 2 to 3 years has been calculated which would give ample time for monitoring and for remedial action to be taken.

5.0 PREVENTIVE AND REMEDIAL MEASURES

The discharge of mine water into the Red River will occur naturally via the adits in the event of closure of South Crofty. It has therefore been recommended that the silt be removed from the adits post-closure to prevent its discharge into the Red River.

If the minewater quality is found to deteriorate during flooding then treatment may be necessary before discharge to the Red River is acceptable. Treatment options include pumping followed by lime dosing, flocculation and sludge disposal, or gravity drainage via the Dolcoath adit followed by passive treatment using a wetland. Although preliminary cost estimates have been made, these should be treated with caution since the final costs will depend upon the water quality and scale of treatment required.

It is considered prudent to prepare a contingency plan defining the procedures to be instigated in the case that South Crofty is to close, thus enabling mitigating measures to be properly planned and implemented.

6.0 CONCLUSIONS

The South Crofty mine water study has indicated that if the mine were to close, a major environmental incident on the scale of Wheal Jane is unlikely. The potential for the formation of acid main drainage has however been identified in the upper levels. It will therefore be imperative, if the mine closes, to closely monitor the recovering mine water level and quality. There will then be time to design an appropriate treatment system, if this proves necessary, so that any potentially adverse impacts may be averted.

1. INTRODUCTION

The South Crofty mine is located in the Camborne-Redruth mining district of Cornwall, where extensive mine workings in the vicinity of the current operation date from the 18th Century. South Crofty itself has been in operation for some ninety years and is the last remaining underground metalliferous mine in Cornwall. It is currently operated by South Crofty plc (formerly Carnon Consolidated Ltd) (SC).

Following the closure of Wheal Jane and the much publicised discharge of metal-rich acidic mine drainage, concerns have been expressed regarding the potential impacts of the closure of South Crofty. Accordingly, in January 1994, the National Rivers Authority (NRA) commissioned Knight Piésold and Partners (KPP) to undertake an evaluation of the potential environmental effects of mine closure and in particular to address the consequences of cessation of dewatering and water level recovery.

Initial visits were made to both SC at South Crofty and to the NRA at Exeter to identify the available data and establish an appropriate methodology for the study, which was subsequently agreed with the NRA. Preliminary information on mine workings and dewatering, together with a description of the adit system, were provided by SC. The data available from the NRA included details of local hydrology, meteorology, land use maps and the results of chemical and biological water quality monitoring.

In May 1994 an interim report (Ref. 1) was submitted which contained the findings of the data evaluation. It was prepared in fulfilment of the NRA brief and summarised the studies undertaken, including the data collection and analysis, appraisal of the current operations with respect to geology, hydrology and water quality, and a description of the predictive methods used to evaluate the impact of mine closure. Further work was recommended, including a detailed survey of the adit system at South Crofty and preliminary analysis of rock samples to assess their acid producing potential.

This final report completes the minewater study and includes a summary of the earlier findings together with the results of the additional work and their implications. Recommendations are made for monitoring and for remedial action in the event that operations at South Crofty cease and deterioration of the mine drainage occurs. Preliminary cost estimates have been prepared for a range of pollution control measures which may have to be considered.

2. THE SOUTH CROFTY MINE

2.1 Location

The South Crofty mine site lies between the towns of Camborne and Redruth to the east of the Red River (see Fig. 1). The underground workings extend to approximately 3 km in length trending east north-east and are slightly less than 1 km in width (see Fig. 2).

2.2 Mining History

Previous mining activity in this area is extensive and has been continuous over the last two centuries. During the 19th Century, operations at South Crofty consisted primarily of small scale working of copper ore in the upper levels. The current mining operation has developed over the last ninety years with the extension of the workings to exploit the deeper deposits of tin ore (Ref. 2). The mineral rights to adjacent areas have also been acquired by South Crofty in order to supplement ore reserves, resulting in the mine having a greater plan area at depth than at surface. All neighbouring mining operations have now been closed and as a result the present dewatered mine lies adjacent to, and in some places beneath, the flooded workings of other mines.

2.3 Geology

The geology of the area around the South Crofty mine comprises sedimentary Devonian country rocks intruded by granite of Permo-Carboniferous age resulting in regional metamorphism and mineralisation (Ref. 3). The areal distribution of the geological units in relation to the mine location is shown in Fig. 3.

The country rock, locally known as killas, comprises the Upper Devonian Mylor Beds, the lithology of which is shales and siltstones with rare sandstones. These strata have been folded and faulted by tectonic movements and the intrusion of the granite which has also led to low grade and localised metamorphism within the aureole. The killas sediments also contain local volcanic units, lavas, tuffs and dykes, collectively known as the Greenstones.

The granites form part of the Cornubian Batholith which extends from Land's End to Dartmoor and which outcrops locally at Carn Brea and at Carnmenellis to the south of the mine. The Carn Brea granite, of interest to this study, outcrops a few hundred metres to the south of the South Crofty surface workings. The surface workings and upper sections of the main shaft lie on the killas, the granite contact dipping north under the killas at about 35° in this location.

As the granite masses cooled after intrusion, hot fluids containing metals in solution escaped under pressure and flowed through fissures and joints in the granite and surrounding killas. Ore minerals were deposited in these pathways as the hydrothermal fluids cooled leading to the formation of the ore bearing rocks of economic importance.

Cassiterite (tin oxide) is the dominant mineralisation with depth, the proportion of sulphides reducing to less than 1% of the ore mass. Towards the surface the dominant mineralisation is copper rich with a higher proportion of sulphide minerals including chalcopyrite. Historically, copper ore was produced in greatest tonnages together with tin, arsenic, tungsten and pyrite. The current production is primarily tin.

The mineral lodes trend generally east north-east and dip sub-vertically at about 60-70 degrees. They are complex and discontinuous but can persist for more than 2 km on strike and up to 600 m dip height with a thickness of 1-2 m. More than thirty mineral bearing structures have been exploited at South Crofty with the most productive being No. 4 lode. Cutting the lodes at right angles are the N-S trending crosscourses which are infilled wrench faults and geologically younger than the lodes. The crosscourses are commonly barren or clay filled with only occasional ore mineralisation. The Great Crosscourse is a major fault/zone of weakness which extends south to north across the mine and marks its historical boundary. The surface expression of the Great Crosscourse at the mine site is the valley of the Red River.

2.4 Mine Operation

The South Crofty mine is currently working at a maximum depth of 470 fathoms (860 m), exploiting tin ore from lodes wholly within the granite. Figs. 4 and 5 show the layout of the workings and the relationship between South Crofty and the surrounding flooded mines. The level in the mine is identified by its depth in fathoms below adit level and named levels are located every 20 to 30 fathoms on average. The mine currently produces ore at depths between the 225 and the 470 fathom levels and in widely dispersed locations underground. Mining methods used depend on the geometry, rock strength and mineral content of the lode structures. The ore extracted is hoisted to surface via New Cooks Kitchen shaft, one of two main operating shafts on the site. The ore is crushed on site and transported to

Wheal Jane for processing into tin concentrate. The current operations extract some 190,000 tonnes per year for processing of which 170,000 tonnes per year of waste products are deposited in the Clemows Valley Tailings Dam.

For operational and safety reasons the workings are maintained dry by the dewatering system comprising pumps located at 420, 380, 340 and 195 fathoms. Pumped water is discharged direct to the Red River at the mine site (NGR SW 663 407), mainly at night to reduce energy costs. Between 1989 and 1993 an average of 6500 cubic metres of water per day was pumped from the mine.

In addition, a mine drainage system based on shallow adits, located between 40 and 60 m below ground level, intercepts some of the surface infiltration from precipitation and discharges it direct to the local rivers. The main drainage adits are those of Dolcoath and Barncoose adits which are discussed more fully in Section 3.3, and in Appendix 4.

3. HYDROLOGY

The groundwater and surface water hydrology of South Crofty and its catchment are strongly influenced by mining and associated workings as discussed in the following sections.

3.1 Groundwater

Groundwater flow in and around South Crofty is dominated by conduits and voids created by mineworkings in both the killas and the granite, supplemented to a lesser degree by fracture flow in the killas. The primary permeability of the unweathered killas is very low but is enhanced by post depositional folding and fracturing at surface where it weathers to a more permeable rock mass. The unweathered granite at depth has a very low primary permeability and few fractures, so secondary permeability is also low.

The low primary permeabilities of the killas and granite ensure that there is little direct flow from the surrounding rocks into the South Crofty mine workings. Consequently, water inflow to the mine is derived primarily from the infiltration of precipitation and inflows from adjacent flooded mineworkings passing through intersections with older workings, both shafts and stopes, supplemented by fracture flow in the killas. The only water make emanating from the granite is minor flows of connate water through crosscourses intercepted by mining activity. The relative magnitude of each of the contributory flows is discussed in Section 4.1.

Regionally, the water table is some 15 m below the ground surface and the gradient generally reflects the local topography. However, in the vicinity of South Crofty, adits constructed since the 18th century have lowered the water table locally by about 40 m. Pumping at South Crofty has resulted in de-watering to around 860 m below adit level in the mine itself. The impact of the dewatering on the regional hydrogeology is discussed in Section 4.3.

3.2 Surface Water

South Crofty lies within the surface water catchments of the Red River and the Portreath stream as shown in Fig. 2. The Red River rises on the Carnmenellis granite outcrop to the south of South Crofty and flows across the workings northwards to the sea at Gwithian. Its catchment consists of heathland, urban areas and abandoned mining areas as well as a natural marsh area and farmland towards the sea. Prior to 1988, tailings from the South Crofty mill were discharged to the

Red River and although this practice has now ceased, the bed and banks of the river are, in places, composed entirely of tailings. It is assumed that for the most part of its length the deposition/erosion regime of the river was in relative equilibrium during the period of operation of the South Crofty mill. However since the cessation of tailings discharge into the river the regime has changed to one of erosion, primarily of the deposited tailings; the river channel has thus been reactivated.

Flow records for the Red River comprise measurements at two week intervals at Gwithian (NGR SW 5852 4207) since 1980 and are shown in the hydrograph Fig. 6. Average flow in the river from 1980 to 1993 was 87,000 m^3/d with a minimum of 15,500 m^3/d and a maximum 360,000 m^3/d. There are a number of small contributing tributaries but the major discharges to the river are the Dolcoath adit flow from the portal at Roscroggan (see Fig. 7), where spot flow measurements ranging from 4,000 to 11,000 m^3/d have been recorded by SC, and the pumped discharge at the mine site where, between 1989 and 1994, an average flow of 6,500 m^3/d was discharged, mainly at night.

The Portreath stream to the east of South Crofty flows south to north from Carn Brea and receives water from the Barncoose adit (see Fig. 7). The stream rises on the granite and flows to the sea at Portreath. Like the Red River this watercourse runs through areas of old mineworkings and extensive tailings deposits. There are no flow records but site observation indicated flow volumes of approximately one tenth of the Red River discharge in February 1994.

3.3 Adit Drainage

The adits were constructed to assist with drainage from the upper levels of the mine workings. The majority were driven on crosscourses or main tin-bearing or caunter lodes which serve as preferential flow paths through which surface water infiltrates. This water could then be intercepted by the adits and diverted away from underlying mineworkings. The adits continue to remove significant volumes of water and hold water levels in the vicinity at adit level, between 30 and 60 m below ground level.

Gravity drainage from near surface at South Crofty is accomplished by an adit system with three main elements (see Fig. 7), the Deep adit comprising Dolcoath Deep and Penhale adits, the Shallow (Pool) adit, and the Barncoose adit. SC make inspection visits to the adits and undertake maintenance and repair work as necessary. A visit to the adits was made by KPP and SC in February 1994 and May 1994. A report was produced by SC in June 1994 (Ref. 4) describing the adit system, its condition and capacity, and proposing recommendations for maintenance work to minimise flow into the workings. The following comments are based on observations and the SC report, which is reproduced in full in Appendix 4.

3.3.1 Dolcoath Deep and Penhale Adits

These two adits comprise the deep adit system which drains South Crofty and the flooded mines to the west and north west. The adit is shown diagrammatically in Fig. 7 and in detail in Fig. 6 and Fig. 11 of Appendix 4 (Fig. A4.6 and Fig. A4.11). The section of the deep adit which is on the South Crofty property is known as the Penhale adit. This extends for approximately 1 km from east to west then connects via a drive through the Great Crosscourse to the Dolcoath Deep adit. The Dolcoath Deep adit extends to the portal on the Red River at Roscroggan (NGR SW 648 418) and is joined throughout by branches from the abandoned mines to the west of the Red River. The system beyond the South Crofty mine is approximately 3 km in length, giving a total length of 4 km.

The condition of the adit is described in Appendix 4, and summarised in Fig. A4.7. It is in generally good condition although at the eastern end where it crosses the South Crofty mine, leakage occurs and water infiltrates to the mine below. SC have made recommendations for repair of the adit at specific locations to reduce inflow to the mine. This work would bring benefits by reducing pumping costs during current mine operations. The closure of the mine would result in cessation of pumping and leakage would no longer be an issue; repair of these sections would therefore be unnecessary.

The sections of the adit which could have an impact post closure are where the roof is in danger of collapse, potentially resulting in adit blockage. No such sections were located during the adit survey, but regular inspection would be required to confirm the integrity of the roof.

Areas of siltation were also identified, particularly along sections where flows of less than 400 m^3/d have been recorded. If flows increase following mine closure, the silt could be washed into the Red River. It would therefore be appropriate to remove the silt in advance of full mine water level recovery. This process would be relatively straightforward given current access to the workings.

Flow measurements taken in the Dolcoath and Penhale adits by mine staff are shown in Fig. A4.8. These indicate that the majority of the flow in the Deep adit is made on the western side of the Great Crosscourse, and is derived from old flooded workings. A flow of less than 500 m^3/d has been recorded in the South Crofty property to the east of the Red River, and most of this is probably from the interconnection with the shallow adit at Phillip's shaft. Spot flow measurements from 1990 indicated that in summer the flow from the adit portal was about 4500 m^3/d while in winter it rose to 8500 - 11000 m^3/d (Ref. 5). A weir was installed at the Dolcoath adit portal at Roscroggan in March 1994. A logger was subsequently installed and flows are now being measured hourly, indicating a flow of some 7000 m^3/d during the summer of 1994. The details are included in Appendix 6.

The dimensions of the Deep adit range from a height of 2 m and width of 1.3 m to a height of 1.6 m and width of 0.5 m. The markings on the adit walls indicate that they are large enough to carry all the seasonal maximum flow at present although there are reports of water reaching the roof in the lower sections of the adit (Appendix 4) implying that at times, water flows under pressure along some lengths of the adit.

3.3.2 Shallow/Pool Adit

The Shallow or Pool adit was constructed between 1710-1730, the main section being approximately 1 km long with branches increasing the total length by another 1.5 km as shown in Fig. A4.3 and Fig. A4.10. The shallow adit extends from South Crofty in the east and used to discharge westwards to the portal in the Red River valley below Tuckingmill (NGR SW 658 415). The entire adit flows over the area dewatered by South Crofty as shown on Fig. 7.

The western section is now blocked and, until recently, the majority of water from the shallow adit drained into South Crofty's deep workings via the Burgess winze. In April 1994 this was stopped by the construction of a 1 m high concrete dam and water is now pumped down Phillips shaft into the Deep adit.

There is a potential connection between the shallow and deep adit where they intercept Phillip's shaft and Palmer's shaft. The shallow adit is however at approximately 40 m bgl, 20 m higher than the deep adit.

The shallow adit follows a tortuous route along much of its length and in places is no more than 1.4 m high. The back and walls were reported to be in poor condition along several sections although water can flow without serious interruption. Areas of silt have also been identified as shown in Fig. A4.3. Much of this can be attributed to the presence of radon doors which effectively block the adit except for two small pipes at their base. The locations of the radon doors are shown in Fig. A4.4.

The discharge through the Shallow Adit has been measured on several occasions by SC and is shown on Fig. A4.5. The flow is about 150-200 m^3/d during the summer with high water marks on the walls indicating a past flow of up to 4000 m^3/d. It is thought that this high flow probably occurred when the shallow adit was functioning more efficiently, possibly before the radon doors were installed.

3.3.3 Barncoose Adit

Mine workings to the east of South Crofty are drained by the Barncoose adit which runs south to north from Carn Brea to the portal at Tolskithy on the Portreath stream (NGR SW 681 424), at a depth of about 30 m bgl. This adit collects infiltrating surface water and flow from the surrounding abandoned, flooded mines, but does not pass over the dewatered South Crofty workings, as indicated in Fig. 7. It is however thought that some flow drains from the Barncoose and Wheal Fortune flooded mines to the west of the Barncoose adit into the South Crofty workings. The Barncoose adit, which has a total length of approximately 2.5 km, is shown in detail in Fig. A4.1 and Fig. A4.9.

The central north-south section of the adit is in generally good condition, passing through sections ranging in age from 17th century to recent times. The dimensions vary from 2 m by 1.2 m wide to 1.3 m by 0.6 m wide. At Barncoose Engine Shaft, flow is constricted by a 0.2 m diameter pipe. The east-west sections of the adit which are constructed on lode are in poor condition as summarised on Fig. A4.2 and are allowing water to pass into the South Crofty workings, adding to the cost of pumping.

In 1930 and 1950 blockages in the Dolcoath Deep system caused water levels to rise and water to drain eastward towards and out of the Barncoose adit via old mine workings. Therefore, although the Barncoose adit is not part of South Crofty, it acts as an important safety valve and is considered an integral part of the adit system which drains the workings at South Crofty.

A weir and logger arrangement was installed in the Barncoose adit at the Tolskithy portal in March 1994 to monitor the discharge as described and illustrated in Appendix 6 and Fig. A6.1. The range of flows from March 1994 to the end of June 1994 are shown in Fig. A6.2. The maximum recorded flow was approximately 3500 m^3/d in April, falling to some 1500 m^3/d in May and June 1994. Rainfall for March and April, measured at Trevince, is also shown in Fig. A6.2. Although the record is short it illustrates that a lagged relationship could exist between rainfall and adit flow. A more detailed interpretation will be possible as more data are collected.

In summary neither the deep nor the shallow adit systems function efficiently at present in intercepting surface waters on the original South Crofty property. Water leaks from the adits in many places and flows through old flooded workings into the present mine workings eventually reporting to the pumps. However, the old mines to the west are well drained by the Dolcoath Deep adit while the Barncoose adit works well in intercepting water to the east and draining the flooded mines in that area.

4. MINE DEWATERING

The existing dewatering operations at South Crofty are assessed in the following sections. These include comments on mine inflows and outflows, the relationship of rainfall to pumped discharge, the regional impact of dewatering and estimates of the volume of dewatered void.

4.1 Mine Inflows

From an examination of the hydrogeology and hydrology of the mine and its environs, it was concluded that the inflow to the mine is derived mainly from three sources, as outlined below:

1) Infiltration of precipitation that is not intercepted by adits

   From surface, water enters the mine directly via shafts and old workings and indirectly via percolation through the soil and fissures in the killas and through lodes and crosscourses. It is then either intercepted by the adits or alternatively flows further into the mine workings. Where the adits are in good condition intercepted waters discharge into the surface water system. However, due to blockages and poor structural condition, water leaks from the adits in many places through abandoned workings and further discharge into the mine occurs.

2) Inflow from abandoned flooded mineworkings

   Water from abandoned flooded mines on the periphery of South Crofty flows through the many drives and workings which have been created during past mining activity. It is estimated that some 60% of the inflow to the present operations may be derived from this source (Ref. 5).

3) Natural groundwater from the granite

   Natural groundwater probably accounts for the smallest inflow to the mine. Hot saline fluids are encountered from below 300 m and isotope studies show them to be a mixture of magmatic and deep circulation meteoric waters. The very low permeability of the granite results in this water not flowing through the rock matrix but through isolated joints/fractures or through crosscourses in the granite, where these are intercepted by mining activity. Four brine sources have been identified and discharges from each are small, the estimate for a single source being about 50 m^3/d during the mine visit on 31/1/94. It has been estimated by SC that natural groundwater accounts for less than 10% of the inflow to the mine.

On the basis of this information it was assumed that the inflows to the mine can be separated into those which are head dependent and those which are not. Head dependent inflows which include those from the natural groundwater in the granite and from surrounding mines will reduce in magnitude as water levels in the mine rise. The rainfall dependent inflow should remain relatively constant as water levels recover. The implications of this for water level recovery are discussed in Section 7.1.

Without a full survey of the mine to identify all the pathways and sources of water it is difficult to directly measure all the inflows. Consequently, the possibility of calculating inflows by other methods was considered. Recharge estimates based on rainfall proved difficult to quantify due to uncertainty concerning the area of contributing precipitation. In addition, without a full gauging system at various points in the adits, it is difficult to separate the actual volume of recharge infiltrating from that intercepted by the adits.

A simplistic steady state approach has thus been adopted in which it has been assumed that total inflow is equal to total outflow and that there is no change in storage within the system (consistent with the current mine pumping regime).

4.2 Pumped Outflows

There are four pumping stations at South Crofty at 420, 380, 340 and 195 fathoms. Centrifugal pumps at each of these levels lift water to the level above in a staged programme, the 195 fathom installation discharging direct to surface.

Figures for pumped discharge are available for 1989-1993 (Appendix 2) and show that on average 6500 m^3/d was pumped out of the mine over that period with a maximum of 9500 m^3/d and a minimum of 5200 m^3/d. The pumped water is discharged to the Red River where it makes up some 7% of the average (1980-1993) river flow at Gwithian. Flows have not been measured in the Red River immediately upstream or downstream of the mine, but from a preliminary examination of relative catchment areas it has been deduced that pumped mine discharge contributes approximately one third of the flow in the Red River immediately downstream of the mine site.

The Dolcoath adit flow which discharges to the Red River downstream of the mine site contributes flow of similar magnitude to the mine discharge. The relative proportions of flow immediately downstream of the Dolcoath adit are therefore approximately 25% pumped mine discharge, 25% Dolcoath adit discharge and 50% Red River flow. These figures are based on the current rather sparse data and may therefore be revised as more information becomes available.

4.3 Relationship of Rainfall to Pumped Discharge

Having assumed that mine inflow is equal to pumped outflow, the relationship between rainfall and pumped outflow has been examined so that a relationship between rainfall and inflow could be established.

Inflow can be derived from pumping records which are available for the last five years and summarised in Appendix 2. Precipitation and actual evaporation values for the same time period were obtained from the Meteorological Office. As this is a fractured system a soil moisture budgeting method for calculating recharge is not considered suitable, so effective rainfall (rainfall minus actual evapotranspiration) has been taken as an indication of recharge (Ref. 7). Effective rainfall and pumped discharge are plotted against time in Fig. 9. The graph indicates that effective rainfall is highest during the winter while in summer the low rainfall and high evapotranspiration result in zero effective rainfall. The pumping rate shows a significant rise with high effective rainfall but with a lag of several months. This lag has been demonstrated in practice during a water tracing exercise undertaken by mine staff in which water flowing into the workings, via a shaft in the shallow adit, took three months to flow to the 335 fathom level in the South Crofty workings (Ref. 5).

The relationship so derived for rainfall and pumping rate has been used to estimate inflows in the future under average and maximum rainfall scenarios. Long term rainfall records are available for the Trevince Meteorological station near Truro. The maximum rainfall during the forty years record from 1952 to 1993 was 1632 mm, occurring in 1960. Annual rainfall of this magnitude has a return period of almost 100 years as indicated by the following table:

Return Period (years)	Annual Rainfall (mm)
2	1186.6
5	1339.0
10	1426.6
20	1503.3
50	1594.8
100	1658.9

The effective rainfall and outflow relationship for the last five years record was thus used to calculate the inflow that might be expected for a rainfall event of 1632 mm (Appendix 2). The inflow of water arising from such rainfall was estimated to be 9700 m^3/d, compared to an average inflow of some 6500 m^3/d for the average 1989 to 1993 rainfall of 1082 mm.

4.4 Regional Impact of Dewatering

The configuration of the dewatered mineworkings at South Crofty has been assessed and is indicated in Figs. 4 and 5 and in the map, Fig. 2. These show a narrow zone of dewatering through the killas with a wider zone of dry workings in the granite beneath. This is confirmed by water level measurements in adjacent mines which show flooded conditions to adit level (some 50 m below ground level) in comparison with a water level 860 m below adit level in South Crofty. In some places therefore the present workings in the granite have flooded workings in the killas above them which confirms low primary permeability of the strata and the dominant flow through mining related workings.

It is apparent, therefore, that the deep dewatering at South Crofty is confined to the mine itself. Further water level data would confirm this but access to shafts for water level measurements is not possible in most places since many shafts have recently been capped for safety reasons. Possibilities for further water level monitoring are included in the recommendations.

The localised impact of dewatering is attributable to the low permeability of the killas and granite, which can maintain a large head difference between flooded and dewatered workings. There is nevertheless some flow from flooded mines into South Crofty through the many interconnections via old stopes, drives and intercepted cross courses.

4.5 Dewatered Void

The volume of the mined out workings was calculated by two independent methods. The first used mine plans and sections to measure the mined out areas, and the second used the recorded total tonnage of ore extracted to derive void volume. A comparison of the two methods is given in the following sections.

4.5.1 Void Estimates from Mine Plans

Mine plans and cross sections have been used to quantify mining voids. For the levels below 225 fathoms, modern sections provided by SC (Ref. 8) show the reserves and present mined out area along each lode. Areas of workings measured from these sections (Appendix 3) have been converted to a void volume by assuming a constant width for the stopes.

The widths of the orebodies taken from the South Crofty Geological Resources document (Ref. 8) indicate that lodes vary between 1 m and 2.6 m. In order to calculate voidage (i.e the volume of rock that has been extracted rather than the size of the orebody) these dimensions must be converted to average stope widths. Inspection of typical stopes underground at South Crofty indicated that an average mining width of 2 m would be appropriate. To this, an allowance must be made for the volume of drives, declines and other development excavations. Similar calculations for the adjacent Highburrow and Dolcoath mines made allowance of 20% (Ref. 9).

For the levels above 225 fathoms the workings are older and sections are not available. After consultation with SC staff, the volume from 225 fathoms up to surface has been assumed to be roughly equivalent to the volume calculated for 225 fathoms to the bottom of the mine. Cross sections of the mine indicate a narrowing towards the upper levels which might suggest that this assumption is an overestimate. However mining activity in the upper elevations has been extensive over the last few hundred years and it is believed that such activity has produced a mined out void volume at least equal to the volume created below 225 fathoms.

The volume of mined out void backfilled with waste at South Crofty is less than 5% and has been ignored for the purposes of these calculations. The calculated volume of mined out workings is shown in Table 1. Full details are given in Appendix 3.

Assumed Stope Width	Volume of Worked Areas			
	225-470 level m^3	225-Adit Level m^3	Total Stope Volume m^3	Total Mined Volume m^3
2 m	1,752,283	1,752,283	3,504,283	4,205,479

Table 1 : Volume of Void from Mine Plans

4.5.2 Void Estimate From Production Tonnages

The mined out volume has also been calculated from records of the volume of ore hoisted which are calculated from both historical and current mine production figures. Historical production records for South Crofty are available from 1854 (Ref. 2). Ore tonnages for the relevant years are listed in Appendix 3.

Modern tonnages were obtained from recent mine records and from a Rio Tinto Zinc publication (Ref. 10). Where data is missing an average production rate has been assumed for the intervening production period (actual rates are listed in Appendix 3). A factor of 20% has been used to account for the volume of waste (Ref. 9).

Tonnage	1854-1905	557,518	
	1906-1958	4,056,122	
	1959-1969	1,020,408	
	1970-1984	2,856,120	
	1985-1993	1,547,046	
Total Tonnage 1854-1993		10,037,214	
Total Volume		3,623,543 m^3	(assuming density = 2.77)
Volume plus 20%		4,348,252 m^3	(to account for waste rock)

Table 2 : Volume of Void from Production Tonnages

The final production derived volume of 4.3 million m^3 compares well with the 4.2 million m^3 from measuring stope plans. The lower figure has thus been used in the subsequent water level recovery calculations and represents a worst case scenario.

It must be emphasised that these data provide only an approximate idea of the total voidage in the mine. Extensive mining over the last few hundred years and incomplete records mean that these void values could be an underestimate.

5. MINEWATER QUALITY

Water quality and hydrological data have been obtained from the NRA, SC and sources in the public domain for the Dolcoath adit and at a number of levels within the mine itself, as detailed in Appendix 1. Whilst information concerning the surface hydrology and chemistry is relatively extensive, data on the groundwater and minewaters of the area are less complete. SC have supplied results from sampling at the pumps in the South Crofty mine. To supplement the information obtained from the NRA and SC, it was necessary to consult various other sources. A BGS publication (Ref. 11) contains analyses of minewaters from South Crofty which are listed in Columns 1 and 2 of Table 3.

	Connate Water	Acid Water March 1984	Mine Discharge Feb 1993	195 fathom Pump Water	340 fathom Pump Water	380 fathom Pump Water
pH	6.65	3.9	7	5.4 (5.7)	5.6 (5.9)	5.4 (5.6)
HCO3-	60	18				
SO4	129	260				
Cl-	9280	2910				
F	3	8.3				
Br	35	11.4				
I	0.091	0.024				
Ca	1840	675				
Mg	55	47				
Na	3520	1020				
K	153	49				
Al		0.48				
Si	16	9.8				
Sr	30	9.7				
Ba	0.94	2.8				
Li	107	31				
B	13.9	3.9				
Fe	4.2	19.3	4.22	9.9 (4)	13.8 (6.8)	54.5 (18)
Mn	3.5	4				
TDS	15250	5080				
Ag	0.1	0.01				
As	0.033	0.13		0.2 (0.1)	0.1 (0.1)	0.1 (0.1)
Cd	0.025	0.025	0.05	0.001 (.001)	0.003 (.001)	0.001 (.001)
Co	0.02	0.041				
Cr	0.03	0.03				
Cu	0.008	0.008	0.13	0.39 (0.24)	0.23 (0.14)	0.34 (0.2)
Mo	0.1	0.1				
Ni	0.075	0.13				
U	0.00008					
W	0.15	0.15				
Zn	0.02	0.12	0.85	1.9 (1.2)	1.2 (0.8)	1.1 (0.7)

NB: All data, except pH, expressed as mg/l.
195, 340, 380 fathom pump values are mean summer and (winter) concentrations from 2 samples per month in 1993.

Table 3 : Water Quality Data from Mine

An evaluation of the available information confirms the presence of three distinct waters within the mine workings :

- Connate brines, which originate from within the granite and have been recorded as flowing into the deeper workings (see Section 4.1).

- Adit water, which comprises principally the "overflow" from adjacent flooded mine workings and the infiltration of precipitation which falls directly over its catchment.

- Pumped South Crofty discharge, which is a combination of connate brines (probably comprising <10% of the total), inflow from adjacent workings (probably comprising 60 - 70% of the total), leakage from the adit and direct infiltration not intercepted by the adit system.

In addition, a single record (column 2, Table 3) has been identified which indicates the presence of acidic minewater within the South Crofty workings (Ref. 11). However, the source of this data could not be verified and no other data sources support the presence of acidic minewaters. Nevertheless, this record cannot be totally discounted and it is included in the following discussion.

5.1 Connate Water

Saline waters of geological origin are recorded as issuing from the granite into the mine workings at depths of 300-800 m, usually where mining activity has intersected crosscourses in the granite. These structures intersect water bearing rocks of hydrothermal origin and connect them into the mine workings. The connate water exhibits temperatures of up to 50°C and has recorded total dissolved solids of up to 31,660 mg/l. The water may be observed discharging from the walls of the mine, but the quantity of flow (and by inference the driving head) has decreased during the life of the mine.

Trace concentrations of uranium resulting from radioactive decay within the granite have also been noted (Ref. 11). The hydrochemistry of the connate waters is also characterised by low magnesium:calcium ratios; lithium concentrations are elevated with a lithium:chloride ratio of 1:100.

The connate waters are of interest during operation of the mine since they contribute to the pumped discharge. Once the mine is flooded however they are unlikely to be significant either in terms of flow or quality.

5.2 South Crofty Discharge

Water is pumped from the mine via pumping stations at 380, 340 and 195 fathom levels. Samples from the pumping stations were analyzed every two months in 1993 by SC, and a single sample of discharge water was analyzed by SC on 22nd February 1993. These results are summarised in Table 3.

Water quality data at the three South Crofty pumping levels are limited to a few elements, but these indicated a pH in the region of 5.5 and iron concentrations of up to 60 mg/l at the 380 fathom level. Lower iron concentrations were recorded at 340 and 195 fathom levels, where dilution occurs with water from higher levels in the mine, as indicated by pumped flow volumes. It is also possible that the apparent decline in iron concentrations is at least partly due to the precipitation of iron within the mineworkings, since the pH of around 5.5 would be sufficient to permit hydroxide formation in the presence of oxygen.

