BOROUGH OF TELFORD & WREKIN COUNCIL

Ironbridge Gorge Landslides

Ironbridge and Coalbrookdale Ground Behaviour Study

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NON TECHNICAL SUMMARY

The purpose of this non technical summary is to describe the main findings of the Ironbridge & Coalbrookdale Ground Behaviour Study that will provide the reader with an understanding of the fundamental problems that affect development issues within the study area regarding slope instability. This summary concludes with recommendations that will maintain and improve the process of planning and building development.

The main objective of the study is to provide general guidance and information on ground stability conditions along the valley slopes of Ironbridge & Coalbrookdale, and the plateau near Madeley. The brief required the preparation of a series of geomorphological, ground behaviour and planning guidance maps. This series of maps is intended to assist decision-making by informing the planning process, as well as providing a basis for assessing the requirements for stability investigations and reports in support of future development proposals in the study area.

The Ironbridge and Coalbrookdale Ground Behaviour Study has involved a thorough review of the available information with regard to ground conditions, the history of past ground movement, and the development of the study area. The study has also undertaken an engineering geomorphological mapping and a structural damage survey, which has identified the location and extent of ground instability throughout the study area.

As part of the study the ground behaviour has been determined and ground models have been developed from the available information and field mapping. It is recognised that without detailed sub-surface ground investigations and long term monitoring of the slopes that the landslide models should be regarded as provisional.

The slopes of Ironbridge and Coalbrookdale have been shaped by slope instability, primarily through unloading of the lower slope by stream erosion. Most of the northerly bank of Ironbridge has been protected from river erosion by walls of the Wharfage area. However, many of the slopes remain marginally stable because of the combination of weak materials at or close to their residual strength, the steep angle of the slopes, high groundwater levels and human interaction.

The landslide and ground movement can vary from imperceptible movement to rapid failure. Imperceptible movement may hardly be noticeable to the eye, but is likely to be seen over a period of time by cracks in slopes or structures; rapid failures may result in mass movement of the ground and damage to structures in one event. The type of failure is determined by a number of factors, such as geology, topography, groundwater and human influence.

The factors that have a significant effect on slope instability in Ironbridge and Coalbrookdale have been:

- The removal of lateral and underlying support and oversteepening of slopes by fluvial processes;
- The inherent low shear strength of the weathered rock of the Wenlock Shales and Coal Measures;
- The presence of weak geology and often influenced by structural control of bedding and faulting;
- The reduction in strength of the strata overlying, and collapsing into voids created by mining activity;
- High groundwater levels and pore water pressures arising from extreme rainfall events;
- The influence of development and construction, including formation of cut and fill platforms, disturbance of natural drainage, and surcharging of groundwater levels;
- The more frequent flooding events and increased rainfall caused by global warming.

A systematic survey of external damage of all structures, properties, retaining walls and structures where access could be gained was undertaken within the study area. The survey classified damage caused by ground movement on a three-fold severity scale from *slight*, *moderate* to *significant* based on increased levels of damage.

A geomorphological map of the study area has been produced, which summarises the surface morphology of the study area (Drawing A). The map shows the relative positions of the main geomorphological units that occur in the area, and identifies the nature and extent of the individual landslide units.

The geomorphological assessment of the inter-relationships of different types of ground movement provides a framework for understanding the ground behaviour of the valley-side slopes, which is presented on the Ground Behaviour Map (Drawing B). The map demonstrates that the potential problems vary from place to place according to the geomorphological setting, and this has been used as the basis for the Planning Guidance Map (Drawing C).

The types of ground movement within Ironbridge and Coalbrookdale are summarised in the table below.

Type	Description
Mudslides (lobate and elongate forms)	Likely to be seasonally active in response to periods of heavy and prolonged rainfall. Ground movement may comprise differential settlement along head-scarps and side-scarps and translational ground movement. Outward displacement and heave may occur at the toe due to accumulation of mudslide debris lobes. Ground movements of several metres could occur, although creep is expected to be continuous.
River Cliffs	Along Ironbridge and Coalbrookdale valley sides are low steep river cliffs formed in weak rocks subject to slides and erosion due to active undercutting by river action and slope degradation/weathering processes. These slopes may also be formed in colluvium. Ground movements of several 10's of cms could occur.
Deep-seated landslides	Areas susceptible to active differential settlement of landslide blocks due to deep-seated rotational and translational movements. Ground movements are imperceptible and progressive comprising shear, tension, torsion, compression and heave. In the area of Ironbridge, failure of the river wall may accelerate and promote large-scale failures. Ground movements of several 10's of cms could occur, possibly several metres following river wall failure.
Degraded valley-side slopes	Marginally stable slopes with little apparent evidence of contemporary ground movement. The soft weathered Wenlock Shale rock has been over-steepened by fluvial processes and will have been subject to slope instability in the past. The slopes are subject to periodic localised creep and small landslides, particularly associated with poor drainage. Ground movements of several metres could occur.
Plateau Margin and Slope Top Settlement	Tension cracks (fissuring) developed above the steep valley-side slopes due to progressive valley-side failure. Imperceptible and progressive settlement of the Plateau Margin is an indicator of possible impending landslide potential. Ground movements of several 10's of cms could occur.
Shallow valley sides	Generally, movement is restricted to creep resulting in imperceptible and progressive settlement and heave in places. Occasional localised shallow debris slides may develop on localised steeper slopes associated with high groundwater levels. Ground movements of several 10's of cms could occur.
Plateau	The level soft ground areas subject to imperceptible and progressive shrink/swell behaviour associated with saturated fine grained soils. Ground movements of mm/year could occur.

Note. The magnitude of movements suggested in the table above, reflects anticipated movement based on previous experience. Changes in ground conditions and climate and, human activity may promote varying scales of landslide movement. It is likely that any failures will be separated by periods of inactivity, which may last a number of years.

The assessment of ground behaviour has concluded that existing property in actively unstable areas will probably continue to experience damage due to ground movement. New development in actively unstable areas may be expected to be affected by ground movement; such areas should be avoided. More stable areas are likely to remain largely free from significant building damage and may be successfully developed, so long as necessary stabilisation and monitoring measures are adopted and the developer is willing to accept, in some locations, a higher level of risk than would be expected in other circumstances.

These broad conclusions provide the framework for the development of revised planning procedures for the area that take account of the information now available on land instability problems. The overall intention of the following guidance is:

- to ensure that development is suitable and that the possible physical constraints on the use of land are properly accounted for at all stages of planning. Although in some cases the appropriate response might be to prevent the development of land that is unsuitable, the principal objective of the guidance is to encourage the full and effective use of land in an acceptable and appropriate manner.

When setting out proposals for the development and use of land, and allocating land for specific purposes, the local planning authority should use the information presented in this Report as the basis for establishing whether, in general terms, potential sites can be safely developed. Issues that should be considered include:

- the level of risk at the site;
- the nature and scale of any stabilisation measures that would be acceptable at the site.

The local planning authority should take land instability into account when dealing with all planning applications within the area. The results of this study should provide background information to assist making planning decisions, although it is recognised that specialist advice may be needed in certain circumstances.

The recommended procedures are set out below.

Zone	Development Plan Policy	Development Plan Proposals	Development Control
1	Area suitable for development in accordance with the development plan.	Ground movement does not impose any constraints on site development.	No Stability Report required.
2	Area likely to be suitable for development in accordance with the development plan.	Ground movement does not impose significant constraints, although some mitigation/stabilisation measures may be required to ensure the stability of the site and surrounding land.	An Outline Stability Report would normally be required, prepared by a Competent Person.
3	Area likely to be suitable for development in accordance with the development plan provided the developer undertakes appropriate mitigation and stabilisation measures.	Ground movement imposes constraints that would generally require mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	A Standard Stability Report would normally be required which *may* include subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
4	Area unlikely to be	Ground movement imposes	A Detailed Stability Report would

Zone	Development Plan Policy	Development Plan Proposals	Development Control
	suitable for development in accordance with the development plan unless the developer undertakes appropriate mitigation and stabilisation measures.	*significant* constraints that would generally require large-scale mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	normally be required including detailed subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
5	Area very unlikely for built development.	Ground movement imposes *severe* constraints that probably could not be overcome by cost-effective and environmentally acceptable mitigation or stabilisation measures to ensure the stability of the site and surrounding land.	A Detailed Stability Report would be required including detailed subsurface investigation and long-term ground movement (both surface and sub-surface) monitoring and detailed proposed stabilisation methods, prepared by a Competent Person.

Note. All development should investigate for surface and underground workings in Ironbridge, the Madeley Plateau and Coalbrookdale area.
Where industrialisation has been undertaken an appropriate suite of laboratory testing should be scheduled for contaminants.

The planning guidance map (Drawing C) provides the basis for preparing guidance for future planning policy and development control that takes account of the different ground conditions that can be expected. The requirements for stability reports in support of future development proposals, outlined in this report, also account for the different ground conditions and their uncertainties.

The main recommendations arising from this study include (further recommendations are presented in the main report):

- Further geomorphological mapping be undertaken along Jiggers Bank, Lloyds Head, Ladywood and Benthall Edge to understand the full ground behaviour of the areas lying outside sections of the study area.
- There is a requirement to undertake detailed subsurface ground investigation(s) to refine the preliminary ground behaviour models.
- It is also necessary to undertake surface monitoring of the slopes that are known to have been active in the recent past and also undertake a twice-yearly inspection of the slopes and systematic recording and photographic record of instability. It is important that further investigations and monitoring are carried out to enable periodic review of the ground behaviour conditions and planning guidance, particularly in

respect of potential changes in climatic conditions that are predicted to occur, that may, however, be experienced as more frequent flood events.

- Detailed hydrogeological investigations.

- A detailed survey of buildings, walls and roads, identified in this survey, showing significant damage should be carried out by appropriately qualified structural surveyors and appropriate actions identified. BTW's retaining wall database should adopt the damage intensity scoring system used as part of this study to maintain continuity.

- There is a requirement for collaboration between the Environment Agency and BTW to review the current and future requirements of the Wharfage and any river protection measures. This is important, as a decline in the current integrity of the Wharfage may result in significant increase in slope instability in future years.

- Discussions with the Planning Authority should be held regarding the suitability of development in landslide areas identified by this study.

- Publication of supplementary planning guidance notes for distribution with planning application forms should be considered to raise awareness of the development control procedures for development on unstable land.

- Ongoing discussions with professional groups (such as insurers, local engineers, contractors, estate agents) and Utility Services should be held to exchange information on ground conditions within the area.

- Liaison with the public and interested third parties of the Ironbridge Gorge and World Heritage Site (eg Ironbridge Gorge Museum Trust) by meetings and displays.

- A code of practice should be targeted at developers and contractors.

- Advice leaflets to developers and homeowners should be produced to disseminate the findings of this study with respect to ground behaviour conditions and management.

1 BACKGROUND

Ironbridge Gorge developed late during the last glacial period when the northerly flow of the Upper Severn was prevented from flowing into the present-day course of the River Dee by receding ice sheets. This drainage disruption led to the formation of a lake in Shropshire and the southern Cheshire Plain which eventually overflowed southwards across a col at Ironbridge. Since this time, some 13,000 years before present, the River Severn has flowed south on its approximate present alignment, cutting a deep gorge through the Ironbridge area and stimulating the incision of tributary valleys (e.g. Coalbrookdale). During the early stages of the development of the gorge periglacial and permafrost conditions were likely to have influenced valley formation and accelerated erosion and instability of the underlying Silurian and Carboniferous Coal Measure strata.

