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Coastal Mining Subsidence, Wemyss villages, Fife

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Fife; East Wemyss; West Wemyss; Buckhaven; Carboniferous; Coal Measures.

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Front cover

Wemyss area of Fife showing protection wall with outsized dolerite boulders on foreshore preventing further coastal erosion.

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Foreword

The work described in this report was carried out as part of the IGS(N) research programme in the Central Belt of Scotland.

This report records the results of a study by the British Geological Survey (BGS) to calculate the surface subsidence values, occurring along the Wemyss villages coastline and adjacent areas, from all recorded underground coal extractions affecting the area of study.

The calculations are undertaken manually, on a seam by seam basis, because of the complexity of the workings and the number of seams worked in the area.

The results are derived by application of manual methods used by British Coal Subsistence Engineers prior to privatisation of the coal industry and using the knowledge and judgement of a skilled and experienced subsidence engineer/mining surveyor.

The aim of the report is to see what effect mining subsidence has had on the erosion of this part of the Fife coastline and is part of programme of scientific research within the BGS to further understanding of bedrock and Quaternary geology within the Central Belt of Scotland.

Large areas across the central belt of Scotland are former coalfields that have been undermined by many coal and other mineral workings and some of these still present potential subsidence problems for the future.

This report shows the staff skill and expertise BGS has for completing any kind of coal mining subsidence calculation and reporting, whether it is for local or regional government concerning waterways, floodplains, structures etc., or for the various service organisations i.e. water, electricity, gas sewage and drainage.

This report is an example of an area underlain by numerous mined coal seams subject to actual inundation by the sea as a result of mining-related subsidence.

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Summary

This report describes the results of mining subsidence calculations for the Fife coast around the villages of West and East Wemyss, north of Kirkcaldy. This part of the Fife coastline is well known for the increase in coastal erosion it has suffered in recent years. The reasons for the increase are rooted in past deep mining subsidence, the cessation of the disposal of colliery spoil on the Fife foreshore between Buckhaven and Dysart and the associated loss of beach recharge from heaps of mine spoil (known locally as bings) by longshore drift to compensate for the mining subsidence. The mining spoil at Wellesley Colliery, Buckhaven was eroded by the sea and redistributed southwards by longshore drift depositing up to 5 m of 'beach recharge material' on the shores in front of the two villages. Once tipping ceased, coastal erosion (and flooding) re-established itself and retreat of the shoreline accelerated, threatening property and ancient monuments (caves with Pictish and other carvings). The mining subsidence calculations show that the Wemyss foreshore area has been affected by up to 5 m of cumulative and irregularly distributed ground subsidence. The large number of seams (>16) worked and the complexity of the workings will have set up high strains of compression and tension in the strata overlying the worked coal seams. These strains will have caused surface damage and enhanced erosion at the coast. The world famous Wemyss caves have also suffered damage and collapse as a result of mining subsidence and coastal erosion (partial collapse of Court Cave in 1970). Subsidence of up to 2 m, with recent removal of beach material deposits, means the cave system is now even more vulnerable to marine erosion and flooding unless defended.

1 Introduction

1.1 THE HISTORY OF COASTAL CHANGE AND MINING ACTIVITY

The Fife coast between Dysart and Buckhaven has changed greatly over the last 150 years. It is now difficult to imagine that there were once golden sands at the north end of East Wemyss (Thomson, 1995, p.35) and the south end of Buckhaven (Eunson, 1993, pp.7-9) or a rocky and boulder strewn shore north of the old harbour at Buckhaven (Eunson, 1993, p.25). There also were Links at Denbeath (Eunson, 1993, p.37).

Most of the changes in the local coastal landscape reflect the activities and subsequent demise of the local coal mining industry. These mining activities resulted in the placement of mine spoil (redd) on to the foreshore as heaps or bings (e.g. Wellesley Colliery at Links of Denbeath starting in 1906) that were attacked by the sea. Erosion by wave power redistributed the plentiful supply of spoil southwards by longshore drift. This resulted in the burial of natural shore features (including the golden sands) beneath 3-5 metres of black mudstone- and coal-rich beach sand and gravel (Plate 1 and see the photographs of Broken Brae, Buckhaven in Eunson, 1993, pp.28-29).

Deposition of spoil or redd on the foreshore and its erosion and redeposition farther south were not the only processes at work. Over the last 150 years or so, the local collieries such as Wellesley, Michael and Frances mined up to 20 coal seams from within the underlying rocks of the Coal Measures and Passage Formation (Knox, 1954; Browne and Woodhall, 1999) to depths offshore as great as 1000 m below sea level (see Figure 1). The removal of these seams (varying in thickness from about 1-9 m) by longwall and stoop and room methods of working, caused significant subsidence of the ground lowering the level of the original foreshore zone by as much as 5m. Whilst there was a plentiful supply of spoil from the bings to provide the sediment accumulating on the subsiding foreshore, this amount of subsidence was not a problem and indeed the shore advanced seawards.

When policy on the disposal of spoil changed and shore dumping ceased (eg. Frances Colliery about 1981) or mines closed (e.g. Wellesley in 1967; Michael in 1968) a return to active erosion with beach retreat became the norm along the whole of this part of the Fife coast (Plates 1 and 2). The villages of West Wemyss and East Wemyss particularly suffered from coastal erosion, storm or flood damage. Outsized dolerite boulders similar to those shown on Plates 3 and 4 were placed on the upper foreshore at East Wemyss to provide temporary protection measures because Johnstons Factory at East Wemyss was threatened by the coastal retreat. During 2001 a permanent revetment defence was completed to protect this village from erosion and also to a degree from sea level rise.

1.2 OBJECT OF EXERCISE

The object of this study of coastal subsidence between West Wemyss and Buckhaven, Fife is to calculate the amount of subsidence considered to have occurred at the surface as a result of extraction of all recorded underground coal workings affecting the area. The area of study extends from a line some 500 m offshore between the Ordnance Survey Grid references [332000, 694000] to [336000, 698000] and inland to Ordnance Survey reference [332000, 698000] (see Plan1). These calculations are used to create a contoured plan of the area showing the values of surface subsidence at 1 m intervals and comment on the effect this may have on coastal erosion in the area.

1.2.1 Information available

The Catalogue of Abandoned Mine plans, as supplied by the Mines and Quarries Inspectorate, are used to establish which coal plans are relevant to the calculation. This catalogue is a list of plans that are lodged with the Inspectorate.

The mine plans contained the information required for the calculation, including the area of worked coal, method of coal extraction, seam levels, dips and extracted coal thickness (see glossary).

The calculations were made using the National Coal Board's 1966 and 1975 Subsidence Engineer's Handbooks, an adapted table used by British Coal subsidence engineers for producing subsidence profiles (see Table 1); and the Zone Area Method (see Glossary) as applied by Marr, (1975).

Surface levels were taken from the relevant 1:10 000 scale OS maps with interpolation between the contours if required and seabed bathymetry contours were extracted from BGS offshore plans that were compiled from Hydrographic Office and BGS geophysical data (British Geological Survey, 1986) to establish depths.

Ordnance Survey 1:10 000 scale maps were used to create bases for maps and overlays.

2 Seams used in calculation

Extraction of coal from sixteen recorded seams affecting the area of this study. These range from the Pilkembare Coal in the Middle Coal Measures to the Lethemwell Coal in the upper part of the Passage Formation (Figure 1), at depths from fifty to over eight hundred metres.

The coal seams used for the subsidence calculations were:

Pilkembare, Wall, Barncraig, Coxtools, Chemiss, Bush, Wemyss Parrot, Wood, Earl David's Parrot, Bowhouse, Branxton, Boreland, Sandwell, Dysart Main, Lower Dysart and Lethemwell coals (Figure 1).

The Upper and Lower Coxtools were calculated as one seam.

Abandonment plans of the More Coal (Figure 1) were also examined but the seam workings did not cause any surface subsidence within the contoured area.

The Victory Coal mine plans were examined but disregarded as they are found to be characterised by narrow roadways, which are judged unlikely to collapse, and which covered a very small area. If they had collapsed they would have had negligible subsidence effect at the surface.

Two mine plans of the Den Coal workings were examined. However, the data are not included in the subsidence calculation because one was found to be too small in area (approximately 20 m x 13 m) and too deep to cause measurable subsidence at the surface. The other working is partly below West Wemyss and to the northeast and showed only a hatched area with no extracted coal heights, seam levels, method of working and with the limits of the workings uncertain. Because of this lack of information and as it is common for stoop and room method of working to be employed below built up areas, the workings were not included in the calculation of mining-related ground subsidence.

3 Calculation of mining-related ground subsidence

For calculation purposes in this study depth (h) is defined in two different ways. When used with the National Coal Board's Subsidence Engineers Book, adapted table or Zone Area Method of calculation it is taken as the vertical distance from a point on the surface (not rockhead) to a point on the base (pavement) of the coal seam analysed at the centre of the displaced position of the workings affecting that point. This is normal practice to establish an average depth of workings that could cover a considerable area. When using depths to find the position of 0.7 h and 0.5 h from the edge of coal workings the distance was taken from the base at the edge of the extraction to the displaced position of that point at the surface.