Whilst iron tends to decrease in concentration with elevation and dilution in the mine, copper and zinc concentrations tended to increase slightly at the 195 fathom level. Whilst this apparent slight increase does not significantly alter the minewater quality, it may be an indication of the dissolution of copper and zinc sulphides which become preferentially enriched towards the surface.

The tendency of metal concentrations in winter to be below the comparable summer values can be attributed directly to the greater volume of the inflow into the mine workings, as a result of increased precipitation.

The NRA regularly monitor selected parameters in the discharge (which is consented) and this data is summarised, together with the corresponding data for the Red River upstream and downstream of the discharge point, in Table 4. The location of monitoring point Ref. 002 is given in Fig. A1 in Appendix 1.

	Red River U/s South Crofty (Ref. 002)	South Crofty Pumped Discharge	Red River D/s South Crofty
pH	7.3 (6.4 - 7.8)	6.6 (6.0 - 8.7)	7.2 (6.2 - 7.9)
Fe	0.19 (0.01 - 2.8)	1.95 (0.16 - 1352)	0.76 (0.11 - 5.84)
Cd	0.001 (0.001 - 0.05)	0.02 (0.01 - 0.07)	0.01 (0.001 - 0.02)
Cu	0.08 (0.03 - 0.34)	0.20 (0.03 - 16.0)	0.15 (0.01 - 1.60)
Pb	0.003 (0.001 - 0.05)	0.50 (0.03 - 2.8)	0.01 (0.01 - 0.50)
Zn	0.09 (0.02 - 0.13)	1.1 (0.09 - 13.6)	0.13 (0.02 - 1.33)

All data expressed as median (range) of data collected between January 1991 and December 1993; values are in mg/l total concentration, except pH.

Table 4 : Pumped Minewater Discharge and Red River Water Quality Data

It is apparent from Table 4 that, whilst the quality of the pumped minewater varies considerably, the median values (which tend to give a better representation of the "typical" concentrations than arithmetic means) indicate that the South Crofty discharge tends to contain higher concentrations of metals, principally iron, lead, zinc and copper than the receiving waters.

5.3 Adit Water

The water discharging from the Dolcoath adit is composed predominantly of precipitation that has passed through the Killas and upper levels of the South Crofty and adjacent mine workings, possibly supplemented with some deeper minewater draining into the adit under pressure from adjacent flooded voids.

The Dolcoath Adit water at the Roscroggan Portal is monitored regularly by the NRA for selected parameters. This data is summarised, together with the corresponding data for the Red River upstream and downstream of the discharge point, in Table 5. The location of these monitoring points is also given in Fig. A1.

	Red River Roscroggan Bridge (Ref. 003)	Adit Discharge (Ref. 004)	Red River Kieve Bridge (Ref. 005)
pH	7.2 (6.1 - 10.8)	7.0 (6.1 - 7.6)	7.4 (6.6 - 7.8)
Fe	1.12 (0.04 - 66)	0.49 (0.32 - 0.90)	1.08 (0.002 - 3.3)
Cd	0.001 (0.001 - 0.083)	0.001 (0.001 - 0.05)	0.002 (0.001 - 0.05)
Cu	0.14 (0.02 - 1.85)	0.11 (0.04 - 0.26)	0.12 (0.008 - 1.00)
Pb	0.005 (0.001 - 5.63)	0.003 (0.001 - 0.012)	0.005 (0.001 - 13)
Zn	0.4 (0.07 - 11.9)	0.96 (0.09 - 1.2)	0.6 (0.01 - 3.6)

All data expressed as median (range) of data collected between January 1991 and December 1993; values are in mg/l total concentration, except pH.

Table 5 : Adit Discharge and Red River Water Quality Data

It is apparent from Table 5 that the quality of the adit discharge does not vary greatly from the quality of the receiving waters; although there is an indication that iron concentrations in the adit water may tend to be slightly lower than in the Red River whilst zinc concentrations may tend to be slightly higher. It is also apparent that the quality of the adit water is more consistent than that of the pumped minewater with much reduced maximum recorded concentrations for most metals in the adit water compared to the pumped discharge.

5.4 Acidic Minewater

A single sample of acidic minewater from South Crofty was analysed in March 1984 and reported by the BGS in 1988. The precise source of the water was unclear and attempts to verify the data have been inconclusive. The recorded water quality data for this sample indicates an acidic pH (of 3.9) whilst the metal loading is not greatly elevated (with iron at 19 mg/l and zinc at 0.12 mg/l) and is, in fact, lower than the metal loadings of the deeper pumped minewater. Water of this quality is not commonly found in significant quantities within metalliferous mineworkings. Nevertheless, individual water samples collected from within mine workings may reflect localised conditions and it is considered that this sample is probably not representative of the wider water quality within the mine.

Other acidic minewaters in the area, for example at Wheal Jane, also have a pH in the region of 3.9 but sustain much greater metal concentrations, with the combined concentration of iron and zinc currently around 500 mg/l.

6. ENVIRONMENTAL IMPACTS OF MINEWATER DISCHARGES

6.1 Environmental Quality Standards

E.C. Directive 76/464 *On pollution caused by certain dangerous substances discharged into the aquatic environment* and associated "daughter" directives provide for the control of the discharge of two categories of dangerous substances, known as Lists I and II. Article 2 of 76/464/EEC requires that pollution by List I substances, selected on the basis of their toxicity, persistence and bioaccumulation, be eliminated and pollution by List II substances, selected on the basis of their potential to cause deleterious effects on the aquatic environment, be reduced.

For each of the substances included under List I, "daughter" directives identify a single quality objective for each type of water (inland, estuarine etc.), comparable in U.K. terminology to an Environmental Quality Standard (EQS). For List II substances, the EQS's are specified under separate national programmes. In the U.K., a range of National EQS's for List II substances are specified in Appendix 2 of DoE Circular 7/89. Specific EQS's for List II substances relate to a number of different possible use-based Environmental Quality Objectives (EQO's) (eg. protection of sensitive aquatic life, abstraction to potable supply etc.) and for some EQO's may be dependent upon the hardness of the water. DoE Circular 7/89 also defines EQS's for two parameters, iron and pH, which are not included under Directive 76/464/EEC but which are considered in the U.K. to be of comparable importance to List II substances in the protection of the aquatic environment.

The EQS's for List II substances are defined in DoE Circular 7/89 in a way which is consistent with the requirements of other E.C. Directives, principally including 75/440/EEC *On the quality required for surface water intended for the abstraction of drinking water* and 78/659/EEC *On the quality of freshwaters needing protection or improvement in order to support fish life.*

Discharges into a watercourse are evaluated and, where appropriate, consented on the basis that the receiving water quality is maintained as far below the EQS as possible. Breaches of the relevant quality standards for both List I and List II substances are reported to the Department of the Environment. In situations where the quality of freshwaters exceeds the EQS, DoE Circular 7/89 states that the quality should not be allowed to deteriorate further and that pollution by the relevant substances should be reduced within a "reasonable timescale" at least to a level at which the EQS's for the protection of other aquatic life (eg. cyprinid fish) are achieved.

Table 6 lists those List I and List II substances relevant to this study, together with the relevant EQS's as identified by the National Rivers Authority. The hardness of the water in the Red River varies greatly between the sections upstream and downstream of South Crofty. Accordingly, separate EQS's are specified for these two sections of river.

	Red River u/s South Crofty[1]	Red River d/s South Crofty[2]
List I substances :		
Cadmium	5 μg/l AT	5 μg/l AT
Mercury	1 μg/l AT	1 μg/l AT
List II substances :		
Arsenic	50 μg/l AD	50 μg/l AD
Chromium	175 μg/l AD	250 μg/l AD
Copper	6 μg/l AD	28 μg/l AD
Lead	125 μg/l AD	250 μg/l AD
Nickel	100 μg/l AD	200 μg/l AD
Zinc	175 μg/l AT	500 μg/l AT
Other parameters :		
Iron	1000 μg/l AD	1000 μg/l AD
pH	6 - 9 μg/l P	6 - 9 μg/l P

[1] Total hardness range 50 - 100 mg/l $CaCO_3$
[2] Total hardness range 250+ mg/l $CaCO_3$
A Annual average
P 95 % of samples
T Total metal concentration
D Dissolved metal concentration

Table 6 : Summary of Environmental Quality Standards

6.2 Existing Water Quality

The NRA monitor water quality monthly at a number of locations along the Red River, including :

- "Upstream of South Crofty plant & mill" (Grid Ref. SW 6613 4090; NRA Ref. R23A002) - located upstream of the area which is the subject of this study.
- "Downstream of South Crofty plant & mill" (Grid Ref. SW 6610 4120; NRA Ref. R23A104) - located downstream of the pumped minewater discharge point (limited range of determinands since 1991 only).

- "At Roscroggan Bridge" (Grid Ref. SW 6502 4201; NRA Ref. R23A003) - which is downstream of the South Crofty plant & mill.

- "At Kieve Bridge" (Grid Ref. SW 6613 4090; NRA Ref. R23A005)) - which is downstream of the Dolcoath Adit before the confluence with the Trehidy Stream.

The location of these monitoring points is shown on Fig. A1. Table 7 summarises the available water quality monitoring data for these three locations from 1988 - 1993.

The data summarised in Table 6 suggest that relevant EQS's for the Red River may be being exceeded as follows :

- "Upstream of South Crofty" - copper only but consistently.

- "Downstream of South Crofty" - iron occasionally, but limited data available.

- "At Roscroggan Bridge" - copper and iron consistently; cadmium, lead and zinc occasionally between 1988 and 1990.

- "At Kieve Bridge" - copper, zinc and iron consistently; cadmium and lead occasionally.

However, it must be noted that, with the exception of mercury, the NRA monitoring data is recorded as a total metal concentration whilst the relevant EQS's, as defined in DoE Circular 7/89 are, with the exception of cadmium, mercury and zinc, expressed as dissolved metal. It is understood that, in the absence of directly comparable data, it is NRA policy to utilise this available data to evaluate the extent of compliance with the relevant EQS's. Accordingly, the following observations have been made :

I) Copper

The concentration of copper, which, on occasions, exceeds the EQS at the "Upstream South Crofty" monitoring point, tends to be increased further at the "Roscroggan Bridge" monitoring point. However, between 1988 and 1991 the "Kieve Bridge" monitoring point recorded a slight decrease in the copper concentration compared with "Roscroggan Bridge". In contrast, the data from 1993 indicate a

Location	Date	Parameter								
		List I		List II					Misc.	
		Cd	Hg	As	Cu	Pb	Ni	Zn	pH	Fe
"U/s South Crofty" (Ref. R23A002)	1988	n/a	n/a	13	**91**	15	16	88	7.1	510
	1989	1	n/a	5	**92**	5	9	78	7.1	372
	1990	1	n/a	28	**77**	3	3	65	7.1	197
	1991	1	n/a	10	**86**	3	4	90	7.3	182
	1992	0.2	0.02	12	**68**	1	4	77	7.5	188
	1993	0.2	0.02	n/a	**129**	1	6	109	7.5	269
	EQS	5	1	50	6	125	100	175	6 - 9	1000
"D/s South Crofty" (Ref. R23A104)	1991	<20	n/a	n/a	n/a	<225	<50	375	n/a	**1220**
	1992	n/a	n/a	n/a	n/a	n/a	n/a	133	n/a	n/a
	1993	n/a	n/a	n/a	n/a	<10	<30	317	n/a	900
	EQS	5	1	50	28	250	200	500	6 - 9	1000
"Roscroggan Bridge" (Ref. R23A003)	1988	**27**	n/a	21	**292**	34	31	**787**	7.2	**7464**
	1989	1	n/a	29	**229**	3	22	369	7.0	**2035**
	1990	12	n/a	32	**275**	**1250**	24	**3871**	7.5	**3130**
	1991	1	n/a	19	**411**	12	17	434	7.2	**1071**
	1992	0.5	0.02	n/a	**164**	25	15	326	7.2	**1618**
	1993	0.5	n/a	n/a	**118**	3	14	292	7.3	728
	EQS	5	1	50	28	250	200	500	6 - 9	1000
"Kieve Bridge" (Ref. R23A005)	1988	25	n/a	29	**122**	32	32	476	7.4	**3991**
	1989	1	n/a	30	**157**	3	23	**523**	7.3	**1074**
	1990	4	n/a	33	**174**	**340**	23	**1437**	7.3	**1725**
	1991	2	n/a	21	**143**	14	18	**572**	7.3	969
	1992	1	0.03	31	**161**	16	22	**682**	7.4	**1554**
	1993	1	0.35	n/a	**891**	**1114**	26	**5011**	7.3	**13292**
	EQS	5	1	50	28	250	200	500	6 - 9	1000

Notes :
- n/a = data not available.
- All data are annual average values expressed in μg/l.
- Values for metals, except Hg, are recorded as total metal concentration; Hg values given are recorded as dissolved metal concentration.
- The EQS's for cadmium, mercury and zinc relate to total metal concentration.
- All other EQS's relate to dissolved metal concentration.
- Data taken from *EC Dangerous Substances Directive EQS non-compliance 1992* and water quality archive information provided by the NRA.
- Values in **bold** indicate a parameter apparently exceeding the EQS.

Table 7 : Summary of Water Quality Monitoring Data

further significant increase in the copper levels at "Kieve Bridge" above an already elevated level. The toxicity of copper, however, is largely attributable to the presence of the free ion, Cu^{2+} which readily forms non-toxic complexes with both organic and inorganic substances. Consequently, determinations of total copper are likely to include a significant proportion of the non-toxic form. Moreover, even the proportion of dissolved copper which is present as the free ion rarely exceeds 1%, except in waters of unusually low pH. There are considerable difficulties, therefore, in assessing the impact of dissolved copper concentrations on the aquatic environment - a fact acknowledged in DoE Circular 7/89 Notes to Appendix 2 (g), which states that *"higher concentrations of copper may be acceptable where the presence of organic matter may lead to complexation"*.

Accordingly, it is not possible to evaluate the significance of the total concentrations recorded by the NRA beyond noting that the very high total copper loading is consistent with potentially adverse environmental impacts. This potential is enhanced by the cumulative toxic effects of mixtures of copper and other metals, notably zinc.

ii) Zinc

The concentration of total zinc consistently increases at all monitoring locations below "U/s South Crofty", although on only two occasions was this increase sufficient to exceed the EQS at Roscroggan Bridge (1988 & 1990). However, zinc concentrations also increase further downstream at the "Kieve Bridge" monitoring point with the consequence that the EQS for zinc has been exceeded in each of the last 5 years at this point.

The concentrations of zinc recorded at the downstream end of the study area are likely to have an adverse impact upon the biological status of the Red River, especially when combined with the potentially elevated levels of dissolved copper.

iii) Iron

The concentration of total iron at "Roscroggan Bridge" shows a significant increase, above the acceptable background concentration recorded at "U/s South Crofty", with the EQS being exceeded in 5 out of the last 6 years. The iron concentrations remain above the EQS, and in 1993 showed signs of being further increased, at the "Kieve Bridge" monitoring point.

However, the impact of these recorded levels of total iron is unclear, since the effect of iron on the aquatic environment is a function both of the toxicity of dissolved and particulate iron and the physical effects of precipitated iron hydroxides. The WRc publication TR258, *Proposed Environmental Quality Standards for List II Substances in Water - Iron (1988)*, suggests an EQS for the protection both of "freshwater fish" and "other freshwater life" for total iron of 2.0 mg/l. The report also notes that this value "is only marginally above the highest average concentration reported as supporting a healthy fishery" and further states that "field concentrations indicate that healthy invertebrate communities were present in total iron concentrations between 0.7 and 2.7 mg/l".

The available evidence would suggest, therefore, that whilst concentrations of total iron at or marginally exceeding the EQS are unlikely to be having a significant impact upon the aquatic environment, the more elevated levels recorded in, for example, 1988 and 1993 have the potential to exert a significant influence upon the aquatic environment.

iv) Cadmium

Cadmium concentrations apparently exceeded the EQS at "Roscroggan Bridge" in 1988 and 1990 and at "Kieve Bridge" in 1988. However, it appears that the detection/reporting limits (for most of 1988 the available data are reported as mg/l to two decimal places only) may be a major component of this apparent exceedance. Nevertheless, an examination of the monthly monitoring data suggests that significantly elevated cadmium concentrations (up to 41 μg/l) were recorded on individual monitoring occasions.

EC Directive 76\464 identifies cadmium as a List I substance; "daughter" Directive 83\513 stipulates a "quality objective" of 5 μg/l (annual mean) total cadmium in inland surface waters. It is likely that this "objective" was exceeded in both 1988 and 1990.

v) Lead

Recorded concentrations of lead have tended to be well below the stated EQS. However, in 1990 the EQS was apparently exceeded at the "Roscroggan Bridge" and "Kieve Bridge" monitoring points. In 1993 the EQS was again exceeded at the "Kieve Bridge" monitoring point. A review of the monthly data records suggests that these high annual mean values can be related to a few very high values. For example, a single value of 13 mg/l total lead was recorded at "Kieve Bridge" in September 1993;

this value alone accounts for the high annual mean. It is, however, highly unlikely that the recorded concentration reflects a significant increase in the level of dissolved lead, which is the parameter against which the National EQS is set.

Consequently, in the absence of data which might indicate the level of dissolved lead, it is considered that the recorded concentrations of total lead do not present a significant threat to the aquatic environment.

vi) Other metals

There is no evidence to suggest that the concentrations of any other metals are likely to exceed the relevant EQS. However, it is noted that concentrations of arsenic and nickel are both elevated at the "Roscroggan Bridge" and "Kieve Bridge" monitoring points compared to the concentrations recorded at "U/s South Crofty".

6.3 Biological Monitoring

The NRA monitor biological quality routinely at locations close to the water quality monitoring points. The BMWP (Biological Monitoring Working Party, Ref. 15)) scores from relevant sites between 1990 and 1993 are summarised in Table 8.

Monitoring Location	1990			1991			1993		
	Mar	June	Sept	Mar	June	Sept	Mar	June	Sept
"U/s South Crofty"	-	-	-	45	65	68	45	33	37
"Roscroggan Bridge"	0	5	0	-	-	-	7	20	25
"Kieve Bridge"	-	-	-	18	19	15	14	10	47

Table 8 : Summary of Biological Monitoring Data

The biological monitoring data indicate that the Red River in the vicinity of South Crofty is characterised by an impoverished invertebrate fauna, although the status of the river upstream of South Crofty appears to be higher than the river downstream. There is, however, some indication of possible recovery in scores at both Roscroggan Bridge and Kieve Bridge in recent years. This may be of greater significance when compared with South West Water Authority reports of 1979 and 1982 (when mineral processing operations were still undertaken on-site), which recorded "both flora and fauna were entirely absent from the main river...".

The BMWP score for a particular site is determined by many factors, including water quality, substrate, hydrology, and geographical location, and, consequently, a direct comparison of BMWP scores between sites must be undertaken with care. Nevertheless, an indication of the potential biological status of the Red River can be determined by comparison with a monitoring station further upstream ("U/s Brea Tin", Grid Ref. SW 669 392) which regularly yields BMWP scores greater than 100.

It is considered that poor water quality is the principal factor determining the poor biological status around South Crofty, although the degree to which this can be attributed directly to elevated metal loadings is unclear. For example, the total absence of fauna recorded in the 1970's and 1980's was probable associated more with the high concentration of fine suspended solids than with the trace metal concentrations. Whilst the elevated concentrations of metals will constrain the recovery of invertebrate communities, additional factors may also be relevant. The recent NRA "Routine Biological Report" of September 1993 noted, for example, the presence of sanitary waste (at both Roscroggan and Kieve Bridges, which suggests the Red River is in receipt of storm sewer overflow) and the recorded presence of diesel (at Roscroggan Bridge). Both these factors, especially the discharge from storm sewer overflows, have the potential to significantly reduce the biological status of a watercourse.

6.4 Sources of Contamination

An evaluation of the water quality data summarised in Table 7 clearly indicates the presence of at least one source of :

- continuous copper contamination above the "U/s of South Crofty" monitoring point,
- continuous copper and/or iron and/or zinc contamination between the "U/s of South Crofty" and the "Roscroggan Bridge" monitoring points,

There is also the possibility of the existence of intermittent sources of cadmium and lead contamination, and additional copper, zinc and iron contamination, between the "Roscroggan Bridge" and the "Kieve Bridge" monitoring points.

6.4.1 South Crofty Minewater

An evaluation of the monitoring data available for both the pumped minewater discharge from South Crofty and the Dolcoath Adit has been undertaken to assess the extent to which the South Crofty workings might be the source of at least some of this contamination.

The evidence suggests that :

1) **The pumped minewater discharge** represents a significant source of metal input into the Red River. In the absence of detailed flow data for the Red River at the discharge point, it is not possible to determine precisely the implications of this discharge for water quality in the receiving water. However, it is considered that the discharge of pumped minewater could account for the some of the increase in metal loadings recorded at Roscroggan Bridge. Nevertheless, despite the elevated metal loading of the pumped minewater, the discharge volume of around 6500 m^3/day is not considered to represent a source of contamination of sufficient magnitude to account for the whole of the increase in the metal loadings at Roscroggan Bridge.

ii) **The Dolcoath Adit** discharge may represent a significant source of zinc input into the Red River, with typical discharges containing around 1 mg/l. Similarly, in the absence of detailed flow data for the Red River at this discharge point, it is not possible to determine precisely the implications of the Adit discharge for water quality. Whilst, it is considered that the discharge may account for the some of the increase in zinc loadings recorded downstream, the discharge is not considered to represent a source of contamination of sufficient magnitude to account for the greater part of the increase in the metal loadings recorded at Kieve Bridge.

6.4.2 Other Sources of Contamination

A review of available information has identified the following potential sources of contamination :

i) Industrial Discharges and Waste Disposal Sites

There are no records of any current industrial discharges to the Red River or of the presence of any waste disposal sites which might represent a significant source of contamination of the type identified.

ii) Sites of historic mine dumps and former mineral processing areas.

It is known that sites of historic mine dumps and former mineral processing areas are associated with a number of locations along the Red River. Whilst there is little information on the nature of these potential sources of contamination, they are likely to contribute to some degree to the elevated concentrations of metals recorded in the Red River. Contaminated land associated with historic mineral processing works and mine dumps is implicated as a major factor in determining surface water quality at numerous sites in the U.K.

iii) Tailings Disposal

The Red River received tailings directly from South Crofty mill up until 1988. It is likely that the rejuvenation of the river, following the cessation of tailings discharges has resulted in the re-suspension of contaminated sediments which may have a direct adverse impact upon water quality.

7. EFFECT OF MINE CLOSURE

Under operational conditions at South Crofty, an equilibrium has been achieved in which inflow into the mine workings is equal to the pumped discharge. In the event of mine closure, it is likely that this pumping will cease and the water level within the workings will inevitably rise. Once water levels reach adit level (assuming the adit remains largely unblocked) the system will again enter an equilibrium in which discharge from the adits is determined by the magnitude of the inflow.

7.1 Mine Inflow Post Closure

Under current dewatered conditions, mine inflows are believed to comprise approximately 60-70% head dependent inflows from adjacent flooded workings and groundwater and 30-40% inflow resulting from rainfall. As the water level within the workings begins to rise, the head difference between the South Crofty workings and adjacent flooded workings will decline until, when levels equilibrate, the head difference will tend to zero. Consequently, inflows from head dependent sources will fall from 60-70% to zero, whilst the rainfall dependent inflow is expected to remain relatively constant.

The predicted rate of flooding, therefore, will be dependent at least partly upon inflows which will vary according to the rainfall received, within the ranges calculated in Table 9 below.

Rainfall	(mm)	Inflow during flooding		Inflow post flooding	
		(m^3/year)	(m^3/day)	(m^3/year)	(m^3/day)
Average (1989-1993)	1082	1,640,000	4,500	930,000	2,600
Maximum recorded (1960)	1632	2,500,000	6,850	1,420,000	3,900

Table 9 : Water Inflows to Mineworkings

7.2 Duration of Flooding

The main factors in determining the time to flood the workings are the volume of the de-watered void and the rate of water inflow to that void. The storage of the granite itself is small and assumed to be zero compared to the storage available in the mineworkings. Two scenarios have been examined to establish both the upper and lower bound conditions with respect to flooding of the workings.

The volume of the de-watered void as discussed previously (see Section 3.2) indicated a minimum value of 4,200,000 m^3 (see Appendix 3 for full figures). The range of predicted volumes of water inflow are given in Section 7.1. The calculated period for the mine to flood to adit level are shown in Table 10 below.

		Time to fill to adit level (assuming average 2 m stope width)
Average rainfall (1989-1993)	1082 mm	2.6 years
Maximum Rainfall (1960)	1632 mm	1.7 years

Table 10 : Predicted Duration of Flooding

The shortest of these two periods, slightly in excess of one and a half years, suggests that there would be sufficient time to put in place any preventive measures should these be thought necessary. However, whilst this figure may represent a lower bound condition, it is likely to be an underestimate since it is based on the maximum recorded annual rainfall (approaching a return period of 1:100 years) and is also based on a possible under-estimate of the total void space (see Section 4.5).

The more likely time for the mine to flood is in the order of 2 - 3 years. This more realistic prediction equates to a rise in water level within the mine of an average of approximately 1 metre per day. Close monitoring of the rate of flooding will enable the predicted time span to be refined whilst still allowing sufficient time for the implementation of any control measures.

7.3 Minewater Discharge

As the mine floods there will be an immediate impact on the Red River as the pumped mine discharge, currently averaging some 6500 m^3/day ceases. However, as water levels within South Crofty rise, there may be a reduction in the inflow from adjacent flooded workings with a consequent increase in the discharge from these workings to adits and ultimately to surface water courses. Flows from the adjacent flooded mines currently discharge either via the Dolcoath or the Barncoose adits. It is predicted that, during flooding of the mine, the discharge from these adits may increase gradually. There is no available evidence which would suggest that the pattern of discharge will change.

Once the mine is fully flooded, the additional discharge from the Dolcoath and Barncoose Adits is likely to be roughly equivalent to the volume currently discharged during mine pumping operations (an average of approximately 6500 m^3/d). The majority of the flow would be expected to pass through the Dolcoath system since it is at a lower elevation than the Barncoose adit.

Using the assumptions put forward in Section 4, the additional adit discharge could consist of an estimated 60% from previously flooded workings, and 40% from precipitation over the newly flooded South Crofty or approximately 2600 m^3/d (Table 9). This figure has been compared with the estimated increase in flow derived from adit flow observations as discussed below.

The limited data which are available for flows within the adits indicate that they are currently collecting between 500 m^3/d to more than 1500 m^3/d of water per km length where they pass over the flooded mines. By contrast the shallow adit and deep (Penhale) adit appear to collect less than 100 m^3/d per km length in their passage over the dewatered area. The flow not intercepted by the adits drains into the South Crofty workings.

It is unlikely that the shallow adit would be more efficient than at present following flooding, since water levels would probably be held some 20 m below its invert by the deep adit. Water would continue to drain past the shallow adit and eventually be intercepted by the deep adit. Assuming that shallow adit level has similar characteristics to deep adit level, the quantity of flow potentially bypassing the 2.5 km length of shallow adit could range from an average of approximately 1000 m^3/d to more than 3500 m^3/d.

The Barncoose adit would also be expected to continue leaking from its western sections following flooding. Again the water would probably pass towards the deep adit which is at an elevation of 60 m bgl, approximately 30 m below the level of the Barncoose adit. The quantity of water potentially following this course could range from 200 m^3/d to more than 800 m^3/d.

If the portions of the adits receiving the additional flow are, and remain in, good condition they have the capacity to discharge the extra flow and water should not flow into any other adit system. However there is evidence from historical events that when the deep adit has been blocked water levels have risen above this level and threatened to flow east through old workings to the Barncoose adit (Ref. 9). Although the relevant portion of the deep adit is currently assessed to be in good condition, there is no guarantee that it may not become blocked or deteriorate due to a change in conditions. Flow gauging already established at Tolskithy and Roscroggan will give advance warning of any changes in the flow regime while monitoring of shaft water levels will indicate if water levels are moving above the level of the deep adit.

7.4 Minewater Discharge Quality

A tentative picture of the effects of mine closure upon the hydrochemistry of the area has been put forward, based on water quality analyses, assumptions of flow paths and magnitudes during operation and after flooding, and the results of acid-base accounting.

In the interim report (Ref. 1) it was concluded, on the basis of the information available at that time, that there was "no substantial evidence of either the presence of acidic minewaters or of the potential for their generation within the workings to an extent in any way comparable to that experienced in mines such as Wheal Jane". Whilst this is still the case, the results of the acid-base accounting discussed in the following section point to the possibility of acid generation in the upper levels of South Crofty.

7.4.1 Potential for Acid Mine Drainage

Acidic mine drainage (AMD) caused by the oxidation and hydrolysis of metal sulphides, has been generated following the closure of other mines in Cornwall and elsewhere in the U.K. Sulphide minerals, such as pyrite, are oxidised upon exposure to air producing ferric iron, sulphate and hydrogen ions. The resultant acidic waters then accelerate the dissolution of other metal sulphides.

The generation of acidity by sulphide minerals may be neutralised by the presence of acid-consuming compounds such as carbonates, and some researchers have shown that the most reliable indicator of post-mining water quality may be the neutralising potential (NP), (Ref. 12). Laboratory scale test procedures known as **static tests** or acid-base accounting have been developed to determine the ratio of acid producing potential (AP) to neutralising potential (NP).

These tests can only provide an indication of the likelihood of acid generation, since a number of other factors are also important including, for example, the activity of *Thiobaccillus ferroxidans* bacteria, the size and distribution of the sulphide grains and the nature of the secondary porosity of the rock. Nevertheless, it is apparent that when AP exceeds NP there is a potential for acid generation (Ref. 13).

The actual NP/AP ratio at which acid will be generated is site-specific; depending upon the relative reaction rates of acid generating and acid neutralising minerals. It has been shown however that for pH to remain near neutral the ratio of NP/AP should exceed a value of between 1.3 and 4.0 (Ref. 14).

7.4.2 Potential for acid generation at South Crofty

Two of the factors which promote acid mine drainage are the provision of oxygen and water. During mine dewatering there is ample opportunity for oxidation to occur. Following closure, water levels rise, hydrolysis of the oxidised material occurs and acid minewater may form. The critical zone for acid minewater production once water levels have stabilised, is at and around the final equilibrium water level. In many mines, as at South Crofty, this is expected to be at adit level if discharges are not controlled by pumping.

An evaluation of the possibility of acid mine drainage at South Crofty has been made by carrying out static tests on 12 rock samples collected from the Deep and Shallow adits. The samples were taken from exposures in the adit walls at the locations shown in Figs. 10 and 11 of Appendix 4. Every effort was made to collect representative samples from the main lode, caunter lode and crosscourse exposures. It is possible however that sampling was influenced by the ease of sample collection in which case poorly indurated oxidised sulphur rich strata may have been preferentially sampled whilst not being representative of the average rock composition. To achieve truly representative results a much wider sampling campaign would be needed.

The results of sampling from the adits at South Crofty are given in Table 11. The neutralising potential (NP) was estimated from the consumption of hydrochloric acid by rock pulp, and the maximum acid potential was based on the sulphur content. Four of the samples, 2,3,6 and 10 were found to have a higher acid producing than neutralising potential (negative NNP) so could generate acid under certain conditions. The "worst" sample was No. 3 which had a sulphur content of 2%.

The ratio of NP/AP is given in the final column of Table 11. The four samples with negative NNP have a ratio of less than 1.0, again confirming their potential to produce acid. Samples 1,9 and 12 have a ratio of between 1 and 4 so lie in the uncertainty range. The remaining samples, 4,5,7,8 and 11 are not acid producing.