The slopes of Ironbridge and Coalbrookdale have been shaped by slope instability, primarily through unloading of the lower slope by stream erosion. Most of the northerly bank of Ironbridge has been protected from river erosion by walls of the Wharfage area. However, many of the slopes remain marginally stable because of the combination of weak materials at or close to their residual strength, the steep angle of the slopes, high groundwater levels and human interaction.

Stream incision, both by the River Severn and the stream in the side valley of Coalbrookdale, resulted in exposure of important mineral resources, notably coal, fireclay, ironstone and limestone. Mining has been recorded in the area since the 13th Century. However, it was not until the 17th Century and the demand for coal and iron during the Industrial Revolution that Ironbridge came to its fore. Many of the mine workings and associated shafts and adits have not been recorded; it is likely that extensive unrecorded excavation of mineral has been undertaken in the area.

The natural process of valley development has resulted in landslide and ground movement. This can vary from imperceptible movement to rapid failure. Imperceptible movement may hardly be noticeable to the eye, but is likely to be seen over a period of time by cracks in slopes or structures; rapid failures may result in mass movement of the ground and damage to structures in one event, such as the mudflow near Jockey Bank of 1935. The type of failure is determined by a number of factors, such as geology, topography, groundwater and human influence.

The Ironbridge Gorge has been designated a World Heritage Site since 1986 based on its archaeological importance for its unique role in the development of the Industrial Revolution that originated in Britain during the eighteenth century.

1.1 Terms of Reference

In December 2003, the Borough of Telford & Wrekin Council commissioned High-Point Rendel to carry out a slope stability study at Ironbridge & Coalbrookdale (letter dated 17 December 2003, ref E1055 & E1047).

The Terms of Reference were set out in a letter from the Council dated the same as above.

This Report which is submitted in fulfilment of those Terms of Reference, has been prepared with assistance of Professor D Brunsden (Consultant) and Dr E M Lee (Consultant).

1.2 Scope of Study

The main objective of the study is to provide general guidance and information on ground stability conditions along the valley slopes of Ironbridge & Coalbrookdale, and the plateau near Madeley. The brief required the preparation of a series of geomorphological, ground behaviour and planning guidance maps. This series of maps is intended to assist decision-making by informing the planning process, as well as provide a basis for assessing the requirements for ground investigations and reports to assess slope stability to be submitted in support of future development proposals in the study area.

The study brief specified the following tasks:

1. A review of the readily accessible information sources, including published literature, geotechnical data and technical reports, geological and topographic maps and plans, and historical prints and photographs.

2. Engineering geomorphological mapping and survey of damage of structures where accessible.

1.3 This Report

Since 1984, central and local government has carried out extensive research to assess the significance and consequences of unstable land in Great Britain. A summary of research, from which several key conclusions have a direct relevance to the Ironbridge area, is provided in *The Landslide Environment of Great Britain* (Lee, Jones and Brunsden 2000). Points applicable to Ironbridge include:

- There is a legacy of ancient landslides formed during past climatic conditions, i.e. many problems of ground instability are related to inadvertant reactivation of pre-exitsting landslides or failed ground.

- Valley slope ground movement is an intermittent process, with periods of little or no activity separated by rapid and occasionally dramatic landslides, which may involve mass movement of ground in a single event. Alternatively, there may be areas of progressive movement, the speed of which is dependent upon climatic conditions.

- The impact of human activity which can have a significant effect on slope stability, both at the site and on adjacent slopes.[This can be compounded by mining, should mining have been undertaken at shallow depths that may affect the ground surface. It is understood that mining in Ironbridge has been much more extensive than has been recorded.]

The Department of the Environment (now the Department of the Environment, Transport and Regions), commissioned a series of studies (Geomorphological Services Ltd (1986-1987); Lee and Moore (1991; extended in Moore, Lee and Clark (1995)), amongst others, to develop and evaluate approaches to the assessment of potential landslides. As part of these studies it was necessary to collect and test appropriate levels of ground data in support of planning and development decisions on unstable land. This research provided the background to the preparation of planning policy guidance (PPG14; Department of the Environment 1990, 1996), and associated guidance for the investigation and management of landslides in Great Britain, aimed at planners and developers (Clark, Lee and Moore 1996).

This study has adopted a similar approach to the DoE studies. It involved the collection and collation of information regarding the type and extent of ground instability; evaluating the past behaviour of the ground; development of management strategies to reduce the impact of future ground instability; and assessing the ground movement potential, which uses detailed desk study and field mapping techniques.

The ground behaviour assessment and landslide models presented in this report are inferences made from the available information and field mapping. It is recognised that without detailed sub-surface ground investigations the landslide models should be regarded as provisional. The approach adopted for this study provides a framework for enabling general planning and development control principles to be implemented with respect to ground instability. It also assists in identifying key uncertainties and areas where sub-surface investigation is most needed.

2 STUDY AREA

2.1 Study Area Description

The study area is shown in Appendix A on a plan provided by BTW forms part of the brief. The study area, for the purposes of this description, can be divided into three separate units based on their morphology, as follows:

Ironbridge; this area comprises the north and south banks of the River Severn from the King Edward Railway Bridge to the westerly edge of Lloyds Coppice on the north bank and to Lloyds Head on the south bank. The south bank area terminates approximately 100m south of the River Severn; the north bank extends upslope to the Madeley Plateau.

Coalbrookdale; this area comprises the side valley to the west of Ironbridge. This valley system is fed from two tributary streams, which run approximately parallel with Jiggers Bank and Cherry Tree Hill.

Madeley Plateau; this area comprises the high ground bounded by the Ironbridge and Coalbrookdale valley systems and the residential area of Madeley to the east.

The character of the valley-side slopes within the study area varies due to the relative active incision of the streams present within each valley system. The Ironbridge Valley System is formed by erosion of the slopes by the River Severn. The elevation of the wharfage, on the northerly bank, is approximately 40m Above Ordnance Datum (AOD) and steep valley slopes level out to the plateau margins at ~100m AOD. The southerly riverbank is at c38m AOD and extends upslope to the former railway c55m AOD.

Coalbrookdale valley floor ranges from 45m AOD where it intersects the River Seven to 120m AOD at Cherry Tree Hill Lane. The slopes, which are relatively less steep than Ironbridge vary in height to 95m AOD. The Plateau is approximately 120m AOD.

The valley-side slopes between Ironbridge & Coalbrookdale have been extensively developed for industrial, agricultural and residential purposes. Much of the development dates from the Industrial Revolution (e.g. the row of cottages along Tea Kettle Row, Coalbrookdale in 1735), although it was not until the building of the Iron Bridge in 1781 that the town of Ironbridge developed. The 1840 Tithe Map and the 1883 OS Map identify Ironbridge to have been well developed prior to these dates.

The spread of development has, in places, occurred on steeper ground of marginal stability and above areas that have probably been under-mined. Subsequent ground movement, either through downslope movement of first time failures or pre-existing landslides or subsidence through mining, has resulted in damage to buildings.

2.2 Information Sources

Table 2.1 identifies the various sources of information which have been used during this study, including technical reports, maps and local history texts.

Table 2.1: Summary of Information Sources

Information	Date	Source
Madeley Tithe Map	1840	BTW
Topographic maps, 1:2500 scale Series 0, 1 and 2	1883, 1902 and 1927	Ordnance Survey
Geological maps, memoirs and records Geology of Telford and Coalbrookdale Coalfield	1995	British Geological Survey
Land Instability Study	2003	Babtie Group Ltd
Preliminary Report on the Stability of Jockey Bank. Report No 72/5	Undated	Institute of Geological Sciences
Wrekin Local Plan	2000 (Adopted)	BTW
Ironbridge Gorge WHS Management Plan	2001	BTW/ IGMT
Lincoln Hill Mine. Various Phase of Study	1986-89	Ove Arup & Partners
Pennystone Ironstone Mine Survey	1987	Ove Arup & Partners
Crawstone Ironstone Mine	1989	Ove Arup & Partners
Borehole Logs	Various	British Geological Survey
Local History Texts and papers	Various	R Rhodes, W Mann, I Brown, B Trinder, M Wanklyn,
Site investigation reports	Various	Local Engineers

3 DESK STUDY

Various texts describe the history of Ironbridge and the surrounding area (Hayman & Horton 2003; Brown, 1981; Wanklyn, 1982). It is widely regarded that the exposure of mineral resources along the valley sides and the cheap transport links provided by the River Severn enabled economical means of extracting, processing and supplying goods during the 18th and 19th Centuries. More detailed accounts of the development of this area can be read in the texts cited above.

The industrial development of the study area has been attributed largely to the Darby family and their partners of the Coalbrookdale Company and that of the Madeley Wood Company, who provided direction and the intuition necessary to establish Ironbridge and Coalbrookdale as areas of innovation. This can be characterised by the construction of the first Iron Bridge which was opened in 1781 to cross the River Severn.

The study area has been subject to varying socio-economic patterns that reflected the demand of particular minerals throughout the country. The success of the coal and iron industries gave rise to the development of other industries such as brick, tile and fine China. As a section of the industry declined in the area, such as iron in the late 19th Century, so bricks, tiles and pottery became important, based on the abundant supply of clay. This resulted in boom and bust periods during the development of Ironbridge.

3.1 Housing and Infrastructure

3.1.1 Ironbridge

Up until the Iron Bridge was constructed two settlements were established at each end of the town, near Madeley Wood and Dale End. During and shortly after construction of the Iron Bridge a settlement began to grow on the northern bank abutting the bridge. The Tontine Hotel was built in 1780, St Luke's Church in 1837; both Market Street and the High Street comprise buildings of Georgian and Victorian age. Much of Ironbridge was developed prior to the first series Ordnance Map dated 1883.

Figure 3.1 identifies the phases of development based on the OS Series maps: 1883, 1902 and 1927. There appears to be very little development in Ironbridge during the period between 1883 and 1927, apart from the addition of isolated properties. Figure 3.1 also identifies properties and structures that are missing from one OS map to the next; the reasons for any structure not shown on a successive map is not always known, however, properties known to have been lost to ground movement are annotated.

3.1.2 Coalbrookdale

Development of housing in the Coalbrookdale area was necessary for the workers in the industries that developed during the 18th Century. Dale House and Rosehill House were constructed in the early 1700's while Tea Kettle Row is characteristic of properties built for the workforce during the mid-eighteenth century. Carpenter's Row was built around the 1780's and the properties behind this are typical of the early nineteenth century (Hayman & Horton, 2003).

There appears very little new development between the 1883 and 1927 OS Map. Since 1927 housing development has occurred along Dale End and Paradise and Sunnyside at the top of Darby Road.

Terraced houses were mainly confined to the Coalbrookdale area with isolated cottages built elsewhere which were detached or as semi-detached throughout the 18th Century. This may reflect that terraced houses could be built upon the gently sloping ground of the Coalbrookdale Valley following the contours, whereas in Ironbridge, the irregular and undulating ground is likely to have resulted in individual sites.

3.1.3 Recent Housing Developments

The area of Madeley has expanded to the west with much residential housing built on the Madeley Plateau to the east of the study boundary towards the end of the 20th Century. During the fieldwork for this study new housing areas were being built and areas of housing were evident not shown on the base plans provided.

Development of isolated structures and refurbishment continues along the north bank of Ironbridge. This may include rebuilding a property where one formerly stood or constructing a new building on a new plot of land.

The valley floor of Coalbrookdale has recently been subject to new development with many new properties identified along Dale Brook and a new development at the junction between Dale End and Buildwas Road.