The Subsidence Engineer's Handbooks and Zone Area Methods were used to establish maximum subsidence values within the extent of the coal workings examined (see Glossary). Where the extent of a mine working in a seam is sufficiently large to allow all potential for subsidence to occur, the extent is referred to as the Critical Area (see Figure 2b) and the maximum subsidence value is designated S_{max}. Where the extent of mine workings is greater than the Critical Area that area is described as Super-Critical (see Figure 2c) and the maximum subsidence values is also S_{max}. Where the extent of mine workings is less than the Critical Area; referred to as a Sub-Critical Area (see Figure 2a), the actual maximum subsidence at the surface will be less than the potential maximum subsidence, and this value is described as s_{max}. Maximum subsidence values S_{max} and s_{max} are used together with width/depth ratios of the coal seam workings and, where possible, in conjunction with Table 1 to create subsidence profiles. Where there is insufficient information to enable subsidence profiles or contours to be drawn the Zone Area Method is also used to infill these areas.

Values for S_{max} assume subsidence equivalent to 90% of the worked height of the coal seam and to occur at a distance, equal to the depth to the mined coal x 0.7, inside the limits of the workings. Ninety percent subsidence of a worked coal seam is known to occur once the extent of coal extracted is equal to a distance of 1.4 x depth to the mined coal inside the limits of the workings at any given point. For the purpose of the calculations presented here the value of depth of a worked coal seam is taken as the vertical distance from the base (pavement) at the centre of a coal seam working to the displaced position of that point at the surface.

To enable subsidence calculations a grid was drawn across the area of study on north-south and east-west axes with calculation at each grid node. Every point on the surface grid had a numerical value from 1 to 41 (west to east) and a letter from A to OO (south to north) to create a unique reference for each point. Points outwith area of study were ignored [O/W] (see Table 3).

The surface subsidence contours were drawn on plans on a seam by seam basis. The surface grid was displaced relative to the working affecting it to establish values of mining subsidence at each point.

A subsidence value for every referenced point was calculated for each coal seam extracted and the values added together that to give a final total of mining subsidence for each referenced point.

3.1 EXPLANATION OF SURFACE SUBSIDENCE AS ASSOCIATED WITH UNDERGROUND MINING OF COAL

In simple form surface subsidence is caused when an area of coal is worked underground, the overlying strata collapses into the void created by the extraction. These occupy more than their original volume or broken strata bulks (see Glossary) and eventually gives some support to the overlying strata. As the area extracted extends the overlying strata bend to compress this material and eventually this compression effect migrates upwards to the surface resulting in surface subsidence.

Total extraction of coal results in a profile of surface subsidence that is directly related to the shape of the worked area, extraction thickness and dip of the coal. The calculations presented here indicate the surface subsidence above a coal working that is considered to have occurred and calculated from these values. Calculation of subsidence at a series of points along a line will allow construction of a subsidence profile.

The area affected at the surface is always larger than the extracted area (see Figures 2 and 3). As a result of surface monitoring it has been found that the maximum subsidence to reach the surface is 90% of the extracted coal height although in steeply inclined seams maximum subsidence can exceed coal extraction height. Seam dips range between approximately 1 in 3 to 1 in 9 within the area of this study and so the former case is assumed to apply.

Maximum subsidence S_{max} (see Glossary) can be reached no matter how deep the working, as it is related to a ratio of the width of extraction to depth from surface. If this ratio reaches 1.4 in all directions then maximum subsidence (S_{max}) could be attained. For deeper workings the subsidence profiles will cover a larger area and will be much flatter in appearance than for shallower workings. For this study it was assumed that 90% subsidence occurred when an area of coal is worked and the width/depth ratio in all directions reached 1.4.

The main factors that govern the shape of the subsidence profiles are the value of maximum subsidence (S_{max} and s_{max}) and the width/depth ratio of the extracted coal working. These factors also determine the location of the transition point which is the position at which subsidence is calculated to be half the predicted maximum (½ S_{max}) (see Figure 2). The transition point migrates along the subsidence curve away from the area of workings, its location dependent on the above mentioned width/depth ratio, as the area of extraction extends.

There are two types of maximum subsidence values; one for sub-critically extracted areas (s_{max}, Figure 2a) that is also referred to as partial maximum subsidence and one for critical/super-critical areas (S_{max}, Figures 2b and 2c). In a sub-critical condition, when maximum subsidence has been reached, that point can still further subside if coal is worked within the zone of influence (Figure 2). Critical/super-critical conditions are reached when all the coal within the zone of influence of that point has been worked and no matter how much more coal is extracted in that seam, it will not subside any more. The profiles in these calculations integrate the effects of both types of maximum subsidence.

A subsidence curve at the surface is generated due to downward movement of ground caused by loss of support over mine workings. The curve records zero subsidence at one side of the working deepens to maximum subsidence approximately at the middle before decreasing at the other side back to a value of zero. Maximum subsidence values are extremely important in these calculations as values along the subsidence curve are all relative to this value.

Vertical movement of a point on a subsidence curve is called subsidence and horizontal movement is called displacement. When all points on a subsidence curve have subsided to their maximum position and they will not subside any more, providing no more coal is worked, the profile for the area of extracted coal is then said to be fully developed. Fully developed curves used in this exercise were taken as subsidence profiles that had only been affected by one area of worked coal and stretched from maximum subsidence (S_{max} or s_{max}) to zero subsidence.

The nature of overlying strata can affect the shape of a subsidence profile. Faults can create steps in the subsidence profile, horizontal intrusions or bands of thick strong sandstone in the overlying strata can bridge coal extractions reducing significantly the maximum subsidence value. These effects can be negligible or considerable and can cause the subsidence effect at the surface to be delayed for a considerable time. For this study these effects could not be assessed or quantified and so were not included in the construction of the subsidence profiles.

Most subsidence from coal extraction occurs within the first few months with residual subsidence taking anything up to two or three years to complete. Workings in the area of the study were abandoned over fifteen years ago and were assumed to be complete.

Effects from mining can be subsidence, tilt, vertical strain, horizontal movement or strain, curvature and twisting.

Collapsed stoop and room workings have no satisfactory mathematical way of predicting values of subsidence at the surface and for this exercise were ignored. Stooped out areas in this study were treated as longwall extractions.

3.2 METHODS USED FOR MINING SUBSIDENCE CALCULATIONS

Two methods are used to calculate mining subsidence; National Coal Board Subsidence Engineer's Handbook (1966, 1975) in conjunction with an adapted table to create profiles and the Zone Area Method (Marr, 1975).

3.2.1 British Coal Method of mining subsidence prediction

The National Coal Board 1975 Subsidence Engineer's Handbook is used to establish maximum subsidence values (s_{max}) (see Figure 3) for worked areas of coal. The older 1966 Subsidence Engineer's Handbook (1966) is used to establish these values when the extraction widths are greater than 500 m because data in the 1975 handbook are for extraction widths of less than this value.

An adapted table used by British Coal subsidence engineers to calculate subsidence profiles is then used where profiles had fully developed. This profile can only be calculated along lines that are affected by one area of worked coal in a particular seam. The effects of other seams on that profile were ignored, as it is impossible using this method to create multi-seam working profiles.

A combination of the handbooks and tables is the best system to use but they cannot be applied where the coal extraction has formed many irregular shaped worked areas or where a fully developed profile has been affected by more than one area of coal extraction.

If a sub-critical area of coal extraction (see Figure 2a) does not approximate to a rectangular shape and the maximum subsidence position was not affected by any other working, then the maximum subsidence was established by the following method. Firstly the largest possible rectangle was taken within the coal workings (Figure 4), this was created by trial and error method and its maximum subsidence found using the National Coal Board's Subsidence Engineer's Handbook, then another outer rectangle was drawn touching the external limits of the workings (Figure 4) and the maximum subsidence value was calculated for this area. The maximum subsidence for the worked area of coal between the two rectangles was found by taking these two calculated values and showing consideration for the percentage of coal worked between the two rectangles, an estimate made of the value. For example 50% extraction within this area (Figure 4) would result in maximum subsidence being taken as equal to the mean values of the above calculations.

3.2.1.1 WHEN NOT TO USE BRITISH COAL'S SUBSIDENCE ENGINEER'S HANDBOOK

The handbook should not be used for:

- Depths shallower than say 50 m.

- Dips steeper than about 1 in 3.
- Predicting subsidence over stoop and room workings where the stoops have only been sporadically extracted.

In this study some small areas were dipping at up to 1 in 2.6 but since there is no ready method to calculate these profiles quickly and satisfactorily and the areas affected were small, normal profile calculations were used for these areas.

3.2.2 Zone Area Method of mining subsidence prediction

The Zone Area Method of subsidence prediction consists of a series of concentric circles around a surface point creating zones between each adjacent ring; the external radius of the outer circle being equal to the radius of the area of influence ie 0.7 x depth to mined coal (Section 3). The number of zones used is dependent on the depth to the workings and for this study 3, 5 or 7 circles were used. Since the diameter of the outer ring reduces with the depth, it would be physically extremely difficult to use 7 concentric rings for very shallow workings (see Figure 5). The circles should always be drawn at the same scale as the mine plan on which they are to be used.

Lines were drawn from the centre of the circles to the external radius of the outer circle (either ten or twenty). These lines divide each concentric zone into smaller equal area segments, which helps in the estimation of subsidence from workings within each zone. The sum of the value within each of the segments is multiplied by either ten or five (Table 2) to give a total percentage of extraction within each zone. This figure is multiplied by a factor from a table to create a value that is multiplied by the worked height of coal to give a subsidence value for that point.

For this study the Zone Area Method and table used was as adapted and presented by J E Marr (1975) to the Institute of Mining Engineers. It is a method used by British Coal subsidence engineers when predicting subsidence at a point on the surface, which is affected by workings of irregular or complex shapes.