Sample No.	0.1M HCl consumed (ml)	NP kg $CaCO_3$/t (1)	Sulphur %	AP kg $CaCO_3$/t (2)	NNP kg $CaCO_3$/t (3)	Predicted Behaviour (4)	NP/ AP
1	3.67	9.08	0.222	6.94	+2.14	U	1.3
2	5.08	12.57	0.627	19.59	-7.02	A	0.6
3	2.09	5.17	2.040	63.75	-58.56	A	0.1
4	3.22	7.97	0.034	1.06	+6.91	N	7.5
5	2.50	6.19	0.016	0.49	+5.70	N	12.6
6	2.24	5.55	0.222	9.94	-4.39	A	0.6
7	4.43	10.97	0.012	0.38	+10.60	N	28.9
8	2.26	5.59	0.020	0.63	+4.97	N	8.9
9	2.30	5.69	0.154	4.81	+0.88	U	1.2
10	1.95	4.83	0.202	6.31	-1.48	A	0.8
11	2.34	5.79	0.019	0.60	+5.19	N	9.7
12	1.86	4.60	0.100	3.13	+1.49	U	1.5

Notes

(1) NP = Neutralisation Potential (kg $CaCO_3$/t)
(2) AP = Maximum Acid Potential (kg $CaCO_3$/t)
(3) NNP = Net Neutralisation Potential (kg $CaCO_3$/t)
(4) A = Acid generating potential U = Uncertain N = Non-acid forming

Sample No.	Date	Location	Comments
1	24/05/94	Penhale adit, east of Maynes shaft	main lode
2	24/05/94	Penhale adit, west of Maynes shaft	main lode
3	24/05/94	Penhale adit, west of Maynes shaft	main lode
4	24/05/94	Dolcoath Deep adit, near Whim Round shaft	cross course
5	24/05/94	Dolcoath Deep adit, junction w/S Crofty branch	caunter lode
6	24/05/94	Penhale adit, west of Maynes shaft	main lode
7	25/05/94	Start of Penhale adit, near Phillips shaft	main lode
8	25/05/95	Penhale adit, west of Phillips shaft	main lode
9	25/05/94	Penhale adit, near shaft	main lode
10	25/05/94	Penhale adit	main lode
11	25/05/94	Shallow adit, near Bickfords shaft	main lode
12	25/05/94	Shallow adit, near Pryces shaft	cross course

Table 11 : Results of Acid-Base Accounting for Samples from South Crofty adits

The results of acid-base accounting at South Crofty indicate that there is potential for acid generation. Whether acid would actually be generated following mine closure cannot be predicted from these results. The possibility of **kinetic tests** has been considered as a means of confirming acid generation. These tests examine reaction rates under specified conditions and can incorporate factors such as reaction equilibria and the relative rates of acid production and neutralisation. The benefits of such tests for South Crofty are questionable however, bearing in mind that they are time consuming and expensive and that representative sampling is difficult in the upper levels of the mine.

Despite the clear indications from the tests that there are rocks which are capable of acid generation, there is still evidence to suggest that significant changes in water quality are unlikely, principally :

1) Water is currently draining into the adit (and the deeper workings) through the upper dewatered levels and there is no evidence in the discharge water quality of the Dolcoath adit of significant acid generation (see Section 6).

2) Water draining from the Barncoose Adit is derived from the upper levels of adjacent workings and, although there are no water quality data for this discharge, there are no reports of the discharge being especially acidic.

In summary, it is not possible at present to predict the acid generation in the upper levels at South Crofty if the mine were allowed to flood. It is therefore proposed that conditions should be closely monitored following closure so that if the quality deteriorates remedial measures can be actioned. Proposals for monitoring and the remedial works which may be required are given in Sections 8 and 9.

7.4.3 Future water quality

In the event of closure of South Crofty, the current pumped discharge would cease and it has been predicted that there would be a roughly comparable increase in adit discharge. This increase would take place gradually until water levels in the mine reached equilibrium at the level of the deep adit.

In the early stages of flooding, the increase in adit flow would be derived from precipitation over the mine workings. There is no evidence of significant metal loadings or acidity in these adits at present so there is no reason to assume that conditions would change as water levels began to rise at South Crofty.

Once the water level reached deep adit level however, discharge of water from the newly flooded mine would commence and in addition to a flow increase, changes in quality may also occur.

A visual inspection of parts of the adit system noted the presence of quantities of sediment retained within the adit. In the event that the flow through the adit were to increase significantly after flooding, this sediment may be flushed out of the adit system with a consequent adverse short term impact upon water quality.

An increase in metal concentrations could also result as oxidised minerals in the upper levels of the mine became hydrated. Furthermore if conditions became strongly acidic, dissolution of metals could occur in sections of the adit which are in equilibrium at existing pH's.

Although it is not possible to predict future mine water quality, there is evidence from the acid-base accounting test results that the potential for acid generation exists. Monitoring of water quality following cessation of pumping will identify any deterioration that does occur.

The following sections examine the potential consequences of a deterioration in mine water quality on the Red River. The existing median total metal concentrations for iron, cadmium, copper, lead and zinc are approximately:

pumped discharge	3 mg/l	pH 6.6
Dolcoath adit	2 mg/l	pH 7.0

Water within the mine has been reported to have higher concentrations of iron, giving mean metal concentrations of 55 mg/l at a pH of around 5.5.

It has been estimated in Section 7.3 that the relative contributions to flow in the Red River immediately downstream of the mine are as follows:

During operation

Red River 50%
Pumped discharge 25%
Dolcoath adit 25%

Following flooding

Red River 50%
Dolcoath adit 50%

The total river flow after flooding is expected to be roughly comparable to that measured at present. A proportion of the *increased* Dolcoath adit flow (approximately 40%, Section 7.3) will be derived from rainfall over the currently dewatered area. This could amount to 10% (i.e 40% x 25%) of the flow which finds its way to the Red River immediately downstream of the Dolcoath adit. The remaining increase in Dolcoath adit flow would be derived from inflow over those areas already flooded.

Under current operating conditions, metal concentrations in the Red River upstream of South Crofty are approximately 0.3 mg/l, which increase to approximately 1.4 mg/l downstream of the mine pumped discharge and Dolcoath adit.

Three scenarios for post-flooding have been examined, assuming that the 10% mine water contribution to the Red River immediately downstream of the Dolcoath adit has varying levels of metal concentrations as follows:

i) 3 mg/l as in the currently pumped discharge
ii) 55 mg/l as in the mine at present
iii) 200 mg/l. This figure has been used as an upper bound condition, being more than metal concentrations encountered at South Crofty but less than the concentrations in flooded mine water discharge from Wheal Jane where conditions are more sulphidic.

Using a simple mixing model and assuming that no chemical reactions take place, the metal concentration in the Red River could change from an average of 1.4 mg/l to the values shown below:

Metal concentrations (mg/l)	
10% contribution	Red River
3	1.3
55	6.5
200	21

From these figures it is not inconceivable that the water quality in the Red River could improve marginally once the pumped discharge ceases. This could occur if the water quality in the Dolcoath adit remained essentially unchanged.

At the other extreme a high metal concentration in the South Crofty mine water could increase metal loadings in the Red River significantly. This condition would be further exacerbated by the presence of low pH which could result in dissolution of metals in other sections of the adit and from the banks of the Red River.

If the results of monitoring post-closure indicate that acid conditions are forming it will be important to isolate the poor quality water to prevent self-propagation of larger volumes of acidic mine water. This could be achieved in part by reducing inflows to South Crofty by repairing the western sections of the Barncoose adit and reinstating the shallow adit. In this way it is possible that more than 1000 m^3/d could be intercepted and discharged direct to surface. The cost benefits of such action could be calculated once the final water quality is known.

7.5 Impact on Other Activities

In the event that the water quality in the Red River did deteriorate, a review of potential activities which might be affected has been undertaken :

7.5.1 Licensed Abstractions

Details of licensed abstractions were obtained from the licence file at NRA Exeter. There are no surface water abstractions from the Red River or the Portreath stream. However, four groundwater abstractions were identified in the vicinity of the mine site (see Fig. 8), including :

- 15/49/26/G/202 NGR SW 655 414 : Borehole to 60 m depth in killas abstracting 4315 m^3/yr for domestic consumption at a caravan park.
- 15/49/26/G/76 NGR SW 660 426 : Borehole abstracting 1659 m^3/yr for agricultural purposes.
- 15/49/26/G/189 Boswyn Shaft and Copper Hill Adit : Abstracts from adit and shaft to augment public water supply - no longer active.
- 15/49/26/G/201 NGR SW 667 389 : Abstraction from shaft of up to 3500 m^3/d to augment public water supply - no longer active.

It is considered that none of these identified abstractions are likely to be influenced by the predicted changes in the hydrology or hydrochemistry around South Crofty. However, this can only be verified by monitoring of the abstraction points.

7.5.2 Waste Disposal Sites

Details of local waste disposal sites were obtained from the Sitefile database at the NRA, based on a search radius of 5 km around South Crofty. The search revealed four waste disposal sites and one waste transfer station within this area (see Fig. 8). The disposal sites identified are primarily unlicensed depositories in old quarries or the shafts of abandoned mines and the details of waste type are only known with certainty for the one licensed site. There appears to be no readily available data relating to such matters as dates of operation, depths, environmental management of the sites which include :

- North Roskear (NGR SW 655 413) - Unlicensed landfill in abandoned mine, 500 m west of the Red River, on the killas and filled with domestic waste.
- Tolgarrick (NGR SW 658 412) - Unlicensed old quarry 200 m west of Red River, on the killas, waste type unknown.
- Tolskithy Lane (NGR SW 673 423) - Unlicensed small quarry on the killas, waste type maybe domestic or builders.
- Tregajorran (NGR SW 677 410) - Licensed landfill on granite, now closed. Filled with inert construction waste.
- Wilson Way (NGR SW 676 412) - Waste transfer site.

The recovery of groundwater levels associated with the cessation of pumping at South Crofty is not considered likely to affect these sites, unless there was some unforeseen change in the pattern of minewater discharge.

7.5.3 Conservation Areas

Local nature conservation areas, as defined by the Cornwall Trust for Nature Conservation, exist on the banks of the Red River below South Crofty. These are acknowledged to be of County significance but it is understood that none are of national importance.

The valley and floodplain of the Red River support a variety of habitats including mature wet woodland, mire and heathland through to bare ground showing the early stages of re-colonisation. The wetland areas are of particular note but are fed from rainwater and valley side seepage and not from the low quality river. The wetlands are particularly important for dragonfly and damselfly fauna.

It is considered that these Conservation Areas will not be affected by any of the predicted changes in the hydrology or hydrochemistry of the Red River.

7.5.4 Aquatic Ecology

Although the extent to which the elevated concentrations of metals are constraining the recovery of invertebrate communities in the Red River is unclear, any deterioration in water quality can only reduce that rate of recovery.

8. RECOMMENDED MONITORING

Monitoring of river flows, water quality and rainfall in the vicinity of South Crofty are undertaken currently by the NRA, SC and the Meteorological Office. Although this data has, in general, proved sufficient for the purposes of this preliminary assessment, a more comprehensive and targeted data monitoring programme will be required in order to refine the predictions of future flow rates and water quality that might result from mine closure. This programme will need to provide for the collection of both baseline data, against which to compare any changing hydrological regime, and for the collection of data during groundwater recovery, to refine the predicted final quality and flow pattern.

8.1 Baseline Monitoring

8.1.1 Adit Flows

Gauges to measure adit flows were installed in March 1994 at the portals of the Dolcoath and Barncoose Adits. The gauging weirs are connected to data loggers and provide flow measurements at hourly intervals. These two sites are the most probable discharge points for any South Crofty minewater post closure. Flow measurement at these locations will provide baseline data against which the impacts of a changing hydrological regime can be assessed more accurately.

The installation and initial data collection has been undertaken by Knight Piésold and Partners. Once the equipment has been thoroughly tested, it will be handed over to the NRA for continuing monitoring.

8.1.2 Water Quality

The following refinements of the current sampling programme are suggested in order to enable the most effective monitoring of variations in water quality:

1) Establish routine monitoring of the discharge at Barncoose Adit and of the minewater at each of the underground pumping stations at South Crofty.

2) These two additional monitoring locations, together with existing monitoring points should be sampled monthly for pH, temperature, dissolved oxygen, total hardness, alkalinity, suspended solids, iron, copper, zinc, arsenic, lead, cadmium, mercury, chloride, sulphate, sodium, potassium, magnesium, calcium and lithium to facilitate both an identification of the source of the

minewater and the assessment of the environmental implications of any change in hydrological regime.

3) The metal analysis should be undertaken for "total" metals, as is current practice, and for dissolved copper, dissolved lead and dissolved iron. In the event that the total concentration of other elements, such as arsenic, increases, then it may be necessary to determine the dissolved concentrations of these additional metals.

8.1.3 Water Level Monitoring

Whilst there is currently no standing water within the active South Crofty workings, the determination of water levels in the adjacent flooded workings would provide information of value in predicting the rate and extent of re-watering of the active workings. Most of the shafts in the adjacent abandoned mines have been backfilled and capped but a few are accessible for dipping, these include Williams (NGR SW 661 399), Chappies (NGR SW 665 406) and Maynes (NGR SW 664 411). These shafts were dipped in February 1994 and showed water levels either at adit level or in flooded workings below adits (Appendix 1). As such they should show a rise in level if flooding in South Crofty is causing water to rise above adit level.

Access to Williams and Chapples is through holes in the concrete cap and they can be dipped with a conventional dipmeter, Maynes was dipped from adit level via a ladder from surface and is easily accessible in the company of SC staff.

8.1.4 River flow monitoring

River flows are currently measured on the Red River at Gwithian. Additional measurements are recommended on the Red River close to the mine and the Dolcoath adit portal at Roscroggan. This could be achieved at minimum cost by installing a weir and gauging post at the chemical sampling points 002 (downstream of Brea Tin)and 003 (Roscroggan) shown on Fig. A1. Monthly readings could then be taken at the same time as chemical sampling.

8.2 Monitoring In the Event of Closure

8.2.1 Adit Flows

The analysis of data from the gauging weirs at Roscroggan and Tolskithy Portals should be continued. If there is a sufficient dataset from pre mine closure then the gauges should show a gradual increase in flow from the pre closure figures as the water level begins to rise and water flows down the adits. Any sudden drop in flow readings will indicate a blockage in the adit and the possibility of discharge occurring at another point. For example if Dolcoath is blocked the water may flow into the Barncoose Adit, and the gauges at both the Tolskithy and Roscroggan Portals will reflect this.

8.2.2 Water Quality

It is recommended that the frequency of water quality monitoring suggested above, Section 8.1, be increased upon the cessation of pumping to fortnightly, and further increased to weekly when water level monitoring indicates that levels are approaching adit level.

In addition to the routine sites in the catchment and the extra sites suggested above, the chemistry of the water rising in the shaft should also be monitored for the parameters listed in Section 8.1.2. Fortnightly sampling should be undertaken from as great a depth within the workings as is practical. The frequency of this sampling should be increased to weekly as water levels within the mine approach adit level.

8.2.3 Water Levels

It is recommended that in the event of closure, water levels be measured in the mine itself, to monitor the actual rise in level, and in surrounding abandoned mines, to check if the rise in South Crofty is having an effect there. The best point to measure levels in the mine is the central shafts, New Cooks Kitchen or Robinsons. Palmer's shaft could also be used to give an indication of water levels relative to the deep and shallow adits during and after flooding. The final selection of water level monitoring locations should be made following mine closure when shaft accessibility will be known.

New Cooks Kitchen shaft extends down to the 380 fathom level and a pressure transmitter system could measure levels from 600 m below ground. Such a system attached to a data logger will give advance warning of water level rise. In order to reduce costs a 500 m dipmeter could be used initially and a pressure transmitter installed when water levels rise above 200 m bgl and more extensive data are required.

A system comprising a pressure transmitter, data logger and cable to measure water levels in a 600 m shaft has been priced at £3,200 while a 500 m dipmeter costs £500.

The monitoring at the surrounding shafts; Williams, Chapples and Maynes (if accessible) should be continued to check that rising water levels in the mine are not affecting the adjacent flooded mines.

9. PREVENTIVE AND REMEDIAL OPTIONS

In the event of closure of South Crofty mine, it is anticipated that water levels will rise over a period of 2 - 3 years and an increased discharge from the Dolcoath Adit to the Red River will result.

The findings of this study and in particular the results of acid-base accounting indicate the presence of potentially acid generating material in the adits. The evidence from other flooded mines and the quality of adit waters indicate however that a major discharge of acidic metal-rich minewaters, similar to the Wheal Jane incident, is unlikely to occur. Nevertheless, regular monitoring of flows and water quality are required to confirm this prediction and to give advance warning of any change in quality or flow regime.

In the short term, the increased flow from Dolcoath adit may result in sediment currently held within the adit being flushed into the Red River, this could be prevented by undertaking a relatively straightforward programme of adit maintenance.

9.1 Adit Maintenance

The sections of adit where silt has built up have been identified in Appendix 4. The areas of silt should be removed if the mine is to be closed to prevent its discharge in to the river. There would be time to carry out works such as this immediately following closure and before water levels rose. The system would also benefit from removal of the radon doors which currently restrict flow in several sections. Adit work involves underground working in often cramped conditions. It is therefore recommended that if any repairs or maintenance were to be carried out in the adits that experienced operators be used. Such works would also be subject to Mines and Quarries regulations.

Once the mine has flooded, the adit system will be the principal control of water levels discharging significant quantities of water through the Roscroggan Portal. Were the integrity of this system to be compromised, flow rates may change in an unpredictable manner and additional discharge points may emerge. It is clearly beneficial to maintain the adit system in good condition. Consideration should thus be given to continuing the adit maintenance programmes.

A detailed survey of the adit system was undertaken by KPP and SC in May 1994, and the findings are presented in full in Appendix 4. There are several sections of the adit system in need of repair to prevent flow passing into the workings at South Crofty and adding to pumping costs. Whilst this work would be worthwhile in terms of current operations, the prevention of inflow is unlikely to prove beneficial if the mine closes.

The main areas in which repairs are recommended are those sections which are blocked by obstructions or where the roof is in danger of collapse. There is no immediate requirement for roof repair work, but it is recommended that regular inspections are carried out by SC and reported to the NRA. This could be done annually, and as a matter or urgency if the mine closes. The cost of an inspection visit and report would be approximately £4000.

It may also prove beneficial, following closure, to divert water away from South Crofty by repairing sections of the Barncoose and Shallow adit, as discussed in Section 7.4.3. The cost and potential benefit of such repairs should be assessed once the final minewater quality is known.

9.2 Treatment of Mine Discharge

In the event that water quality analyses of minewater following abandonment indicate deterioration of mine drainage quality, it may be necessary to treat the minewater prior to discharge. Treatment strategies may involve a combination of pumping or gravity flows in conjunction with active and/or passive treatment.

9.2.1 Pump and Treat

If the minewater is found to deteriorate in quality as water levels recover, to such an extent that there would be a significant deleterious effect on local rivers, it may be necessary to pump to maintain levels below adit level. The minewater would then be isolated from the remaining flows and a relatively small proportion of flow would have to be treated. The quantity of flow which may require treatment could range from an estimated 2000 to 6000 m^3/d. Seasonal variations could be minimised by carefully controlled pumping.

One possible treatment method would be lime dosing, as at Wheal Jane, followed by flocculation and sludge disposal. Using figures obtained from Wheal Jane to treat water with a metal loading of 400 to 500 mg/l, the annual cost of treatment, given the flows above could range from £250,000 to £500,000 plus £120,000 per annum for pumping. Capital costs could be kept to a minimum by using pumps and lime dosing equipment from Wheal Jane. In addition there is equipment at

South Crofty, including a thickener, drum press and a small sludge lagoon which preliminary calculations indicate would be adequate to cope with a flow of 10,000 m^3/d with 1000 mg/l of suspended solids.

Costs are also included in Appendix 5, which contains a response to questions from the DoE regarding different treatment options.

9.2.2 Gravity and Passive Treatment

It may be preferable to allow the mine drainage to take place through the Dolcoath adit under gravity and treat the water using a passive system. The flows would be greater than for the pump and treat option, since the entire adit discharge, averaging some 13,000 m^3/d would be involved. Assuming that the mine water emanating from South Crofty had a concentration of 55 mg/l, the Dolcoath adit discharge concentration could be in the region of 20 mg/l. Preliminary estimates of the land requirement to treat 13,000 m^3/d with a metal loading of 20 mg/l indicate that a 50,000 m^2 wetland may be required. This could entail a capital cost of approximately £2 million. The operating costs would be expected to be an order of magnitude less than for the pump and treat option, possibility amounting to some £50,000 per year. The capital cost of passive treatment increases roughly in proportion to metal loading and flow, so at high concentrations the area of land required and costs involved would make passive treatment unviable.

The relative benefits and costs of minewater treatment options (or even whether there will be a requirement for treatment) cannot be discussed more fully until the final water quality and scale of treatment is known with more certainty. This will be possible once water levels have recovered to the upper sections of the mine and thorough analysis and interpretation of mine drainage quality has been undertaken.

10. CONCLUSIONS

An evaluation of the potential environmental impact of closure of the South Crofty mine and cessation of pump operations has been undertaken. The preliminary results were presented in an interim report in May 1994. Further studies have since been undertaken, including an adit survey and rock sampling for acid-producing potential. This report describes the recent findings and proposes revised recommendations for monitoring and remedial work based on the current knowledge of the hydrology and hydrochemistry of the mine.

The mine is currently dewatered at an average rate of 6500 m^3/d and the water discharged to the Red River. The upper levels of the mine and surrounding area are drained by a system of adits, To the east, the Barncoose adit drains into the Portreath Stream, whilst to the west and over the South Crofty property, the Dolcoath adit drains into the Red River. The combined discharge from the Dolcoath adit and the mine averages some 13000 m^3/d and contributes approximately half of the flow in the Red River at that location.

Water quality in the Red River exceeds EQS at times for copper, iron, zinc, lead and cadmium. The mine and adit discharges contribute to the contamination in the river, but other sources are also present. Average metal concentrations in the river downstream of the adit discharge are between 1 and 2 mg/l.

Following cessation of pumping at South Crofty, there is expected to be an initial decrease in flow and slight improvement of water quality in the Red River. As the mine floods the adits will gradually carry more flow until, when the mine is flooded to adit level, the increase in flow will be roughly equal to the current mine discharge. The majority of this is expected to discharge via the Dolcoath adit.

The quality of flooded mine discharge and its potential impact on the Red River have been estimated by assuming a range of concentration values from 3 to 55 mg/l based on conditions at South Crofty. There is currently no evidence of acid minewater but the results of acid-base accounting indicated the *potential* for acid generation in the upper levels, so an upper bound concentration of 200 mg/l has also been used. The results indicated that river EQS would continue to be exceeded post-closure, and further deterioration is possible if acid mine drainage forms.

Monitoring of water quality is recommended if the mine is allowed to flood, to identify any deterioration in quality. Estimates of the time to flood vary from a minimum of 1.7 years to a more realistic 2 to 3 years. This would give ample opportunity for preventive and remedial measures to be actioned.

The main potential impact of cessation of pumping is deterioration of water quality in the Red River. No other adverse impacts have been identified in the catchment.

Recommendations have been made to monitor flows, water levels and water quality in pre- and post-closure programmes. These recommendations, and a contingency plan to be instigated if South Crofty closes, should be addressed in the near future so that mitigating measures can be properly planned and implemented if necessary.

If acid mine drainage is found to be forming it may be necessary to treat the water before discharge to the river. The options include pump and treat or gravity flow followed by passive treatment. The final decision on the most cost effective option will need to be made once the final water quality is known, but the indications are that it would be preferable to pump the minewater if it deteriorates significantly to avoid self-propagation of acidity. A low level of contamination could be handled effectively by passive treatment and thus avoid pumping costs.

This report concludes the South Crofty minewater study. In summary, although there is no existing evidence of acid conditions at adjacent mines or in adits, static tests have indicated the potential for acid generation in the upper levels. Monitoring during mine flooding will be vital to confirm the final discharge water quality. There will then be ample time to adopt any preventive or remedial measures which may be required.

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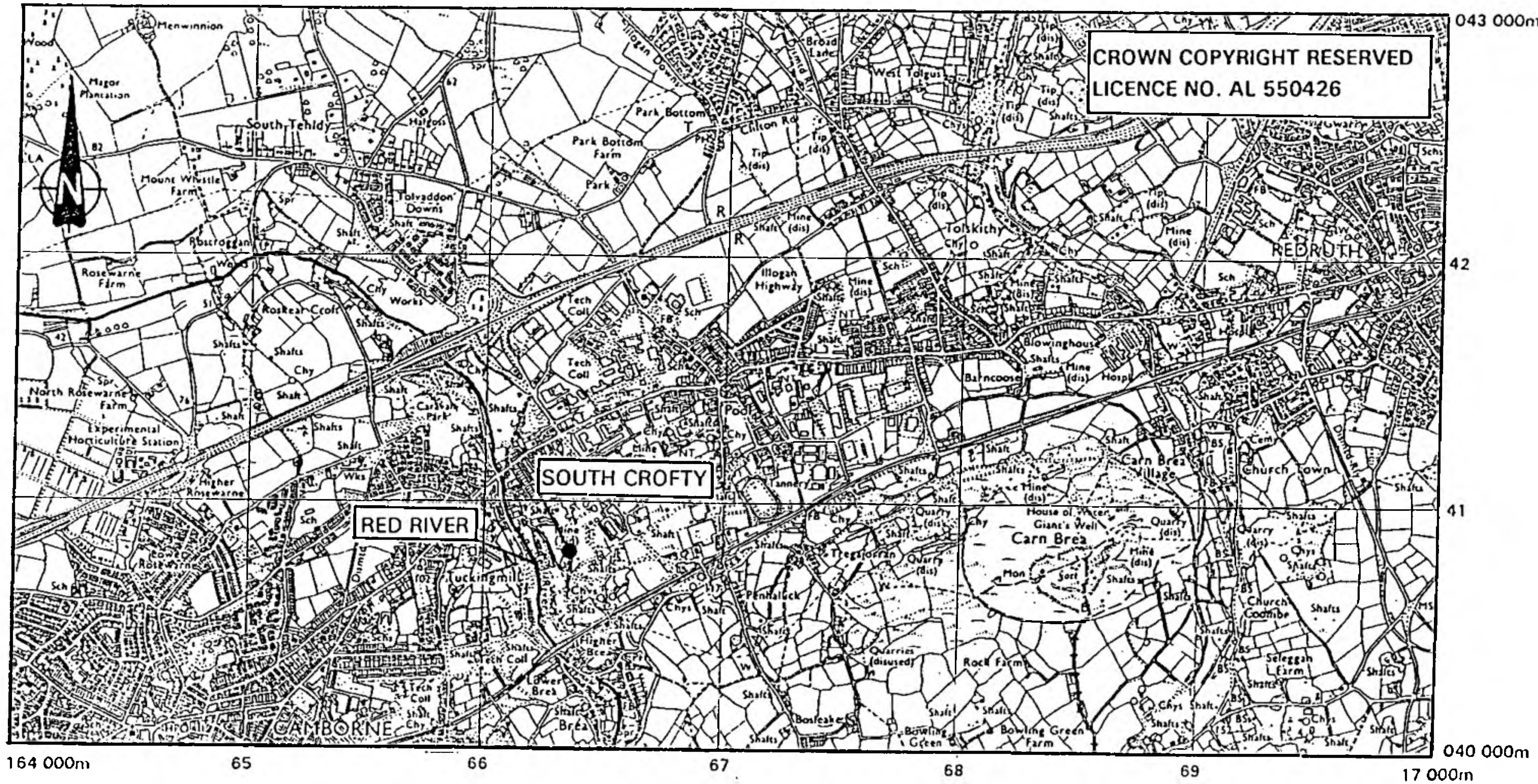


MINE LOCATION MAP

FIG.1

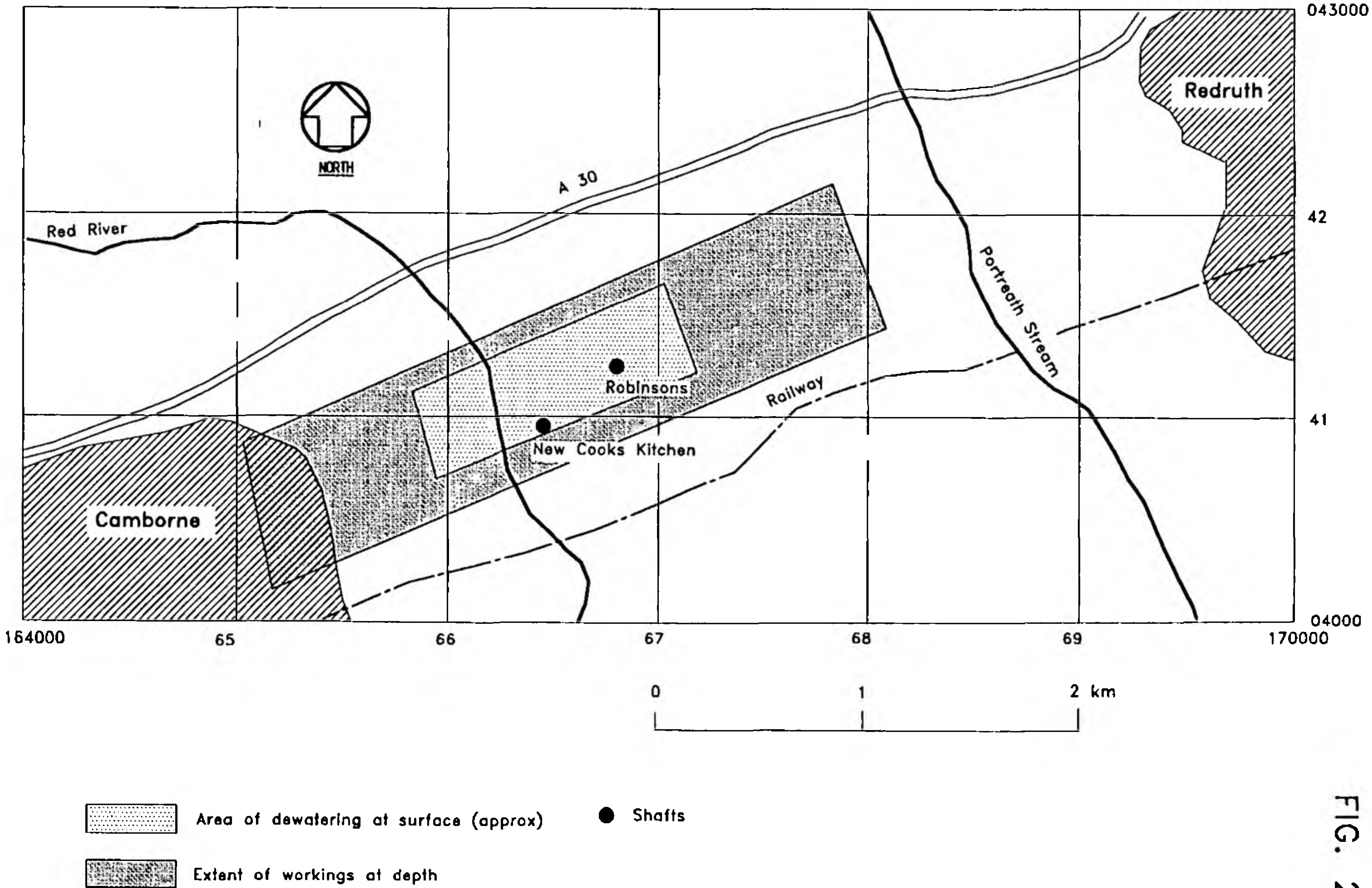
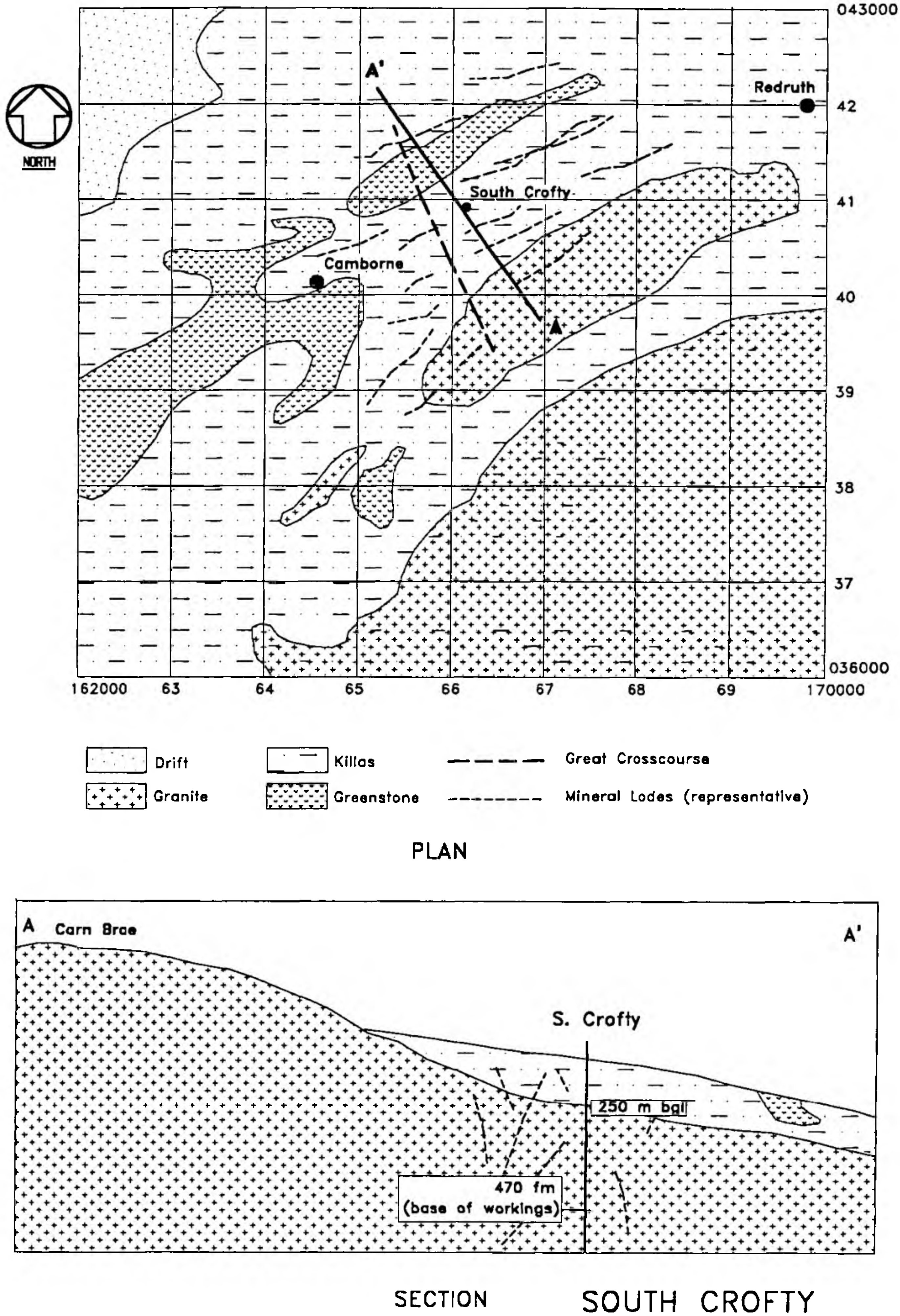