3.1.4 Industrial Development

It is reported that mining for coal, ironstone and limestone was undertaken during the middle ages, with coal becoming a major part of the trade on the River Severn during the 16th century (Hayman & Horton, 2003). The advantage of mining in the Ironbridge Gorge was that mineral was exposed along the valley sides. Coal that outcropped along the valley sides could be excavated with shallow pits or adits.

Iron has been reported to have been produced in 1536 at a bloomery in Coalbrookdale where the iron was formed using charcoal. The use of coal in producing iron was not used until the seventeenth century with the first recorded blast furnace at Coalbrookdale in 1658. Forges relied on substantial amounts of water and a series of pools were built to store the water needed to work the wheels that drove the bellows. These pools were situated at the upper end of the Coalbrookdale valley (Upper Forge Pool at Loamhole Brook pond), the Lower Pool, now filled in, near the Upper Forge. The pools formed the Upper and Lower Works in Coalbrookdale. During the early 1700's mainly household utensils were cast; however, engine cylinders and cannons were also manufactured. The casting of ordnance continued until the end of the Napoleonic Wars in 1815.

It was the construction of the Iron Bridge in 1779 (opened in 1781), that identified Coalbrookdale to be at its industrial zenith and initiated the development of Ironbridge town. The demand for iron began to fall into the 1820's and the Coalbrookdale Company commenced specialising in ornamental cast iron.

3.2 Mining

3.2.1 Introduction

There is little detailed archaeological evidence for mining in the study area. However, there is evidence to suggest that one of the earliest forms of mining, by bell pits, was undertaken in the Ironbridge area, south of the River Severn in Benthall and Broseley. As early as 1649 coal mining was being undertaken in driven adits some 900m long. During the seventeenth century the longwall system of mining was introduced and became the principal method of deep mining.

Along with coal, ironstone and clay mining was also undertaken, however, it was not usual for these minerals to be extracted at the same time. Other mineral worked included limestone for flux, fertilizer and mortar. Limestone quarries were worked in Benthall and

Lincoln Hill, the latter supplying furnaces at Coalbrookdale and Bedlam in the late eighteenth century.

Pennystone and Crawstone Ironstone seams had largely been worked out by the end of the nineteenth century. Improved technology and more efficient pumps to drain the shafts and adits enabled mines to go deeper. For example, the mines in the Madeley area were dependent upon the Lloyds Pumping Engine, situated in Lloyd's Coppice. It is reported that mining took place by the Madeley Wood Company until nationalisation of the coal industry in 1947.

Local investigations into the industrial archaeology of the area (Morris, undated and unpublished) indicates that mining operations at the Lodge Pits in 1796, to work the relatively deep Clod Coal found the seam to have already been worked; it is likely that much of Ironbridge was undermined where mineral was easily accessible along the valley-sides.

3.2.2 Mining in Ironbridge and Coalbrookdale

Recorded areas of mining are shown Figure 3.1 along with all recorded pits and adits. These areas comprise known adits and levels, but do not necessarily record the full extent of underground excavations. The following adits/ levels are known:

- Lincoln Hill Limestone working
- Pennystone Ironstone workings
- Crawstone Ironstone workings
- Open cast mining at Madeley Plateau

It is understood that BTW have undertaken surveys of the adits at Crawstone, Pennystone, Paradise and some of the adits on Lincoln Hill in November 2003 and November 2004. Details of which are to published at a later date.

3.2.2.1 Lincoln Hill Limestone Mine

Ove Arups undertook a number of studies in this area, leading to the infilling of all accessible voids by gravel and PFA paste in 1987. In 1989 a further study into limestone workings in the Lincoln Hill was also undertaken by Ove Arup to assess the extent of limestone works.

The limestone workings are shown on Figure 3.1. Arups record working for limestone to have been undertaken as early as 1647. Various phases of work have occurred at Lincoln Hill, including:

- Surface quarrying up to the 1760's
- Excavation in the quarry face between 1760 and 1810
- Underground mining beneath the quarry between 1780 to 1870
- Deep mining to the southeast of the quarry between 1790 and 1890
- Robbing of pillars beneath the quarry between 1880 and 1907

As part of the 1989 study a number of areas were recorded as having been subject to ground collapse through crown holes. Two crown holes developed on Lincoln Hill road, north and south of Cristiana and one within the property boundary of Cristiana itself. The remaining crown holes were within the area of Lincoln Hill and immediately north of the White Horse Public House area, which lies north of the area known to have been mined (see Figure 3.1).

It is also reported that the northern area of Lincoln Hill was used as a municipal tip in the early part of the 20th Century (anecdotal).

3.2.2.2 Pennystone Ironstone Mine

The Pennystone Ironstone Member lies between the Big Flint Coal and the New Mine Coal in the Middle Coal Measures. It comprises weak friable silty mudstone with isolated lenses and nodules of Sideritic ironstone.

The mine entrance is located to the east of No 10 St Luke's Road, Ironbridge at c90mAOD. The mine was partly surveyed by Ove Arups & Partners in 1987. The adit exposed Pennystone Ironstone and the overlying Big Flint Rock sandstone. The adit was up to 2m high. The report recorded found the following notable observations:

- The tunnel sloped gently downhill and was flooded after 60m. A further 30m of flooded section was surveyed, after which the survey was terminated due to deep water.
- The adit was lined with a brick arch for the first 20m which was deformed and is cracked.
- Small roof falls had occurred at 28m and 34m from the entrance. The largest roof fall occurred between 50m and 58m into the adit. The void has migrated upwards

between 1.5m and 2.0m. The roof in this section has large open joints and shows bedding separation.

It was considered that the majority of the dry section has not been worked and that it was an access tunnel to workings deeper into the hillside. Hollows found within the floor of the adit may be due to either mining or from possible collapse of coal workings beneath the adit.

In Ove Arups 1987 Report it is stated that the nature of the mudstone and its use for back stowing would have longed weathered and any support for the roof would have been removed and collapse would have already occurred in the area prior to their study. Arups also state that “there is a possibility of surface effects being experienced from a collapse of all or part of the adit, but its condition does not justify immediate infilling”.

3.2.2.3 Crawstone Ironstone Mine

The Crawstone Ironstone lies between the Little Flint coal and Lancashire Ladies Coal in the lower third of the Lower Coal Measures.

The mine entrance is located at the rear of No 7 New Road, Ironbridge at ~65mAOD. The mine was surveyed by Ove Arups & Partners in 1985 and 1989. Based on Ove Arups two surveys the following statements have been taken from Ove Arups 1989 Report:

- The mine has been worked from a point 80m from the mine entrance
- A worked area of ~125m in diameter was observed
- The level of the mine falls in a northeasterly direction away from the entrance of the mine
- The working face varied between 0.7m and 1.0m and was overlain by a white sandstone
- The tunnel was largely back stowed
- No specific feature of subsidence was identified during aerial photography survey
- The mine showed no signs of roof instability which would lead to surface instability
- The 1989 survey recorded that surface effects due to collapse of any part of the galleries “is practically impossible beyond (that is, to the north of) the surface position of Church Hill. (Gallery width 1.4m, depth 25m).

- Future surveys would only be required for the first 70m of the adit at 2-3 year intervals.

3.2.2.4 Other Mining

The BGS Geological Plan and BGS held borehole logs identify an area within the Plateau of having extensive mining, mainly open cast. Details on the plan record the mineral extraction from various levels throughout the Coal measures from clay, probably where it is exposed at surface level, from the Upper Coal Measures (Hadley Formation) to coal in the Lower Coal Measures (Little Flint).

3.3 Wrekin Local Plan

The Wrekin Local Plan identifies that there are several areas of active slope instability. Policy EH14 Land Instability states:

The Council will permit development proposals within the Mineral and Mining Consideration Area, areas of suspected slope instability or where it is suspected there is made-up ground provided that the proposal demonstrates that:

a) its structural integrity shall not be compromised by slope instability

b) where active systems exist, the instability shall not be exacerbated by the development.

c) The development can tolerate the ground conditions by special design

d) There is long term stability of any structures built on filled ground.

It also states:

Applications for development within the Mineral and Mining Consideration Area, areas of suspected of slope instability or where it is suspected there is made-up ground, must be accompanied by appropriate supporting information which shows that the issue of land instability due to shallow undermining and other factors has been addressed to the Council's satisfaction.

The following stability requirements of The Wrekin Local Plan with regard to development in the World Heritage Site are:

SG6 Development in the World Heritage Site *h) the development shall demonstrate that the site is stable and takes account of any potential gas migration,*

j) the development shall demonstrate that it can be adequately drained.

The Wrekin Plan identifies the following designated sites within the study area:

- Sites of Special Scientific Interest: Lincoln Hill and Ladywood
- Scheduled ancient monuments: the Iron Bridge, Bedlam Furnaces and Coalbrookdale Works.
- Key sites for environmental improvements: Coalbrookdale works and the Market Square, Ironbridge
- Wildlife Sites: River Severn, Lloyd's Coppice, Dale Coppice, Loamhole Dingle, Captain's Coppice and Vane Coppice
- Ancient Woodland: the majority of the study area with Coppices'.

Sites with development potential have been defined at the corner between Buildwas Road and Dale End and the triangle between Madeley Road and Waterloo Street nearest the roundabout. The former having been developed prior to this project.

3.4 Ironbridge Gorge World Heritage Site Management Plan (2001)

The main aims of the Management Plan with regard to instability are:

- To ensure that all reasonable steps are taken to investigate and monitor land instability within the World Heritage Site
- To identify and undertake appropriate measures to deal with existing damage caused by instability and to minimise potential dangers and inconvenience from future movement
- To ensure that appropriate arrangements are in place to respond to major incidents of land movement within the World Heritage Site

The management plan identifies land instability as 'an ever-present problem'. It recognises that the gorge is still evolving and that past mining has also led to instability. The following land instability problems have been identified as having a negative effect on the World Heritage Site:

- Damage to highways and drainage leading to increased maintenance or complete replacement
- Damage to structures and buildings (both public and private)
- Damage to archaelogical heritage of the area.
- Disruption to people and services due to ground movement or related construction and repair works.

The management plan recognises Lloyd's Head and Jigger's Bank within the study area as experiencing significant ground movement, albeit currently slow and in sparsely developed areas. It is also recognised that underground workings beneath undeveloped land around the Lincoln Hill area could be at threat from instability.

4 SLOPE INSTABILITY

4.1 Slope Instability In Ironbridge and Coalbrookdale

Ground movement related problems in the Ironbridge & Coalbrookdale area are related to three key factors:

- geology
- stream incision.
- human activity, notably mining in the area and historic building methods and development.

Ground movement occurs when the downward pull of gravity exceeds the strength of the slope materials. Failure or landslide occurs to restore equilibrium, where the destabilising forces equal or are greater than the resisting forces along the slip plane. If the resisting forces are greater than the destabilising forces, the slope has a margin of stability.

The degree of the margin of stability depends on the destabilising influences that may affect the slope; the extent and magnitude of the landslide is dependent upon ground conditions and how they may be affected by these destabilising factors. The causes of slope instability have been well documented by others (eg. Jones and Lee, 1994).