Although this is the correct method a simplification to it can be applied. A group of circular girds were drawn up at the start of the study for depth values ranging from fifty metres to eight hundred metres in depth at fifty metre intervals. The nearest appropriate circular grid was used to establish subsidence values. This was the method used by British Coal subsidence engineers and was found to yield very little difference in the subsidence values to the proper circle radii with a considerable reduction in staff resources. This method can be used to establish (s_{max}) values for use with the adapted table for partial subsidence profiles. British Coal Subsidence Engineers accepted the method as being the best available for manual predictions over irregularly shaped workings but is only used where you cannot apply the Subsidence Engineer's Handbook and adapted table.

This method is known to have certain limitations i.e. subsidence values can be up to 10% higher than values derived using the subsidence handbook method of prediction. No account of high values arising from the simplified method has been accounted for in this study because it is not known whether the higher values would apply or not.

Points for calculations should not be taken in the vicinity of the edge of the working or waste edges. A point taken directly over the waste edge of a large extraction for example would fill 50% of the circles i.e. half of maximum subsidence would occur here, but it is known that this is not necessarily the correct value for this position.

The Zone Area Method was mainly used to infill values of subsidence to enable contours to be drawn on seam plans.

3.3 APPLICATION OF THE MINING SUBSIDENCE METHODS TO THE WEMYSS AREA

When establishing values of subsidence at the surface from workings which are not level but inclined, the displaced position must be used (Figure 3 and Glossary).

There are two methods when working out the displaced position of a point to establish its value of subsidence. One is to displace the workings relevant to the surface and the other is to displace the surface point relevant to the underground workings. For this study the second option was chosen, although both methods will give you the same result, as is described in the following paragraphs.

1. A surface plan of the area to be contoured was drawn at a scale of 1:10 000 with an Ordnance Survey Grid and coastline. A baseline defining the offshore extent of the study was then drawn on this plan approximately 500 m towards the south-east.
2. The Abandonment Coal Mine Plan Catalogue for the area was examined and the plan numbers affecting the area to be contoured were extracted.
3. A map of coal extraction for each seam was drawn up from the above abandonment plans showing the limits of the workings, extracted coal thickness, spot levels and seam contours. Various depths across the workings are established by taking the difference between the seam and displaced surface levels and these are put on this plan for future use in width/depth ratios used to find maximum subsidence and displacement.
4. Another map was compiled as the abandonment plans were examined, showing the dips in different seams at various positions across the area to be contoured. These are used in the calculations if workings had no levels to establish dips for displacement and so dip in the nearest seam within the zone of influence to the working, which is affecting a particular point, is then taken for the displacement of that point.
5. A surface subsidence contour overlay map is then created on a seam by seam basis using the following method. Since the surface parts were going to be displaced the contours on this map were relative to the workings.
   - i) A map was prepared of the area to be contoured and placed on top of the map of coal extraction. A line was drawn around the outside of the workings at a distance of 0.7 x depth to edge of working defining the limit of subsidence (Figure 3).
   - ii) A further second line was drawn round the same workings at a distance 0.5 x depth beyond the edge of the workings. This is to help in the interpretation of the contours between ¼ maximum subsidence and limit (zero) subsidence. Only about 3% of maximum subsidence occur at this point and the position is used to assist in the contouring of the plan.
   - iii) A line at 0.7 x depth to workings is drawn within each area of extraction that has reached maximum subsidence (S_{max}), this delimits the area which has reached maximum subsidence ie 90% height of worked coal.
   - iv) The values of maximum subsidence within these areas at various points are marked on the subsidence plan (the amount of subsidence at points within this area is dependent on the thickness of coal worked affecting each area).
   - v) The Subsidence Engineer's Handbook is used to establish maximum subsidence (s_{max}) positions within other parts of the workings for use with the adapted table.

vi) The Zone Area Method is then used to establish maximum subsidence values (s_{max}) within workings, which cannot be found using the Subsidence Engineers Handbook, for use with the adapted table for creating subsidence profiles.

vii) Values of subsidence are plotted along all fully developed profiles.

viii) Zone Area Method is used to infill any gaps.

ix) The subsidence contours are then drawn on the plan.

3.3.1 Application of the British Coal mining subsidence prediction method

The Subsidence Engineer's Handbook was used whenever possible to establish values of maximum subsidence (S_{max} and s_{max}) within the coal workings.

When these values had been established the adapted table for the calculation of the subsidence profile was used to create subsidence profiles which had fully developed from maximum subsidence to zero subsidence without the curve being affected by any other working in that seam.

The transition points (see glossary) were located along the full profiles from the adapted table used by British Coal for subsidence profiles and where possible a line was drawn joining these points together. Since this is where ½ maximum subsidence occurs, this line was then given values that varied depending on the maximum subsidence value for the coal extraction affecting the profile for that point.

Initially only the positions of 0.25, 0.5 and 0.75 of the maximum subsidence value were established, later interpretation was used for other values interpolated between maximum subsidence and limit of subsidence using the adapted table. These points were estimated but calculation of fuller profiles could be undertaken if greater detail was required and more time available.

3.3.2 Application of the Zone Area Method of mining subsidence prediction

The Zone Area Method was used to establish values of subsidence in the middle of the areas of unworked coal that could not be calculated using the Subsidence Engineer's Handbook. It was also used to establish additional values of subsidence at locations, where needed for coverage to allow each seam to be contoured.

If the Zone Area Method was used to calculate a value of subsidence in the middle of an extracted area of coal and the subsidence profile from that working was not affected by any other extraction the adapted table (Table 1) was used to develop a full profile.

When the Zone Area Method was used for calculation, the coal extraction thickness for any one point was taken as the average within the zone of influence. If no thickness was within the zone of influence then the nearest ones to the zone were taken.

3.4 PROCEDURE TO CREATE FINAL MINING SUBSIDENCE PLAN

1. A plan for each seam plan was then drawn up showing contoured values of subsidence derived from the British Coal and Zone Area methods.
2. A map overlay with an Ordnance Survey grid of one hundred metre spacing covering the area of study, the rows lettered and the columns numbered, was prepared.

3. The subsidence value for every one hundred-metre grid point from each seam was then extracted by applying the grid on top of the subsidence contours and recorded in Table 3. The displaced position for that point was taken as the depth to the centre of the working affecting each point divided by the average dip from the worked coal within the zone of influence in the average direction of full dip for that area. If no levels were available to establish a dip, the necessary information was taken from the nearest available worked seam (3.3 paragraph, 4). Depths were interpolated between the nearest values on the coal extraction plan (Section 3.3, paragraph 3). If the position of the point after it had been displaced, did not fall on a contour or value of subsidence an estimate was made from the adjacent subsidence values. This process was continued for every seam.
4. Every point then had a subsidence value for each seam worked shown on the subsidence value table (Table 3). Addition of the values in the subsidence value table gave a total value of subsidence for each point that was used to create a final contoured map of surface subsidence, contoured in metres. This map was digitised and applied onto a base map showing the coastline, villages and towns (Figure 6 and Plan 1).

3.4.1 Notes relevant to the mining subsidence calculations

Where more than one leaf of a coal seam was worked and the area worked within various leaves was clearly defined, they are treated as individual seams and calculations were done for each leaf e.g. the Barncraig Coal. If the extent of different leaves cannot be differentiated then only one calculation was done taking the average thickness of worked coal within the zone of influence for any point e.g. the Chemiss and Dysart Main coals. It should be noted that extraction thickness of the Dysart Main Coal varied from 1.15 m to 4.35 m and for some areas the number of leaves extracted was uncertain.

Pillars (Figure 3) between extractions of coal that are less than one tenth of the depth of the seam were assumed to have collapsed and were treated as if they had been extracted.

Where an area is identified as having been worked by stoop and room method and the stoops have not been taken out, it is assumed to be still standing and was disregarded for this exercise. Where the stoops have been taken out the area was treated as if it there had been total extraction of the seam.

The subsidence effects of any faults cutting through this area are not included in this study because it is not possible to predict with available information how it affects the subsidence profile.

It was assumed that no stowing (see Glossary) had taken place in any of the workings for this study although in reality mine economics mean that as much mine waste as possible is disposed of underground and this would reduce the actual subsidence than those values presented here.

4 Results

Subsidence at the surface from recorded underground workings in the area studied, using the calculation methods described varies, from 0 to 6.3 m (Plan 1). Values of subsidence in the area along and adjacent to the coastline ranged from 0 to 5.0 m (Plan 1).

Areas within this study will have had major surface subsidence that could have affected property, roads, services and site locations. On Plan 1 where deep surface mining subsidence hollows could exist, water and gas pipes may be damaged, electricity pylons tilted or water/gas, sewage or drainage pipes affected.

High strains of compression and tension will have been set up in the strata overlying the worked coal seams within the area of study due to the very complex workings. Parts of the area underlying the coastline will have been subjected to both compressive and tensile strains affecting the strata. This is likely to cause the strata to be severely fractured and disturbed resulting in enhanced coastal erosion. Opening of fractures and joint bedding plane slip, block rotations etc. will have contributed to roof partings in the Wemyss caves resulting in their closure (Plate 5). Areas where the highest surface subsidence values occur are not necessarily where the most damage occurs as strains can cause more damage than subsidence.

5 Uncertainties

The surface subsidence values presented in Plan 1 are subject to a number of known sources of uncertainty that are listed below.