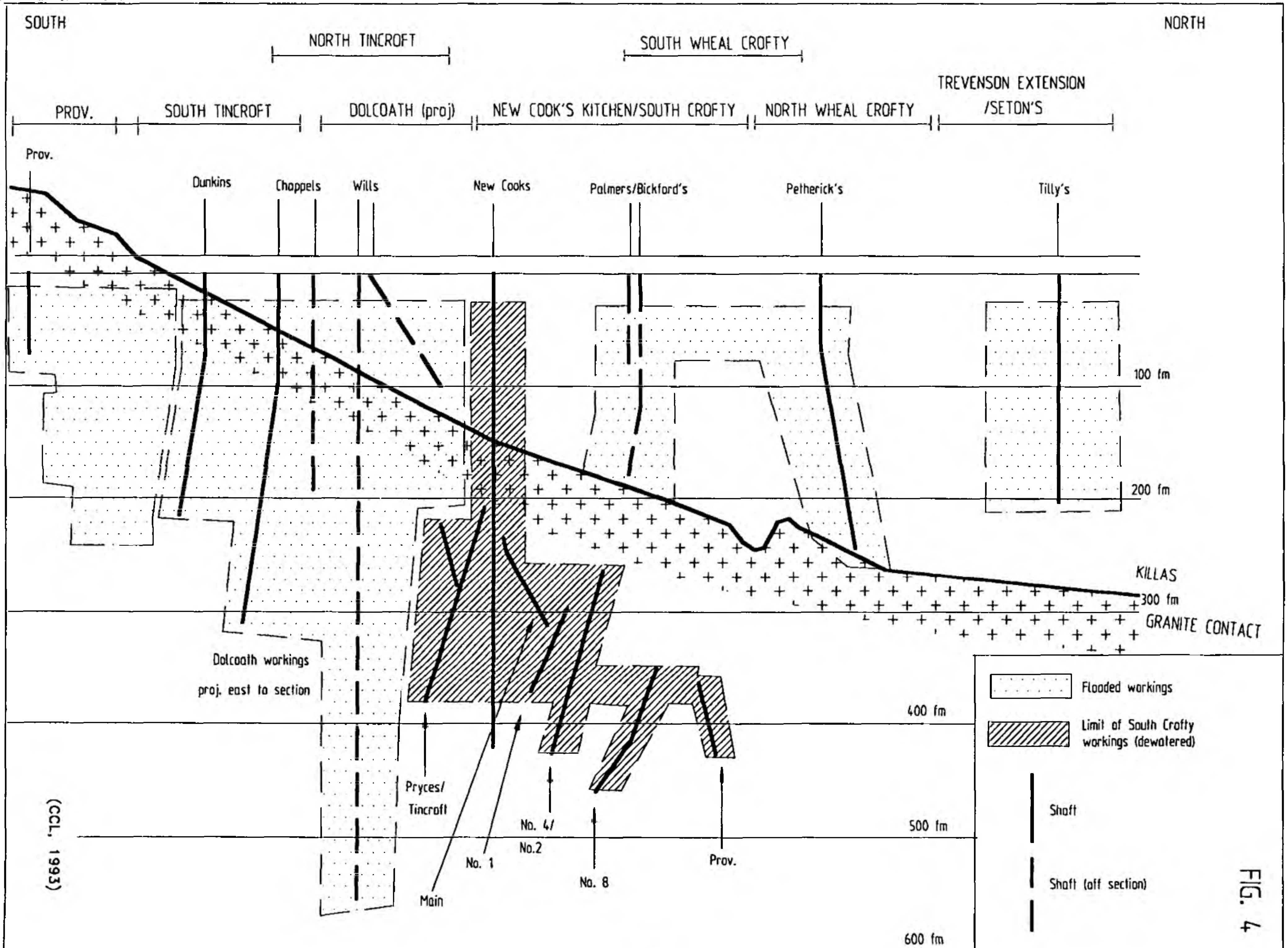
FIG. 2

SOUTH CROFTY
MINE EXTENT AND DEWATERING

FIG. 3



SOUTH CROFTY
GENERAL GEOLOGY



CROSS SECTION CAMBORNE/REDRUTH MINING AREA

(CCL. 1993)

FIG. 4

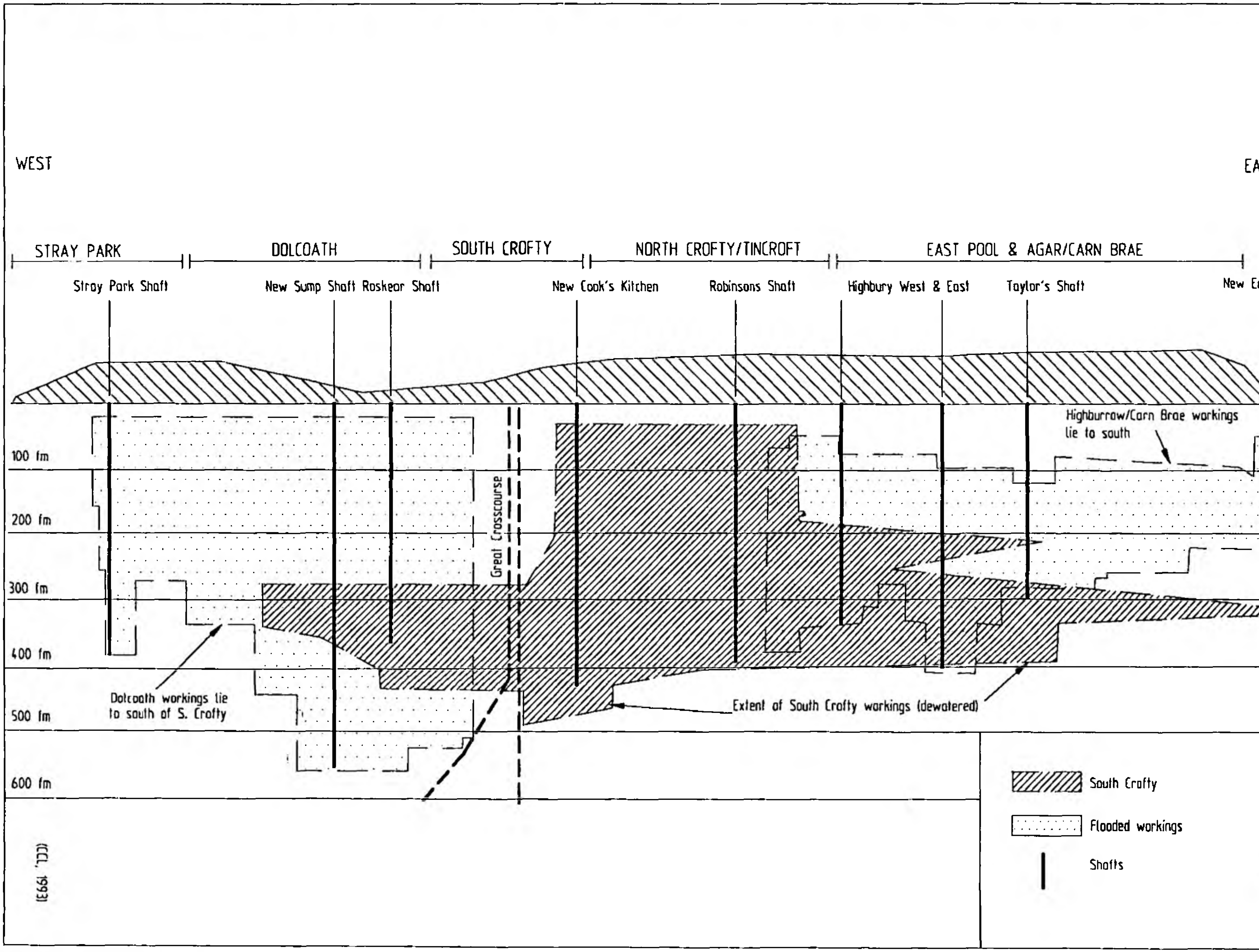


FIG. 5

LONG SECTION CAMBORNE/REDRUTH MINING AREA

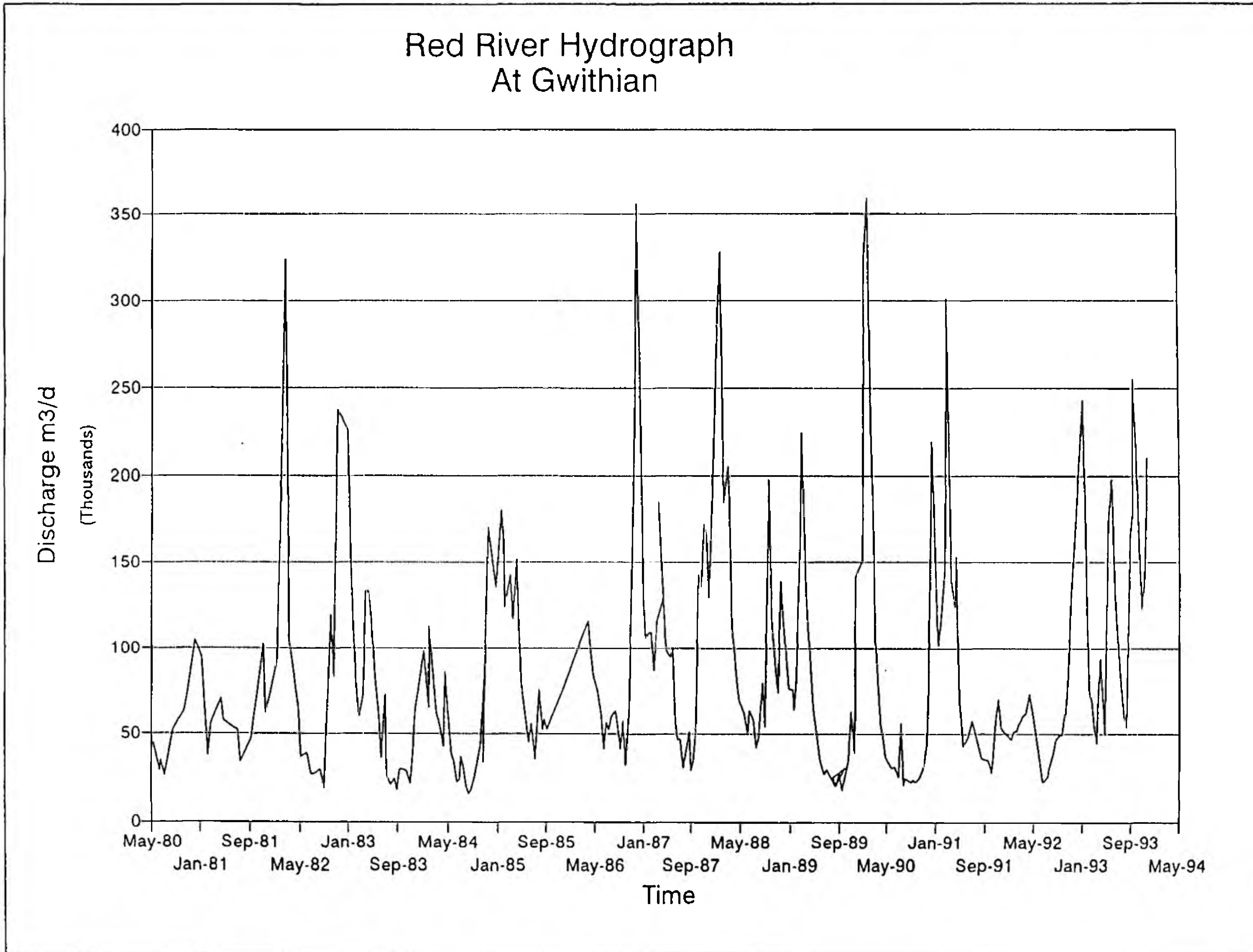
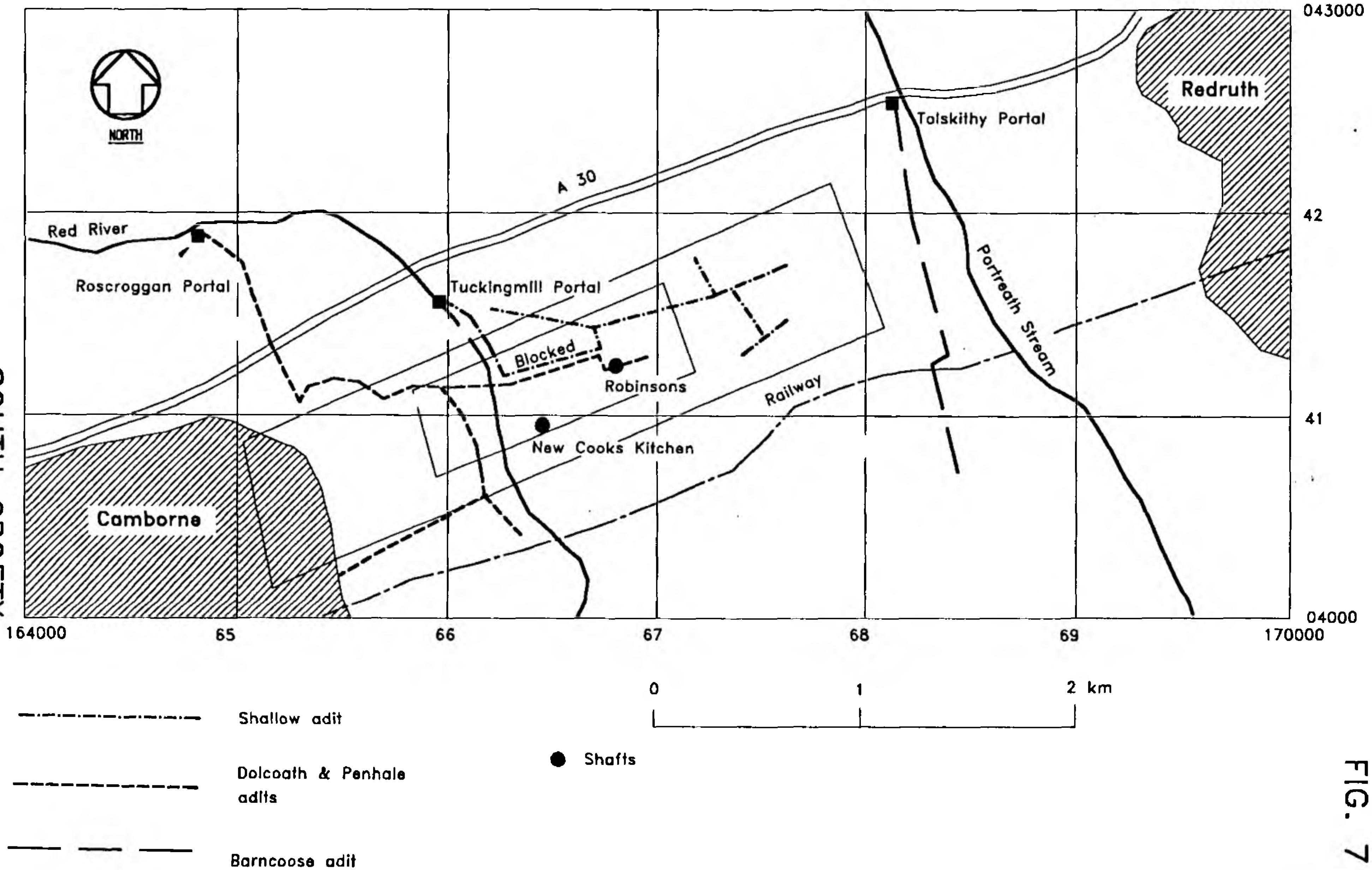

Red River Hydrograph
At Gwithian
Discharge m3/d
(Thousands)
400
350
300
250
200
150
100
50
0
May-80
Jan-81
Sep-81
May-82
Jan-83
Sep-83
May-84
Jan-85
Sep-85
May-86
Jan-87
Sep-87
May-88
Jan-89
Sep-89
May-90
Jan-91
Sep-91
May-92
Jan-93
Sep-93
May-94
Time

Fig. 6



SOUTH CROFTY
PLAN OF MAJOR ADIT SYSTEM

FIG. 7

SOUTH CROFTY
WASTE DISPOSAL, ABSTRACTIONS, DISCHARGES AND CONSERVATION AREAS

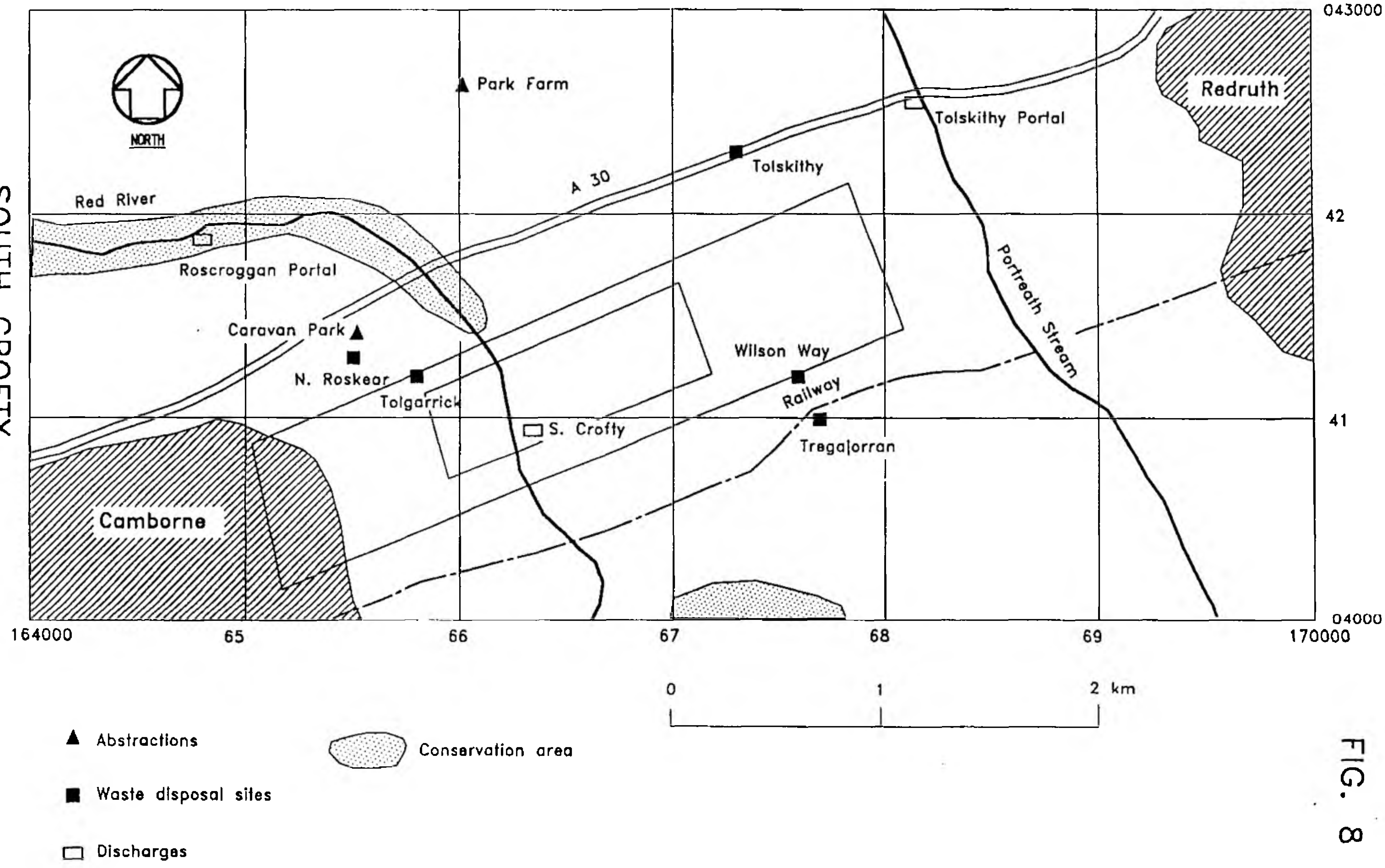


FIG. 8

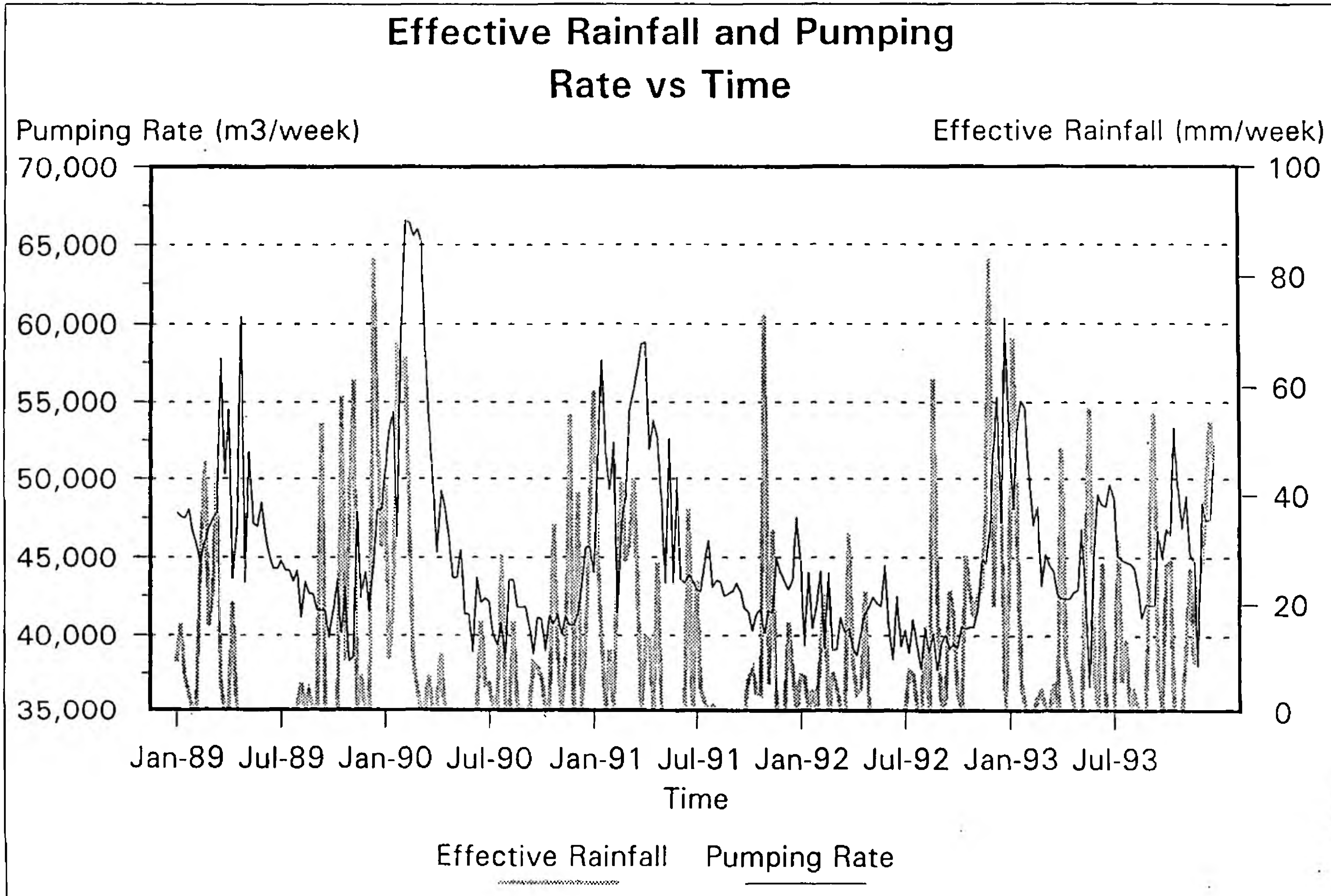

Effective Rainfall and Pumping Rate vs Time
Pumping Rate (m3/week)
Effective Rainfall (mm/week)
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
100
80
60
40
20
0
Jan-89
Jul-89
Jan-90
Jul-90
Jan-91
Jul-91
Jan-92
Jul-92
Jan-93
Jul-93
Time
Effective Rainfall
Pumping Rate

Fig. 9

APPENDIX 1 : DATA COLLECTED

A1.1 SC data

The following data was supplied by SC:

- Flow rates from each pumping station in the mine and discharge to surface from 1989 to 1994 at weekly intervals.
- Plans of the adit system and reports on the adits and water inflows to the mine and associated reports.
- Summary of geological resources as of January 1994, with sections along each lode below 225 fathoms showing the stoped out areas between each level.
- Production tonnages 1990 to 1993.
- A report on the hydrochemistry of mine and granite waters.
- Information on the Consent to Discharge to the Red River including water quality and mine layout.

Discussions with mine staff clarified the existing situation with respect to hydrology, geology and water inflows as well as the layout and operation of the workings. Additionally two visits underground were made, one to examine the general operating conditions, typical stope size, groundwater inflow and pumping stations and one to examine the adit system and to dip shafts not accessible from surface. The water level in Maynes shaft was measured at 60 m below adit level.

Water levels were also measured at two shafts from surface, as follows:

- 1/2/94 - Williams shaft 86.69 m below concrete top
- 1/2/94 - Chapples shaft 50.24 m below top of tubing

A1.2 NRA DATA

The following data was supplied by the NRA:

- Flow monitoring of the Red River at Gwithian (NGR 5852 4207) from 1984 to 1994 at approximately two week intervals.
- Daily rainfall at Camborne Met station from 1984 to 1994.

- Water chemistry at 14 different sites throughout the Red River and neighbouring catchments from 1988 to 1993.
- Land Use maps of the surrounding area.
- Waste disposal and waste transfer sites within a 5 km radius of the mine with waste type, geology and waste composition.
- Licensed abstractions (surface and groundwater) within the catchment, locations and amounts abstracted.
- Consented discharges to the Red River and catchment.
- Biological monitoring (invertebrate) of the Red River.
- Red River Catchment action plan.

A1.3 OTHER DATA SOURCES

Local planning and land use information was provided by Kerrier District Council. English Nature and the Cornwall Trust for Nature Conservation supplied information on nature conservancy areas in the Red River catchment. Geology was described from published maps and guides as well as a walkover of the area and information provided by SC.

A1.4 METEOROLOGY

Daily rainfall totals from the Camborne Met station (NGR 628 407) from 1984 to 1994 were provided by the NRA, these data were then converted to weekly figures to allow a comparison with the weekly mine pumping rate figures. Weekly soil moisture deficit and actual evapotranspiration figures at Camborne Met station from 1989 to 1993 were provided by the Meterological Office.

A 1.5 ADIT FLOW MONITORING

One-off measurements of the discharge at Dolcoath adit were available as part of a mine study on the local hydrology (Ref. 5), together with measured and estimated flows at different points within the adit system.

A1.6 WATER QUALITY DATA

Water quality and hydrochemistry data were obtained from the NRA and from SC.

A total of 14 sampling sites exist within the Red River catchment and these were monitored at various times from 1988 to December 1993. These sites are located on the Red River, its tributaries (Roseworthy, Tehidy and Reams streams) and at Dolcoath adit (see catchment map, Fig A1).

All sites were monitored for the following parameters: pH, temperature, dissolved oxygen, chemical oxygen demand, Hg, Cd, Nitrate, sulphate,Na, Ca, Mg, Ca, Zn, Al, Pb, As, Fe, Ni, Cl, F, ammonia, suspended solids and total hardness.

The data available for each sampling point are summarised in Table A1 and average seasonal results from the Red River, upstream and downstream of South Crofty, and from Dolcoath adit are presented in Tables A2 to A5.