The factors that have a significant effect on slope instability in Ironbridge and Coalbrookdale have been:

- The removal of lateral and underlying support and oversteepening of slopes by fluvial processes;
- The inherent low shear strength of the weathered rock of the Wenlock Shales and Coal Measures;
    - The presence of weak geology and often influenced by structural control of bedding and faulting;
    - The possible reduction in strength of the overlying strata collapsing into voids created by mining activity;
    - High groundwater levels and pore water pressures arising from extreme rainfall events;

- The influence of development and construction, including formation of cut and fill platforms, disturbance of natural drainage, and surcharging of groundwater levels;

- The more frequent flooding events and increased rainfall caused by global warming.

4.2 Slope Stability Review

There are few records of slope instability events or impacts in the Ironbridge & Coalbrookdale study area. A number of landslides have been recorded by the National Landslide Database (Geomorphological Services Ltd 1986); local sources provide evidence of other slides. The following lists the landslides to have been recorded within the study area:

- Ironbridge Gorge (general), undated; unspecified landslide type (Landslide database No 440001).

- Ironbridge School, 1969; landslide of fill material forming the playground behind school (BGS, 1995; Landslide database No 440003).

- Jockey Bank, no date; Complex landslide multiple rock slump and mudflow (Landslide database No 440006).

- Stoney Hill, undated, unspecified landslide type (Landslide database No 440016).

- South Ironbridge, undated, unspecified landslide type (Landslide database No 440024).

- Ladywood, undated, complex landslide multiple rock slump and mudflow (Landslide database No 440032).

- Cherry Tree Hill Lane, undated, translational, soil slab slide (Landslide database No 440033).

- Woodside, undated; translational, soil slab slide (Landslide database No 440034).

- Jockey Bank, 1935 (anecdotal); Mudslide adjacent to Jockey Bank area resulting in damage to and subsequent demolition of property (IGS, 1972; Landslide database No 440067).

- Jockey Bank/ Lloyd's Coppice; undated; multiple rotational (IGS, 1972; Landslide database No 440068).

- Madeley Hill, undated; translational, planar, mudslide (IGS, 1972; Landslide database No 440070).

- Jigger's Bank, undated; unspecified landslide type (Landslide database No 440076).

- Madeley, undated; unspecified landslide type (Landslide database No 440077).

The BGS Geological Plan only identifies the area of Lloyd's Coppice as a zone of active rotational landslips.

Ironbridge is a known area of landsliding, which Babtie (2003) identify as a zone of active/ recent slope instability with widespread evidence of damage to infrastructure. Babtie's instability survey was undertaken at the strategic level. This report comprises the first systematic survey that has identified individual landslide systems within the Ironbridge and Coalbrookdale area.

4.3 The Impacts of Ground Movement

As part of the current study a systematic survey of damage to structures has been undertaken to provide an indication of the nature and extent of landslide impacts in the area. The survey included all properties, retaining walls and structures where access could be gained.

The advantage of undertaking a systematic damage survey is that it provides complete coverage of the study area. Records held by building control and planning departments of a Local Authority are generally biased to the more serious or obvious damage cases but nevertheless provide an important record that may be used for comparison. The latter records also provide additional detailed information on ground conditions and the nature of damage in some cases.

BTW have undertaken a series of inspections of retaining walls in the Ironbridge area and have developed a database assessing the structural integrity of private and public walls. BTW's retaining wall survey was an assessment based on their interpretation of the severity of damage to a wall. This project has used a systematic assessment, whereby, the magnitude and type of crack or tilt of a wall or structure can be used to assess the type of ground movement.

The damage survey was restricted to observations of external damage to buildings, walls and roads that could be attributed to ground movement, such as settlement, heave, torsion and rotation. The survey classified damage caused by ground movement on a three-fold severity scale from slight to significant based on increased levels of damage. Table 4.1 defines the damage intensity. Field records of damage to structures along with a CD-ROM containing a full photographic record of the extent of the damage is presented in Appendix B.

Table 4.1 Damage Survey Classification (adapted from Alexander 1986, 2002)

Damage Intensity	Description
Slight	Slight evidence of cracking Negligible tilting Multiple slight cracking
Moderate	Moderate evidence of cracking Moderate cracking Slight vertical and horizontal displacement Slight tilting in buildings and garden walls Slight bowing in walls Slight deformation of walls.
Significant	Significant evidence of cracking Significant cracking Moderate tilting Moderate vertical and horizontal displacement Multiple bowed walls Rotation of structure

Figure 4.1 presents the distribution of damage throughout the study area, which shows marked concentrations of moderate to significant damage. These concentrations appear associated with steep valley sides and at the plateau margin. Other damage appears more widespread although there are notable linear distributions of damage above and at the base of the valley-side slopes. In general the more severe damages corresponds with those areas where damage has been reported by previous surveys (Table 4.2).

Table 4.2 Reported Areas of Ground Instability

Location	Description	Reference
Hodgebower	Fissures observed during housing development; fissures appeared ‘bottomless’	BTW; anecdotal
Belle Vue Road	Shallow superficial failure, observed during mapping. (Local evidence states this failed in 2000)	
Above Waterloo Street	Loss of property possibly by crown hole development	Anecdotal
Severn Terrace, Christiana	Crown hole development and settlement	Ove Arups, 1987, anecdotal
Lincoln Hill road	Crown hole development and settlement	Ove Arups, 1987
Paradise	During landscaping of a garden, a ground collapse occurred requiring a ladder to get persons out of the hole. Adits reported along rear of houses	Anecdotal

Location	Description	Reference
Woodbine	Original wall of developed cottage beginning to bow	Anecdotal
Cherry Tree Hill	Culvert encountered at ~7m bgl during borehole investigation	Anecdotal
Jigger’s Bank	History of ground movement	BTW

5 VALLEY SLOPE DEVELOPMENT

5.1 Geology

The geology for the area is described in the Geology of Telford and the Coalbrookdale Coalfield (BGS, 1995) and the Sheet Memoirs 152 and 153. British Geological Survey (BGS) County Series Maps (1:10,560 scale);

In addition to the above, a number of BTW-held site investigation and studies, and BGS-held borehole records have been reviewed as part of this study to obtain and correlate all available geological information

5.1.1 Solid Geology

The geological formations of the study area comprise sedimentary rocks of Silurian and Carboniferous age. They include limestones, clays, siltstones, mudstones, sandstones and coals. The various formations were originally deposited in more or less horizontal strata, but have since been tilted, folded and faulted, forming structures that were then dissected by erosion to produce the present landscape.

The solid strata to be found in the study area are summarised in Table 5.1, along with the thicknesses of each unit. Figure 5.1 identifies the geology in plan form for the study area.

The Carboniferous strata are mainly exposed along the slopes of Ironbridge town as far as Lincoln Hill where the Limestone Fault, trending NE-SW, has displaced Silurian strata against younger Carboniferous strata to the west. The strata at Ironbridge dip to the east at ~8^{o}. Towards the Jockey Bank area a further fault trending NE-SW (the Jockey Bank Fault) has displaced Lower Coal Measures against those of the Ironbridge area by some 15m.

The Limestone Fault also exposes Coal Measure strata to the north of new development at Forges Close on the Plateau. The Coal Measures are largely exposed along the Plateau surface where they terminate against the Lightmoor Fault, which also trends in a NE-SW direction. Towards the south west and west of the ‘Plateau Coal Measures’ Wenlock Shales are exposed.

Wenlock Shales are evident throughout Coalbrookdale and the dip of these beds is 15^{o} to the west, however, the younger strata of the Tickwood and Benthall Beds are exposed along Lincoln Hill, where they dip at ~40^{o} to the south east.

The Upper Coal Measures lie uncomformably on the Middle Coal Measures and the Lower Coal Measures lie uncomformably on the Silurian strata.

Table 5.1 Ironbridge and Coalbrookdale Stratigraphic Sequence (After BGS, 1995)

Age	Unit	Sub-division	Description	Maximum Thickness (m)
Carboniferous	Upper Coal Measures	Coalport Fm	Pale grey smooth to silty mudstones and pale to dark grey persistent sandstones, thin pyretic coals, *Spirorbis* limestones	185
		Hadley Fm	Brick-red and purple blocky mudstones, coarse lenticular sandstones with angular rock fragments	0-120
	Productive measure's	Middle Coal Measure	Grey mudstones with many workable coals and ironstones, subordinate sheet sandstones and fireclays	50-100
		Lower Coal Measures	Massive cream-coloured sandstones and grey fireclays, workable coals, subordinate ironstones and fireclays	20-70
		Upper Limestone	Grey ruby and massive limestones with mudstones and calcareous sandstones	40
		Little Wenlock Basalt	Amygdaloidal olivine basalt lava	25-60
Silurian		Wenlock Limestone	Flaggy and nodular limestones and siltstones, with 'ballstones' reefs	4-30
		Benthall Beds	Coarse grained shelly limestones and flaggy silty limestones, with thin bentonitic clay seams	15-30
		Tickwood Beds	Greenish grey siltstones with calcareous nodules	15-25
	Wenlock Shale	Coalbrookdale Beds	Bluish grey silty mudstones with abundant bentonitic clay seams	c. 200

5.1.2 Superficial Geology and Made Ground

Glacial deposits are evident on the plateau areas around Madeley and have been found to be up to 17m in thickness within the Lees Farm boreholes (IGS, 1974). Small isolated pockets of glacial deposits are identified on the drift geological map on the north western side of Lloyds Coppice.

Deposits of colluvium are described as being present on the Lloyds Coppice slopes, mainly consisting of debris from old landslide events which may have originated from solid or drift deposits (Babtie, 2003).

The floor of the Coalbrookdale valley is largely covered by industrial works that obscures much of the underlying geology. However, alluvium can be expected adjacent to the stream channels.

The Plateau area, north of Ironbridge, has deposits of waste from mines and, brick and tile works. The BGS Geological Map also identifies substantial areas of made ground along the Plateau top, in particular, a large area of opencast excavation. This area has recently been landscaped, but there is morphological evidence to suggest waste heaps.

The extensive industrial development around Ironbridge and Coalbrookdale has involved the construction of embankments and cuttings for the railway and various roads; furnace pools have been excavated and subsequently filled in and there has been substantial terracing and landscaping to accommodate housing.

5.1.3 Geological Landsliding Controls

It is evident that the composition and the structure of the geology has a control on landsliding in the study area. This can be summarised as follows:

- sequences of weak clays and mudstones separated by stronger rocks of the Coal Measures;
- groundwater flows are channelled along the more permeable strata of the rocks;
- the beds dip along the valley sides
- faulting provides ‘lateral shear surfaces’ for landslide development

5.2 Geomorphology

Geomorphology is the study of landforms and the processes which shape them. An understanding of the relationships between landforms and geological formations is a fundamental aspect of such studies. It is necessary to realise that some landforms have been shaped gradually by weathering and erosion over many hundreds of thousands of years, and may be regarded as relict landforms, a legacy of past climates and processes. Other have developed in more recent times, such as valley systems, as a result of contemporary erosion by streams and extreme rainfall or storm conditions.

5.2.1 Landform development

The valley-side slopes within the study area would have largely formed during the late Devensian and early part of the Holocene (i.e. the last 13,000 years or so), as a result of erosion by stream incision through the Carboniferous and Silurian rocks. This incision would have promoted widespread landsliding on the valley-side slopes. It is likely that the valley development would have followed a similar pattern to that proposed by Skempton (1953):

> Stage 1: downcutting and undercutting by a river generates shallow surface slides, once critical slope angles have been attained;
>
> Stage 2: the attainment of critical slope heights due to continued incision results in the development of deeper slides;
>
> Stage 3: when downcutting slackens or ceases and / or the river ceases to erode the valley side-slopes, the slopes degrade through shallow landsliding to a relatively stable angle.