- Exact thickness of coal extracted is unknown in some areas.
- An average value for the coal extraction height was taken within the zone of influence of each point.
- Where more than one leaf of a coal seam was extracted, the exact extent of extraction in each leaf is unknown in some areas.
- Subsidence profiles were constructed by interpolation between the maximum, ¾, ½, ¼ and zero subsidence values. All the points from the adapted table would normally be plotted for each subsidence profile.
- Due to time constraints interpolation was used in some areas on the seam subsidence contour plan where additional subsidence values were added using the Zone Area Method (Section 3.3 paragraph 5 (viii).
- When the contoured subsidence plan was used to extract values for the gridded subsidence value table an estimated interpolated value was used when the point did not fall on an exact subsidence contour value.
- An average value for the direction and rate of dip of workings affecting each was used to calculate the displaced position of that point.
- No allowance was made for the up to 10% higher values that could be found when using the 'simplified' Zone Area Method.
- Some areas of stoop and room workings contained small stoops and may have collapsed causing increased values of subsidence above these areas.

6 Comments

An area to the north west of line A-B (see Plan1*)* could have been affected by unrecorded workings in the Bowhouse Coal therefore subsidence within this district should be taken as minimum values. The thickness of coal in this area is about 1.37 m, so an additional 1.23 m of subsidence values would be added to the area north west of this line if S_{max} was reached in any part of the area.

Workings in the Den Coal are known to exist in the West Wemyss area. These workings were assumed to be stoop and room and no calculations of subsidence were done for this area. If the method of working instead were total extraction it would affect the values of subsidence in this area increasing it by up to a maximum of 0.6 m. Subsidence values within this area (shown blue on Plan 1) should therefore be taken as minimum.

7 Conclusions

Maximum potential subsidence values in the area of East and West Wemyss villages associated with longwall mining methods, range from 0 to 5.0m.

Strains will exist within the strata overlying the workings today and could result in increased surface damage some time in the future, even if no further coal is worked. If any attempts are made to extract reserves of coal within this area it is totally unpredictable what subsidence values and damage would occur at the surface from the calculations presented here.

All of the potential mining subsidence should have occurred within a few years of the cessation of underground mining activities and providing no other coal is worked in the area the surface should remain stable. However many stoops and stoop and room workings exist within the extent of the study and some of these will still not have collapsed. Failure of these stoops could occur at any time and although this would not normally cause severe damage at the surface, high strains in the overlying strata could be released causing more serious damage than might otherwise be anticipated.

Many buildings within the study area will have been subjected to both tensile and compressive strain pulling from all directions as a result of the number of seams worked and the complexity of the workings. These buildings could be subjected to possibly serious damage by the release of any minor strains existing within the immediately underlying strata.

In the areas of shallower coal workings more severe surface damage can be expected.

Similarly the Wemyss caves (Plates 5, 6 and 7) could be subject to further roof falls and pillar or wall collapse possibly resulting in further closures.

Subsidence of up to 2 m, with recent removal of beach material deposits from the colliery waste tips, means the cave system is now even more vulnerable to marine erosion and flooding unless defended.

WORKSHEETS AND MAPS AVAILABLE IN REPORT APPENDIX IR/03/060 NOT ATTACHED (AVAILABLE ON REQUEST).

Glossary

Angle of draw (Limit angle) The angle of inclination from a vertical line connecting the edge of a working to the edge of the subsidence area.

Bulking factor When overlying layers of rock collapse into a cavity, it occupies a larger area than when it was originally layered in the strata. Friable strata has a high bulking ratio of about 1.7, whereas sandstone and conglomerates could be as low as 1.2.

Critical Area An area of working which causes the complete subsidence at one point on the surface.

Depth (for calculation) This was taken as the vertical distance from a point on the surface (not rockhead) to a point at the centre of the displaced position of the floor of the workings affecting that point.

Dip (depth/dip displacement) This is the grade the coal is dipping at i.e. 1 in 3 and for displacement the value 3 would be used in this case for the depth/dip ratio.

Displaced position When coal which is not lying horizontally is taken out, the final effect on a point subsiding at the surface, is to displace it laterally in the direction of the full dip of that working (see Figure 2b). The displacement distance for this exercise was taken as depth/dip ratio (see Glossary).

Extracted height of coal This is the actual thickness of coal (and dirt) taken out which may not necessarily be the same as the seam thickness.

Leaves of coal Coal seams are sometimes too thick or varied too much in quality throughout the thickness to be taken out at the same time. They were extracted in two, three or maybe four layers, these layers are called leaves.

Limit of subsidence This is the position where the subsidence curve reaches zero (Figure 3). For this exercise it was taken as 0.7 x depth to edge of workings.

Maximum subsidence This refers to the maximum value of vertical movement along a subsidence profile on the surface as a result of working an area of coal underground. It is referred to as (S_{max}) when the working is a critical/super-critical area and (s_{max}) when it is sub-critical. For this study (S_{max}) is taken as 90% of worked height of coal.

Panel The area of coal extracted by a longwall face.

Pillars Area of coal left in between coal workings (sometimes called a stoop). This could vary in size depending on the strength of the coal and how much protection was needed for the adjacent coal working.

Profiles fully developed When coal is extracted underground causing subsidence at the surface a subsidence curve or profile is formed (see Figures 1a-c). It is said to be fully developed when the points along this curve have subsided to their maximum values and will subside no more provided no other coal is worked affecting the profile. In this study it is also where the curve goes from maximum subsidence to zero.

Recorded coal workings These are plans which are registered in The Abandonment Coal Mine Plans Catalogue.

Seam levels Levels on the floor of the seam that are relevant to OD. These enabled depths and dips of coal seams to be established.

Stoop See pillars

Stoop and room workings This was a method of working coal underground whereby roadways were driven through the seam (rooms) and stoops of coal were left in to help support the roof.

There are various other names throughout the coalfields for this method of working coal e.g. pillar and stall, room and pillar. Economically as much coal as possible was extracted by this method, extraction ratios therefore varied depending on the strength of the coal, by experience it was established what size of pillar could be safely left in. This also meant that the stoops had very low safety factors built in and were subject to collapse after time.

Stowing This was a process whereby as coal was extracted the workings were back-filled with stone or packing to reduce the amount of spoil to be transferred to the surface and also subsidence which occurred at the surface.

Sub-Critical Area An area of working smaller than the critical area. [When a point at the surface under examination does not undergo complete (S_{max}) subsidence].

Super-Critical Area An area of working greater than a critical area where an area of subsidence at the surface is likely to have undergone complete subsidence.

Transition Point This is the point on the subsidence profile where compressive strain change over to tensile strains i.e. no strains exist, and 50% maximum subsidence occurs with maximum tilt.

Waste edge This is edge of the coal extraction area and is sometimes called the rib edge or ribside.

Zone Area Method This is a method of predicting subsidence and when used for calculations in this study it was as applied in a paper presented by J E Marr MSC, C ENG, FELLOW to The Institute of Mining Engineers in 1975.

Zone of influence This is area affected on the surface by the extraction of coal underground. (Figure 2).