Site (NRA No)	Location	Period of Record	Sampling Frequency	Samples (total no)
R23A001	u/s Brea Tin	29/1/88 - 6/12/93	monthly	70
R23A002	d/s Brea Tin	29/1/88 - 6/12/93	monthly	77
R23A003	Roscroggan	29/1/88 - 6/12/93	monthly	82
R23A004	Dolcoath	29/1/88 - 6/12/93	monthly	70
R23A005	Kieve Bridge	29/1/88 - 6/12/93	monthly	76
R23A006	Gwithian	11/1/88 - 6/12/93	3 per month	401
R23A007	Pendarves	15/1/88 - 6/12/93	monthly	71
R23A008	Penponds	15/1/88 - 6/12/93	monthly	73
R23A009	Roseworthy	15/1/88 - 6/12/93	monthly	6

Table A1 : Water Quality Data from NRA

Appendix 1 : Data Collected

Season	pH	SO4 mg/l	Na mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Zn mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Al mg/l	As mg/l	Cd mg/l	Hg mg/l	Ni mg
W 88	6.4	19	14.7	27	12.1	3.7	.042	.019	.429	.005		.009	.005		.005
S 88	6.4	16.3	15.6	27	10.1	3.6	.027	.014	.405	.004		.01	.003		.004
W 88/9	6.0	17.4	15.1	27	10.6	3.7	.045	.016	.602	.003		.01	.002		.003
S 89	6.7	19.1	16	27	10.8	4.2	.028	.021	.292	.003		.01	.001		.008
W89/90	6.7	16.8	16.8	29	10.5	4.1	.034	.015	.184	.003		.01	.001		.005
S 90	7.1	13.7	15.9	28	8.5	3.4	.017	.011	.255	.003		.01	.001		.001
W 90/1	6.7	16.8	21.6	38	10.1	3.5	.033	.017	.449	.015		.01	.001		.002
S 91	6.6	13.6	15.2	28	9.6	3.4	.024	.012	.341	.004		.01	.001		.001
W 91/2	7.4	13.4	15.5	29	9.7	3.5	.017	.008	.321	.002	.18			.02	.001
S 92	7.2	11.8	15.6	28	9	3.4	.017	.01	.250	.001	.11			.02	.001
W 92/3	7.1	14.1	16.7	28	11.3	3.9	.027	.012	.330	.001	.15			.02	.001
S 93	7.0	13.6	15.4	27	10.4	3.6	.022	.012	.420	.001	.12			.02	.001
W 93	6.9	14.3	15.3	28	11.7	3.7	.029	.014	.490	.001	.15			.02	.001

Table A2 : NRA Sampling Site R23A001 - Upstream Brea Tin

Season	pH	SO4 mg/l	Cl mg/l	Na mg/l	Ca mg/l	Mg mg/l	Cu mg/l	Fe mg/l	Zn mg/l	Pb mg/l	Al mg/l	As mg/l	Cd mg/l	Hg mg/l	Ni mg/l
W 88	7.1	24.6	28	15.2	16.1	4.7	.125	.62	.097	.005		.02	.005		.005
S 88	7.2	24	28	16.3	14.7	4.9	.092	.64	.088	.01		.01	.01		.02
W 88/9	6.8	21	27	15.5	14.4	4.9	.075	.26	.087	.01		.01	.008		.015
S 89	7.3	24.8	28	16.2	13.8	4.8	.160	1.03	.079	.01		.09	.001		.018
W 89/90	7.1	25.1	28	17.8	14.4	5.1	.081	.137	.072	.003		.02	.001		.006
S 90	7.2	21.9	28	16.1	12.5	4.1	.063	.151	.054	.003		.04	.001		.002
W 90/1	7.2	23.5	29	16.7	13.8	4.3	.083	.288	.076	.003		.02	.001		.004
S 91	7.1	25	29	16.0	14.6	4.7	.071	.166	.081	.004		.01	.001		.003
W 91/2	7.6	22.4	29	16.1	14	4.8	.069	.2	.074	.002	.14			.02	.003
S 92	7.5	21.2	28	16.2	14	4.8	.066	.16	.084	.001	.11			.02	.003
W 92/3	7.4	21.9	30	17.3	16	5.1	.109	.24	.102	.001	.16			.02	.007
S 93	7.5	22.6	28	15	15	4.9	.13	.26	.112	.001	.14			.02	.006
W 93	7.4	22	29	16	30	5.1	.13	.26	.112	.001	.11			.02	.007

Table A3 : NRA Sampling Site R23A002 - Upstream South Crofty

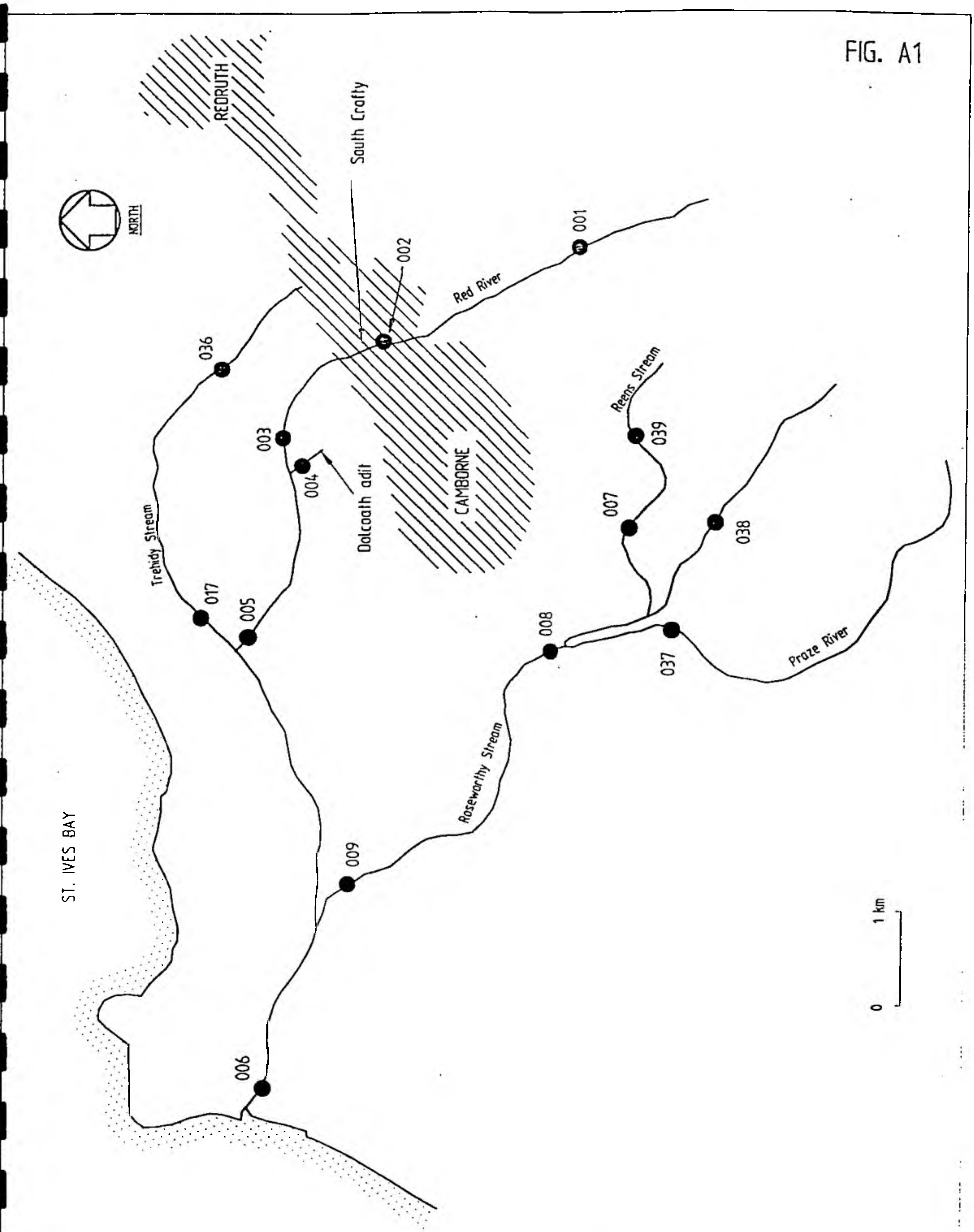
Season	pH	SO4 mg/l	Na mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Zn mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Al mg/l	As .02l	Cd mg/l	Hg mg/l	Ni mg/l
W 88	7.3	57.7	86	245	71	7.7	.44	.53	24.6	.04		.01	.02		.04
S 88	7.3	102	226	626	166	16.6	1.24	.35	5.8	.04		.02	.03		.03
W 88/9	7.0	64.6	136	378	100	11.9	.344	.1	0.9	.02		.04	.01		.02
S 89	7.1	100	302	878	228	20.3	.371	.34	3.6	.005		.04	.001		.03
W 89/90	7.0	113.4	262	765	188	18.3	1.36	.268	2.3	.57		.04	.005		.023
S 90	8.1	127.5	374	1039	263	19.7	6.8	.268	4.4	1.85		.04	.08		.03
W 90/1	7.1	74.7	175	509	130	13.2	.43	.51	1.5	.03		.02	.002		.019
S 91	7.0	97	269	755	205	12.3	.56	.48	1.4	.009		.02	.001		.022
W 91/2	7.3	81.4	114	318	86	10.3	.35	.2	1.9	.036	1.23			.02	.013
S 92	7.2	80.8	199	581	155	14.7	.37	.1	0.9	.003	1.02			.02	.018
W 92/3	7.2	42.2	44	168	37	7	.21	.1	0.45	.003	.39			.02	.009
S 93	7.3	51.2	98	280	77	9.2	.24	.1	0.88	.003	.77			.02	.014
W 93	7.2	66.3	126	378	99	11.9	.39	.1	1.0	.003	.98			.02	.018

Table A4 : NRA Sampling Site R23A003 - Roscroggan Bridge

Season	pH	SO4 mg/l	Na mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Zn mg/l	Cu mg/l	Fe mg/l	Pb mg/l	Al mg/l	As mg/l	Cd mg/l	Hg mg/l	Ni mg/l
W 88	6.9	86.4	26.7	47	34.3	14.6	1.08	.173	.577	.005		.03	.005	.02	.02
S 88	6.9	89.3	29.8	50	34.9	16.2	.94	.111	.407	.004		.02	.004	.02	.02
W 88/9	6.6	87.5	27.4	46	33.2	15.6	1.01	.15	.485	.003		.02	.003	.02	.023
S 89	6.9	85.5	28.4	46	33.9	15.9	.85	.094	.560	.004		.03	.001	.02	.02
W 89/90	6.9	86.8	28.6	48	34.5	16.5	.9	.118	.456	.004		.02	.003	.02	.022
S 90	7.2	88.3	30.5	53	35.3	16.6	.7	.066	.403	.004		.02	.002	.02	.014
W 90/1	6.9	90.2	28.4	52	35.3	15.8	.97	.12	.586	.003		.02	.003	.02	.017
S 91	6.8	87	26.2	47	33.7	15	.99	.106	.481	.004		.02	.002	.02	.019
W 91/2	7.1	81.5	27.9	48	35	16.3	.97	.102	.660	.002	.13				.019
S 92	7.1	85.9	27	47	34	16	.94	.094	.830	.001	.11				.019
W 92/3	7.0	75.3	28	56	33	13.3	.86	.13	.560	.001	.18				.017
S 93	6.9	83	27	44	32	15.5	1.0	.13	.490	.001	.14				.02
W 93	6.9	85	25	41	32	15.1	1.04	.16	.470	.001	.14				.019

Table A5 : Dolcoath Adit NRA Sampling Site R23A004 - Dolcoath Adit

FIG. A1



RED RIVER CATCHMENT

SHOWING NATIONAL RIVERS AUTHORITY SAMPLING SITES

APPENDIX 2
Rainfall, Pumping Rate and Water Inflows

Meteorological and Mine Discharge Data

Date	Weeks 1989 – 1993	Rainfall mm	Actual Evap mm	Effective Rainfall mm	Pumping 195 fathoms m3	Pumping 340 fathoms m3	Pumping 380 fathoms m3	Pumping 420 fathoms m3
07/01/89	1	15.5	6.3	9.2	47858	50400	19100	8150
14/01/89	2	22.8	6.4	16.4	47592	51123	20124	9292
21/01/89	3	11.5	4.3	7.2	47502	50675	19913	9476
28/01/89	4	9.1	5.3	3.8	48053	50528	19681	9119
04/02/89	5	0.6	3.4	0	46639	49695	19553	9304
11/02/89	6	7.5	6.5	1	45772	49147	19669	9400
18/02/89	7	37.4	7.5	29.9	44679	48735	19535	8996
25/02/89	8	53.3	7.3	46	46070	49764	20124	9916
04/03/89	9	27.1	11	16.1	46925	51484	19450	9042
11/03/89	10	29.5	7.5	22	47481	52496	19864	8686
18/03/89	11	54.9	10.3	44.6	47897	54505	20667	9351
25/03/89	12	15.4	9	6.4	57813	54634	20338	9367
01/04/89	13	8.7	9.1	0	50276	54490	19841	9306
08/04/89	14	12.2	13.1	0	54523	52932	19510	8549
15/04/89	15	33.9	13.5	20.4	43586	49876	20817	12362
22/04/89	16	12.7	12.2	0.5	46881	53744	20688	10360
29/04/89	17	15.5	15.8	0	60464	52555	20949	9367
06/05/89	18	1.3	17	0	43340	51955	21022	9306
13/05/89	19	2.7	22	0	51740	50647	19905	10165
20/05/89	20	2.3	22.1	0	47178	49668	19589	10053
27/05/89	21	0	22.3	0	46986	49448	19337	7549
03/06/89	22	7.8	16.9	0	48503	48667	19303	7404
10/06/89	23	7.8	14.3	0	46498	48437	19336	8958
17/06/89	24	3.2	12.7	0	45196	48134	19654	9754
24/06/89	25	0	8.2	0	44232	47225	19161	9882
01/07/89	26	11.9	13.7	0	44232	47225	19161	9882
08/07/89	27	10.4	11.9	0	44780	47479	19776	9936
15/07/89	28	0	3.4	0	44138	47228	19444	9663
22/07/89	29	0	2.6	0	44125	48762	20268	10127
29/07/89	30	3.4	3.4	0	43410	46011	18724	9534
05/08/89	31	0.8	0.8	0	44136	44242	18374	9379
12/08/89	32	21.6	16.2	5.4	41159	44999	18855	9699
19/08/89	33	8.5	13.9	0	43433	45935	19123	9746
26/08/89	34	8	4.6	3.4	42611	44907	19038	10132
02/09/89	35	8.9	12.3	0	42611	44908	19038	9650
09/09/89	36	0.3	0.3	0	41625	44449	19092	9838
16/09/89	37	62.4	9.3	53.1	41625	44449	19092	9838
23/09/89	38	5.5	14.3	0	41625	44449	19092	9838
30/09/89	39	0.6	11.8	0	39844	43936	19017	9461
07/10/89	40	6.4	11.4	0	41660	43557	18857	9199
14/10/89	41	8.9	10.6	0	43471	43141	18586	9657
21/10/89	42	67.4	9.2	58.2	40132	43603	18957	9547
28/10/89	43	18.1	8.7	9.4	43043	43248	18761	9546
04/11/89	44	50.5	10.4	40.1	38273	42943	18637	9815
11/11/89	45	69.2	8.2	61	38528	44488	18867	8816
18/11/89	46	5.6	7.2	0	47872	45721	18726	9313
25/11/89	47	13.2	6.2	7	42365	44932	18284	8738
02/12/89	48	0	4.2	0	44048	44440	18530	8628
09/12/89	49	0	5.3	0	41640	45871	19351	9686
16/12/89	50	90.2	7	83.2	44397	45934	19131	9613
23/12/89	51	59.2	7.3	51.9	48028	50260	18520	9190
30/12/89	52	35	4.3	30.7	48028	50260	18520	9190
07/01/90	53	45.4	3.5	41.9	50643	51404	19046	9061
14/01/90	54	13.8	3.9	9.9	53245	52926	20553	9975
21/01/90	55	25.1	5.2	19.9	54391	52387	19551	9178
28/01/90	56	76.7	8.7	68	46347	52906	18987	8664
04/02/90	57	69.4	8.5	60.9	60017	61630	21286	9451
11/02/90	58	71.4	6.1	65.3	66593	63171	24659	9435
18/02/90	59	43	6.2	36.8	66412	66580	28688	9479
25/02/90	60	18.6	7.8	10.8	65573	57830	20587	9450
04/03/90	61	18.7	13.3	5.4	66046	61455	23415	9475
11/03/90	62	0.4	8.5	0	65138	59292	20694	9513
18/03/90	63	2.8	10.9	0	58243	57209	19613	8949
25/03/90	64	17.5	10.6	6.9	53674	53460	19254	8916
01/04/90	65	0.3	11.1	0	49619	51102	19295	8672
08/04/90	66	3.1	15	0	45321	50650	20183	8343
15/04/90	67	24.6	13.5	11.1	49262	48464	19144	8372
22/04/90	68	15.8	17.6	0	48122	47513	19319	9424
29/04/90	69	2.6	15.6	0	46379	47589	19313	9659
06/05/90	70	0	29.6	0	43676	46334	25199	9433
13/05/90	71	1.8	14.9	0	43676	46334	25199	9438
20/05/90	72	12.5	16.8	0	45538	45848	19674	9739
27/05/90	73	0	12.8	0	41377	45941	20030	10899

Meteorological and Mine Discharge Data

Date	Weeks 1989 – 1993	Rainfall mm	Actual Evap mm	Effective Rainfall mm	Pumping 195 fathoms m3	Pumping 340 fathoms m3	Pumping 380 fathoms m3	Pumping 420 fathoms m3
03/06/90	74	11.2	14.7	0	41377	45941	20030	10236
10/06/90	75	11.6	19.5	0	38921	45668	20153	10019
17/06/90	76	7.6	7.9	0	43719	44800	19924	10240
24/06/90	77	38.8	22	16.8	42104	44456	19756	10028
01/07/90	78	24	19	5	42402	44932	19635	9929
08/07/90	79	24.9	19.4	5.5	42172	44729	19515	10142
15/07/90	80	0	29.1	0	40049	44273	19375	10486
22/07/90	81	0	8.7	0	39360	44825	19888	10227
29/07/90	82	43.1	14	29.1	40834	45089	19919	10225
05/08/90	83	0	26.4	0	38437	45181	20288	10130
12/08/90	84	0	8.1	0	43548	44089	16383	9785
19/08/90	85	36.5	19.7	16.8	43548	44089	16335	8814
26/08/90	86	0.4	13.8	0	41813	44366	22107	10764
02/09/90	87	16.5	19.1	0	41813	44366	17367	8532
09/09/90	88	3.2	7	0	41882	44385	19529	7982
16/09/90	89	0	0	0	40633	44495	19570	7970
23/09/90	90	22.2	13.1	9.1	38770	44665	20915	8084
30/09/90	91	20.6	12.2	8.4	41155	43302	19238	7724
07/10/90	92	21	14.4	6.6	41065	43176	18776	6970
14/10/90	93	10.5	10.8	0	38989	43037	19019	7626
21/10/90	94	9.6	7.8	1.8	41273	43039	19261	7887
28/10/90	95	45.3	10.7	34.6	40752	42533	19361	7734
04/11/90	96	21.9	11	10.9	41374	42338	18930	7196
11/11/90	97	7.5	8.4	0	40075	43026	18745	7085
18/11/90	98	19.3	8.1	11.2	41233	42833	18681	7315
25/11/90	99	64.2	9.4	54.8	40663	43105	17929	7182
02/12/90	100	0	4.6	0	40705	43745	18460	6805
09/12/90	101	46.8	6.6	40.2	41308	44230	18330	6710
16/12/90	102	0.5	5.3	0	43385	45252	18471	6973
23/12/90	103	19.4	4.5	14.9	45688	44798	17283	6406
30/12/90	104	45.4	6.6	38.8	45688	44798	17283	6406
07/01/91	105	67.6	8.4	59.2	43986	47707	17248	6395
14/01/91	106	35.7	7.5	28.2	51554	52317	13837	6421
21/01/91	107	19.7	6.4	13.3	57712	51515	17974	6346
28/01/91	108	0.1	3.5	0	51622	50883	18495	6604
04/02/91	109	16.1	4.5	11.6	49274	49610	18385	6499
11/02/91	110	6.7	6.4	0.3	52411	55960	21975	7763
18/02/91	111	34.1	6.4	27.7	41444	41373	16522	5625
25/02/91	112	46.3	4	42.3	47369	48893	19701	6485
04/03/91	113	35.4	7.6	27.8	48760	50773	21167	6453
11/03/91	114	39.7	8.2	31.5	54504	51458	18659	6397
18/03/91	115	48.9	6	42.9	55734	53745	18591	6294
25/03/91	116	32.2	11	21.2	57132	55542	19372	6297
01/04/91	117	6.6	8.5	0	58705	55837	20468	6536
08/04/91	118	29.8	15.6	14.2	58814	53658	19125	6355
15/04/91	119	25.9	12.3	13.6	51915	52712	19070	6452
22/04/91	120	11.4	21.9	0	53838	51860	18700	6150
29/04/91	121	41.3	13.7	27.6	52691	50490	18673	6244
06/05/91	122	12	17.1	0	48708	49626	18796	6286
13/05/91	123	1.9	14.6	0	43337	48590	18864	6870
20/05/91	124	0.9	15.5	0	52657	48017	19029	6649
27/05/91	125	0.5	22.6	0	43301	46626	18604	6397
03/06/91	126	0.7	14.5	0	50134	46098	18440	6514
10/06/91	127	6.5	15.6	0	43563	45258	18810	6454
17/06/91	128	17.7	19.5	0	43329	44787	18645	6598
24/06/91	129	55.9	18.6	37.3	43880	44567	19001	6767
01/07/91	130	15.5	17.3	0	43495	44641	21248	7154
08/07/91	131	44.6	20.4	24.2	42978	45005	23906	7191
15/07/91	132	20.8	16.7	4.1	42805	45221	23824	7771
22/07/91	133	15.4	14	1.4	44619	45660	19536	7091
29/07/91	134	3.1	17.6	0	46106	45798	19412	7187
05/08/91	135	16.1	15.3	0.8	43084	44992	19234	7044
12/08/91	136	3.7	13	0	43528	45151	18810	7162
19/08/91	137	2.7	16	0	43398	44923	20221	7563
26/08/91	138	13.5	18.6	0	42545	44863	20056	7118
02/09/91	139	1.3	18.6	0	42716	44638	18227	6898
09/09/91	140	0	14	0	42835	44370	18280	6983
16/09/91	141	2.9	7.6	0	43372	44435	18418	7330
23/09/91	142	10.7	12.1	0	42835	43877	18050	6919
30/09/91	143	12.4	14.4	0	41763	43845	18104	7047
07/10/91	144	19.2	12.8	6.4	41474	43452	18351	7079
14/10/91	145	17.8	9.8	8	40305	37554	18078	7193
21/10/91	146	16.9	13.6	3.3	41358	43976	18395	7437

Meteorological and Mine Discharge Data

Date	Weeks 1989 – 1993	Rainfall mm	Actual Evap mm	Effective Rainfall mm	Pumping 195 fathoms m3	Pumping 340 fathoms m3	Pumping 380 fathoms m3	Pumping 420 fathoms m3
28/10/91	147	8	5.1	2.9	41715	43503	18102	7029
04/11/91	148	81.2	8.1	73.1	40157	43470	17615	6659
11/11/91	149	14.5	9.4	5.1	41601	45424	17743	6812
18/11/91	150	41.2	7.4	33.8	41440	45305	17638	6777
25/11/91	151	2.7	6.8	0	44941	46252	17592	6764
02/12/91	152	0.3	2.8	0	44036	46194	17618	6678
09/12/91	153	0	6.5	0	43430	45666	17534	6676
16/12/91	154	19.7	3.1	16.6	42930	45319	17570	6608
23/12/91	155	16.1	8.1	8	43602	44929	17500	6770
30/12/91	156	0.9	3.7	0	47627	44399	17285	6953
07/01/92	157	11.8	4.8	7	44882	44140	17603	7473
14/01/92	158	10.2	3.7	6.5	39369	42411	17757	8585
21/01/92	159	0	2.6	0	44069	44168	17596	8430
28/01/92	160	7.6	3.8	3.8	40445	43594	17559	8208
04/02/92	161	0	3.5	0	41969	44036	17645	8006
11/02/92	162	19.8	7.3	12.5	44116	43749	17484	7857
18/02/92	163	29.5	7.6	21.9	39205	43160	17240	7895
25/02/92	164	0.5	6.8	0	44004	43861	18447	8263
03/03/92	165	14.3	6.8	7.5	39058	44703	18498	7845
10/03/92	166	12.9	8.8	4.1	39180	44434	18460	7952
17/03/92	167	1.9	6.4	0	41174	44534	18532	7944
24/03/92	168	4.8	12.1	0	40166	44619	18417	8085
31/03/92	169	46.1	13	33.1	40472	43666	18083	7800
07/04/92	170	21.5	12.3	9.2	39264	43709	18377	7776
14/04/92	171	21.1	17.8	3.3	38716	44068	18533	8043
21/04/92	172	15.5	11.2	4.3	40196	45408	21003	8850
28/04/92	173	38.2	15.9	22.3	41427	44653	18559	7786
05/05/92	174	7.1	18.4	0	41794	43962	17493	7231
12/05/92	175	7.5	15.9	0	42499	45177	17838	7136
19/05/92	176	0.5	27.5	0	42073	44920	21687	7370
26/05/92	177	1.6	23.3	0	41875	44702	18018	7186
02/06/92	178	12.1	17.6	0	44503	44403	17779	6865
09/06/92	179	7.2	12.2	0	40549	44206	18260	7035
16/06/92	180	0.7	11.2	0	38495	45320	19248	8424
23/06/92	181	0	6.3	0	42517	44060	18405	7076
30/06/92	182	0.5	7.6	0	39314	44246	18659	7730
07/07/92	183	6.8	10.5	0	40364	44023	18885	8323
14/07/92	184	20.6	13	7.6	38896	44046	18810	8050
21/07/92	185	25.5	18.7	6.8	41052	43453	18746	7979
28/07/92	186	5	19.6	0	39366	43620	19414	8207
04/08/92	187	5.6	7.5	0	37852	42440	17950	7579
11/08/92	188	33.8	17.8	16	40429	42700	18362	8092
18/08/92	189	14.4	17.2	0	38923	42275	18077	7740
25/08/92	190	78.3	17	61.3	40162	42404	18348	7787
01/09/92	191	39.2	19.2	20	37754	42995	18809	8336
08/09/92	192	17.7	17.7	0	39549	42718	19092	8255
15/09/92	193	16	13.6	2.4	40057	43157	19343	8474
22/09/92	194	32.5	10	22.5	39239	43569	19037	8611
29/09/92	195	28.2	10.2	18	39469	43863	18104	8647
06/10/92	196	15.9	12.6	3.3	39254	44302	19471	8655
13/10/92	197	1.3	12	0	40573	43569	18753	7732
20/10/92	198	40.3	11.3	29	40414	43573	18482	7783
27/10/92	199	35.2	12.8	22.4	40541	43531	18407	7452
03/11/92	200	25.1	7.4	17.7	40540	43639	18278	7655
10/11/92	201	27.3	5.7	21.6	41495	44426	18537	7578
17/11/92	202	33.2	10.3	22.9	44883	46397	19632	8459
24/11/92	203	41.5	5.3	36.2	44598	44834	18075	7030
01/12/92	204	90.4	7.2	83.2	46682	47027	18567	7279
08/12/92	205	25.6	6	19.6	51751	55149	23145	7664
15/12/92	206	54	2.9	51.1	55376	53326	20287	7327
22/12/92	207	40.8	5.6	35.2	47253	52173	19142	7099
29/12/92	208	0	2.5	0	60397	53453	19965	6722
07/01/93	209	35.5	4.4	31.1	52757	51042	18296	6349
14/01/93	210	77	8.2	68.8	48112	50244	18841	6875
21/01/93	211	36.2	5.9	30.3	53269	52480	20242	7416
28/01/93	212	11.4	6.5	4.9	55114	53281	20623	7388
04/02/93	213	0.7	2.5	0	54632	52498	20130	7210
11/02/93	214	1.1	3.3	0	50237	50736	18882	7093
18/02/93	215	1.7	5.1	0	47066	49255	19148	7366
25/02/93	216	10.7	8.3	2.4	48308	48222	18533	7221
04/03/93	217	13.3	9.7	3.6	43184	47399	19433	7185
11/03/93	218	1.4	7	0	45237	46410	18312	7163
18/03/93	219	0.7	9.2	0	44495	45680	18214	7097

Meteorological and Mine Discharge Data

Date	Weeks 1989 - 1993	Rainfall mm	Actual Evap mm	Effective Rainfall mm	Pumping 195 fathoms m3	Pumping 340 fathoms m3	Pumping 380 fathoms m3	Pumping 420 fathoms m3
25/03/93	220	15.9	10.9	5	44113	44689	17991	7111
01/04/93	221	11.7	11.6	0.1	42616	43760	17689	6949
08/04/93	222	63	14.2	48.8	42396	43687	18044	7177
15/04/93	223	22.6	12.3	10.3	42359	43262	17852	6859
22/04/93	224	19.5	13	6.5	42369	43427	17788	6954
29/04/93	225	10.6	19.1	0	42804	44097	18240	7327
06/05/93	226	1.9	20.7	0	42957	43851	17989	7478
13/05/93	227	10.2	16.6	0	46864	43771	18134	7369
20/05/93	228	53.6	22.1	31.5	42108	45157	19728	7494
27/05/93	229	73.6	17.6	56	36475	44236	19380	7836
03/06/93	230	26.6	19	7.6	45158	46696	20432	7949
10/06/93	231	7.2	18	0	49033	48661	20741	7595
17/06/93	232	45	17.4	27.6	48376	47451	19200	7476
24/06/93	233	1.1	21.6	0	48268	50049	21774	7626
01/07/93	234	2.9	20.9	0	49647	49601	21819	7464
08/07/93	235	7	20.2	0	48804	48374	21421	8157
15/07/93	236	51.4	19.6	31.8	45067	49063	21583	8119
22/07/93	237	23.8	18.4	5.4	44846	48673	21861	8031
29/07/93	238	29.8	16.2	13.6	44722	49136	22033	8542
05/08/93	239	11.2	19.6	0	44599	48853	21755	8259
12/08/93	240	21.2	18.3	2.9	44292	48502	21729	8555
19/08/93	241	0.8	20.3	0	43059	48860	22274	8995
26/08/93	242	5.7	18.9	0	41078	47486	21456	8474
02/09/93	243	4.4	16.4	0	42005	47375	20565	7992
09/09/93	244	53.5	17	36.5	41937	45799	19516	7253
16/09/93	245	71.7	16.4	55.3	41942	46605	20388	8069
23/09/93	246	19.6	12.2	7.4	46738	49590	23348	8040
30/09/93	247	6.9	14.1	0	44892	49092	23040	7892
07/10/93	248	40	12.8	27.2	46854	48772	22593	7473
14/10/93	249	37.4	9.7	27.7	46425	51184	25031	7739
21/10/93	250	1.4	11.5	0	53417	54102	28575	7636
28/10/93	251	0.1	7.9	0	49351	52025	29048	7534
04/11/93	252	2.7	4.9	0	46888	51393	25531	7820
11/11/93	253	17.9	7	10.9	48923	50919	22345	8382
18/11/93	254	34.9	8.2	26.7	45253	50793	25269	8322
25/11/93	255	14.6	5.5	9.1	44699	50618	25756	8240
02/12/93	256	29.8	5.7	24.1	37989	49220	24429	7652
09/12/93	257	36.5	9.2	27.3	48506	50439	25477	8514
16/12/93	258	49.7	10.6	39.1	47369	50087	24415	7347
23/12/93	259	59.2	5.5	53.7	47490	51393	20131	7516
30/12/93	260	51.8	5.7	46.1	51094	53317	20480	7495

Inflow Calculation

	Total Rainfall mm	Total Effective Rainfall mm	Total Pumping Rate m3/yr	Head Dependent Flow m3/yr	Rainfall Dependent Flow m3/yr	Total Inflow Under Flooding Conditions m3/yr
Average 1989–1993	1082.0	657.0	2352004.9	705601.5	940802.0	1646403.4
Maximum 1952–1993	1632.0	991.0	3547571.2	1064271.3	1419028.5	2483299.8

APPENDIX 3
Production Tonnages and Voidage

Historical Production Figures (taken from Dines, 1956)

New Cooks Kitchen mine 1877–1891 470 tons of black tin and 2820 tons of 7% copper ore
470 tons of black tin = 42112 tons of tin ore
South Wheal Crofty 1854–1905 5080 tons of black tin, 36908 tons of 5% copper ore
1110 tons pyrite, 3250 tons arsenic.
Wolfram output ranges from 50–150 tons annually

Historical and Recent Production Figures (taken from RTZ, 1985)

1906–1959 75,000 tons per year
1960–1967 92,000 tons per year
1985 250,000 per year

Year	South Crofty Ore (tonnes)
1970	95,620
1971	113,750
1972	145,000
1973	162,831
1974	139,342
1975	205,371
1976	218,800
1977	214,701
1978	236,000
1979	210,760
1980	239,691
1981	233,139
1982	182,265
1983	211,545
1984	247,311

1854–1905	Tons of ore Black Tin	Copper	Wolfram	Arsenic	Pyrite
New Cooks	42,112	2,820			
South Wheal Crofty	455,168	36,908	5,000	3,250	1,110
Total tons	546,368				
Total tonnes	557,516				

Recent Production Figures (taken from mine records)

South Crofty Hoisted Tonnage 1990–1993 (tonnes)

	1990	1991	1992	1993
Jan	25,000	16,020	13,750	12,450
Feb	19,170	12,600	13,470	15,500
Mar	19,250	11,300	15,050	14,900
Apr	14,700	13,850	15,200	16,250
May	11,300	11,050	11,950	13,780
June	15,566	11,960	12,450	15,100
July	21,670	13,950	14,600	18,300
Aug	9,200	9,970	12,600	13,150
Sept	14,800	13,050	13,700	13,200
Oct	17,680	15,050	16,200	17,300
Nov	15,550	12,380	14,700	13,250
Dec	10,160	10,400	12,700	12,400
Sub Total	194,046	151,580	166,370	175,580
Total	687,576			
Average	171,894			

Voidage with different stope widths

Stope Width (m)	Total plus 20% safety	Total Volume	Total Adit–225 (225–470 x 1)	Total 225–470	Level (fathoms) 225–245	245–260	260–290	290–310	310–335	335–360	360–380	380–400	400–420	420–445	445–470
1	2,102,740	1,752,283	876,142	876,142	28,000	54,213	146,107	185,900	183,063	111,500	78,160	49,400	34,800	2,500	2,500
1.5	3,154,109	2,628,425	1,314,212	1,314,212	42,000	81,319	219,160	278,850	274,594	167,250	117,240	74,100	52,200	3,750	3,750
2	4,205,479	3,504,566	1,752,283	1,752,283	56,000	108,425	292,213	371,800	366,125	223,000	156,320	98,800	69,600	5,000	5,000
2.5	5,256,849	4,380,708	2,190,354	2,190,354	70,000	135,531	365,266	464,750	457,656	278,750	195,400	123,500	87,000	6,250	6,250
3	6,308,219	5,256,849	2,628,425	2,628,425	84,000	162,638	438,320	557,700	549,188	334,500	234,480	148,200	104,400	7,500	7,500
3.5	7,359,589	6,132,991	3,066,495	3,066,495	98,000	189,744	511,373	650,650	640,719	390,250	273,560	172,900	121,800	8,750	8,750

S. Crofty – Measured areas of stopes below 225 Fathoms (square metres)

Lode	Level (fathoms) 225–245	245–260	260–290	290–310	310–335	335–360	360–380	380–400	400–420	420–445	445–470
No 1	9900	9900	31500	22500	7650	3600					
No. 2	9000		1800	13200	8000	8400	3000	5600			
No. 2 NCK (S)					3600	4500	2250				
2nd S. DIPPER			4950	2700	3600	5400	5400				
No. 3	6300	7200	19800	19350	8550	1800					
No. 3B				9900	12150	5400	9360				
No.4		2400	32000	36800	35000	13600	22900	7200	7200		
No. 4 (S)				2700	4050	4050					
No. 6			7200	7425	4725	0					
No.6 (N)				1800	4050	4050					
No. 8					1600		6400	12800	6120	2500	
No. 9			1800	9900	15300	11700	2700				
Dolcoath North			3200	12000	7200	5600					
Dolcoath North (N)											
Dolcoath South (W)			6400	13200	18000	3600					
Dolcoath South (S)					6075						
Dolcoath Middle				2700							
Great											
Intermediate		900									
Little Middle											
Main		5850	6300	3375							
New North			6750								
North		2363	7007	4950							
North Pool A Zone						6000					
North Pool B Zone						4500	1750				
North Pool C Zone					5400						
North Pool Quartz							1800				
No. 3B Pegmatite					2363	2700	3600				
Province									2880		
Pryce's		7200	7000	11600	8400			8000	9000		
Roskear A								14200	7200		
Roskear B											
Roskear C							3600	1600	2400		
Roskear D											
Roskear E											
Roskear G											
Roskear South					17100	13500	5400				
Roskear No. 1 North					2250	2700					
Tincroft	2800	11200	3200	6400	8000	10400	10000				
Wet		7200	7200	5400							
Total m2	28000	54213	146107	185900	183063	111500	78160	49400	34800	2500	2500

APPENDIX 4
South Crofty Adit Systems

SOUTH CROFTY ADIT SYSTEMS

CONTRACTED BY:

KNIGHT PIESOLD PARTNERS
WHEAL JANE OFFICE
BALDHU
TRURO
TR3 6EE

COMPLETED BY:

CARNON CONSULTANCY
SOUTH CROFTY MINE
DUDNANCE LANE
POOL
REDRUTH
TR15 3QH

SOUTH CROFTY ADIT SYSTEMS

Historical Background

South Crofty Mine, currently operated by Carnon Consolidated Limited, includes over twenty mines which operated during the nineteenth century. These mines were drained by a great number of adits over the centuries, although by the middle of the nineteenth century most water was evacuated via three or four main, deep adit systems. At present South Crofty is drained by three deep adits, which cope, to varying degrees of efficiency, with extremely large volumes of water. These three main adit systems (Barncoose, Shallow and Deep) are the subject of this report.