Valley development took place during post glacial times when the region was affected by periglacial and permafrost conditions. This would have resulted in accelerating landsliding and valley development.

Although the Ironbridge town riverbank is mostly protected and active erosion in Coalbrookdale is relatively small, the valley side slopes remain immature and prone to landslide activity (i.e. they have not reached Stage 3 of the Skempton model).

Geological control has determined the course of Dale Brook through the relatively incompetent Wenlock Shales. The more competent limestone beds forming Lincoln Hill, the Tickwood and Benthall Beds, are more resistant to erosion than the geology either side of Lincoln Hill; the Coal Measures to the east and the Wenlock Shales to the west.

5.2.2 Geomorphology Map

A geomorphological map of the study area has been produced (Drawing A), which summarises the surface morphology of the valley-side slopes and surrounding features. The map shows the relative positions of the main geomorphological units that occur in the area, and identifies the nature and extent of the individual landslide units.

The spatial pattern of surface features, such as broad benches, steep slopes, enables the interpolation of the extent and behaviour of landslides and their mechanisms of failure. In this way, the geomorphology map identifies a number of different landslide forms and their inter-relationships.

The geomorphological map is the product of extensive field mapping supported by an interpretation of aerial photography and available geological information of the area. Geomorphological field mapping comprised a detailed tape and inclinometer survey of accessible areas, including private land where accessible. Many of the developed areas of Ironbridge and Coalbrookdale have masked morphological features making it difficult to assess the true geomorphology. Geomorphological judgement, where possible, has had to be applied in some areas to assess ground conditions and features that have been obscured by development. It should be noted that the study boundary around Jigger's Bank, Benthal Edge, Ladywood and Lloyd's Head was near to the base of these slopes and, therefore, limited mapping outside the study area and the amount of interpretation with which these slopes could be assessed. Time constraints prevented mapping these slopes in their entirety.

The following main features are identified on the Geomorphology Map and are listed below:

- Plateau
- Plateau Margin
- Steep valley-side slopes and river cliffs of Ironbridge (the Ironbridge Landslide System)
- Mudslides of Ironbridge
- Shallow valley-side slopes
- Degraded valley-side slopes and stream cliffs of Coalbrookdale

- Mudslides of Coalbrookdale

- Deep-Seated Valley Rotational Landslides

The main geomorphological units of Ironbridge and Coalbrookdale are summarised in the following sub-sections; the main landslided systems are described in more detail in Tables 5.2 and 5.3.

5.2.2.1 Ironbridge Geomorphological Units

A series of overlapping systems have developed on the valley-side slopes of Ironbridge gorge, including rotational landslides and elongate mudslides. The systems include are discussed below.

The **Plateau** forms the higher ground above the valley-side slopes, varying in elevation at around 100m OD. Immediately above the valley-side slopes the Plateau is gently sloping (up to 10^o towards the river). Further inland, the Plateau is generally level with undulating slope gradients of 1 or 2^o. Abandoned streams near Rough Park and Madeley Road, have dissected the Plateau in places. The Plateau is characterised by an undulating surface with deposits of spoil from mining, quarrying and brick works. The ground is saturated and many of the fields waterlogged.

The **Plateau Margin** is the area of ground between the valley-side and the plateau surface and is centred mainly around Hodgebower and Belmont Road. This section of the slope is subject to changes in stress following ground movement of the valley-side slopes below. The Plateau Margin is effectively the old plateau surface relaxing as a result of being undermined from historic slope failures during valley development. The development of Ironbridge and the construction of the Wharfage has reduced the effects of stream erosion and, therefore, the rate of ground movement and the expansion of failures upslope has also been reduced. The change in the ground stresses has resulted in fissure development, which was observed during the development of a plot of land adjacent to Hodgebower.

The **Steep valley-side slopes and river cliffs** of Ironbridge extend from Lincoln Hill to the Jockey Bank area. They are around 60m in height and extend from the Wharfage area to Hodgebower above. The slopes are dominated by a series of rotational slides.

The slopes have been extensively developed in the past for residential and retail purposes, with associated access roads and services. The natural form of the slopes has been largely altered or obscured by development which has typically involved construction of cut and fill platforms. The majority of cuttings are supported by retaining walls of various age and construction. At the base of the slopes, there is a noticeable platform or terrace that has been utilised by the High Street and Waterloo Road. Although this terrace has largely been developed it is considered that the feature represents an area of landslide debris accumulation from the upper slopes.

Of particular significance is the area around the High Street/ Waterloo Street roundabout, where there is obvious evidence of significant damage to structures and roads and, landsliding below Ironbridge School. However, landscaping and terracing have prevented this landslide system being mapped although it is more than likely linked to the river cliff failure mapped downslope. This area will be discussed more fully in Section 6.2.

The **Mudslides of Ironbridge** are evident on the flanks of Ironbridge town. Each comprises a source/head, track and accumulation zone.

Mudslides are a form of mass movement in which masses of softened argillaceous, silty or very fine sandy debris advance primarily by sliding on discrete boundary shear surfaces in relatively slow moving, lobate and elongate forms. They are marginally stable and sensitive to reactivation caused by changes to the slope geometry and hydrogeology, either artificially by man or through natural processes such as erosion and extreme rainfall events and are probably seasonally active in response to high groundwater levels during the winter. There is much evidence of widespread seepage, ponding and surface drainage in these areas.

The larger mudslide, east of Ironbridge town, extends from valley side top to river level. This mudslide is bounded by The Lloyd's Coppice landslide system to the east and the Jockey Bank area to the west. Interpretation of the geological map identifies the Jockey Bank Fault to limit the westerly upper part of the landslide system. The source of the system is from the Hadley Formation which is exposed in the upper half of the valley. It has been recorded (R Rhodes, undated) that a mudslide occurred in this area in 1935; no other movement has been recorded.

The westerly system, again, is limited by a fault, the Limestone Fault, which runs along the westerly track of the system. This mudslide has largely been developed upon a head and track system. At this location the mined seams of the Lower Coal Measures are exposed almost at the top of the valley and the area is known to have been undermined from Lincoln Hill.

The **Shallow valley sides** of Ironbridge have been formed by abandoned stream valleys which are likely to have ceased running or have been diverted either through natural means or human activity. Stream incision has been low and ground is subsequently gently sloping.

Table 5.2 Ironbridge Landslide Systems

Ironbridge Landslide System	Location	Comments
Plateau Margin	Upper slopes centred along Hodgebower level	Relatively gentle convex slopes, forming the transition between the plateau surface and the valley-side slopes. Localised stress relief fissure developed, especially close to valley edge.
Valley-side Rotational System	Ironbridge town	Spreads and blocks of displaced material bounded by very steep scarp slopes; often the spread/ blocks have been extensively landscaped, removing evidence of minor scarps and individual landslide blocks. Five major boundaries have been mapped. These range in width from 100m to 150m across Ironbridge town, extending from the lower slope to the valley-top. The depth of the system is likely to be less than 10m.
Westerly Mudslide	Adjacent to Lincoln Hill within the westerly flank of Ironbridge	Mudslide system head and track; steep valley-confined mudslide, containing a series of displaced blocks of material bounded by steep to very steep scarp slopes; extensive terracing and landscaping has obscured morphology. The width of this system is approximately 75m wide and extends from the lower slope to the valley top, some 200m. The depth of the system is likely to be less than 5m
Elongate Mudslide	Between Jockey Bank and Lloyds Coppice	Comprising a broad head with rotational landslide blocks and a linear track bounded by distinct lateral slopes, with large debris lobes. At the base of the system the mudslide has been landscaped and would have extended to the river level. The width at the head is almost 200m where it tapers downslope to ~40m at the toe of the slope. The system depth is probably around 10m.
River Cliff Rotational Failures	Ironbridge	Steep slopes parallel to the river developed in landslide debris apron material in which relatively localised rotational landslides have developed. These failures vary laterally in size and the shear zone is probably at ~2m depth at river toe level.
Valley-side Landslide Complex	Lloyds Coppice	The western extension of the Lloyds Coppice rotational landslide complex. This requires further mapping to determine the extent and magnitude of the system

5.2.2.2 Coalbrookdale Geomorphologcial Units

In Coalbrookdale localised areas of deep-seated landslides and mudslides, associated with the outcrops of Coal Measures and Wenlock Shales have developed along valley-sides. Elsewhere slopes generally show few signs of instability, other than creep and shallow failures; the landslide systems are discussed below.

The **Mudslides of Coalbrookdale** form the most northerly valley-side slopes of the study area along Cherry Tree Hill and Jigger's Bank. The slopes are formed of Wenlock Shales which terminates against the Lightmoor Fault near the Museum of Steel Sculpture; this, coincidently, also forms the easterly boundary of the Cherry Tree Hill Mudslide system. They are characteristically subdued with the benches gently inclined at gradients of 2-12^{o} with intervening scarp slopes typically less than 30^{o}. There are features of slope instability in localised areas, comprising heave, tension cracks and lobate features consistent with shallow transitional mudslides. Mudslides are a form of mass movement in which masses of softened argillaceous, silty or very fine sandy debris advance primarily by sliding on discrete boundary shear surfaces in relatively slow moving, lobate and elongate forms. They are marginally stable and sensitive to reactivation caused by changes to the slope geometry and hydrogeology, either artificially by man or through natural processes such as erosion and extreme rainfall events and are probably seasonally active in response to high groundwater levels during the winter. There is much evidence of widespread seepage, ponding and surface drainage in these areas.

A gabion wall is located immediately above Cherry Tree Hill at the toe of the mudslide suggesting a former active section of slope.

Deep-Seated Landslides of Coalbrookdale have been identified along Darby Road. The deep-seated rotational landslides are contemporary landforms influenced by historic stream erosion and groundwater conditions. They are developed in the Wenlock Shales and failure is possibly up to 15m below surface. The landslides comprise linear benches with gradients typically less than 5^{o}, separated by scarp slopes with gradients of 15-25^{o}; the benches are locally tilted backwards with ponding and soft ground accumulated to the rear side of the benches, a characteristic of deep-seated rotational and translational landslides. The landslides are probably subject to imperceptible creep, although the cumulative displacement over time can be significant. Such movement causes progressive settlement and shearing of the ground, resulting in cracking, ground heave and associated damage.

The **Degraded valley-side slopes and stream cliffs of Coalbrookdale** are associated with past and present incision of where the southerly flowing streams of New Pool (Lightmoor Brook) and Loamhole Brook drain into Dale Valley, with an outlet by Dale End Car Park into the River Severn. The valley slopes are cut into the Wenlock Shales and Upper Coal Measures and have characteristic upper and lower valley slope forms. The upper valley slopes are degraded showing subdued relict ground failure features, sloping (up to 35^o) and probably represent valley slopes above gently lying slopes (up to 22^o) of former stream-initiated instability. The lower valley slopes (up to 42^o) are associated with contemporary incision/erosion by the streams and are locally unstable due to the steepness of the slopes formed in the Wenlock Shales coupled with high groundwater levels.