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Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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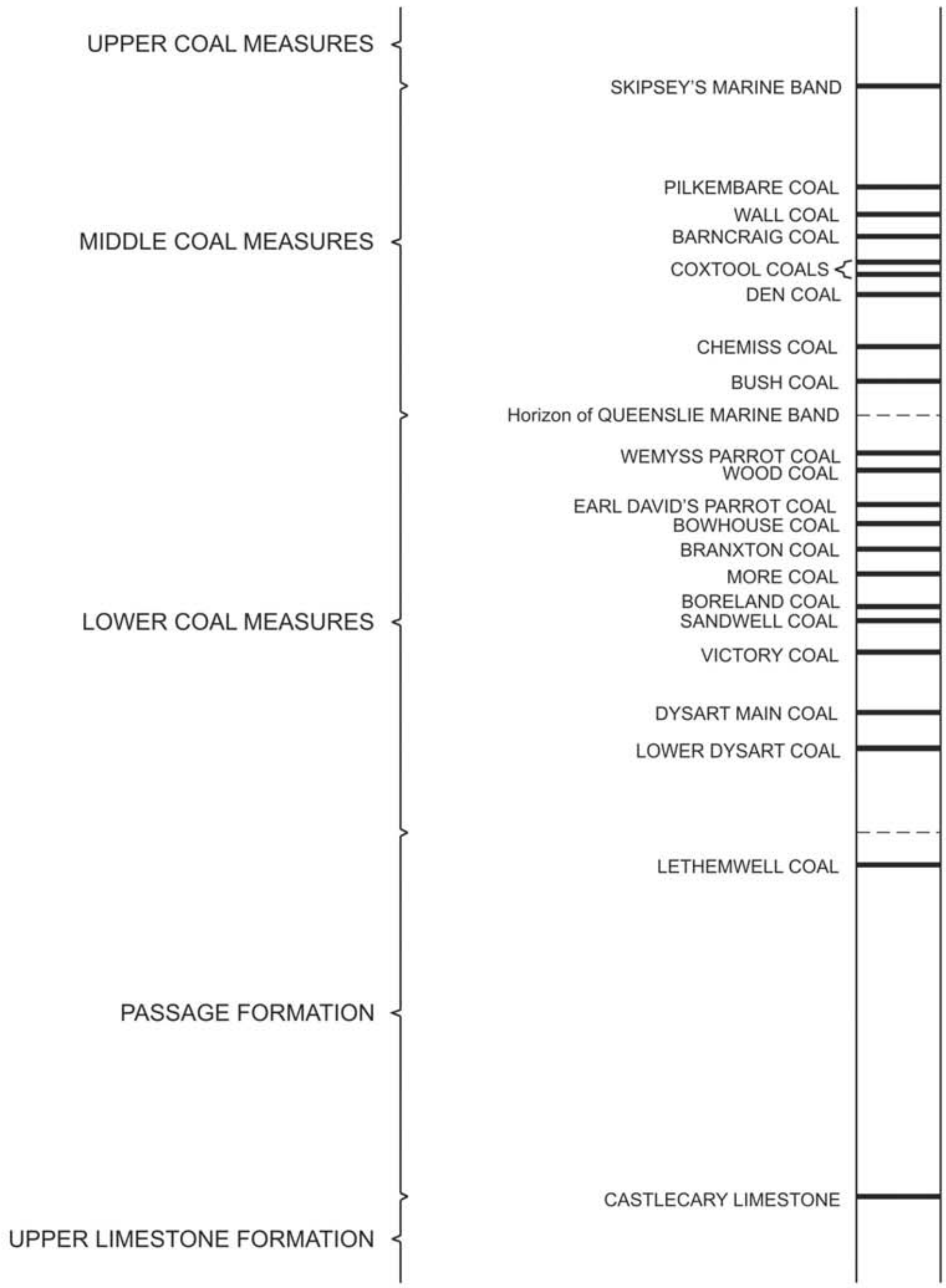
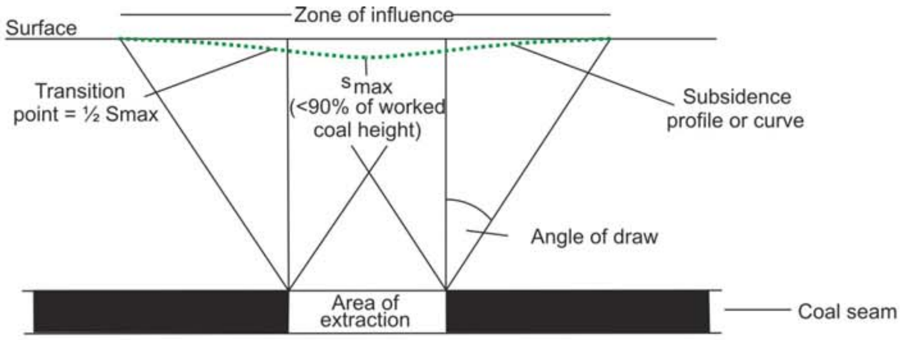
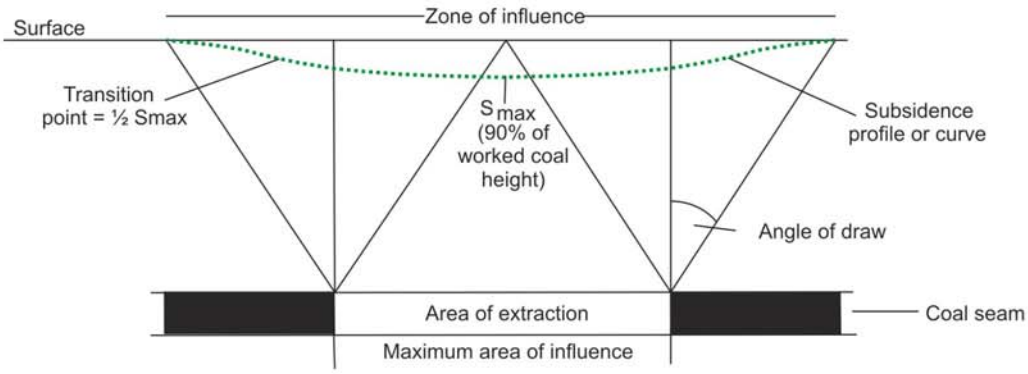


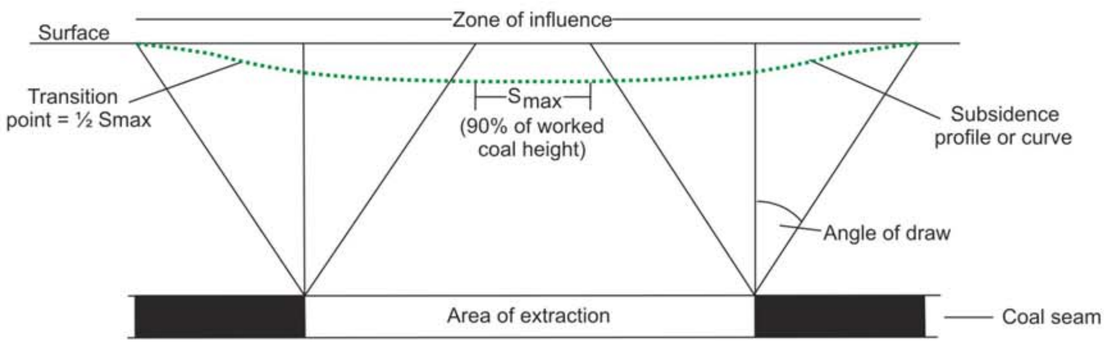
Figure 1 General vertical section through worked coal seams within the area of study



(a) SUB-CRITICAL AREA (where w/h ratio <1.4)



(b) CRITICAL AREA (where w/h ratio =1.4)



(c) SUPER-CRITICAL AREA (where w/h ratio >1.4)

w=width of coal extraction

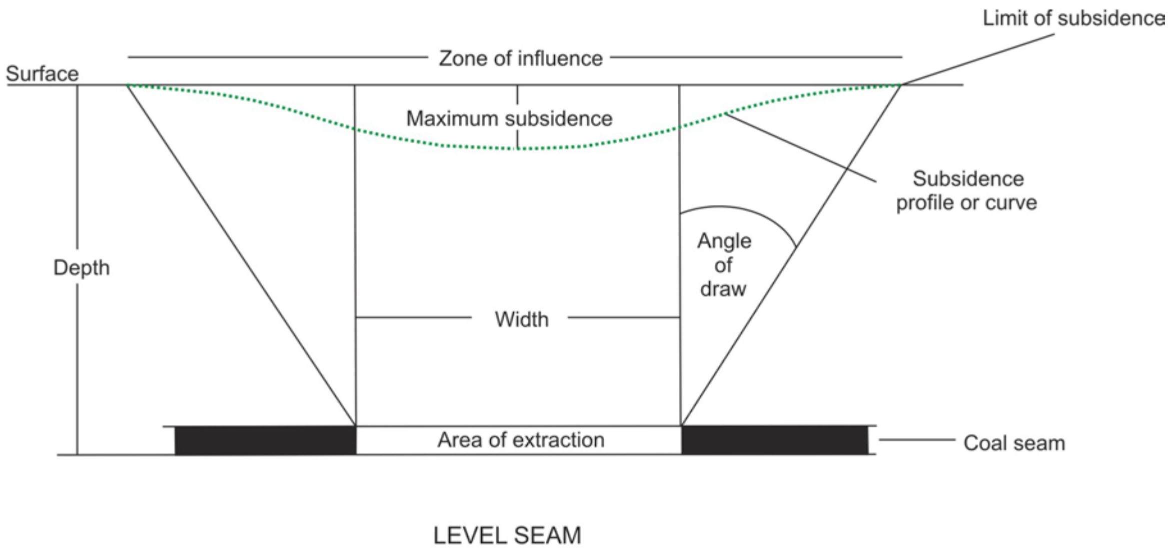
h=depth of coal from surface

s_{max} = maximum possible vertical movement along a subsidence profile created by a sub-critical area of coal extraction

S_{max} = maximum possible vertical movement along a subsidence profile created by a critical or super-critical area of coal extraction

Figure 2 Diagrams showing the effect on fully developed subsidence profile of various coal width extractions for (a) a Sub-Critical Area (b) a Critical Area (c) a Super-Critical Area

(Not to scale)



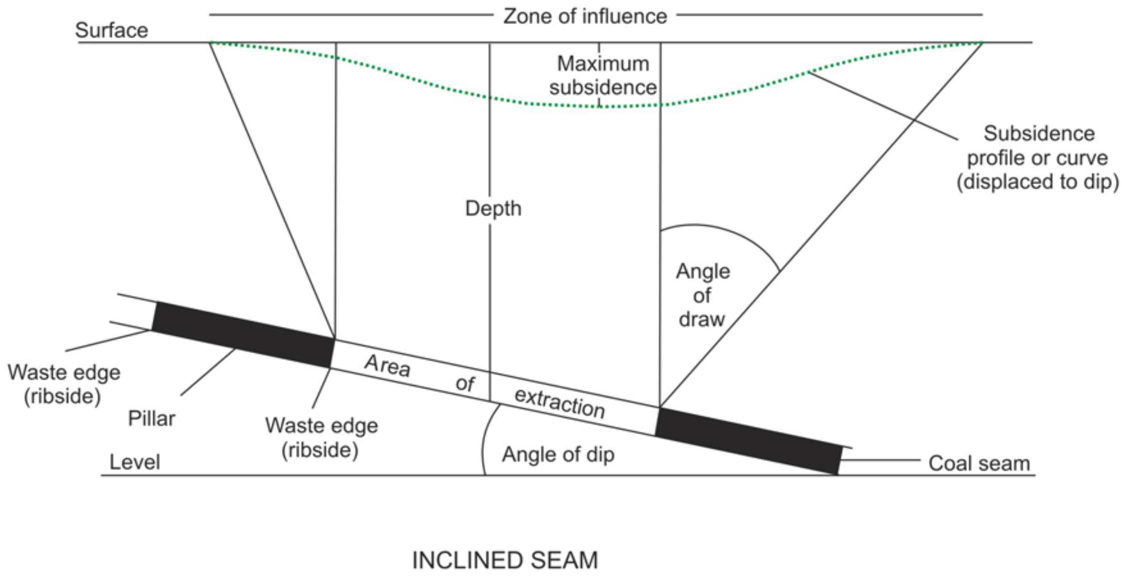


Figure 3 Diagrams showing a susidence profile in a level seam and a displaced subsidence profile in an inclined seam