1.1 Barncoose Adit

On the extreme eastern side of the mine the Barncoose Adit System drains water from all of the mines along the Tolskithy Valley and at the eastern end of Carn Brea. The adit drains infiltrating surface water from the eastern end of the Carn Brea Mine, including land over and around Barncoose Mine and Wheal Druid, as well as Wheal Tehidy and Wheal Fortune to the north. There is evidence to suggest that during winter, when the ground is saturated and all of the sumps are full, large volumes of Carn Brea Mine water from as far west as Wheal Fanny and Tregajorran Mine also makes into the Barncoose Adit System. Wheal Union, Wheal Uny and the half a dozen Tolgus Mines on the Redruth side of the valley also drain into the Barncoose Adit. The adit was complete throughout the central part, to the foot of Carn Brea at Wheal Druid, by the middle of the eighteenth century. The section between Dunns shaft and the portal was probably started in the late seventeenth century. The adit replaced several ancient, shallow adits.

1.2 Pool Adit (South Crofty Shallow Adit)

Pool Adit, for over a century one of the most significant mine drainage systems in cornwall, formerly ran from its portal below Tuckingmill, through Trevenson Mine (North Wheal Crofty) and Penhellick Mine (South Wheal Crofty) into Old Pool Mine (East Pool). Eighteenth century branches of Pool Adit drained several ancient, shallow mines between Tuckingmill, Brea and Pool.

Pool Adit forms the Shallow Adit System of South Crofty. Extensions of the adit drain ground at the eastern and southern extremities of East Pool, from parts of Wheal Agar and from North Pool Mine. Currently, this adit drains into the deep workings of South Crofty, via a winze beside Burgess Shaft, Pool. Pool Adit was started in 1710 and complete to Old Pool Mine by the 1720s. The adit replaced several older adits, some of them very shallow.

1.3 Dolcoath New Deep Adit (South Crofty Deep Adit)

Dolcoath New Deep Adit removes water from the western side of the mine. The old Dolcoath, Cooks Kitchen, New Cooks Kitchen, North Roskear, South Roskear, Wheal Seton and West Wheal Seton mines are all drained to some extent by this adit system. Undoubtedly, many small, ancient mines and a few large nineteenth century mines on the extremities also drain into the system. A large proportion of all infiltrating surface water between Tuckingmill and Camborne Town is carried to the Red River by this drainage system. When the adit was completed, by the 1780s, it replaced a large number of shallow adits.

Dolcoath Shallow Adit, also known as Cooks Kitchen Deep Adit, continued to drain water from the area around the Tuckingmill Valley until the 1960s. Water from it now flows into the Dolcoath New Deep Adit.

South Crofty Deep Adit was connected to Dolcoath New Deep Adit during the nineteenth century. The section between Phillips Shaft and Maynes Shaft is known as Penhale Adit, after the mine manager at the time of its renovation at the beginning of the twentieth century.

2. Description, Present Condition and Capacity of Adit Systems

2.1 Barncoose Adit (Plans 1 & 2)

The main part of the adit consists of a relatively straight tunnel which runs from its portal, beneath the Camborne-Redruth By-Pass at Blowinghouse Viaduct, to Wheal Druid Whim Shaft, between the main line railway and Carn Brea. This spinal adit is approximately 1.5km long. Branches into Wheal Fortune, Wheal Tehidy, Barncoose Mine and Wheal Druid add another 1km or so to the total length of adit tunnel.

The condition of the adit is generally good. The section from the portal to the first shaft, a distance of some 130m, is piped, and no access can be made. The next section, some 50m in length, is through arched stonework and is generally in good condition. The height and width through the stonework is uniformly 2m x 1.2m. In this section there is a short concrete lined part with an access shaft. Between the arched stonework and a new section of adit, a distance of some 350m, the adit consists of an ancient (possibly late 17th century or very early 18th century) tunnel mostly no higher than 1.3m and 0.6m wide. The walls, which are in good condition, bear the tool marks of the pre-gunpowder era. This whole section is driven in a crosscourse (fault) and although pursuing a relatively straight line overall, the adit zig-zags along fault planes within the crosscourse. Despite the small dimensions of this section, we saw nothing to indicate that it is incapable of carrying the highest potential through-flow.

From a point just to the north of Dunns Shaft (the adit is 30m deep here), the original adit tunnel was in a very poor condition. In the late 1940s it was decided to by-pass a section some 100m in length, and then drive a new tunnel through to the main Wheal Fortune/Wheal Tehidy lode. This new drive cut out a long and poor section of adit which had been driven either on weak crosscourse material or on lode, the latter being largely stoped above and below adit level. The new section of adit is uniformly 1.8m high by 1.3m wide. Where it joins the original adit on Wheal Tehidy/Fortune lode there is a section supported by brickwork and concrete.

The tunnel south to Barncoose Mine is the original early 18th century adit. It is in good condition throughout its 500m length. The height through this section is approximately 1.7m and the width varies from 0.5m to 0.7m. There is a diversion in the adit as it approaches Barncoose Engine Shaft, which appears to have been driven in the last century.

At Barncoose Engine Shaft the water from the south is carried past by means of an 8" pipe. Little of the infiltrating surface water at Barncoose Mine is making it to the adit system. The stoped out workings on the west of the Engine Shaft have no surviving launders. The adit level to the east is also ineffective.

The adit tunnel to Wheal Druid, some 400m in length, is in a similar condition and carries similar dimension as that between Wheal Fortune and Barncoose Mine. At Wheal Druid Whim Shaft, where the adit enters Wheal Druid Mine, the adit tunnel splits into three.

2.2 Branches and Feeders

The original main drive south beneath Carn Brea, to South Carn Brea Mine, is now only accessible for a relatively short distance. This is due to the collapse of ground. A certain amount of water is entering the adit from each of the three tunnels.

The ground around adit level at Wheal Druid is frequently saturated, so that all adit walls are exuding water. In winter this is far more pronounced. The apparent explanation is that there are numerous ancient, shallow mine workings all around Wheal Druid, and these are flooded to a higher horizon than the adit. By comparison, the walls at Barncoose are generally dry. The explanation appears to be that all of the water at Barncoose which is not exhausted by the adit goes straight into the area drained by South Crofty's pumps.

At Wheal Tehidy the workings are flooded to adit level and the overflow forms a considerable proportion of the water flowing from the portal. Wheal Tehidy is connected to the Tolgus mines which are all flooded. This group of mines may well be connected underground, and the potential underground reservoir which could feed the Wheal Tehidy connection into Barncoose Adit is vast.

Wheal Fortune is drained by the pumps of South Crofty Mine. Recent work carried out in the adit has improved the efficiency of the launders and allowed the water make to flow into the main adit tunnel.

2.3 Problem Areas & Recommendations

The Wheal Fortune branch has required extensive maintenance work in recent years. In 1991-2 work was carried out to remove heavy silting and fallen debris from the launder at Dobrees Shaft. This allowed water which had been dammed and diverted into Dobrees shaft, to run past along the adit. Subsequently, work was carried out to repair the launders between Dobrees and Woolcocks shafts and re-line them with strong plastic material. This section of adit needs frequent examination to ensure that it continues to work efficiently.

The section of adit westward from Engine Shaft needs attention. Especially during wet weather large volumes of water enter our deep workings in this area. The old launders need repairing and possibly lining with plastic. The main difficulty in carrying out this work, is the distance through very low, flooded adit tunnel that materials and gear have to be carried. Should it be possible to lower materials and gear through Wheal Fortune shaft, to the north-west of Engine Shaft, the work could easily be carried out.

At Barncoose Mine there are two problem areas. The workings to the west of the main adit cannot easily or economically be tackled. The launders and timber supports have mostly gone and refurbishing the adit would be a major reconstruction job. However, to the east of the main adit, where the branch goes past Miners shaft to Davies Shaft, it is possible that work might be carried out to good effect.

This work would involve clearing blockages, reinstating launders and lining them, and checking and scaling the back in places. Access for materials and gear would be a major difficulty here. The original access shafts at Barncoose have been capped in recent years. The best solution would be to bring materials and gear through from Wheal Druid, where Wheal Druid Whim Shaft is open to surface. To bring materials through the adit from Dunns Shaft would involve some 650m of fairly tortuous tunnel. From Wheal Druid Whim Shaft the distance is nearer 400m. Although this is still a long haul through low, cramped and far from straight tunnel, it is probably the best option.

The drive westward from Wheal Druid Whim Shaft carries water over launders which are in good condition. Unfortunately, within 100m of this Shaft, there are launders which are in a rotten condition. These launders cross a gunnis into which water runs from the western side. Both the launders and the support timbers need replacing. The close proximity to Wheal Druid Whim Shaft make this task fairly straightforward.

2.4 Pool Adit (South Crofty Shallow Adit) (Plans 3,4 & 5)

The section of Pool Adit System which we are interested in is that between Wheal Agar Engine Shaft and the winze beside Burgess Shaft. There are also branches which drain the south part of East Pool, North Pool and Palmers Section of South Crofty. The section of adit between Burgess and Johns shafts and the original adit portal is now blocked or destroyed completely. The several branches that fed into the defunct section, mostly from Longclose, Cherry Garden, Wheal Seton and the north and central parts of Trevenson (North Crofty), now exhaust into South Crofty's deep workings.

The 300m section of adit between Wheal Agar Engine Shaft and Michells Shaft is extremely constricted, crooked and varies in condition. It was partially driven on lode and is at its most tortuous where it crosses the mine boundary between Wheal Agar and East Pool Mine. Tool marks indicate that it was driven from both directions. The height varies in this section between 1.4m to 1.7m and the width is as narrow as 0.5m. Before reaching Michells Shaft the adit height increases to over 2m and has been stoped above adit.

Going west from Michells Shaft to Milestone Shaft the tunnel is reduced again to a height of no more than 1.4m. This section also was driven through the boundary between East Pool and Wheal Agar mines, and twists and turns for a distance of some 80m.

After leaving Milestone Shaft the adit tunnel again goes through the mine boundary and again its height and width is restricted as it twists this way and that toward the western end of the mine. Along this 300m stretch, several side tunnels leave the main adit and old workings and shafts are encountered. The adit has been driven partially on lode, and where the back has been stoped, the timbers tend to be very low. The adit through this section is generally in poor condition, although for the most part the water flows through unimpeded. The section ends where it passes into South Crofty Mine (Penhellick Vean), and the connection is marked by a rapid fall in elevation as the water flows down a series of cataracts.

The section between South Crofty boundary and Tredinnick Shaft is through very old workings for 350m. There is documentary evidence for this section being driven during the 1710s and 1720s. In places the adit is very low, especially where launders carry the water and low timbers protect the back. There has been extensive stoping through this section, some above the adit and some parallel to it. Shafts and short drives into old workings are frequent. For the most part the adit is no more than 1.5m-1.6m high. Despite the relatively poor condition of the walls and back through this section, the water flows without serious interruption.

The section between Tredinnick Shaft and the winze beside Burgess Shaft varies between low tunnel over launders and below timbers to a drive along a crosscourse which is up to 2m in height. Again, there are numerous connections to old workings, including disused adit tunnels, old stopes and defunct shafts. It is in this section that a 1m high concrete dam has been constructed, so that water can be pumped over a blockage in the Shallow Adit to Phillips Shaft and the Deep Adit System at Penhale Adit. Since April 1994 the water which flowed down Burgess Winze has been contained behind the dam wall and has built up along the adit tunnel.

2.5 Branches & Feeders

The principal branch of Shallow Adit brings water from East Pool's South Lode, via South Shaft, Pearces Shaft, Caravan Shaft and Engine Shaft. This 300m tunnel comes into the main system from the south and joins it just east of Michells Shaft. This branch is mostly between 2m and 2.3m in height and is quite wide. One long section, driven along South Lode between South Shaft and past Pearces Shaft, is nearly 500m long. There is a crosscut south from the lode drive just west of Pearces Shaft which extends some 80m.

From Milestone Shaft there is a 350m crosscut to the north. This passes Bull Shaft and goes on to Cap Shaft, where the adit is blocked by a 'run in'. Another drive goes from Milestone Shaft to the east. The crosscut from Cap Shaft makes considerable volumes of water during wet weather. Neither tunnel gives much water in dry periods.

The crosscut to Palmers Section was driven in a crosscourse. The first part of the tunnel from the main adit to Pryces Shaft is high and narrow, being 2.3m high in places and less than 0.5m wide. The tunnel is some 2m as it goes past James Shaft and turns towards Bickfords and Palmers Shafts. During wet weather this branch makes some water but is now generally relatively dry. It is in sound condition for the most part.

Around Serpells Shaft there are several short tunnels and workings, all of which are making water.

Between Tredinnick and Burgess Shafts there are several side tunnels and old adit sections which make varying volumes of water.

2.6 Problem Areas and Recommendations

The whole of the Shallow Adit System is a problem. The radon doors which have been erected in several places throughout the system inhibit the flow of water to such an extent that through-flow is either stopped completely or slowed down to such an extent that silting and consequent seepage takes place.

This is demonstrated by the fact that the measured flow from North Pool branch, at Milestone Shaft, is at times similar to the flow into the winze at Burgess Shaft, some 600m to the west.

Before the introduction of the radon doors the flow through Shallow Adit was continuous from the eastern extremities to the winze. There was some loss en route, but by and large the water flowed right through the system.

Whilst it is not recommended that the radon doors be removed, it should be pointed out that they do contribute substantially to inefficiency in the drainage system.

The 350m to 400m section of adit between Milestone Shaft and the South Crofty boundary, has some areas which need attention. The roof needs securing, old timbers need replacing and the floor needs examination to ensure that the water flows through efficiently.

By using lycopodium spore tracer it was proved that the water entering Burgess Winze gravitated to South Crofty's deep workings. To remedy the situation, it was decided to dam the water at Shallow Adit, close to Tredinnicks Shaft, and then to place a small submersible pump into the adit and pump the water along the adit to Phillips Shaft and let it down into Deep Adit by means of a flexible pipe. This had the advantage of speed and economy. It should bring quick and cheap results. This work has now been completed and is working efficiently.

2.7 Dolcoath New Deep Adit (South Crofty Deep Adit) (Plans 7 & 8)

The main Deep Adit System is approximately 4km in length. This includes the branch to Eastern Valley and Middle Engine Shaft at Dolcoath and Cooks Kitchen Mines. The discharge at the portal can vary from 4,500 m^3d to 9,000 m^3d. This water mostly comes from Dolcoath, Cooks Kitchen and North and South Roskear Mines and represents a large proportion of infiltrating surface water for the area between Pengegon, Brea, Tuckingmill and Camborne Town.

The Deep Adit at South Crofty itself is usually known as Penhale Adit. Between Palmers Shaft and Maynes Shaft the adit was renovated and enlarged in the early years of the present century under the direction of the mine manager, Captain Penhale. The section between Palmers and Robinsons is on lode and has been stoped above and below adit in one or two places. Just north of Robinsons Shaft the adit follows a crosscourse before again coming onto a lode just east of Phillips Shaft. The adit is in reasonable condition throughout this section.

At Phillips Shaft arrangements have been made to catch the water coming down the shaft and direct it into the adit. The pumped water from Tredinnick Shaft will also be piped down Phillips Shaft from Shallow Adit. The first section of adit west of Phillips Shaft is in good condition and where there are launders, these are sound and easily maintained. There is a build up of silt in places along this stretch of adit. This silting is partially caused by the horizontal plane of the section, as well as the tendency for the water to back-up where it has been dammed to direct it into the launders. For a distance of about 150m east of Maynes Shaft the adit system is very difficult to negotiate. The launders occupy a large part of the tunnel, which is itself very low. The whole launder through this section was renovated some three years ago. A strong plastic material was used to re-line the old launders, and although far from perfect, the adit now does carry the biggest proportion of water coming into the adit away into the main drain. Long sections of this adit cross worked-out areas on timber supports.

The section immediately west of Maynes Shaft is in poor condition. Water coming into the adit is largely lost. Once into the Great Crosscourse water flows properly into the main Dolcoath New Deep Adit. At the junction with the adit from Whim Round, Valley and Middle Engine Shafts, the water flow increases dramatically. The adit through Wheal Susan into South Roskear Mine is old and small but is in relatively good condition. Between South and North Roskear, a new 300m section of adit tunnel was driven in the late 1940s. This tunnel is some 2m high by 1.3m wide and is in good condition.

Once past Pressure Shaft, the adit becomes restricted again, being no higher than 1.6m and only 0.5m wide in places. The water discharges into Doctors Shaft, on North Roskear Lode, and reappears at Daylight Shaft (Prince William Henry Shaft). In winter, there is frequently a flow past Doctors Shaft along the adit to Daylight Shaft, but normally this 250m section is relatively dry.

From Daylight Shaft, the adit runs 1km northwards to the portal at Roscroggan. This whole section is low and narrow. The average height is about 1.7m and the width 0.5m. The adit is generally in good condition throughout this section. In the lower section the water sometimes reaches the roof of the adit in winter. The adit discharges into the Red River through a deep trench which recently has had a 1m diameter concrete pipe installed.

2.8 Branches & Feeders

The adit which drains water from the western end of New Cooks Kitchen and the eastern end of Dolcoath mines via Whim Round Shaft was reconstructed in the late 1950s. The whole south running adit, between Wheal Susan and Valley Shaft, which was driven in the Great Crosscourse, was found to be in poor condition. The ground was weak and collapse were frequent. In the late 1950s a new adit tunnel was driven from Whim Round Shaft to Middle Engine Shaft (Cooks Kitchen) and Valley (Eastern) Shaft (Dolcoath). Over a quarter of the water being made by Dolcoath New Deep Adit comes from these workings.

The tunnels leading into the section between Maynes Shaft and the main adit system all make water but not in large volumes. Water also enters the adit from some of these tunnels at their western ends.

The two principal tunnels which feed into the main adit at South Roskear feed half of the total adit water into the system. This water comes from the extensive workings at South Roskear and to the west. These ancient mines include Wheal Gerry, Wheal Chance and Parkanbowen. It is probable that a proportion of this water comes from the eastern and central areas of Dolcoath as the South Roskear adit system is linked to Dolcoath's direct adit route to the portal.

2.9 Problem Areas & Recommendations

The principal problem areas in the Deep Adit System lie at South Crofty. The work carried out at Penhale Adit requires constant monitoring. It appears at present to be working efficiently. In the longer term, and in more economically relaxed times, a total reappraisal of this section is needed. With careful planning and the expenditure of reasonable amounts of cash this section can be improved immeasurably. This would ensure that the maximum quantity of water passes out of South Crofty drainage area into Dolcoath New Deep Adit.

With the bringing in of the new arrangements between Burgess and Phillips shafts (the water pumped from Shallow to Deep Adit), there will be an increased volume of water passing through Penhale Adit to Dolcoath New Deep Adit.

The worst piece of adit is that between Maynes Shaft and the Great Crosscourse. The first section, immediately to the west of Maynes Shaft, is a chaotic series of old, ineffective and inadequately arranged launders, poorly located and neglected feed channels, both wooden and plastic, and badly supported floor. It is apparent that if the water from South Crofty at Deep Adit level is to flow efficiently and in reasonable volumes to Dolcoath New Deep Adit work must be done here.

Piece-meal repairs might bring quick results, however, in the longer term, it seems clear that total stripping out and replacement is needed. The main advantage for this work is close proximity to Maynes Shaft and the sound condition of the shaft. Materials and gear can be brought right to the site without problem.

The section from the eastern side of the Great Crosscourse through to the main adit system, where the water flow increases ten-fold, has small, local areas of silting. These could be easily and economically cleared.

3. Geological Purpose of the Adits

The majority of the adits in the South Crofty mining area have been driven on crosscourses, main tin-bearing lodes and caunter lodes. All three types of structure served as water routes where surface water infiltrated the soil and, on reaching the soil-bedrock interface, continued underground through these structures. With the adits being driven on these structures, any water travelling through them could be very effectively intercepted and diverted away from mine workings below adit level. This system has worked very well, however increased use of concrete/tarmac in development on surface prevented water entering the soil and greatly increased run-off of surface water into the nearest drain system, which often enters the mine workings, thus by-passing the adit system.

3.1 Geology of Barncoose Adit (Plan 9)

The country rock found in Barncoose Adit is largely Killas, a series of metamorphosed slates of the Devonian Mylor formation. In places, the Killas has been extremely bleached, and hematized. The adit system was driven largely along a north-south direction, following one of the quartz-chalcedony-sulphide fissure filled crosscourses. Considerable secondary copper staining on the back and sidewalls indicates the high sulphide content. Occasional granitic elvan dykes have been exposed, these tend to be highly competent and unweathered. Where ground has badly deteriorated, the adit has been re-located, running parallel to the original development, driven 'off-structure' in virgin country rock. One such area being to the south of Dunns Shaft.

From the level plan, the east-west adit development, namely that draining Wheal Fortune, Wheal Tehidy and Barncoose Mines, follows Main Lode and Caunter Lode structures. These, in places, have been mined for their copper and tin content. The ground conditions in these parts of the adit remain satisfactory.

3.2 Geology Shallow Adit (Plan 10)

As in Barncoose Adit, the adit system is confined to Killas country rock. The condition of which is reasonably competent. From the level plan, it can be seen that the majority of the adit system has followed the 'water-bearing' crosscourses, Main Lode and Counter Lode structures. Very little development has been done in virgin country rock.

As in the Barncoose Adit, the adit walls are heavily stained with secondary copper mineralisation, indicative of the high primary copper content in the structures driven.

3.3 Geology of the Deep Adit (Plan 11)

The Deep Adit system is confined almost entirely to the killas country rock, which, in large part, is less weathered and more competent than in the Shallow and Barncoose Adits. As seen from the level plan, the adit system is extensively developed on the east-west striking Main Lode and Caunter Lode structures which, in main, are reasonably competent quartz-tourmaline-hematite-sulphide rich lodes. The north-south adit development follows less competent quartz-chalcedony-hematite structures which, despite being of 'softer' rock, retain reasonable competency.

As with Barncoose Adit, areas where ground has badly deteriorated, have been by-passed by crosscuts in competent rock, mostly driven 'off-structure'.

Conclusions

The adit systems at the western and eastern ends of the mine work very efficiently. The Shallow Adit from East Pool into the Robinsons Section of the mine, and Deep Adit between Robinsons Section and the Great Crosscourse are generally not efficient. Many of the problems detailed above can be economically and quickly rectified, whereas others need time, planning and financial commitment to bring up to the required standard.

Recommended Areas for Immediate Attention

1. Deep Adit west of Maynes Shaft.

2. Barncoose Adit at Wheal Fortune Engine Shaft.

3. Barncoose Adit west of Wheal Druid's Whim Shaft.

Each of these tasks require the removal of old launders and support timbers and replacing them with new ones. It is impossible, within the constraints placed by the time limits, to adequately estimate the cost of materials and man hours involved in carrying out the above work.

J A Buckley B.A.(Hons), M.Phil, M.C.S.M., F.R.Hist.S.
M J Hodgson B.Sc. (Hons), M.Sc., M.I.M.M.

FIG. A4.1

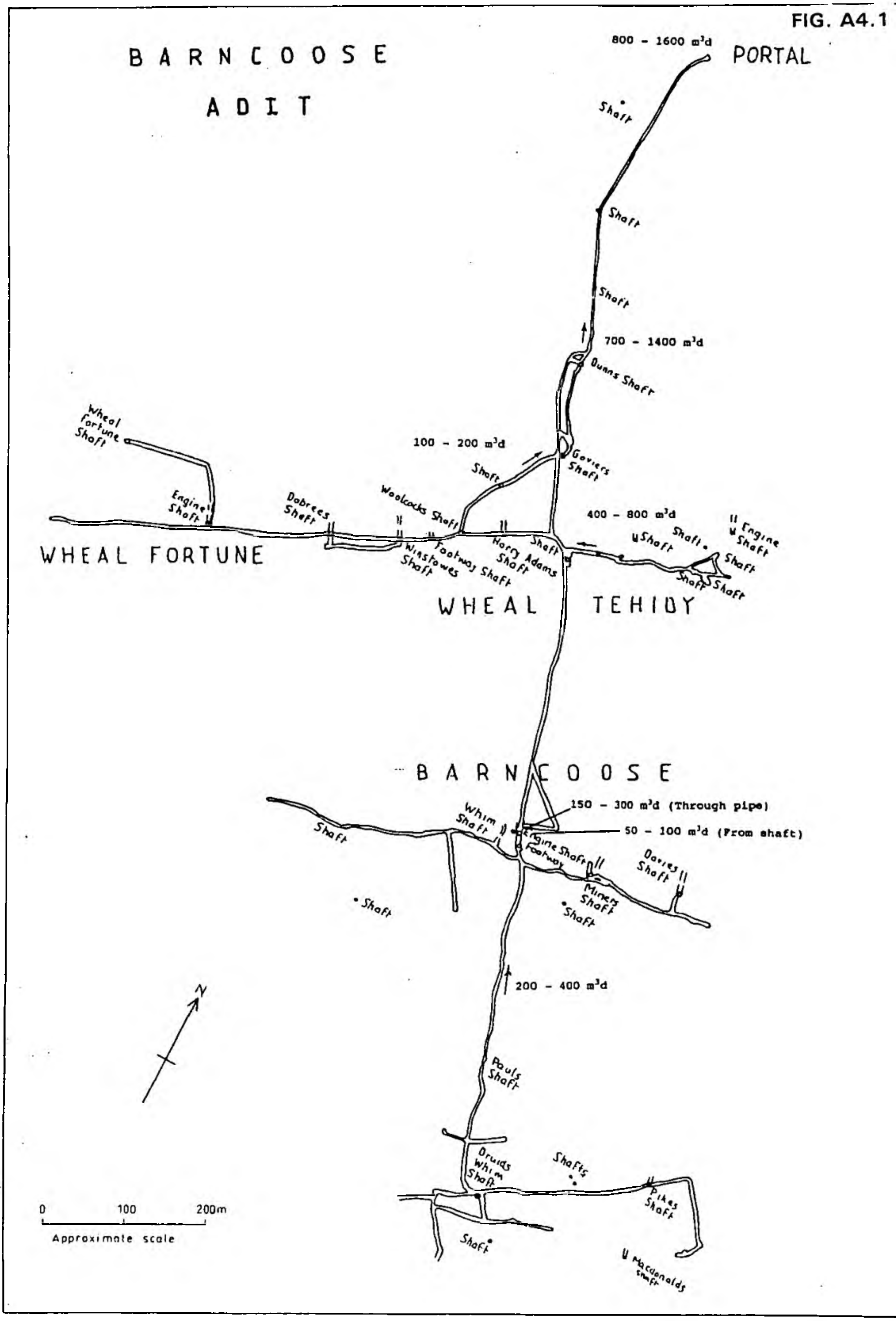
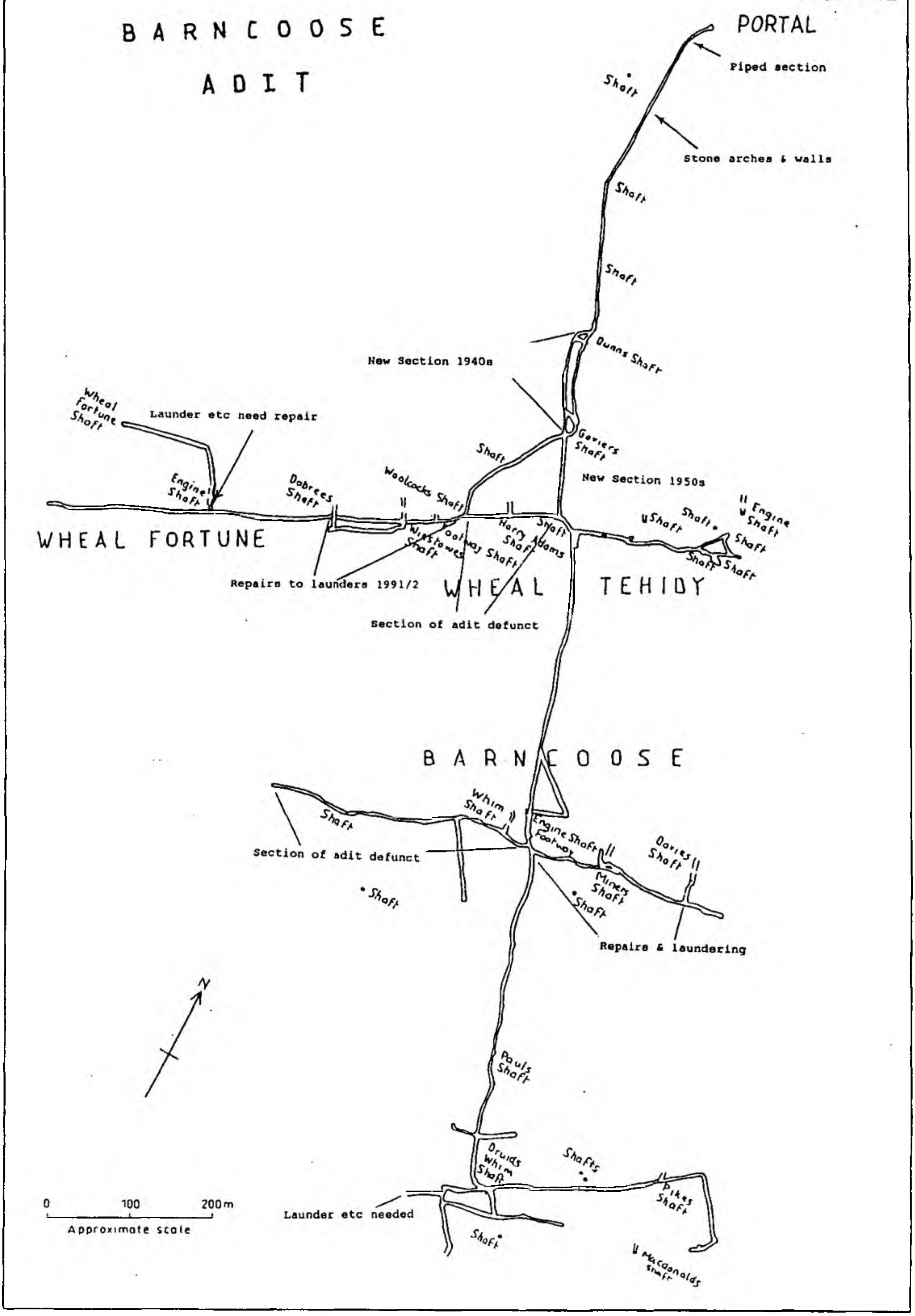

BARNCOOSE
ADIT
800 - 1600 m³d
PORTAL
Shaft
Shaft
Shaft
700 - 1400 m³d
Dunns Shaft
Wheal Fortune Shaft
100 - 200 m³d
Goviers Shaft
Shaft
Engine Shaft
Dobrees Shaft
Woolcocks Shaft
400 - 800 m³d
Engine Shaft
Shaft
Shaft
WHEAL FORTUNE
Winstowes Shaft
Footway Shaft
Harry Shaft
Adams Shaft
Shaft
Shaft
Shaft
WHEAL TEHIDY
BARNCOOSE
150 - 300 m³d (Through pipe)
Whim Shaft
50 - 100 m³d (From shaft)
Shaft
Engine Shaft
Footway
Davies Shaft
Miners Shaft
Shaft
Shaft
N
200 - 400 m³d
Pauls Shaft
Druids Whim Shaft
Shafts
Pikes Shaft
0
100
200m
Approximate scale
Shaft
Macdonalds Shaft