Table 5.3 Coalbrookdale Landslide Systems

Coalbrookdale Landslide System	Location	Comments
Valley-side Rotational System	Darby Road and Rough Park	Spreads and blocks of displaced material bounded by very steep scarp slopes. In Darby Road the spread/ blocks have been extensively landscaped, removing evidence of minor scarps and individual landslide blocks. In Rough Park the landslide system has retrogressed upslope towards the Plateau surface. Both systems have probably been triggered by stream erosion removing support of the ground upslope. These system comprises a series of rotated blocks of varying sizes, generally, 10-30m long and up to 15m deep.
Elongate Mudslide	Cherry Tree Hill and Jiggers Bank	In Cherry Tree Hill area the mudslides comprising a series of broad heads with rotational landslide blocks and linear tracks bounded by distinct lateral slopes, with large debris lobes. At the base of the system the mudslide has been landscaped (including a gabion wall retaining structure) and would have extended to the valley floor of Lightmoor Brook. Four major mudslide systems have been mapped along Cherry Tree Hill, varying in width between 30 and 100m. The track of the systems are up to 200m in length. The depth is likely to be 10m plus. The Jigger's Bank system was not mapped in its entirety, however, the lateral length is over 300m.

5.3 Ground Models

The four ground behaviour landslide models (Models A to D) are shown on Drawing A. A fifth ground behaviour landslide model for Lloyds Coppice (Model E) has not been drawn in section based on key areas of the landslide complex falling outside the study area boundaries. The models are based on the geomorphological features and the limited geological and geotechnical information available to this study for key sections through each landslide. They provide general indications of landslide geometry, sub-surface geology and the likely mode and mechanisms of failure. It is noted that in the absence of detailed sub-surface ground investigation the slope behaviour models should be regarded as preliminary. Key points to note for each section are as follows:

- **Model A: Ironbridge Landslide System**, characterised by relict degraded shallow landslides within Coal Measures. The slopes are highly degraded with gently sloping benches less than 12^{o} and scarp slopes less than 35^{o}. The scarp and bench morphology indicates strong lithological control on the mechanism of landsliding. The pattern of landsliding identifies a headland and embayment system where the headland is formed between successive failures (the embayments) and is prone to lateral unloading by the preceding slides. These headlands are formed within the Plateau Margin ground behaviour unit. Several zones of failure may be identified. The degradation of this slope has resulted in an accumulation zone just above the toe of the slope which provides gentler sloping relatively inactive ground. The river cliff may comprise *in situ* geology of the Lower Coal Measures, however, it is likely that this slope comprises colluvium of the degraded upper slope. River incision and stream erosion has resulted in steeply dipping slopes associated with deeper-seated translation failures. A river cliff failure can be observed below the High Street roundabout which may give reason for the damaged structures and ground instability upslope of this area around the former school.

- **Model B: Ironbridge Mudslide System**, the area between Jockey Bank and Lloyd's Coppice is subject to mudsliding. The system is known to have catastrophic movement evident by the 1935 mudslide that required the demolition of properties built on the system. The mudslide has no discernible toe and is likely to flow beneath the Bird in the Hand Public House and Waterloo Street. Movement is likely to comprise imperceptible creep and accelerated movement following periods of prolonged rainfall. The system is characterised by rotational failures at the head of the system forming the scarp and lobate features throughout the elongated track.

- **Model C: Coalbrookdale Mudslide System**, the area of Jigger's Bank and above Cherry Tree Hill are formed within the weathered rocks of the Wenlock Shales. A series of mudslides have developed above Cherry Tree Hill which form broad heads in a series of headlands and embayments. Similarly, to the Jockey Bank (Ironbridge) mudslide movement is likely to comprise imperceptible creep and accelerated movement following periods of prolonged rainfall. The system is characterised by rotational failures at the head of the system forming the scarp and lobate features throughout the elongated tracks.

- **Model D: Coalbrookdale Deep-seated Landslide System**, characterised by an active deep-seated landslide developed within the Wenlock Shales. This slope has formed on the inside bend of Loamhole Brook and the confluence of Lightmoor Brook as they flow into Coalbrookdale valley. The slope in this area is easterly-facing and steeply dipping; the bedrock dips to the east, possibly facilitating landsliding. It is considered that the weathered Wenlock Shale undermined by stream action and the orientation of the strata has promoted deep-seated rotational failures within this area.

- **Model E: Lloyd's Coppice Landslide System,** this system has not been mapped in its totality as the main part of the system falls outside the study area. Further mapping of this system is recommended in order to assess the extent and magnitude of this system. The system is located within the Middle and mainly Upper Coal Measures and aerial photography and BGS mapping identifies most of the northern valley side to be a complex of rotated blocks. The landslide complex can be divided into three zones within the slope representing active rotational failures at the head of the system, with an accumulation zone mid-slope and stream induced translational failures within the colluvium at the base of the slope. The system is presently active, with some areas showing more activity than others.

It is considered that the southern part of the study area comprising Benthal Edge, Ladywood and Lloyd's Head require further mapping to identify and to assess ground behaviour. The boundary of the study area is limited to the base of these slopes and these constraints prevented mapping of these slopes in their entirety. This is also true for much of Jigger's Bank.

6 GROUND BEHAVIOUR ASSESSMENT

6.1 Introduction

Ground instability and its potential can be assessed by understanding the ground behaviour conditions and the impacts of past ground movement. The method was developed for the landslide potential study at Ventnor, Isle of Wight (Lee and Moore, 1991 and Moore, Lee and Clark 1995) and has been successfully applied elsewhere (Rendel Geotechnics, 1997 and HPR, 2002). The method is appropriate for the Ironbridge and Coalbrookdale study area where the ground conditions and impacts of ground movement are variable across the site.

The ground behaviour assessment is based on the following information:

- The stability review, which summarises past records of ground movement;
- the damage survey carried out as part of this study; and,
- An understanding of valley development, which involves the geomorphology, geology and structure, and consideration of the causes of ground movement.

The geomorphological assessment of the inter-relationships of different types of ground movement provides a framework for understanding the ground behaviour of the valley-side slopes, which is presented on the Ground Behaviour Map (Drawing B).

The remainder of this section presents the results of the ground behaviour assessment, which includes consideration of the types of ground movements that can be expected, and an explanation of the Ground Behaviour Map.

6.2 Types of Ground Movement

The nature of ground movements in the Ironbridge and Coalbrookdale area can be divided into two distinct groups, namely:

- Deep seated movements associated with the progressive creep of deep-seated landslides;
- Shallow or superficial slope movements arising from the erosion or failure of steep slopes, the differential movement and settlement of clay slopes, and subsidence, compression or ground heave.

The impact of deep-seated movement is restricted to the areas of major landslides identified on the Geomorphological Map (Drawing A). Little is known about the rates of shallow or surface movement. Evidence of crack damage to buildings, walls and roads indicates that movement is ongoing and that rates of movement may be of the order of mm/year. With reference to Table 4.1, creep of deep-seated landslides may partly explain areas of known instability at Darby Road.

The nature and significance of ground movements varies across the study area, with different valley-side slopes and landslide systems characterised by different problems. The relative risks in the area can be determined by comparing the types of ground movement hazard with the pattern of existing development and services. The nature of ground movement is summarised in Table 6.1.

The pattern of damage to buildings, walls and road within the Ironbridge and Coalbrookdale area is related to the various forms of ground movement. There appears to be a strong relationship between the types of ground movement that can be expected in different geomorphological units across the study area. Each geomorphological unit or landslide feature has its own characteristic range of stress conditions which will affect buildings, walls and roads, producing a characteristic type and distribution of damage.

For example, the concentration of significant damage and subsequent demolition of property at Jockey Bank has resulted from mudslide activity, which has undermined and caused recession of the slope top below the properties on Wrekin View. Active settlement of the slope and translational movement of the debris to the riverside has occurred. Outward displacement and heave of mudslide lobes at the base of the slopes has promoted destruction of property. Similar ground movement has occurred at Jigger's Bank and the slopes above Cherry Tree Hill.

The nature of ground movement in the area of the High Street roundabout is somewhat different, and comprises settlement of landslide blocks. This has caused widespread damage to development due to differential shear and crack damage, tilt of structures and ground heave at the toe of the slope. Anecdotally, the failure of the Ironbridge School play area (which lies at the boundary between the Middle and Lower Coal measures) followed the demolition of two properties downslope and heavy rain. At the toe of the slope, there is evidence of a river cliff failure that may have reduced support to the ground upslope. This area is heavily obscured due to development and this particular landslide boundary could not be mapped. However, interpretation of the damage survey map has enabled a landslide boundary to be determined based on the concentration of damage to structures and the interpretation of geomorphology.

Table 6.1 Types of Ground Movement

Type	Description
Mudslides (lobate and elongate forms)	Likely to be seasonally active in response to periods of heavy and prolonged rainfall. Ground movement may comprise differential settlement along head-scarps and side-scarps and translational ground movement. Outward displacement and heave may occur at the toe due to accumulation of mudslide debris lobes. Ground movements of several metres could occur, although creep is expected to be continuous.
River Cliffs	Along Ironbridge and Coalbrookdale valley sides are low steep river cliffs formed in weak rocks subject to slides and erosion due to active undercutting by river action and slope degradation/weathering processes. These slopes may also be formed in colluvium. Ground movements of several 10's of cms could occur.
Deep-seated landslides	Areas susceptible to active differential settlement of landslide blocks due to deep-seated rotational and translational movements. Ground movements are imperceptible and progressive comprising shear, tension, torsion, compression and heave. In the area of Ironbridge, failure of the river wall may accelerate and promote large-scale failures. Ground movements of several 10's of cms could occur, possibly several metres following river wall failure.
Degraded valley-side slopes	Marginally stable slopes with little apparent evidence of contemporary ground movement. The soft weathered Wenlock Shale rock has been over-steepened by fluvial processes and will have been subject to slope instability in the past. The slopes are subject to periodic localised creep and small landslides, particularly associated with poor drainage. Ground movements of several metres could occur.
Plateau Margin and Slope Top Settlement	Tension cracks (fissuring) developed above the steep valley-side slopes due to progressive valley-side failure. Imperceptible and progressive settlement of the Plateau Margin is an indicator of possible impending landslide potential. Ground movements of several 10's of cms could occur.
Shallow valley sides	Generally, movement is restricted to creep resulting in imperceptible and progressive settlement and heave in places. Occasional localised shallow debris slides may develop on localised steeper slopes associated with high groundwater levels. Ground movements of several 10's of cms could occur.
Plateau	The level soft ground areas subject to imperceptible and progressive shrink/swell behaviour associated with saturated fine grained soils. Ground movements of mm/year could occur.

Note. The magnitude of movements suggested in the table above, reflects anticipated movement based on previous experience. Changes in ground conditions, climate and human activity may promote varying scales of landslide movement. It is possible that any failures will be separated by periods of inactivity, which may last a number of years.

Other types of ground movement appear related to the settlement and recession of steep slopes. The problems encountered along Paradise, Wellington Road and Carpenter's Row can mostly be explained as a result of the imperceptible and progressive settlement of an accumulation zone. Tension cracks and differential settlement within the Plateau are apparent in some locations, notably above Rough Park Way. Also, poor drainage of groundwater from the made ground deposits (eg spoil heaps, brick and tile waste, etc) of the Plateau has possibly varied settlement rates as a result of the washing out of fines within this material. In addition, the saturated Plateau ground, observed during the fieldwork, is likely to result in swell/shrinkage dependent upon seasonal variations (see Drawing A).

The valley-side slopes along Ironbridge are reported to have ground movement related problems and these appear mostly related to periodic localised instability of scarp slopes and ground heave.

Ground movement can also be expected on the valley-side slopes associated with two streams Loamhole Brook and New Pool. These slopes are subject to superficial settlement and creep, and in localised places shallow mudslides have developed resulting in tension and settlement at the crest and ground heave at the toe of the mudslide. Ground movement problems such as these have been encountered along Cherry Tree Hill.