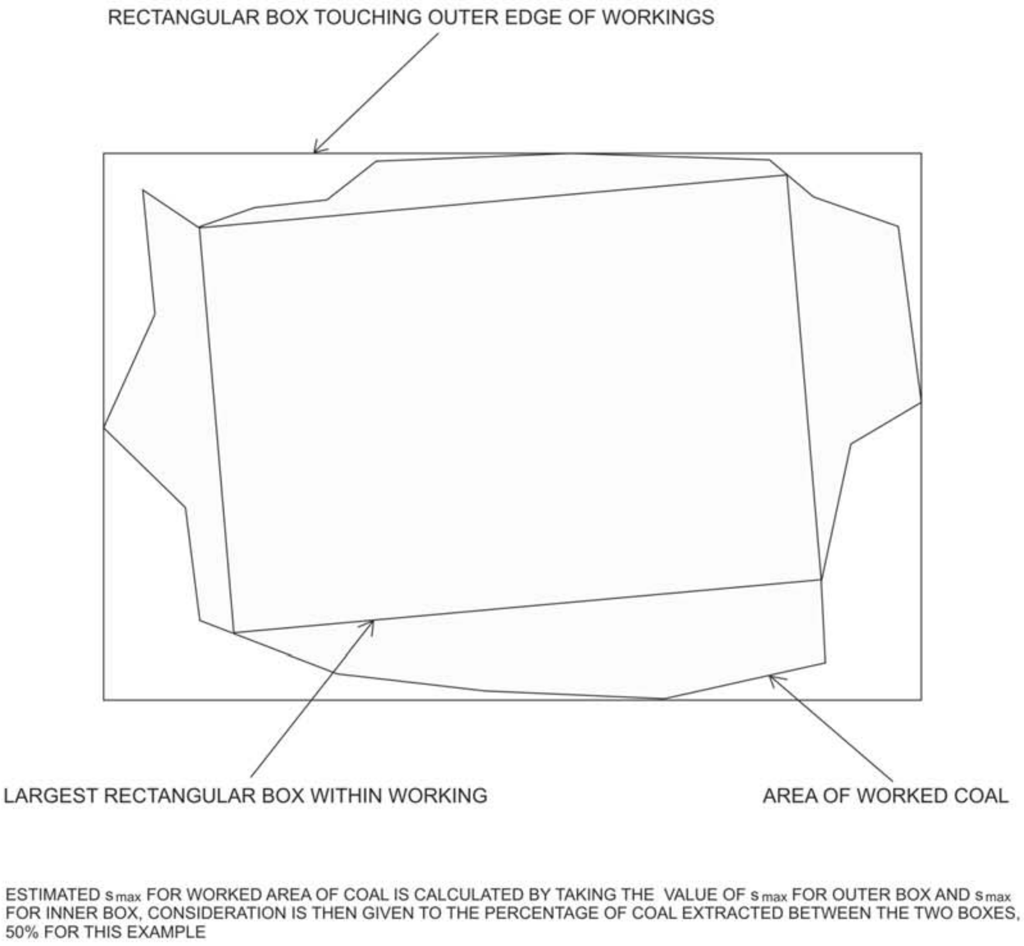


Figure 4 Establishing estimated s_{max} for an irregular-shaped coal working

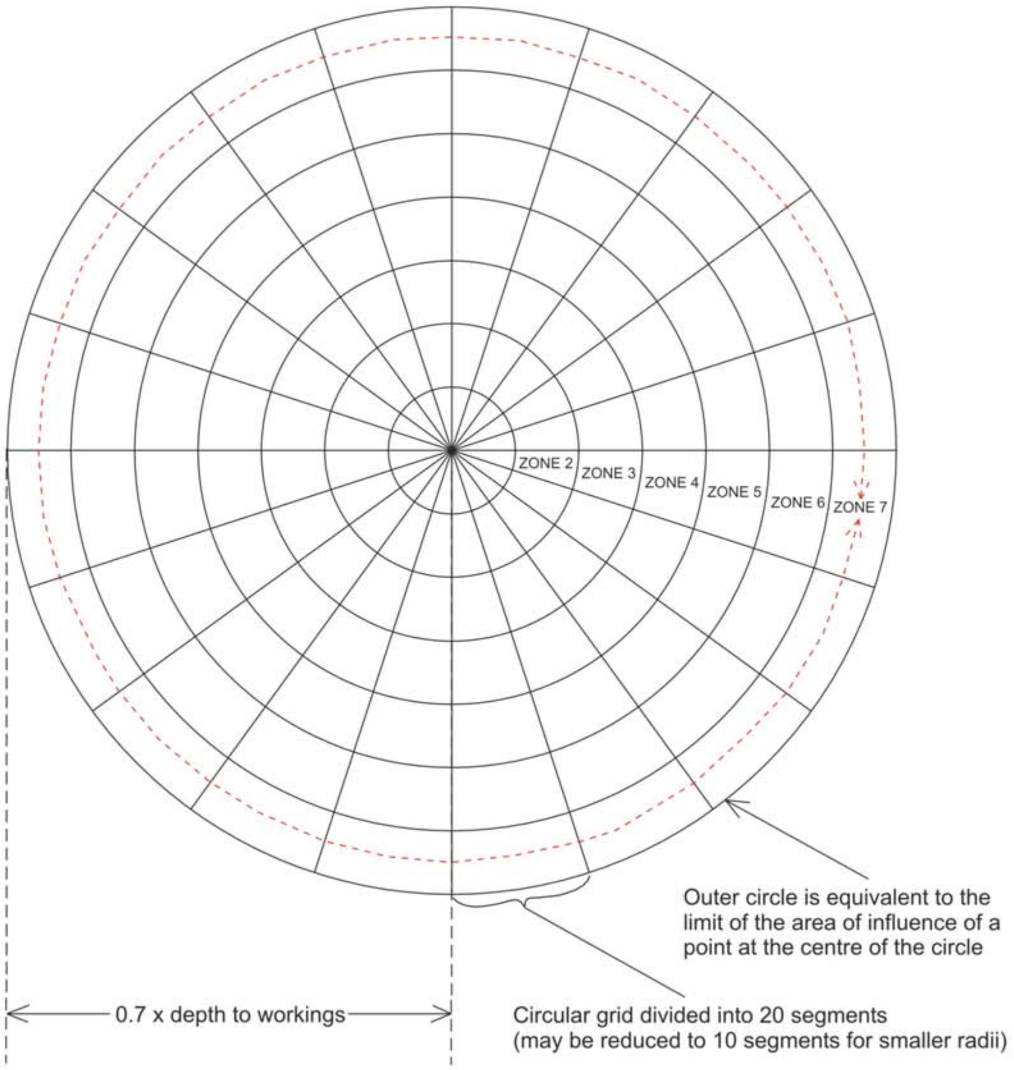


Figure 5 Grid used in Zone Area Method of subsidence prediction

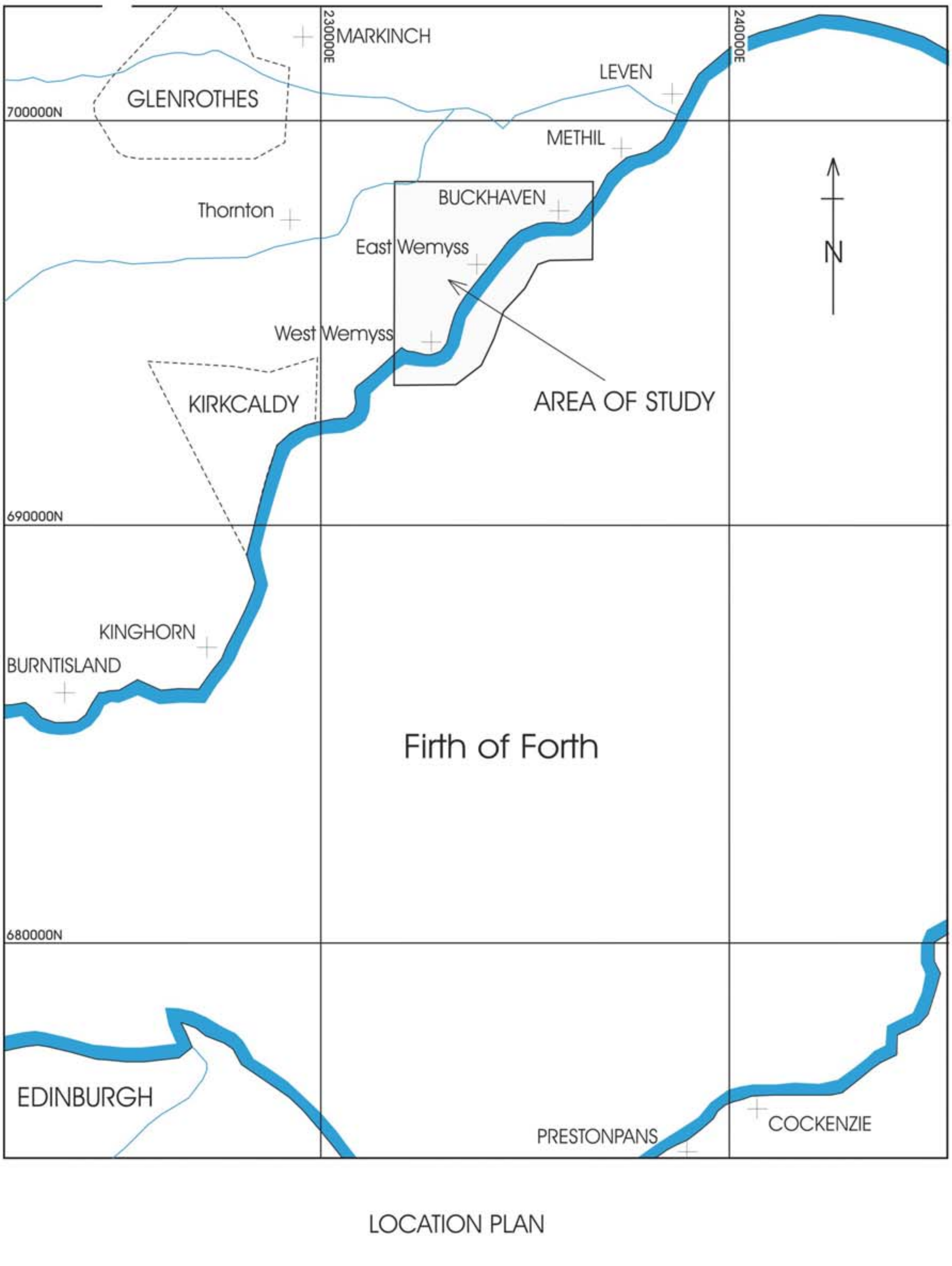


Figure 6 Extent of the area of study, shown in detail on Plan 1

Plate 1 Erosion of the coastline at Michael Colliery [NT 3375 9613]