FIG. A4.2


BARNCOOSE
ADIT
PORTAL
Piped section
Stone arches & walls
Shaft
Shaft
Shaft
Dunns Shaft
New Section 1940s
Wheal Fortune Shaft
Launder etc need repair
Shaft
Gaviers Shaft
New Section 1950s
Engine Shaft
Dobrees Shaft
Woolcocks Shaft
WHEAL FORTUNE
Winstowes Shaft
Footway Shaft
Harry Shaft
Adams Shaft
Shaft
Shaft
Engine Shaft
Shaft
Shaft
Shaft
Repairs to launders 1991/2
WHEAL TEHIDY
Section of adit defunct
BARNCOOSE
Whim Shaft
Shaft
Engine Shaft
Footway
Davies Shaft
Section of adit defunct
Miners Shaft
Shaft
Shaft
Repairs & laundering
N
Pauls Shaft
Druids Whim Shaft
Shafts
Pikes Shaft
0
100
200m
Approximate scale
Launder etc needed
Shaft
Macdonalds Shaft

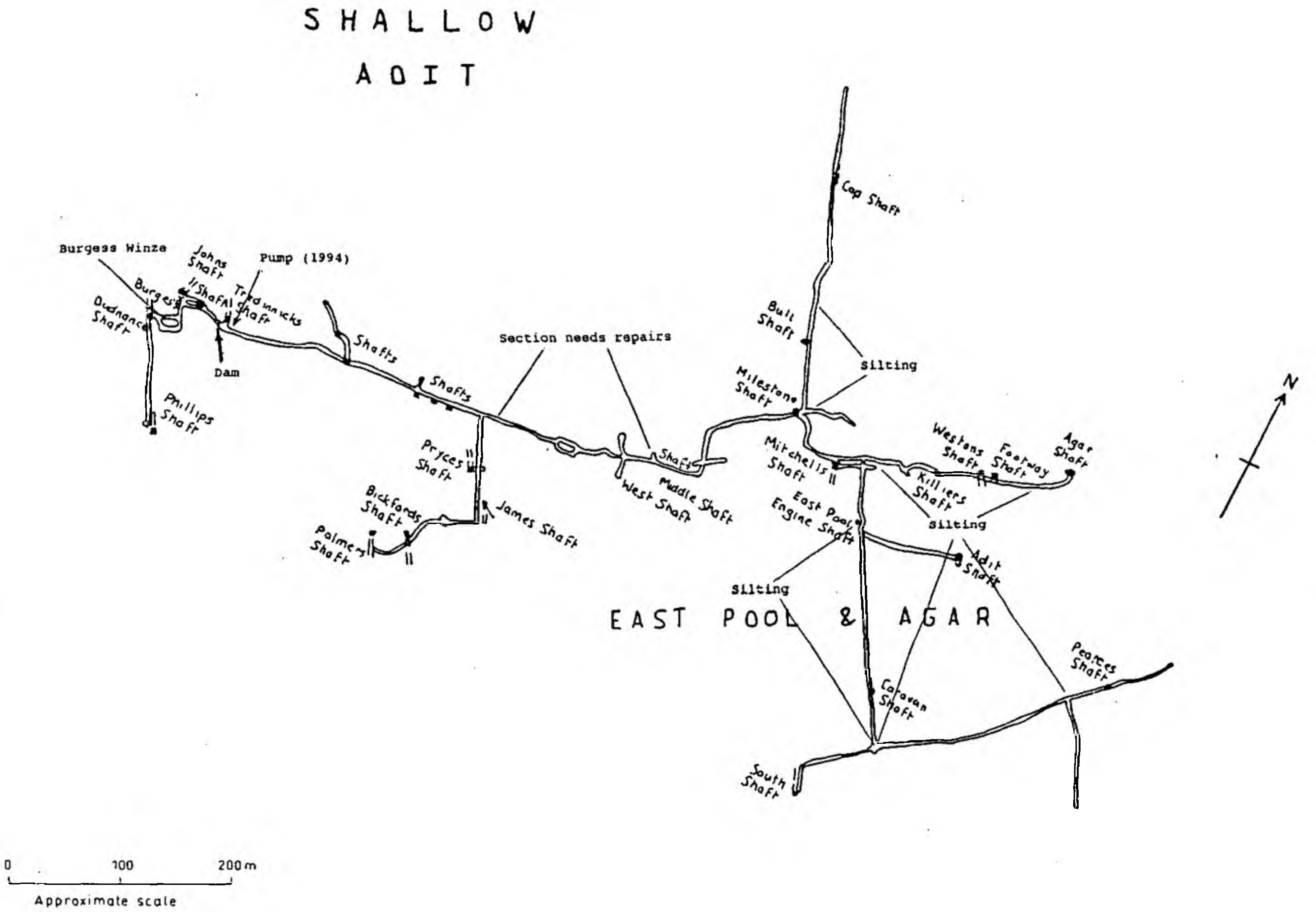
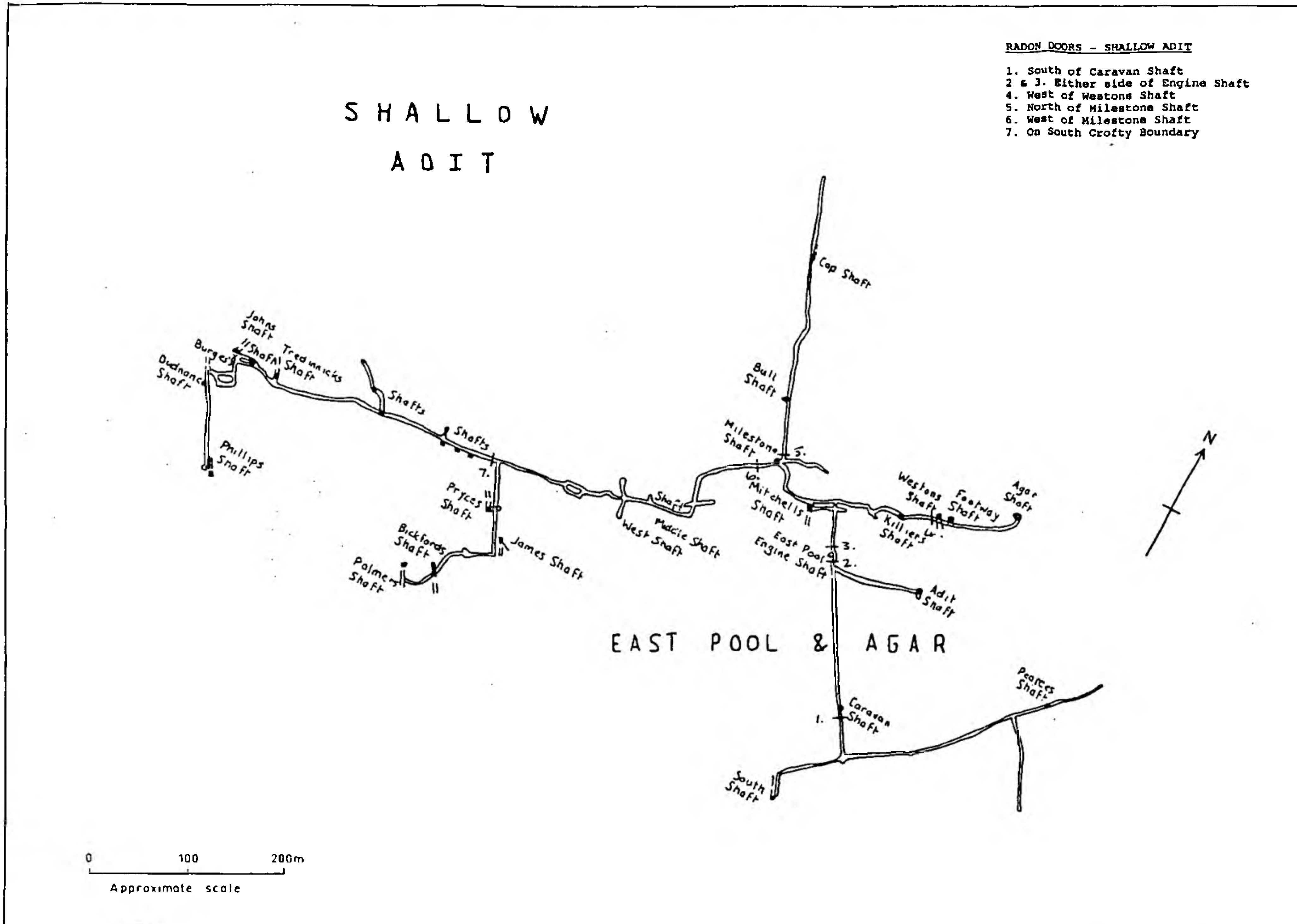
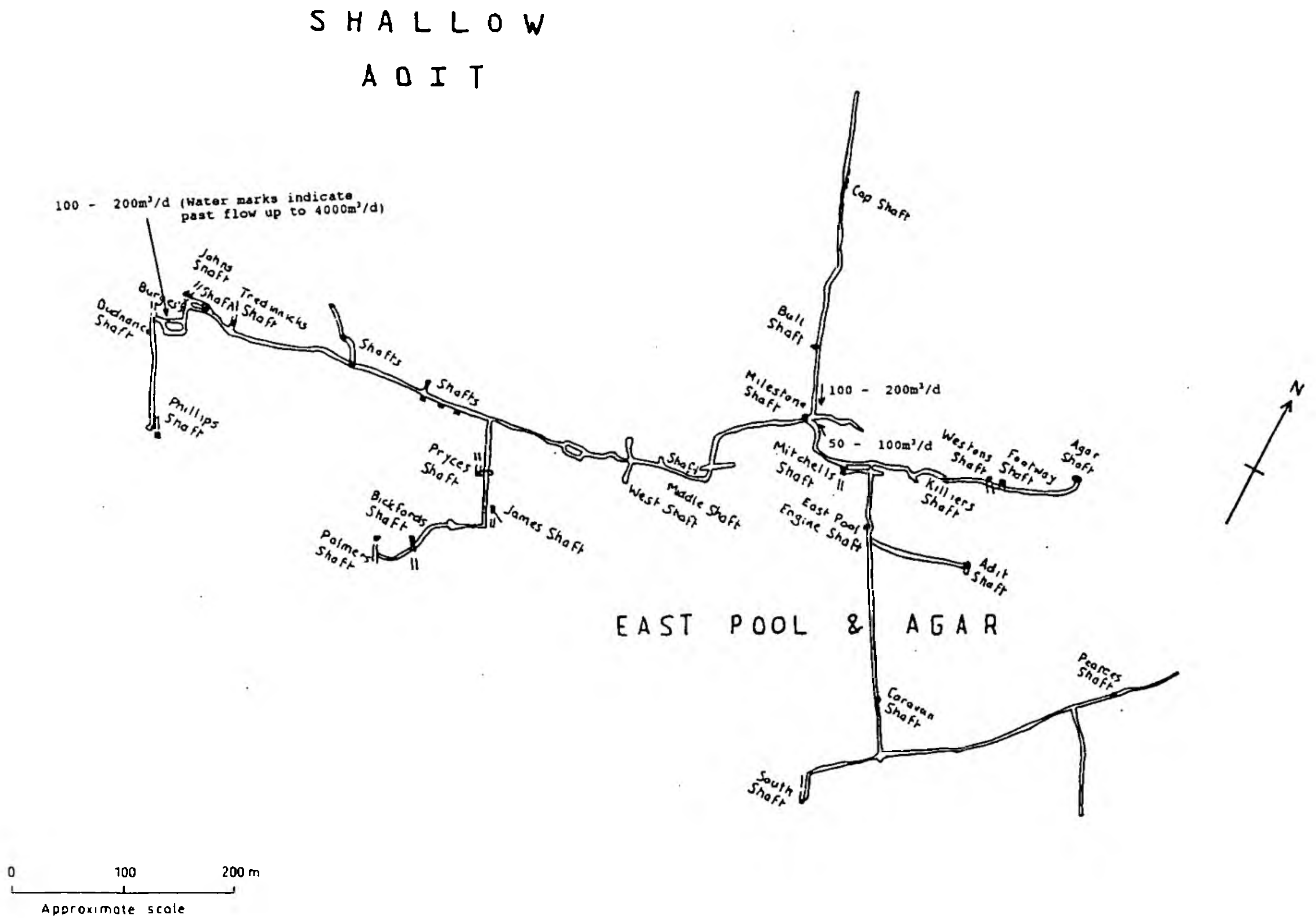

SHALLOW
ADIT
Burgess Winze
Johns Shaft
Pump (1994)
Burgess
Shaft
Dam
Shafts
Shafts
Phillips Shaft
Section needs repairs
Pryces Shaft
Bickfords Shaft
Palmers Shaft
James Shaft
West Shaft
Middle Shaft
Shaft
Cap Shaft
Bull Shaft
Silting
Milestone Shaft
Mitchells Shaft
Westons Shaft
Footway Shaft
Agar Shaft
Killiers Shaft
Silting
East Pool Engine Shaft
Adit Shaft
Silting
EAST POOL & AGAR
Caravan Shaft
Pearces Shaft
South Shaft
N
0
100
200 m
Approximate scale

FIG. A4.3



RADON DOORS - SHALLOW ADIT
1. South of Caravan Shaft
2 & 3. Either side of Engine Shaft
4. West of Westons Shaft
5. North of Milestone Shaft
6. West of Milestone Shaft
7. On South Crofty Boundary
SHALLOW ADIT
EAST POOL & AGAR
Cap Shaft
Bull Shaft
Milestone Shaft
Johns Shaft
Burgess
Tredinnicks Shaft
Oudnance Shaft
Phillips Shaft
Shafts
Shafts
Pryces Shaft
Bickfords Shaft
Palmers Shaft
James Shaft
West Shaft
Shaft
Mitchells Shaft
East Pool Engine Shaft
Westons Shaft
Footway Shaft
Killiers Shaft
Agar Shaft
Adit Shaft
Caravan Shaft
Pearces Shaft
South Shaft
N
0
100
200m
Approximate scale

FIG. A4.4



SHALLOW
ADIT
100 - 200m³/d (Water marks indicate past flow up to 4000m³/d)
Johns Shaft
Burgess
Shaft
Tredinnicks Shaft
Ordnance Shaft
Phillips Shaft
Shafts
Shafts
Pryces Shaft
Bickfords Shaft
Palmers Shaft
James Shaft
West Shaft
Middle Shaft
Shaft
Cap Shaft
Bull Shaft
Milestone Shaft
100 - 200m³/d
50 - 100m³/d
Mitchells Shaft
Westons Shaft
Footway Shaft
Agar Shaft
Killiers Shaft
East Pool Engine Shaft
Adit Shaft
EAST POOL & AGAR
Pearces Shaft
Caravan Shaft
South Shaft
N
0
100
200 m
Approximate scale

FIG. A4.5

DEEP ADIT

RADON DOORS - Deep Adit

1. West of Palmers Shaft
2. North of Robinsons Shaft
3. East of Phillips Shaft
4. West of Phillips Shaft

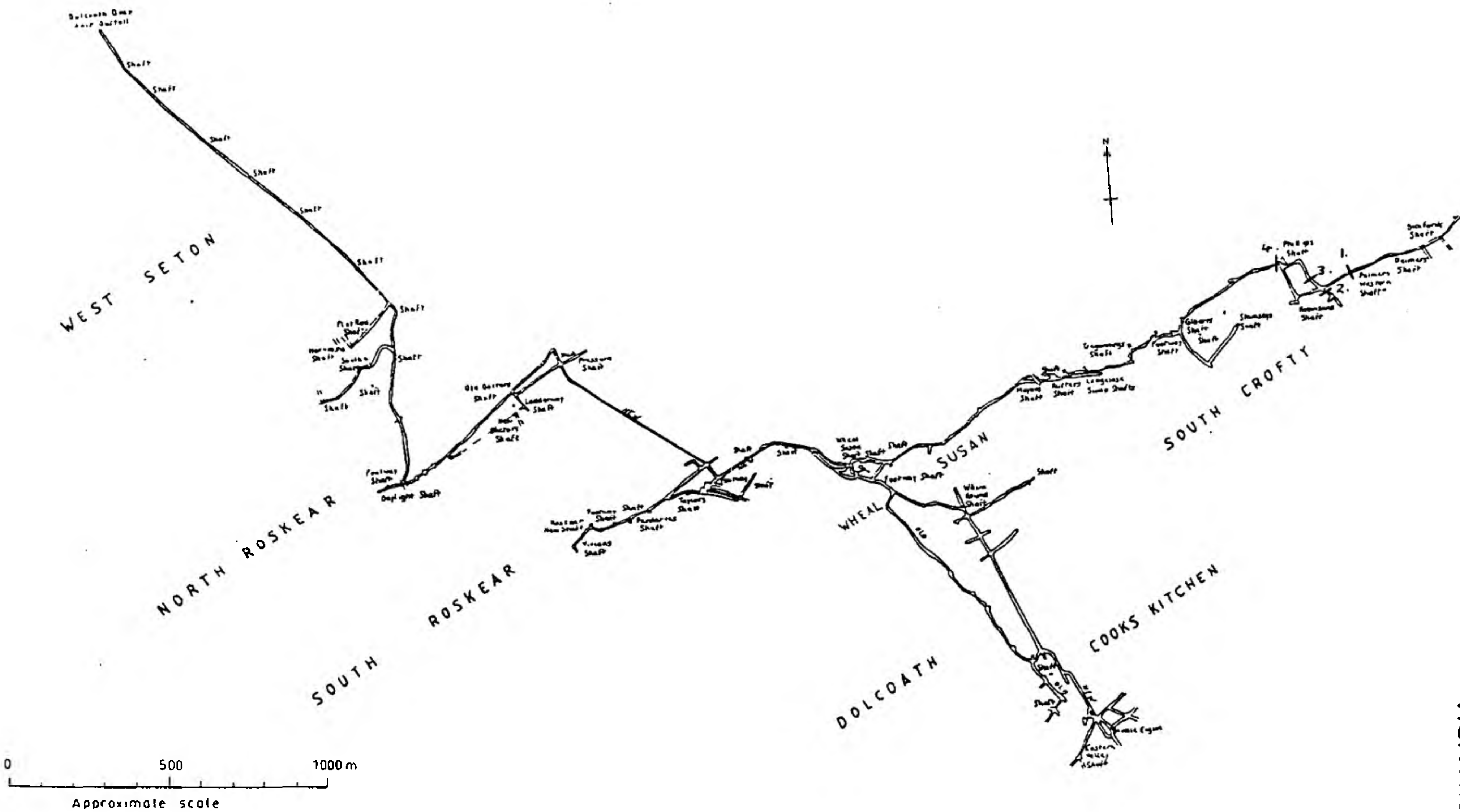


FIG. A4.6

DEEP ADIT

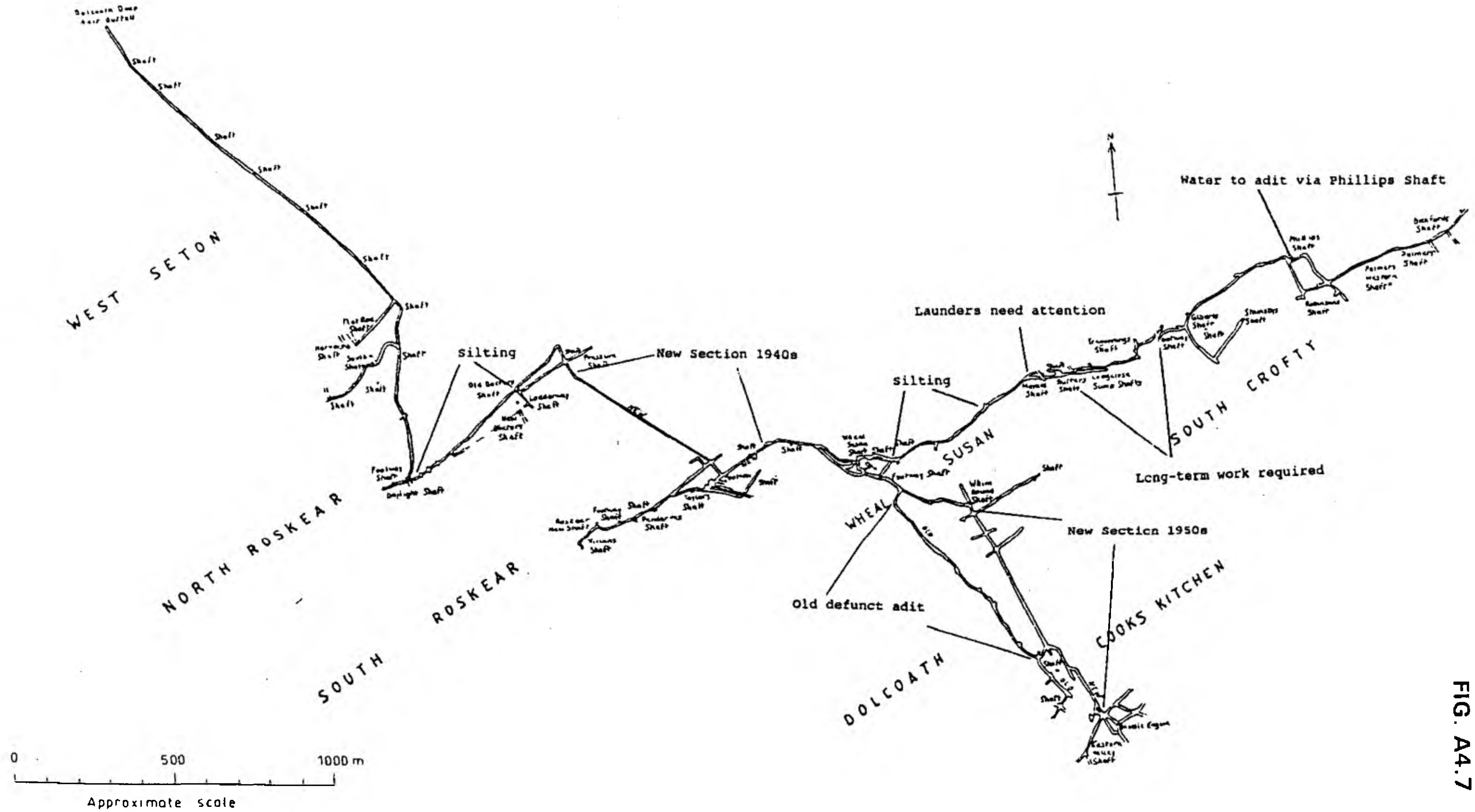


FIG. A4.7

DEEP

ADIT

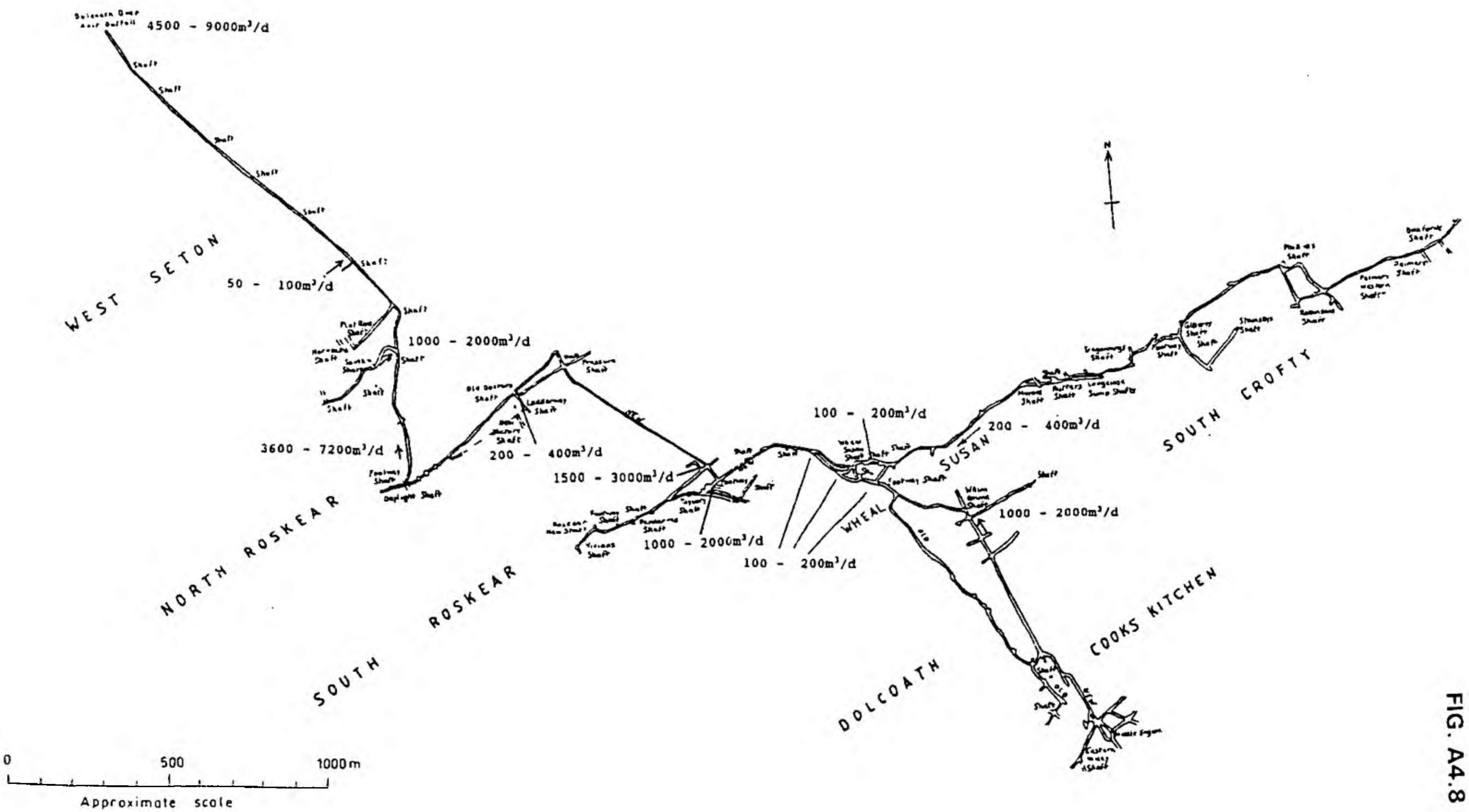
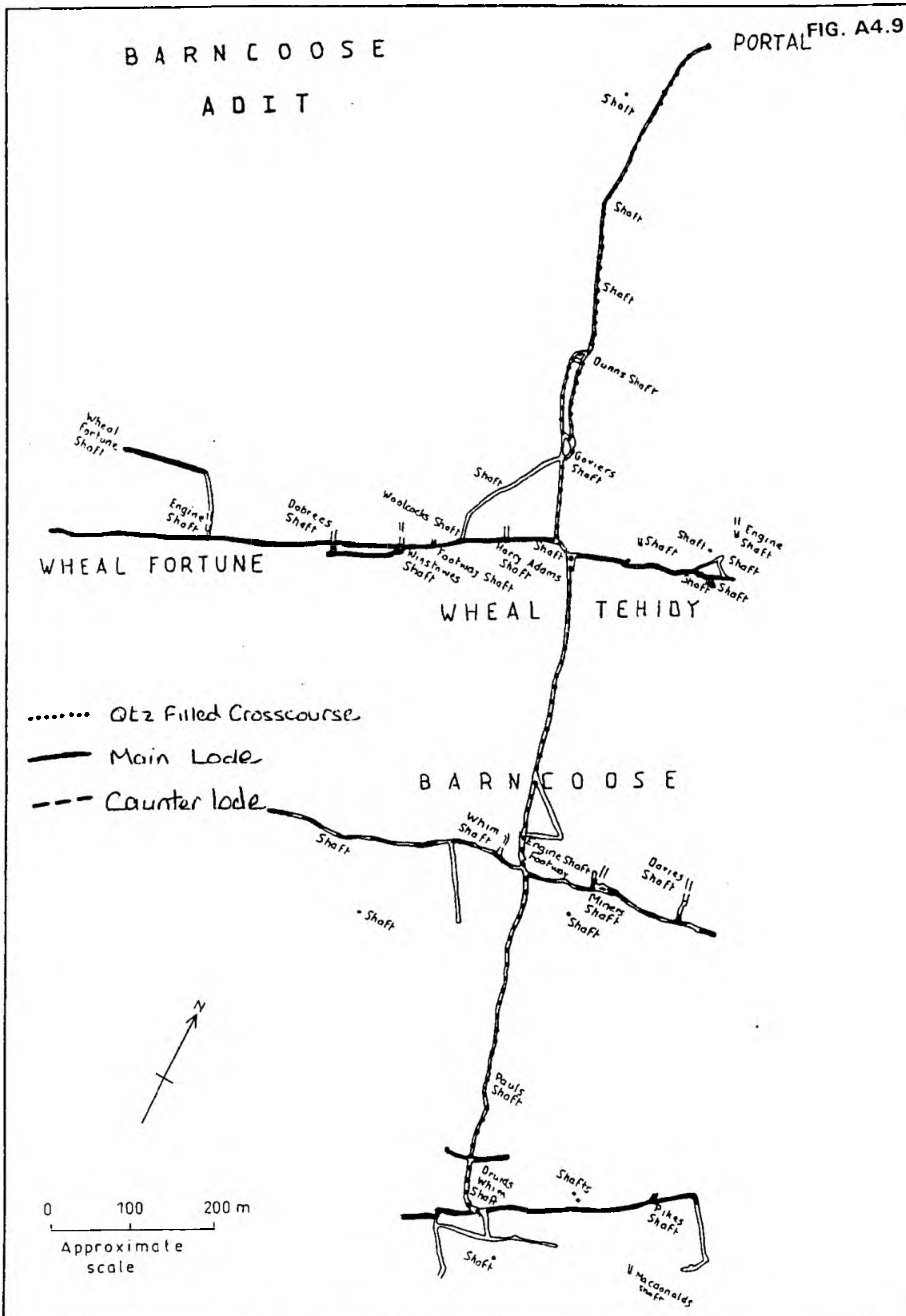


FIG. A4.8

FIG. A4.9



BARNCOOSE ADIT
PORTAL
Shaft
Shaft
Shaft
Dunns Shaft
Goviers Shaft
Shaft
Wheal Fortune Shaft
Engine Shaft
Dobrees Shaft
Woolcocks Shaft
Winstowes Shaft
Footway Shaft
Harry Adams Shaft
Shaft
Shaft
Shaft
Engine Shaft
Shaft
Shaft
Shaft
WHEAL FORTUNE
WHEAL TEHIDY
Qtz Filled Crosscourse
Main Lode
Counter lode
BARNCOOSE
Whim Shaft
Shaft
Engine Shaft
Footway
Davies Shaft
Miners Shaft
Shaft
Shaft
N
Pauls Shaft
Druids Whim Shaft
Shafts
Pikes Shaft
Shaft
Macdonalds Shaft
0 100 200 m
Approximate scale