Not all damage to property can be attributed to ground instability, ie landslides. The new development along Beech Road shows some structural damage to properties and this is possibly related to ground settlement caused by shrink and swell behaviour of the clay strata of the Coal Measures.

6.3 Ground Behaviour Map

The ground behaviour map for Ironbridge and Coalbrookdale is presented as Drawing B. Ground behaviour is the interpretation of the geomorphological units and their associated impact. The map identifies discrete ground behaviour landslide units. The contemporary processes and impacts of ground movement in these areas can be expected to be somewhat different, as explained in the legend.

The Plateau, shallow valley-side slopes and valley floors are not characterised by large-scale landslides. The Plateau Margin has been defined to account for the potential settlement of the slope top – the Plateau. The landward boundary is arbitrarily defined in places or is based on the building damage survey in the absence of an obvious geomorphological boundary.

The map demonstrates that the potential problems vary from place to place according to the geomorphological setting, and this has been used as the basis for the Planning Guidance Map.

7 PLANNING GUIDANCE

7.1 Introduction

The principal objective of this study has been to develop an appropriate planning response to the land instability problems within the area. The assessment of ground behaviour has concluded that existing property in actively unstable areas will probably continue to experience damage due to ground movement. New development in actively unstable areas may be expected to be affected by ground movement; such areas should be avoided. More stable areas are likely to remain largely free from significant building damage and may be successfully developed, so long as necessary ground investigation and appropriate stabilisation and monitoring measures are adopted and the developer is willing to accept, in some locations, a higher level of risk than would be expected in other circumstances.

These broad conclusions provide the framework for the development of revised planning procedures for the area that take account of the information now available on land instability problems. The overall intention of the following guidance is:

- to ensure that development is suitable and that the possible physical constraints on the use of land are properly accounted for at all stages of planning. Although in some cases the appropriate response might be to prevent the development of land that is unsuitable, the principal objective of the guidance is to encourage the full and effective use of land in an acceptable and appropriate manner.

7.2 Development Plan Policies

It is suggested that the following amended policy should be considered for inclusion within the development plan:

Development of areas of known or possible land instability will only be permitted where the Council is satisfied that the site can be developed and used safely and not add to the instability of the site or adjoining land and that stabilisation measures are environmentally acceptable.

Significant building development in areas which are suspected as being potentially susceptible to this problem will normally be subject to development control procedures as outlined in Table 7.1 and on the Planning Guidance Map.

The Planning Guidance Map identifies those areas where particular development controls will apply. The guidance map and accompanying advice should be taken into account in all applications for development.

Applications for minor development, and those involving change of use only will not normally be subject to these procedures, except where this may be required in the public interest.

7.3 Development Plan: Allocation of Land

When setting out proposals for the development and use of land, and allocating land for specific purposes, the local planning authority should use the information presented in this Report as the basis for establishing whether, in general terms, potential sites can be safely developed. Issues that should be considered include:

- the level of risk at the site;
- the nature and scale of any stabilisation measures that would be acceptable at the site.

7.4 Development Control

The local planning authority should take land instability into account when dealing with all planning applications within the area. The results of this study should provide background information to assist making planning decisions, although it is recognised that specialist advice may be needed in certain circumstances.

The recommended procedures are set out below, and summarised in Figure 7.1.

1. *Pre-application stage;* the procedures for dealing with the land instability problems need to be widely publicised to inform potential developers of the necessary requirements before they make a planning submission. This might involve:
   - *Publication of clear policies and explanatory text within the development plan;*
   - *Publication of a Supplementary Planning Guidance note on the land instability issues;*
   - *Pre-application discussions between planning and building control officers and potential developers;*

- *Provision of a guidance note for applicants with the planning application form;*

- *Inclusion of specific questions on the planning application form to alert applicants to the land instability issues.*

2. *Receipt of Application;* after registering the application, the Planning Department should decide whether or not land instability is a matter for consideration. This will depend on:

- *The nature and scale of the proposed development;*

- *Its location with respect to the zones shown on the Planning Guidance Map.*

Developments which normally might be considered minor in scale and character to be normally exempt from these procedures are listed in Table 7.2.

3. *Development Control Requirements;* the applicant should be informed of the development control requirements and a copy of this letter should be sent to Building Control.

For developments which require planning permission, but which are exempt from these requirements, an advisory note should be issued, drawing the applicant's attention to the possible risk of land instability and consequent liabilities, and also the requirements which are likely to be imposed by Building Control.

In all other cases it is recommended that the applicant should be required to submit a *Stability Report* prepared by a Competent Person (see below).

In recognition of the fact that the responsibility for the stability and safe development of the site rests with the developer (and his/her specialist advisors), it is recommended that the Stability Report is accompanied by a *Stability Declaration Form*, completed by the author(s) of the Stability Report (see below).

In order to avoid putting applicants to unnecessary expense (especially in those situations where factors other than potential land instability may lead to a refusal of planning consent), it is advised that applicants discuss, with the Local Authority, all of the development control requirements prior to submitting their application. Pre-application discussions will provide an opportunity for applicants to be advised on the specific requirements for any proposal at an early stage.

4. *Determination Process;* a number of options are available:

- *Applications submitted without a Stability Report;* it should be normal practice to first consider whether the proposal meets other planning criteria. If not and the application is likely to be refused on other grounds, it would not be necessary to request a Stability Report.

  Where the proposal is not rejected on other grounds, and is not exempt from the instability development control procedures, it will normally be necessary to recommend that a Stability Report must be provided before the application is determined.

- *Application submitted with a Stability Report;* the Stability Report should be reviewed by the planning officer, in consultation with the Building Control section. The intention of this review is to determine whether the Report meets the Council's requirements with regard the assessment of instability issues and the type of development involved. This would be achieved primarily with reference to the Stability Declaration Form that would have been completed by the developer's advisor and included within the report.

  If the information in the Stability Report is either incomplete or insufficient in detail to aid determination, the planning officer should, in the first instance, refer it back to the applicant.

  In some circumstances, the planning officer may need to seek independent verification of the Stability Report. This should be done by appropriate specialists.

  If there is no response or an inadequate response to the request for additional information, the planning officer should recommend a refusal of planning permission on the grounds of insufficient information.

  If the Stability Report and any subsequent reviews conclude that the development can proceed with appropriate mitigation/stabilisation measures then the planning officer should recommend appropriate conditions to ensure their implementation (Table 7.3).

- *Post Determination;* copies of the Stability Report and conditions should be forwarded to Building Control.

Where the building control function is to be provided by an approved inspector, the Council should send a standard letter with an *Initial Notice* acceptance. This will ask the approved inspector to ensure that account is taken of the Stability Report, drawings showing foundation design and other mitigation/stabilisation measures, and the terms of the planning permission.

When planning permission is granted conditional upon submission of a Stability Report, it is essential that development does not proceed until both the Report and the designs for mitigation/stabilisation measures have been agreed as appropriate.

7.5 Stability Reports

Stability reports should be prepared by a Competent Person who should be able to demonstrate relevant specialist experience in the assessment and evaluation of slope stability. A Competent Person would *normally* be expected to be either:

- A Chartered Geologist;
- A Member of the Institution of Civil Engineers;
- A Member of the Institution of Mining and Metallurgy.

The local planning authority may wish to maintain a list of persons and organisations who have proved themselves capable of providing adequate reports. This list should be made available to prospective developers wishing to engage a specialist. The developer should be advised of the advantage of obtaining such reports from persons or organisations who possess and maintain professional indemnity insurance. This provision will promote a degree of commercial responsibility for the opinions expressed and will help to safeguard both the developer's and local planning authority's interests in the event of the development being damaged subsequently.

Before making a stability report, the competent person should undertake such inspections and investigations as are considered necessary to allow an opinion to be made on the stability of the proposed development site and its surrounding area. In order to satisfy the local planning authority the stability report should demonstrate:

- an adequate appreciation of ground and groundwater conditions and any other relevant factors influencing slope stability, based on desk studies, site reconnaissance and appropriate subsurface investigation, laboratory testing and monitoring;

- that the site is stable and has an adequate margin of stability or can be made so as part of the development works, for the foreseeable conditions which will operate at the site;
- that the site is not likely to be threatened or affected by reasonably foreseeable slope instability originating outside the site boundaries;
- that the development is not likely to result in slope instability or erosion of adjacent property.

In preparing the stability report, the competent person should consider all factors which might influence the stability of the site and surrounding area in relation to its suitability for the proposed development. The report should therefore contain:

- a factual record of the sources of information and investigations carried out;
- a description and engineering interpretation of the relevant ground and groundwater conditions;
- an account of any stability calculations;
- conclusions on the stability of the site and the influence of the proposed development. Geotechnical design parameters should be clearly established;
- recommendations for slope stabilisation measures, site inspections and monitoring;
- that the development is not likely to be threatened from any ground movement associated with underground workings or that the development may exacerbate collapse/ failure of any underground workings.

Three levels of Stability Report are envisaged, reflecting the variations in severity of instability problems across the area:

Outline Stability Report, based primarily on a desk study involving a review of available information relating to instability problems in and around the proposed development site;

Standard Stability Report, comprising an inspection of the site and surrounding area to assess the geomorphological context of the proposed development and to identify any recent ground cracking or structural damage to property. A ground investigation and subsurface investigations involving trial pitting, boreholes and groundwater monitoring *may be required* in certain areas.

Detailed Stability Report, comprising an inspection of the site and surrounding area to assess the geomorphological context of the proposed development and to identify any recent ground cracking or structural damage to property and a thorough investigation of surface and sub-surface conditions at the site and surrounding area, together with appropriate ground movement and groundwater monitoring.

Notwithstanding the above, it is considered any proposed sites adjacent to former quarries, underground excavations and areas of made ground (eg the Ironbridge Valley- side), and all proposed sites within the area of Madeley Plateau, undertake the appropriate level of sub-surface investigation to identify and determine below surface level workings that may affect a development. In addition, the extent of industrial workings in the area makes the ground susceptible to contamination through industrial processes. Any stability report should test by laboratory methods the extent of any contaminants as may reasonably be expected at a site.

In order to ensure a comprehensive report, which can be readily assessed by the local planning authority, the report should follow a standard format where possible (see Table 7.4).

The Stability Declaration form (*to be prepared by the Council*) should indicate the main categories of investigation that need to be covered in a Stability Report. This should be completed by the author(s) of the Stability Report.

High-Point Rendel

Table 7.1 Planning Guidance

Zone	Development Plan Policy	Development Plan Proposals	Development Control
1	Area suitable for development in accordance with the development plan.	Ground movement does not impose any constraints on site development.	No Stability Report required.
2	Area likely to be suitable for development in accordance with the development plan.	Ground movement does not impose significant constraints, although some mitigation/stabilisation measures may be required to ensure the stability of the site and surrounding land.	An Outline Stability Report would normally be required, prepared by a Competent Person.
3	Area likely to be suitable for development in accordance with the development plan provided the developer undertakes appropriate mitigation and stabilisation measures.	Ground movement imposes constraints that would generally require mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	A Standard Stability Report would normally be required which *may* include subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
4	Area unlikely to be suitable for development in accordance with the development plan unless the developer undertakes appropriate mitigation and stabilisation measures.	Ground movement imposes *significant* constraints that would generally require large-scale mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	A Detailed Stability Report would normally be required including detailed subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
5	Area very unlikely for built development.	Ground movement imposes *severe* constraints that probably could not be overcome by cost-effective and environmentally acceptable mitigation or stabilisation measures to ensure the stability of the site and surrounding land.	A Detailed Stability Report would be required including detailed subsurface investigation and long-term ground movement (both surface and sub-surface) monitoring and detailed proposed stabilisation methods, prepared by a Competent Person.