Plate 2 Erosion of the coastline near Frances Colliery, south of Wemyss [NT 3090 9376]

Plate 3 Outsized dolerite boulders placed on upper foreshore providing protection from coastal erosion View looking north at East Wemyss (c.1995) [NT 3420 9690]

Plate 4 Outsized dolerite boulders placed on upper foreshore providing protection from coastal erosion View looking south at East Wemyss (2002) [NT 3426 9690]

Plate 5 Closure of Court cave, Wemyss due to subsidence damage from underground coal mining (c.1995) [NT 3428 9694]

Plate 6 Early picture of Court cave, Wemyss (c.1912)

Plate 7 Early picture of Wemyss caves (c.1912)

SUBSIDENCE PROFILE								TRANSITION POINT							TRANSITION POINT
w/h	S/m	PART MAX. SUBSIDENCE	0.00	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1.00	OVER GOAF/SOLID
1.40	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.55	0.15
1.38	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.54	0.15
1.36	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.53	0.14
1.34	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.52	0.14
1.32	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.52	0.14
1.30	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.51	0.14
1.28	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.50	0.14
1.26	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.49	0.14
1.24	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.28	0.48	0.14
1.22	0.90		0.85	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.27	0.47	0.14
1.20	0.90		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.27	0.46	0.14
1.18	0.89		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.21	0.27	0.45	0.14
1.16	0.89		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.27	0.44	0.14
1.14	0.89		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.27	0.43	0.14
1.12	0.88		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.26	0.42	0.14
1.10	0.88		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.26	0.41	0.14
1.08	0.87		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.26	0.40	0.13
1.06	0.86		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.25	0.40	0.13
1.04	0.86		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.25	0.39	0.13
1.02	0.85		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.20	0.25	0.38	0.13
1.00	0.84		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.19	0.24	0.37	0.13
0.98	0.84		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.13	0.19	0.24	0.36	0.13
0.96	0.83		0.84	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.19	0.24	0.35	0.13
0.94	0.82		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.19	0.23	0.34	0.13
0.92	0.81		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.19	0.23	0.33	0.13
0.90	0.80		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.19	0.23	0.32	0.12
0.88	0.78		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.18	0.22	0.32	0.12
0.86	0.77		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.18	0.22	0.31	0.12
0.84	0.76		0.83	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.18	0.21	0.30	0.12
0.82	0.74		0.82	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.17	0.21	0.29	0.11
0.80	0.73		0.82	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.17	0.20	0.28	0.11
0.78	0.72		0.82	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.12	0.17	0.20	0.28	0.11
0.76	0.70		0.82	0.35	0.24	0.14	0.08	0.04		0.04	0.08	0.11	0.16	0.20	0.27	0.11
0.74	0.69		0.81	0.35	0.24	0.14	0.08	0.04		0.04	0.07	0.11	0.16	0.19	0.26	0.10
0.72	0.68		0.81	0.35	0.24	0.14	0.08	0.04		0.04	0.07	0.11	0.16	0.19	0.26	0.10
0.70	0.66		0.81	0.35	0.24	0.14	0.08	0.04		0.04	0.07	0.11	0.15	0.18	0.25	0.10
0.68	0.64		0.80	0.35	0.24	0.14	0.08	0.04		0.03	0.07	0.10	0.15	0.18	0.24	0.09
0.66	0.62		0.80	0.35	0.24	0.14	0.08	0.04		0.03	0.07	0.10	0.14	0.17	0.24	0.09
0.64	0.60		0.79	0.36	0.24	0.14	0.08	0.04		0.03	0.07	0.10	0.14	0.17	0.23	0.09
0.62	0.58		0.79	0.36	0.24	0.14	0.08	0.04		0.03	0.06	0.10	0.14	0.16	0.22	0.08
0.60	0.56		0.78	0.36	0.25	0.15	0.08	0.04		0.03	0.06	0.09	0.13	0.16	0.21	0.08
0.58	0.54		0.78	0.37	0.25	0.15	0.08	0.04		0.03	0.06	0.09	0.13	0.16	0.21	0.07
0.56	0.52		0.77	0.38	0.25	0.15	0.08	0.04		0.03	0.06	0.09	0.13	0.15	0.21	0.07
0.54	0.50		0.76	0.38	0.26	0.13	0.08	0.03		0.03	0.06	0.09	0.12	0.15	0.21	0.06
0.52	0.47		0.76	0.39	0.26	0.13	0.07	0.03		0.03	0.06	0.09	0.12	0.14	0.20	0.06
0.50	0.45		0.75	0.39	0.26	0.13	0.07	0.03		0.03	0.05	0.09	0.12	0.14	0.20	0.05
0.48	0.42		0.74	0.40	0.26	0.13	0.07	0.03		0.03	0.05	0.08	0.12	0.14	0.20	0.04
0.46	0.39		0.73	0.40	0.26	0.13	0.07	0.03		0.03	0.05	0.08	0.12	0.14	0.20	0.03
0.44	0.37		0.72	0.40	0.27	0.13	0.07	0.03		0.03	0.05	0.08	0.12	0.14	0.20	0.02
0.42	0.34		0.71	0.40	0.27	0.13	0.07	0.03		0.03	0.05	0.08	0.12	0.14	0.20	0.01
0.40	0.31		0.70	0.40	0.27	0.13	0.07	0.03		0.03	0.06	0.09	0.12	0.15	0.20	0.01
0.38	0.28		0.69	0.40	0.27	0.13	0.07	0.03		0.03	0.06	0.09	0.12	0.15	0.21	0.02
0.36	0.26		0.67	0.39	0.27	0.13	0.07	0.03		0.03	0.06	0.09	0.13	0.16	0.21	0.04
0.34	0.24		0.65	0.39	0.27	0.13	0.07	0.03		0.03	0.06	0.10	0.13	0.16	0.22	0.05
0.32	0.21		0.64	0.38	0.26	0.13	0.07	0.04		0.03	0.06	0.10	0.14	0.17	0.23	0.07
0.30	0.18		0.62	0.37	0.26	0.13	0.07	0.04		0.03	0.07	0.10	0.15	0.17	0.24	0.10
0.28	0.15		0.60	0.37	0.26	0.15	0.09	0.04		0.03	0.07	0.11	0.15	0.18	0.25	0.12
0.26	0.13		0.57	0.36	0.26	0.15	0.09	0.04		0.03	0.07	0.11	0.16	0.19	0.26	0.15
0.24	0.11		0.54	0.35	0.26	0.16	0.09	0.04		0.04	0.08	0.12	0.17	0.20	0.28	0.17