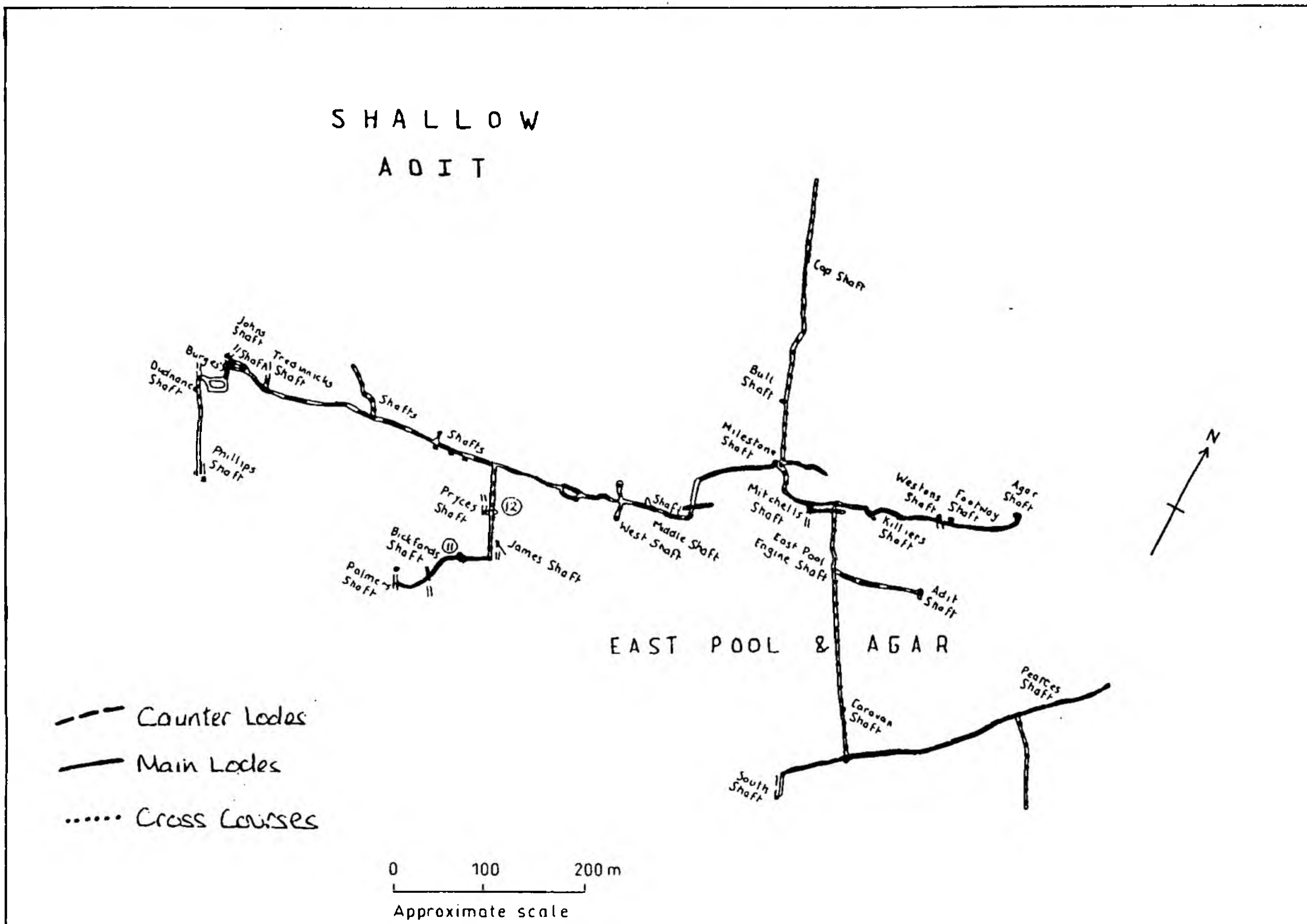

SHALLOW
ADIT
Cap Shaft
Johns Shaft
Burgess Shaft
Tregonnicks Shaft
Dudnance Shaft
Shafts
Shafts
Phillips Shaft
Pryces Shaft
12
Bickfords Shaft
11
Palmers Shaft
James Shaft
Bull Shaft
Milestone Shaft
Shaft
Middle Shaft
West Shaft
Mitchells Shaft
East Pool Engine Shaft
Westons Shaft
Footway Shaft
Agar Shaft
Killiers Shaft
Adit Shaft
N
EAST POOL & AGAR
Pearces Shaft
Caravan Shaft
South Shaft
Counter Lodes
Main Lodes
Cross Courses
0
100
200 m
Approximate scale

FIG. A4.10

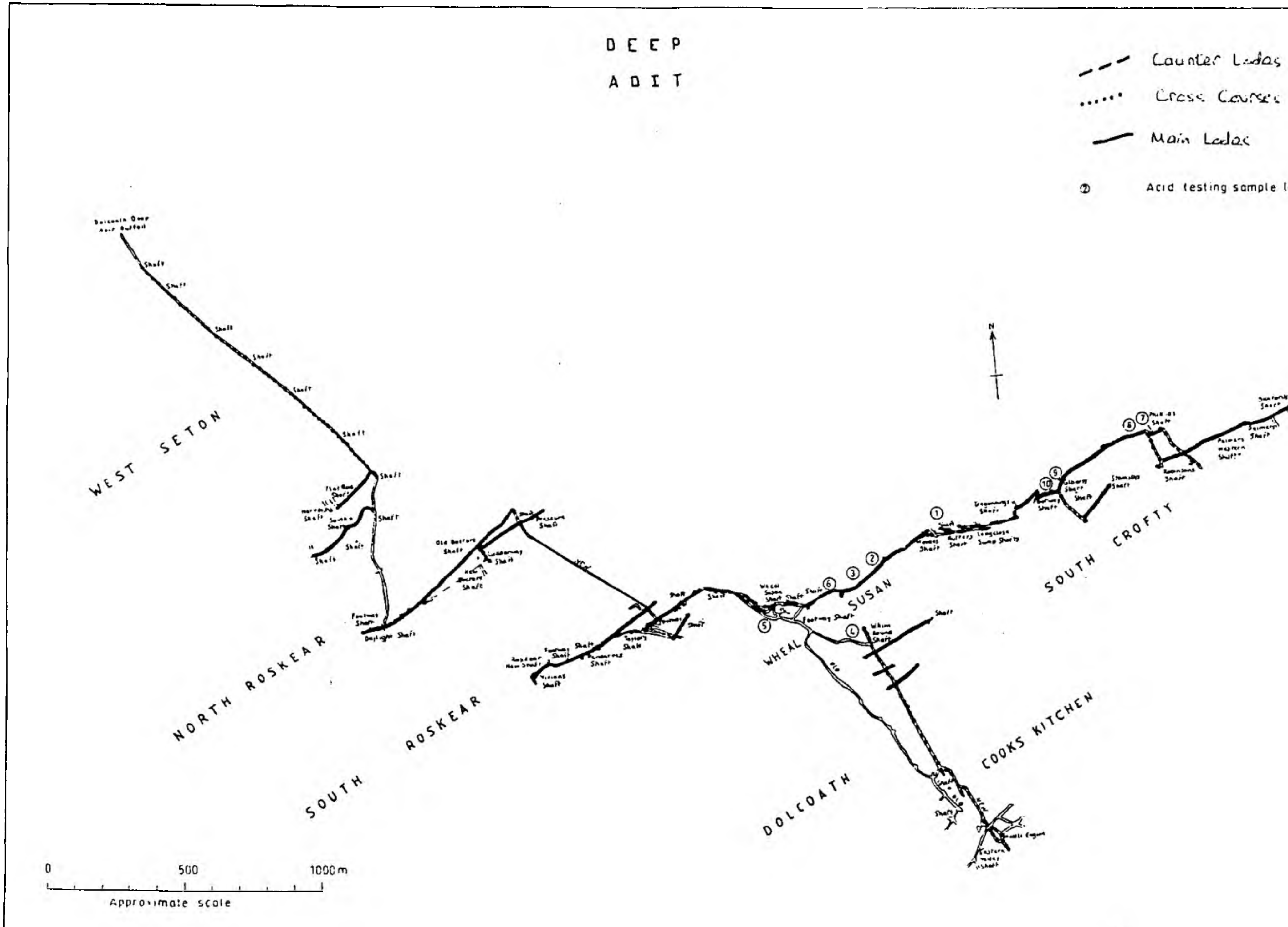

DEEP
ADIT
Counter Lodes
Cross Courses
Main Lodes
Acid testing sample locations
N
WEST SETON
NORTH ROSKEAR
SOUTH ROSKEAR
WHEAL SUSAN
SOUTH CROFTY
COOKS KITCHEN
DOLCOATH
0
500
1000m
Approximate scale

FIG. A4.11

APPENDIX 5

DoE Correspondence

APPENDIX 5 : DoE CORRESPONDENCE

The following queries were raised by the DoE in a fax dated 6th April 1994, addressed to the NRA, and requiring an urgent response:

QUOTE

a) What is the estimated cost per annum of keeping the pumps operating at South Crofty as at present (i.e. any revision to the earlier figure of £490 000)?

b) What is the estimated annual cost of deferring action until the workings are filled with water and how long after the present pumping stopped would the costs begin to occur? (Please give pumping and treatment costs separately).

c) What is the estimated annual cost of allowing the workings to flood to half their depth before commencing pumping and treatment from the half depth point and when would the costs begin to occur? (Please give pumping and treatment costs separately).

d) Does the KPP report identify any alternatives to options a-c above and, if so what are the cost implications and when would they fall?

e) In all cases : is the duration of the action proposed definite or indefinite and if the former, for how long would it be necessary?

UNQUOTE

KPP responded in a fax to the NRA, dated 8th April 1994, as follows:

QUOTE

As you will be aware the DoE are requesting information which is outside the scope of our report but we have been able to provide broad estimates for much of the information requested. The following responses adopts the paragraph number system referred to in the DoE letter.

a. The present mine dewatering is undertaken by staged pumps installed at a number of levels in the workings. We do not have any additional information that would make us revise the cost of this pumping (presently estimated at £490,000). Studies carried out by CCL have indicated that the cost of pumping could be reduced by some 20% if sections of the adits were repaired. The cost of undertaking such repairs has not been assessed by KPP. To balance against this there may be cost implications arising from maintaining the workings open in the event of mine closure to ensure access to the pumps - this figure is difficult to estimate but may be derived following discussion with Carnon.

b. If the pumps are switched off and the mine is allowed to flood, it is estimated that adit level would be reached in a minimum time of 1.7 years, or probably more realistically in 2 to 3 years. Any pump and treatment costs would then be incurred, if such action was seen as necessary.

Under such a scenario the preferred pump installation method would be to install submersible pumps in one of the main mine access shafts at approximately 75 m below ground level, i.e. some 20 m below the level of the deep adit. The cost of pumping to control groundwater levels has been estimated as £120,000 again excluding shaft maintenance costs.

The cost of shaft maintenance will be considerably less than the cost of maintaining all or part of the workings open, as in Options a. and c.

Note that VAT has not been included in the estimates of pumping costs at this stage.

Appropriate treatment methods would need to be selected once the quality of the discharge water was confirmed. Possible methods include lime dosing followed by precipitation, or both active and passive treatments. The quantity of water to be treated would be in the order of 4,500 m^3/day, and the operating costs incurred could range from £250,000 to £500,000/year* excluding the capital cost of construction of a sedimentation facility (*we would prefer to re-assess this figure given time, it should be used with caution, similarly we could not rapidly cost a disposal facility for this site given its location and history).

The indications from the present study are that the quality of the discharge water may be acceptable without treatment and comparable to existing surface water quality. In this case mine drainage could discharge by gravity via adits direct to the Red River. The only costs envisaged would then be maintenance of the adits and regular flow and quality monitoring which would be incurred in all cases. This ignores cost implications arising from the imposition of stringent EQS levels for the Red River such as the cyprinid directive. (Target EQS levels for this river need clarification if this is to be costed).

c. There may, on further investigation, be cost benefits in allowing the workings to flood to half their depth. The estimated time for this to occur would be a minimum of .8 years or more realistically 1.3 - 1.5 years, again after which time, costs wold start to be incurred.

This may be beneficial, if on investigation the superficial geology is indicated to have a high acid producing potential and dilution from underground sources is required. If the mine was allowed to fill to only half the depth, pumping could continue to take place from 195 fathom level. Since the sump at 195 is only just below the pumps, the water level would have to be maintained at a lower level to avoid risk of flooding the pumps during heavy rainfall events. A submersible pump would consequently be required to maintain the water level at some 50 m below 195 level. The total cost of pumping from 195, and acquiring and operating the submersible pumps is estimated to be £213,000 again ignoring the costs of keeping the mine open.

The treatment methods required may differ from those adopted if the mine was allowed to refill completely, as the quality of water is likely to vary with depth. The quantity of water to be pumped and the cost of treatment may at this stage however be assumed to be similar to that indicated in b. above.

Half flooding the mine will involve keeping the mine open to allow access to the pumps. The cost of this has not been included in the pumping costs.

d. In the event of closure of South Crofty it is recommended that the mine be allowed to flood. Installation of a submersible pump below adit level would then be required if pumping and treatment is necessary. Alternatively it may be possible to allow the mine water to drain via the adits to the Red River if the water quality is acceptable. Based on presently available data it is not possible to confirm that water quality will be acceptable and sampling of rock from upper levels has been advocated. To date however all indications are that acid generation will not be a significant problem and water quality is likely to be suitable for direct discharge into the Red River, subject to target ESQ levels.

e. In all cases, the duration of pumping will be dependent on the quality of the water. If water quality is acceptable then pumping on mine abandonment can cease and the only costs incurred will be for maintenance of the adits as discussed in b. above. At present there are indications that water quality will not be a problem at South Crofty, but if there is an unexpected deterioration in quality as the water level recovers, the time taken to flood the workings, under average rainfall conditions, will enable a treatment strategy to be instigated. The above conclusions are based on information available to date. The Knight Piésold report recommends sampling to confirm the present quality indications. On completion of this work it should be possible to quantify more precisely the impact of mine closure.

UNQUOTE

The NRA subsequently responded to the DoE as follows:

QUOTE:

CARNON CONSOLIDATED : SOUTH CROFTY

As we have explained to you, the NRA received an incomplete draft of our consultants report on the implications in the event of closure of South Crofty only last week. We expect to receive the draft of the additional section of the report, which will deal with water quality issues and is thus a key part of the work, during the coming week. Staff in Cornwall Area are scheduled to meet with our consultants later in the month to discuss the draft prior to finalisation.

In addition, I think it is important to note that much of the information you have requested, and in particular the costings are outside the scope of the initial study.

However, with the assistance of our consultants we have attempted to go as far as we can towards providing answers to your questions. They have of course been produced in some haste and I must ask that you recognise that we have not had a proper opportunity to digest and consider the report and that the costings given below are preliminary and will need further work and subsequent revision.

The following refers to your questions following the same referencing system. We have also prepared a schedule which attempts to summarise this information (copy attached).

a) We have no reason to revise the cost estimate of £490,000 per annum to keep the existing pumps running. The draft report does however note that Carnon have examined ways to reduce inflow to the mine and hence pumping costs. One possibility would be to undertake various works on the adit systems in area of the mine to intercept drainage from the upper levels which currently enters the deeper workings. We understand that Carnon have estimated that pumping costs could be reduced by 20% but we are not in a position to estimate the costs of the improvements to the adit system.

   To pursue this option it would of course be necessary to maintain access to the mine and these costs may not have been adequately covered.

b) If action were deferred until the workings are filled, the following costs might arise during the period of filling;

i) In order to increase confidence in predictions of the quality of mine water ultimately discharged it would be essential to undertake surveys of the upper workings of the mine which are likely to be the source of the poorest quality water in the event of flooding. Estimated costs - £50K.

ii) During the period of filling it would be necessary to monitor the level and quality of water in the mine and also adjacent shafts and adits. A preliminary cost of this work is say £50K per annum.

iii) There also may be benefits in undertaking works on the adit system during this period, however we are unable to provide costs (see a) above).

The time for the mine to fill has been estimated by our consultants to be a minimum of 1.7 years but probably more realistically 2-3 years. This would of course provide a period in which decisions could be made about any treatment which might prove necessary and any necessary plant provided and construction undertaken. This of course begs the question of who would be responsible and how it would be financed.

When the mine is full there are two potential scenarios. If the minewater remains similar to the existing pumped discharge then it may be acceptable to allow the mine to overflow by gravity via the adit systems without treatment. Apart from maintenance of the adits there would be no additional costs.

The second scenario is that the minewater is unacceptable for direct discharge and that some form of treatment is required. Under this scenario the preferred pump installation method would be to install submersible pumps at approximately 75m below ground level (ie some 20m below the level of the deep adit, to provide for buffer or emergency storage). The costs of pumping in this way have been estimated at £120,000 per annum (excluding maintenance costs), say £180,000 p.a in total.

Costs of treatment are more difficult to estimate since the method adopted will depend on the quality of the mine water and on the target quality.

Assuming that lime dosing were adopted, a very preliminary cost for operating costs would be in the range £250,000 - £500,000 per annum. This excludes the capital costs of constructing a sedimentation facility which could present difficulties on this site.

Passive treatment may also be an option but at this stage we are unable to provide any costs.

c) The costs of pumping from the 195 fathom level following allowing the mine to fill to this level (approximately half depth) are estimated at £213,000 p.a (excluding any costs of maintaining access). Say £250,000 in total. This would include the installation of a submersible pump to feed the existing pumps and keep the level safely below the existing pumps which are not submersible.

The mine would fill to this level in a minimum of 0.8 years but more realistically 1.3 - 1.5 years, after which time costs would begin to be incurred.

The filling period would allow time for the investigation of the upper parts of the mine to determine potential for high acid and metal production and monitoring would be necessary. Costs would be as mentioned under a).

This option could have advantages if high acid production was found to be a feature of the upper levels of the mine. With further work it may be possible to establish if there is a cost benefit of keeping the upper levels of the mine dry as opposed to allowing it to flood and having to undertake treatment of the poorer quality water.

The treatment requirements will again depend on the quality of the water but if treatment were required costs may be assumed to be the same as those suggested under b) above.

d) No other options are presented in the KPP report other than the possibility that if quality is acceptable, discharge by gravity and without treatment would be possible via the adit system (as already mentioned under b)) and the possibility of alternative treatment methods (eg passive treatment) as already mentioned.

e) All options which involve pumping to avoid flooding of all or part of the mine imply indefinite action. If the mine were allowed to flood we are unable to say how long pumping and/or treatment would need to continue and the duration will depend on the quality of the mine water and the target quality set for the river. Drainage from older flooded mines in Cornwall demonstrates that some degree of contamination remains for very long periods of time. Following the initial effects of flooding it is likely that quality would tend to improve with time (eg. as at Wheal Jane) but will eventually "stabilise" at a lower level of contamination.

As indicated above, much depends on the quality of water which arises in the flooded mine. The work by our consultants suggests that there is little danger of an "incident" of the type which occurred at Wheal Jane and that the mine water will not have such high levels of metals as experienced at Wheal Jane. The prediction of the quality of the mine water after flooding is an issue we wish to discuss further with our consultants and it may be that additional work will be required to provide the necessary confidence (including the survey of the upper mine workings and additional water quality monitoring within the mine).

It will also be important that there is a clear understanding of the target quality for any treatment and this will need to be linked to EQS's in the Red River. We understand that the EC is to review the situation relating to Wheal Jane and relevant EC legislation. It remains the NRA's view that the effect of discharging water from the flooded South Crofty mine without treatment is likely to result in a deterioration of water quality and has the potential to infringe or increase infringement of EQS's set in relation to the EC Dangerous Substances Directive.

Appendix 5 : DoE Correspondence

SOUTH CROFTY - MINEWATER

PRELIMINARY COST ESTIMATES

OPTION	PERIOD COST DEFERRED (YEARS)	PUMPING COSTS	TREATMENT COSTS	DURATION	OTHER COSTS	RISK/COMMENTS
a) Continue Existing Pumping Regime	0	£490k*	0	Indefinite	1) Monitoring as current programme. 2) Possible improvement of adits.	Low Risk, High Cost No change over - current situation
b) Allow Mine to Flood						Moderate Risk, High Cost
i) With Pumping and Treatment	1.7 - 3.0	£180k	£250 - 500k (+ settlement)	?	1) Monitoring rising minewater - £50k p.a 2) Survey of upper workings - £50k 3) On-going process monitoring.	i) Possible Problem over providing settlement. ii) Potential environmental improvement over current situation.
ii) With Gravity Discharge, No Treatment	1.7 - 3.0	0	0	Indefinite	1) Monitoring rising minewater - £50k p.a 2) Survey of upper workings - £50k 3) Refurbishment of adits - no figures available	High Risk, Low Cost i) May be unacceptable - discharge quality too poor. ii) May allow deterioration over current quality.

Appendix 5 : DoE Correspondence

OPTION	PERIOD COST DEFERRED (YEARS)	PUMPING COSTS	TREATMENT COSTS	DURATION	OTHER COSTS	RISK/COMMENTS
c) Allow Mine to Flood to 195fm Level i) With Treatment	0.8 - 1.5	£250k*	£250 - 500k (+ settlement)	Indefinite	1) Monitoring rising minewater - £50k 2) Survey of upper workings - £50k 3) On-going process monitoring	Low Risk, High Cost i) Possible problem over providing settlement. ii) Potential environmental improvement over current situation.
ii) Without Treatment	0.8 - 1.5	£250k*	0	Indefinite	1) Monitoring rising minewater - £50k 2) Survey of upper workings - £50k	Moderate/Low Risk, Moderate Cost i) Possible marginal deterioration over current situation or no change.

* There may be additional costs to maintain access to workings to allow for servicing etc.

UNQUOTE

APPENDIX 6
Adit Flow Gauging

APPENDIX 6 : ADIT FLOW GAUGING

Flow gauges were installed at the portals of the Dolcoath and Barncoose adits in March 1994 to provide baseline data. At each site a thin plate weir with a pressure transducer and data logger has been installed. These enable regular measurements of the water level to be taken and converted into flow.

At the Dolcoath adit portal at Roscroggan the weir is located downstream of the adit portal and just upstream of the confluence with the Red River. At this point there is a regular trapezoidal channel and backwater effects on nearby houses are minimised; also the weir is screened from casual view. The weir was designed to fit into the channel and consists of a trapezoidal plate with trapezoidal notch.

At the Barncoose adit portal at Tolskithy the weir has been placed in the Barncoose adit back from the portal and underground at an access shaft, to prevent vandalism. At this point there is a regular channel formed by a concrete pipe. The weir consists of a rectangular notch with a circular base to accommodate the channel.

The thin plate weirs were fabricated from 10 mm thick mild steel plate to the specifications shown in Fig A6.1. They were constructed and installed by SC and bolted onto the channels using rock bolts fixed into holes drilled into the concrete. Caulking rope was used to block any gaps between the weir plate and channel to ensure that flow went over the top of the weir. The pressure transducers were attached by a bracket to the centre bolt on each weir thus fixing them to the base of the channel at the midpoint of the weir. This was done to avoid drilling further holes into the channel although it means that the depth measurement is closer to the weir than the BS:3680 recommends. If this is unacceptable then another hole can be drilled further back from the weir and the transducer placed there.

The measuring and recording equipment was supplied by Technolog Ltd following a costing exercise involving three companies. Both systems consist of a Druck PTX530 pressure transducer and a Newlog DTX data logger together with GPS-1 communications software and a Psion Organiser for downloading data. The data loggers are locked in a steel box and secured near the weirs. At Tolskithy the box is bolted to the wall of the access shaft while at Roscroggan the box is bolted to a post on the bank.

Following installation, head measurement was initiated by using the GPS-1 software loaded onto a portable PC. The loggers were switched on and configured to record every hour and the data was calibrated by taking a manual measurement of the head over the weir. Difficulties were encountered with the logger at Roscroggan which had to be sent back to the suppliers to be reconfigured and, after further problems, recalibrated. The logger at Tolskithy has been recording every hour since 18/3/94 and the data has been confirmed by manual readings.

The logged water level readings have been converted into a head over the weir crest and then into flow by the conversion equations given below:

Barncoose rectangular notch at Tolskithy

$$Q = C_e \frac{2}{3} \sqrt{2g}\ b_e\ h_e^{3/2}$$

where: Q is the volume rate of flow, m^3/s
C_e is the coefficient of discharge, non-dimensional
g is the acceleration due to gravity, m/s^2
b is the measured width of the notch, m
b_e is the effective width, m
B is the width of the approach channel, m
h is the measured head, m
h_e is the effective head, m
p is the height of the crest relative to the floor, m

The effective width and effective head are defined by the equations

$$b_e = b + k_b$$

$$h_e = h + k_h$$

in which k_b and k_h are experimentally determined quantities in metres, which compensate for the combined effects of viscosity and surface tension. k_b has been experimentally defined as a function of b/B and was determined from the graph in BS:3680 to be 0.004 m, giving b_e = 0.504 m.

k_h is taken to have a value of 0.001 m.

The co-efficient of discharge C_e has been experimentally determined as a function of h/p for representative values of b/B, and takes the form:

$$C_e = 0.593 + 0.018 * h/p \quad \text{for } b/B = 0.6$$

giving the final flow equation as:

$$Q = \left\{0.593 + \frac{0.018h}{0.175}\right\} x\ \frac{2}{3}\sqrt{2g}\ x\ 0.504\ x\ (h + 0.001)^{3/2}$$

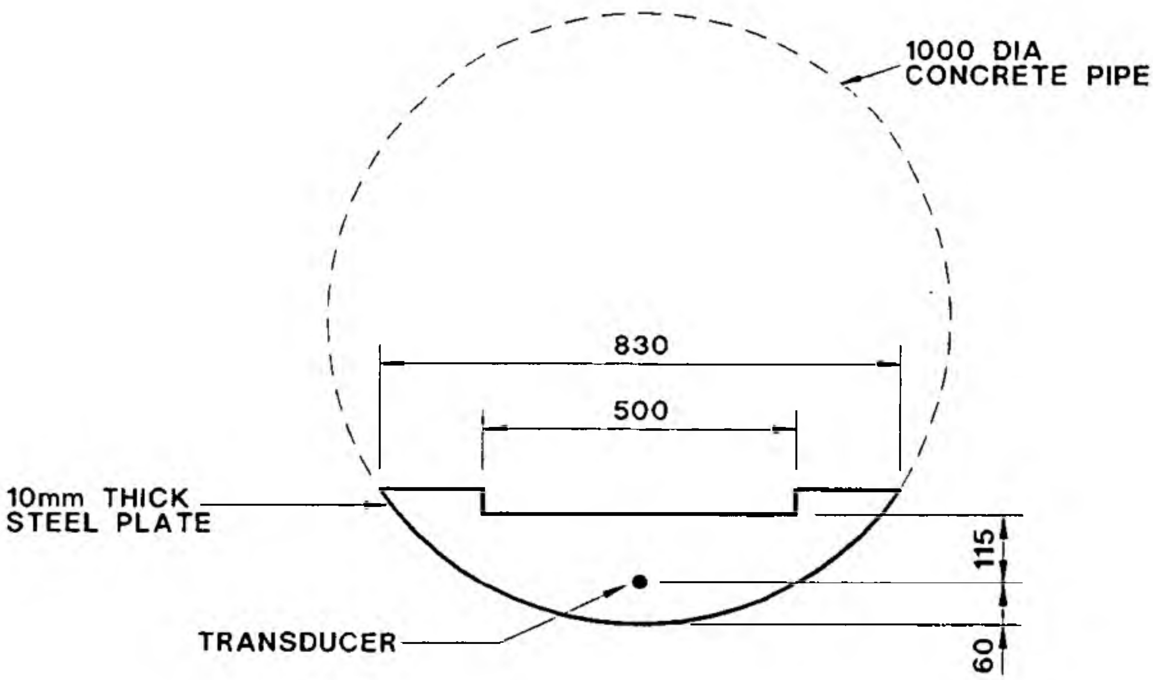
The Tolskithy data was transferred to spreadsheet using a facility on the GPS-1 software and the raw data was converted into flows using the above equations. A graph of these flows can be seen in Fig. A6.2.

Dolcoath trapezoidal notch at Roscroggan

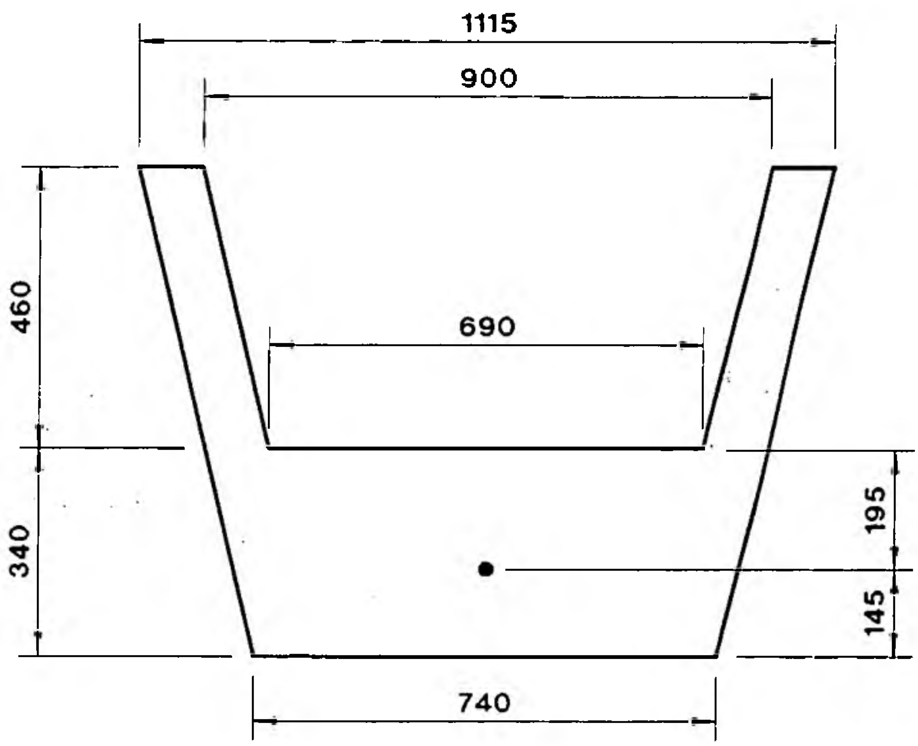
$$Q = 1.859 \times 0.69\, h^{3/2}$$

Flow over the trapezoidal weir was calculated using the formula for the Cipoletti weir shown above. A graph of these flows can be seen in Fig. A6.3

FIG. A6.1



BARNCOOSE ADIT AT TOLSKITHY



DOLCOATH ADIT AT ROSCROGGAN

Fig A6.2 Barncoose Adit at Tolskithy Portal - Recorded Discharge

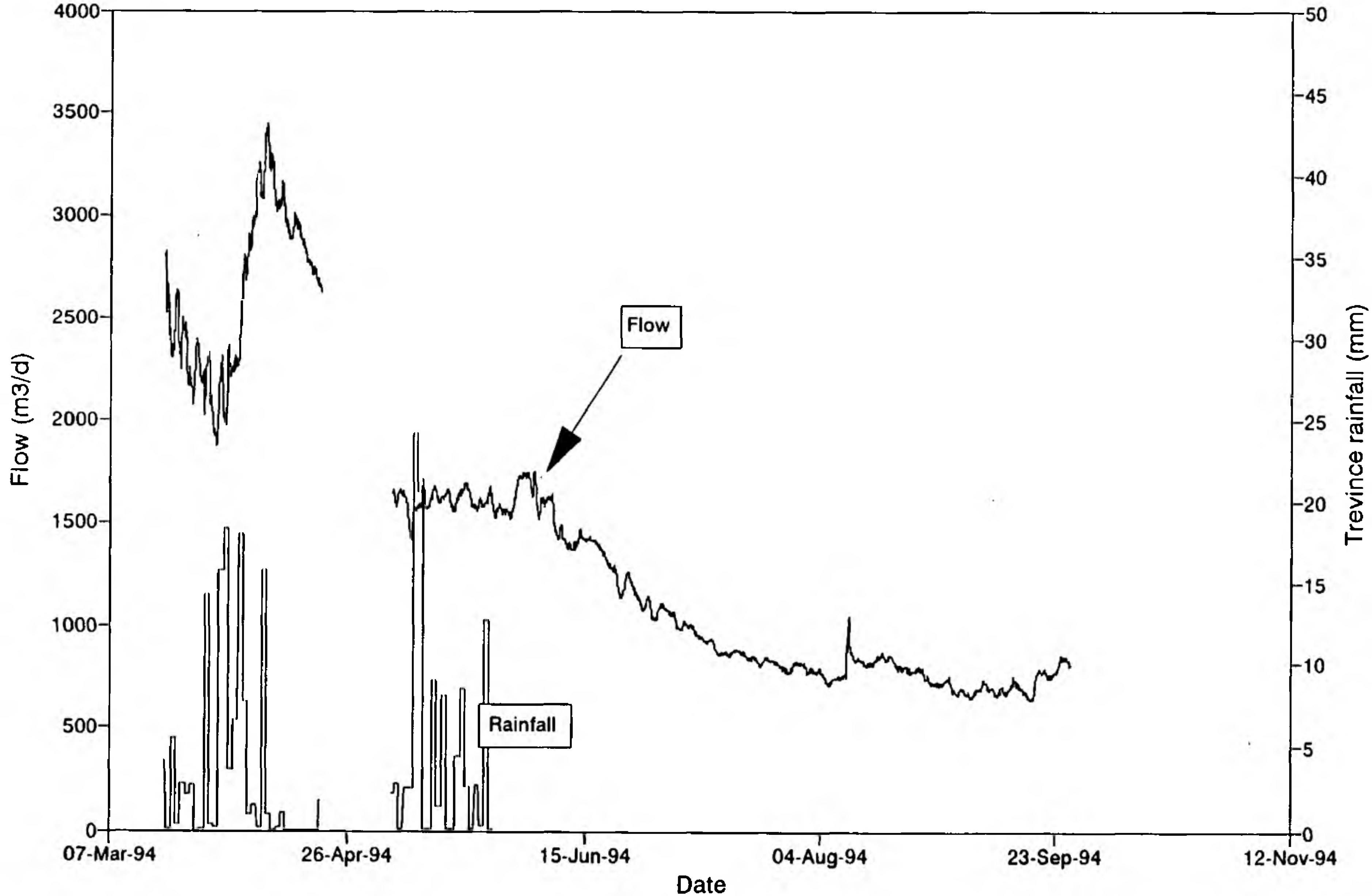


Fig A6.3 Dolcoath Adit at Roscroggan Portal - Recorded Discharge