Note. All development should investigate for surface and underground workings in Ironbridge, the Madeley Plateau and Coalbrookdale area.
Where industrialisation has been undertaken an appropriate suite of laboratory testing should be scheduled for contaminants.

Table 7.2 Possible exemptions from the instability development control procedures

Suggested exemptions include (and will require confirmation from the Local Authority): • all developments in those areas where ground movement does not impose a constraint on development (i.e. Zone 1); • absence of physical development (e.g. change in use, change in external appearance etc.); • signs and advertisements etc.; • minor operations relating to fences, gates walls, etc., provided the public is not put at risk; • temporary buildings not designed to accommodate people.

Table 7.3 Examples of Possible Planning Conditions (based on Thompson et al 1996)

Possible condition for use with either outline planning applications or full/detailed applications submitted without a Stability Report: *No development shall take place until a Stability Report, prepared by a Competent Person, and including details of any mitigation/stabilisation measures, has been submitted to and approved by the local planning authority. Thereafter, development shall be carried out strictly in accordance with the approved details unless the local planning authority give written consent for any variation.* Possible condition for use with full/detailed applications submitted with a Stability Report: *The development shall incorporate the recommended mitigation/stabilisation measures as set out in the Stability Report, unless the local planning authority has given written consent to any variation.*

Table 7.4 Suggested Stability Report format

The structure and content of the report should include: i. *Introduction*; a statement indicating for whom the work was done, the nature and scope of the investigation, its general location, its purpose and the period over which it was carried out. ii. *Description of History*; a detailed description of the site based on the observations made by the competent person during his site review and reconnaissance. It should be referenced to a plan of the site showing national grid co-ordinates and to a scale no smaller than 1:2500. iii. *Investigation*s; information consulted during the course of the desk study should be referred to and listed as an appendix. Fieldwork should be described and full records of boreholes, trial pits or other exploratory methods included as an appendix and their locations shown on a plan. Site tests and laboratory tests and methods should be similarly described and their results included. iv. *Ground Conditions*; descriptions of the ground conditions found during the investigation and an interpretation of their relevance to the stability of the site and surrounding area. Anomalies in any of the data collected should be pointed out. The following items should be discussed, where appropriate: geological conditions; hydrogeology; history of past events and ground movement rates; soil and rock properties; other factors e.g. river bank protection and contaminated land. v. *Evaluation of Stability*; the stability of the site and relevant adjacent area should be evaluated with respect to the proposed development and his assessment of ground conditions. Where stability calculations are carried out, the method of analysis should be stated. The stability calculations should demonstrate both the existing factors of safety and, where appropriate, the factors of safety which would be created by the proposed development and any associated stabilisation measures. It is expected that particular attention should be paid to: the gradients of cut slopes and fills; drainage measures; retaining structures; failure mechanisms and the design criteria applied. vi. *Conclusions and Recommendations*; the Competent Person should summarise the main conclusions of the investigation and list the recommendations to ensure both the long-term stability of the site (taking account of the anticipated life of the development) and also in the short term whilst construction proceeds. It is expected that particular reference will be made to matters such as: the avoidance of fills near the crest of steep slopes; restrictions on the depth of excavation at the toe of steep slopes; the maximum length of trenches excavated along the contours of steep slopes at any one time; avoidance of septic tanks and soakaways; provision of flexible jointed pipes capable of sustaining small movements without leakage; provision for free drainage of groundwater; minimising drainage diversions and their lining where site conditions require them.

Note: The amount of content (eg investigation, stability calculations and design etc) will very much depend on the level of the Stability Report (eg Outline, Stability or Detailed Stability Reports)

8 MANAGEMENT OF SLOPE INSTABILITY

Ground movement can be reduced by undertaking a programme of landslide management. Figure 8.1 identifies a system that could prevent and reduce landslide problems within the study area.

The strategy provides a series of actions that take account of Planning, Building Controls, Engineering and Monitoring issues that could control future movement by reducing the factors that cause ground movement. These are presented in Table 8.1:

Table 8.1 Approaches to Alleviating Ground Movement Problems

Issues	How	By Whom
Ground Conditions	Ground conditions can be improved by engineering works such as ground reinforcement (eg piling, soil nails, retaining walls, geotextiles, reprofiling, drainage, limiting surcharge and unloading on particular sections of the slope).	Landowner or the developer
River walls	The river walls of the Severn were likely to be constructed for mooring purposes only, rather than substantial slope retaining structures. Should the wall fail, renewed toe erosion will inevitably result in landsliding upslope. Where there is no river wall, toe erosion will be ongoing. This is of particular concern given the more frequent flooding events experienced and anticipated as part of the predicted climate change, which is likely to increase erosion and promote high porewater pressures behind the wall and in the slope. Consideration should be given to developing an Ironbridge River Defence Strategy Plan to identify key areas at risk from breaching and the impacts this may have on the stability of Ironbridge town.	BTW, EA, riparian owners
Underground Services	Water leaking into the slopes reduces the strength of the ground and promotes landslide. Therefore, the Water Services Companies should provide a long term maintenance programme that allows limited excavation of trenches for repairs (this may create tension forces in itself and promote further instability) and flexible joints in known areas of ground instability. Gas, electricity and cable companies are also prone to excavate trenches for buried services, the consequences of this are as above	Utility Services
Pipe Leakage and drains	Property owners should monitor and check for leaking pipes and gutters to prevent water entering the slope system. Drains should be regularly checked in order that water does not build up elsewhere in the system. Soakaways should be discouraged. Property owners should be encouraged to repair and maintain their services.	Property owners
Construction	Assessment should be made on the type and size of a structure with regard to the ground it is to be developed on and the type of foundation. A holistic approach should be used assessing the consequences on the adjacent ground, ground conditions, hydrogeology, underground excavations, the foundations and detail of investigation and mitigating engineering measures. Development of Codes of Practice; preventing unsuitable development through building control and planning control.	BTW: Planning & Building Control

Issues	How	By Whom
Monitoring	Areas known to be active should have a regular programme of monitoring where possible trends of movement could be identified against weather records and may form part of an early warning system. This may include crack measuring of structures.	BTW/ Property owners
Communication	Liaison with the public, utility services, emergency services and other consultees (eg IGMT) through displays and meetings to recognise the scale of problems that may affect the study area, and, thus, the World Heritage Site, from ground instability. Furthermore, the Council should consider holding forums between other Local Authorities with similar ground instability problems.	BTW

Note: Any works should consider restrictions imposed as part of the World Heritage Site designation

9 CONCLUSIONS AND RECOMMENDATIONS

The Ironbridge and Coalbrookdale Ground Behaviour Study has involved a thorough review of the available information with regard to ground conditions, the history of past ground movement, and the development of the study area. The study has also undertaken an engineering geomorphological mapping and structural damage survey, which has identified the location and extent of ground instability throughout the study area.

As part of the study the ground behaviour has been determined and ground models have been developed from the available information and field mapping. It is recognised that without detailed sub-surface ground investigations and long term monitoring of the slopes that the landslide models should be regarded as provisional. This has enabled a framework for general planning and development control with regard to slope instability. This process has determined that further monitoring and investigations are required and has aided the location of areas of concern.

The ground behaviour map provides the brief basis for preparing guidance for future planning policy and development control that takes account of the different ground conditions that can be expected. The requirements for stability reports in support of future development proposals, outlined in this report, also account for the different ground conditions and their uncertainties.

The study has identified five landslide ground behaviour units characterised by different failure mechanisms of varying scales. Other ground behaviour units have been identified, and although these are unaffected by active landslides, localised problems of superficial shallow-seated failures, settlement and subsidence of the underlying geology and superficial geology has been recognised.

The Plateau area, north of Ironbridge, has deposits of waste from mines and, brick and tile works. The BGS Geological Map also identifies substantial areas of made ground along the Plateau top, in particular, a large area of opencast excavation, for clay and coal of the Coal Measures. This area has recently been landscaped, but there is evidence to suggest waste heaps and, therefore, possible contamination.

In some areas, such as Coalbrookdale, it is considered that development would be inappropriate due to potential instability of steep slopes, among other factors. In other areas, new development and redevelopment of sites may be feasible provided the advice presented in this report is taken into account and appropriate investigations and precautionary measures are implemented.

Recommendations arising from this study include:

- Further geomorphological mapping be undertaken along Jiggers Bank, Lloyds Head, Ladywood and Benthall Edge to understand the full ground behaviour of the areas of significance lying outside sections of the study area.

- There is a requirement to undertake detailed subsurface ground investigation(s) to refine the preliminary ground behaviour models. Such investigations should comprise deep boreholes (with continuous sampling), the installation of inclinometers and piezometers to monitor subsurface movement and groundwater levels, and laboratory testing of soils and rocks.

- It is also necessary to undertake surface monitoring of the slopes that are known to have been active in the recent past and also undertake a twice-yearly inspection of the slopes and systematic recording and photographic record of instability. It is important that further investigations and monitoring are carried out to enable periodic review of the ground behaviour conditions and planning guidance, particularly in respect of potential changes in climatic conditions that are predicted to occur, that may, however, be experienced in response to more frequent flood events.

- Detailed hydrogeological investigations should be carried out to identify the main sources of groundwater and drainage pathways into the slopes and the apparent saturated ground on the Plateau with a view to identifying drainage options. This would lead to recommendations for drainage design for future developments.

- The study highlights a number of cases of significant damage to buildings, walls and roads. A detailed survey of these should be carried out by appropriately qualified structural surveyors and appropriate actions identified. The Council should maintain records of repeat inspections and actions for specific cases.

- There is a requirement for collaboration between the Environment Agency and BTW to review the current and future requirements of the Wharfage and any river protection measures. This is important, as a decline in the current integrity of the Wharfage may result in significant increase in slope instability in future years.

- BTW’s retaining wall database should adopt the damage intensity scoring system used as part of this study to maintain continuity.
- Discussions with the Planning Authority should be held regarding the suitability of development in landslide areas identified by this study.
- Publication of supplementary planning guidance notes for distribution with planning application forms should be considered to raise awareness of the development control procedures for development on unstable land. The planning application form should include specific questions alerting applicants to the land stability issues.
- Ongoing discussions with professional groups (such as insurers, local engineers, contractors, estate agents) and Utility Services should be held to exchange information on ground conditions within the area. (The Council may consider holding annual forums with these professional bodies on an ‘Ironbridge & Coalbrookdale Management Strategy’. The strategy should be formalised, setting out clear objectives, scope and responsibilities. The implementation of the strategy should be monitored to evaluate the socio-economic implications and effectiveness of decision-making.)
- Liaison with the public and interested third parties of the Ironbridge Gorge and World Heritage Site (eg Ironbridge Gorge Museum Trust) by meetings and displays.
- Consider holding forums with other Local Authorities with similar instability problems.
- A code of practice should be targeted at developers and contractors.
- Advice leaflets to developers and homeowners should be produced to disseminate the findings of this study with respect to ground behaviour conditions and management and show how homeowners can improve their property to minimise impact or instability.
- This should include the effects of vegetations clearance with respect to the mitigation of potential slope instability

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There is a long schedule of site specific appendices accompanying this study. These can be viewed online at:

http://www.telford.gov.uk/info/1008/environment_and_conservation/460/land_instability