STRAIN PROFILE	MULTIPLIERS				EXTENSION (+E)							TRANSITION POINT	COMPRESSION (-E)										
w/h	+E	-E	G	PART STRAIN	0	0.2	0.4	0.6	0.8	1	0.8	0	0.2	0.4	0.6	0.8	1	0.8	0.6	0.4	0.2	0	w/h
1.40	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.55	1.40
1.38	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.54	1.38
1.36	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.54	1.36
1.34	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.53	1.34
1.32	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.52	1.32
1.30	0.65	0.51	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.51	1.30
1.28	0.65	0.52	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.46	0.50	1.28
1.26	0.65	0.52	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.45	0.49	1.26
1.24	0.65	0.52	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.45	0.48	1.24
1.22	0.65	0.52	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.45	0.47	1.22
1.20	0.65	0.52	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.44	0.46	1.20
1.18	0.65	0.53	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.44	0.45	1.18
1.16	0.65	0.53	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.43	0.44	1.16
1.14	0.65	0.53	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.43	0.43	1.14
1.12	0.65	0.53	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.39	0.42		1.12
1.10	0.65	0.54	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.33	0.38	0.41		1.10
1.08	0.65	0.54	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.38	0.41		1.08
1.06	0.65	0.54	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.38	0.40		1.06
1.04	0.65	0.54	2.73		0.79	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.38	0.39		1.04
1.02	0.65	0.54	2.73		0.78	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.37	0.38		1.02
1.00	0.65	0.55	2.73		0.78	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.37	0.37		1.00
0.98	0.65	0.56	2.73		0.78	0.42	0.31	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.36			0.98
0.96	0.65	0.57	2.73		0.78	0.42	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.32	0.35			0.96
0.94	0.65	0.58	2.73		0.78	0.42	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.31	0.34			0.94
0.92	0.65	0.59	2.73		0.78	0.41	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.31	0.33			0.92
0.90	0.65	0.60	2.74		0.78	0.41	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.31	0.33			0.90
0.88	0.65	0.60	2.75		0.78	0.41	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.31	0.32			0.88
0.86	0.65	0.62	2.76		0.78	0.41	0.30	0.25	0.20	0.14	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.30	0.31			0.86
0.84	0.65	0.63	2.78		0.78	0.41	0.30	0.24	0.20	0.13	0.10		0.02	0.04	0.08	0.11	0.17	0.26	0.30				0.84
0.82	0.65	0.66	2.79		0.78	0.41	0.30	0.24	0.20	0.13	0.09		0.02	0.04	0.08	0.11	0.17	0.26	0.30				0.82
0.80	0.65	0.68	2.80		0.78	0.41	0.30	0.24	0.19	0.13	0.09		0.02	0.04	0.08	0.11	0.17	0.26	0.29				0.80
0.78	0.65	0.71	2.82		0.78	0.41	0.29	0.24	0.19	0.13	0.09		0.02	0.04	0.08	0.11	0.17	0.26	0.28				0.78
0.76	0.66	0.74	2.83		0.78	0.40	0.29	0.24	0.19	0.13	0.08		0.02	0.04	0.08	0.11	0.17	0.26	0.27				0.76
0.74	0.67	0.78	2.85		0.78	0.40	0.29	0.23	0.19	0.13	0.08		0.02	0.04	0.08	0.11	0.17	0.25	0.27				0.74
0.72	0.69	0.81	2.88		0.78	0.40	0.29	0.23	0.19	0.12	0.08		0.02	0.04	0.08	0.11	0.17	0.25	0.26				0.72
0.70	0.70	0.84	2.91		0.78	0.40	0.29	0.23	0.19	0.12	0.08		0.02	0.04	0.08	0.11	0.17	0.25					0.70
0.68	0.70	0.88	2.93		0.78	0.40	0.29	0.23	0.18	0.12	0.08		0.02	0.04	0.08	0.11	0.17	0.25					0.68
0.66	0.71	0.92	2.96		0.78	0.40	0.29	0.23	0.18	0.12	0.08		0.02	0.04	0.08	0.11	0.17	0.24					0.66
0.64	0.73	0.96	3.00		0.78	0.40	0.29	0.23	0.18	0.12	0.07		0.02	0.04	0.08	0.11	0.17	0.23					0.64
0.62	0.74	1.00	3.04		0.77	0.40	0.29	0.22	0.18	0.12	0.07		0.02	0.04	0.08	0.11	0.17	0.23					0.62
0.60	0.75	1.05	3.10		0.77	0.40	0.29	0.22	0.18	0.11	0.07		0.02	0.04	0.08	0.11	0.17	0.22					0.60
0.58	0.77	1.10	3.15		0.76	0.39	0.29	0.22	0.18	0.11	0.07		0.02	0.04	0.08	0.11	0.17	0.22					0.58
0.56	0.79	1.15	3.20		0.76	0.39	0.29	0.22	0.18	0.11	0.07		0.02	0.05	0.08	0.11	0.17	0.21					0.56
0.54	0.80	1.22	3.25		0.76	0.39	0.30	0.22	0.17	0.11	0.07		0.02	0.05	0.08	0.12	0.18	0.21					0.54
0.52	0.81	1.30	3.30		0.75	0.39	0.30	0.22	0.17	0.11	0.07		0.02	0.05	0.08	0.12	0.18	0.20					0.52
0.50	0.82	1.37	3.35		0.75	0.39	0.30	0.23	0.15	0.11	0.07		0.02	0.05	0.09	0.12	0.18	0.20					0.50
0.48	0.82	1.43	3.40		0.74	0.39	0.30	0.23	0.15	0.11	0.06		0.03	0.05	0.09	0.12	0.18	0.20					0.48
0.46	0.82	1.50	3.42		0.73	0.39	0.30	0.23	0.15	0.11	0.06		0.03	0.05	0.09	0.13	0.19	0.20					0.46
0.44	0.82	1.58	3.42		0.72	0.40	0.30	0.23	0.15	0.11	0.06		0.03	0.06	0.09	0.13	0.19	0.20					0.44
0.42	0.80	1.64	3.40		0.71	0.40	0.31	0.23	0.15	0.11	0.07		0.03	0.06	0.09	0.13	0.20	0.20					0.42
0.40	0.80	1.72	3.38		0.70	0.40	0.31	0.24	0.19	0.11	0.07		0.03	0.06	0.10	0.14	0.21						0.40
0.38	0.79	1.78	3.32		0.69	0.40	0.31	0.24	0.19	0.11	0.07		0.03	0.06	0.10	0.14	0.21						0.38
0.36	0.77	1.84	3.26		0.67	0.40	0.32	0.25	0.20	0.11	0.07		0.03	0.07	0.10	0.15	0.22						0.36
0.34	0.75	1.90	3.16		0.65	0.40	0.32	0.25	0.21	0.12	0.07		0.04	0.07	0.11	0.15	0.22						0.34
0.32	0.72	1.96	3.05		0.64	0.40	0.32	0.26	0.21	0.12	0.07		0.04	0.07	0.11	0.16	0.23						0.32
0.30	0.70	2.00	2.94		0.62	0.40	0.33	0.27	0.22	0.13	0.08		0.04	0.07	0.12	0.16	0.25						0.30
0.28	0.68	2.06	2.82		0.60	0.41	0.34	0.28	0.23	0.14	0.08		0.04	0.08	0.12	0.17	0.26						0.28
0.26	0.64	2.11	2.70		0.57	0.41	0.34	0.29	0.24	0.14	0.08		0.04	0.08	0.13	0.18	0.28						0.26
0.24	0.60	2.15	2.55		0.54	0.41	0.35	0.30	0.25	0.15	0.08		0.04	0.08	0.13	0.18	0.30						0.24

LOCATION : EAST FIFE COAST **DATE :** 03/11/01

SEAM : BRANXTON

No. 44 ZONE DEPTH USED = 450 metres

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1	20	x5	100	11.9
2	15.4	x5	77	19.2
3	18.4	x5	92	25.4
4	10.2	x5	51	2.2
5	9	x5	45	1.7
6	7.8	x5	39	0.5
7	9.1	x5	45.5	0.2

WORKED HEIGHT = 1.25 m % TOTAL = 61.1

SUBSID. = 0.764 m (1.25 x 0.611)

No. ZONE DEPTH USED =

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1				
2				
3				
4				
5				
6				
7				

WORKED HEIGHT = % TOTAL =

SUBSID. =

No. ZONE DEPTH USED =

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1				
2				
3				
4				
5				
6				
7				

WORKED HEIGHT = % TOTAL =

SUBSID. =

No. ZONE DEPTH USED =

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1				
2				
3				
4				
5				
6				
7				

WORKED HEIGHT = % TOTAL =

SUBSID. =

No. ZONE DEPTH USED =

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1				
2				
3				
4				
5				
6				
7				

WORKED HEIGHT = % TOTAL =

SUBSID. =

No. ZONE DEPTH USED =

ZONE	MEASURED	MULTIPLIER	TOTAL ZONE %	% SUBSIDENCE
1				
2				
3				
4				
5				
6				
7				

WORKED HEIGHT = % TOTAL =

SUBSID. =

NB: multiplier changes to 10 when figure 5 segments decrease from 20 to 10

Table 2 Example of subsidence calculation for Branxton coal workings at point 44 using the Zone area Method of prediction

LETTER (ROW)	CC																				
Location Point (Column)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Pilkembare	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Wood/Wall/4Ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.10	0.20	0.43	0.20	0.64	0.31	0.18	0.43
Barncraig	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.43	0.94	0.84	0.79	0.79	0.79
Coxtools/6Ft	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chemiss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.43	0.71	1.02	0.71	0.58	0.58	0.56
Bush	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wemyss Parrot	1.25	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Earl David's Parrot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bowhouse	POSS. W'K'G	1.40	1.40	1.40	1.40	1.24	0.28	0.00	0.00	0.00	0.02	0.08	0.13	0.51	1.04	1.19	1.22	1.17	1.14	1.07	0.91
Branxton	0.81	1.02	0.94	0.41	0.13	0.38	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.30	0.69	0.86	0.86	0.76	0.46	0.46
Boreland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00
Sandwell	0.99	1.02	0.64	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dysart Main	1.78	0.84	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Lower Dysart	0.10	0.61	0.30	0.08	0.18	0.18	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lethamwell	0.56	0.64	0.53	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL SUBSIDENCE	**5.49**	**5.59**	**3.84**	**1.98**	**1.73**	**1.80**	**0.38**	**0.03**	**0.00**	**0.00**	**0.03**	**0.08**	**0.20**	**0.81**	**2.26**	**3.45**	**4.27**	**4.24**	**3.61**	**3.10**	**3.18**

Location Point (Column)	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Pilkembare	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Wood/Wall/4Ft	0.61	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Barncraig	0.91	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Coxtools/6Ft	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Chemiss	0.84	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Bush	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Wemyss Parrot	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Earl David's Parrot	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Bowhouse	0.64	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Branxton	0.56	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Boreland	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Sandwell	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Dysart Main	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Lower Dysart	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
Lethamwell	0.00	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W
TOTAL SUBSIDENCE	**3.56**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 3 Example of calculation of total subsidence values at grid reference points for lettered row CC and sample points 1 to 42