Revised ES Appendix 17.2

Land Stability Risk Assessment 2020

Proposed Extension to Linhay Hill Quarry

Land Stability Risk Assessment 2020

E & JW Glendinning

August 2020

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1. Introduction

1.1. Preamble

This Land Stability Risk Assessment (LSRA) assesses the land stability risk associated with proposals for future development of Linhay Hill Quarry. It has been prepared by Atkins on instructions from E&JW Glendinning Ltd. This LSRA is referred to as LSRA 2020.

LSRA 2020 is part of an Environmental Statement (ES) submitted to the Dartmoor National Park Authority (DNPA) in support of a planning application for the proposed quarry expansion. It has been prepared in response to a Request for Further Information issued by the DNPA in February 2020 under Regulation 22 of the EIA Regulations 2011 (Regulation 22 Request 2020) (Wood 2020).

LSRA 2020 builds on earlier work on this topic contained in Appendices 17 and 17.1 of the ES submitted to the DNPA as part of a planning application for deepening and extending Linhay Hill Quarry. It also draws on the assessment of the potential impacts on the local surface water hydrology and groundwater regime contained in the updated and revised Hydrogeological Impact Assessment (HIA), referred to as HIA 2020.

Appendix 17 of the ES contains the original Land Stability Risk Assessment associated with the quarry expansion proposals and Appendix 17.1 contains a revised assessment (LSRA 2018) prepared in response to a Regulation 22 Request issued by the DNPA in 2016. LSRA 2018 was also informed by a program of additional data collection and studies on the site and the surrounding area, including further survey and ground investigation and additional geological and hydrogeological desk studies, monitoring and interpretation. Comments from Highways England, other statutory consultees and third parties were also taken into account.

The additional hydrogeological desk study, investigations, monitoring and interpretation was contained in an accompanying HIA, referred to as HIA 2018.

Following review of LSRA 2018, Highways England stated in a letter to the DNPA on 11 April 2019 [1] that it had "*no objection in principle to the proposed development*" subject to the approval of geotechnical submissions relevant to the construction of a screen bank between the application site boundary and the A38.

The Environment Agency stated that "*the information submitted* [in HIA 2018] *has addressed the majority of the issues raised*" in its consultation responses, subject only to clarification on monitoring and mitigation matters, which could be resolved in suitably worded planning conditions.

The Regulation 22 Request 2020 set out a requirement to *"revisit the LSRA, the assessment of residual land stability effects, and the monitoring and mitigation actions proposed in the Karst Management Plan*" in the light of an update to the hydrological conceptual model contained in the HIA, which was also required in the Regulation 22 Request 2020.

Whilst confirming that it was for the applicant to consider the form of its response, some suggestions of topics for consideration in the updated LSRA were put forward in the Regulation 22 Request 2020 as follows:

- increased frequency of land stability monitoring.
- comparison of sinkhole development with records of weather conditions.
- structural surveys of selected properties to be undertaken prior to commencement of quarrying in the extension.

This LSRA seeks to address the land stability issues raised in the Regulation 22 Request 2020. It follows the format of LSRA 2018, but with relevant Sections updated to reflect the requirements of the Regulation 22 Request and information acquired during the intervening period. References used are listed at the end of the LSRA and are numbered thus [x] in the text below.

LSRA 2020 forms the basis for a revised ES Chapter 17 Land Stability which is submitted as part of the response to the Regulation 22 Request 2020.

1.2. Context

Linhay Hill Quarry extracts limestone from an outcrop of the Chercombe Bridge Limestone Formation (CBLF), which is of Devonian age. The CBLF, along with other Devonian limestones that are quarried in South Devon and many other types of limestone, is characterised as being a karst (or karstic) limestone.

Karst is *"the term applied to topography formed by the dissolution of soluble rocks, such as limestone, as a consequence of fluids moving across and through them […] Areas of karst are usually characterised by the distribution of caves, sinkholes (dolines, or doline groups (ponors); points of surface water recharge), springs (points of resurgence of water passing through the rock) and dry valleys"* (British Geological Survey (BGS) website)[1]. Karst is most often seen in limestone, including chalk, but also in gypsum and halite (salt).

Engineering problems associated with karstic rocks include subsidence, sinkholes, uneven rockhead, and reduced rock-mass strength. The development or reactivation of sinkholes and subsidence therefore has the potential to cause damage to buildings and infrastructure such as roads. Waltham [2] comments that *"almost any means by which a new or increased flow of water can pass through a soil cover into underlying fissured limestone, and thereby carry soil away, is likely to form a subsidence sinkhole".* The inadequate control of drainage can disturb previously stable ground, as Waltham [2] states: *"without built drains to carry the runoff away or directly to bedrock, any concentration of drainage input to the soil within a karst terrain becomes a potential site for a new sinkhole".*

Waltham [2] also concludes that "*Predictions of the locations of caves or potential sinkhole sites are next to impossible, geophysical searches have severe limitations and borehole searches can incur significant costs".* Nevertheless, Atkins has carried out work with the aim of increasing understanding of the land stability risk associated with the proposals for deepening and extending Linhay Hill Quarry, though the proposals submitted to DNPA already take account of the conclusion of Waltham [2] that "*Consequently, controlling the drainage on construction projects is usually the most cost-effective means of minimizing the karst geohazard".*

For context, it is important to recognise that limestone is one of the major components of the supply of aggregate in the UK and is also an important source of aggregate supply in other countries. Although karst is developed in the Devonian Limestone in South Devon, the best developed karst landscapes and the longest cave systems in England are associated with the Carboniferous Limestone, which forms the karst landscapes of the Mendip Hills, south and north Wales, the Yorkshire Dales, and the Derbyshire Peak District. All these areas are important sources of limestone aggregate. Thus, limestone is almost invariably quarried from karstic limestone, and it is certainly the case that as well as the areas mentioned above, the limestone worked at the other three limestone quarries in Devon - Moorcroft, Stoneycombe and Westleigh - is karstic limestone, each quarry having other land uses nearby. Karstic deposits of gypsum, chalk, and salt are also quarried or mined in the UK.

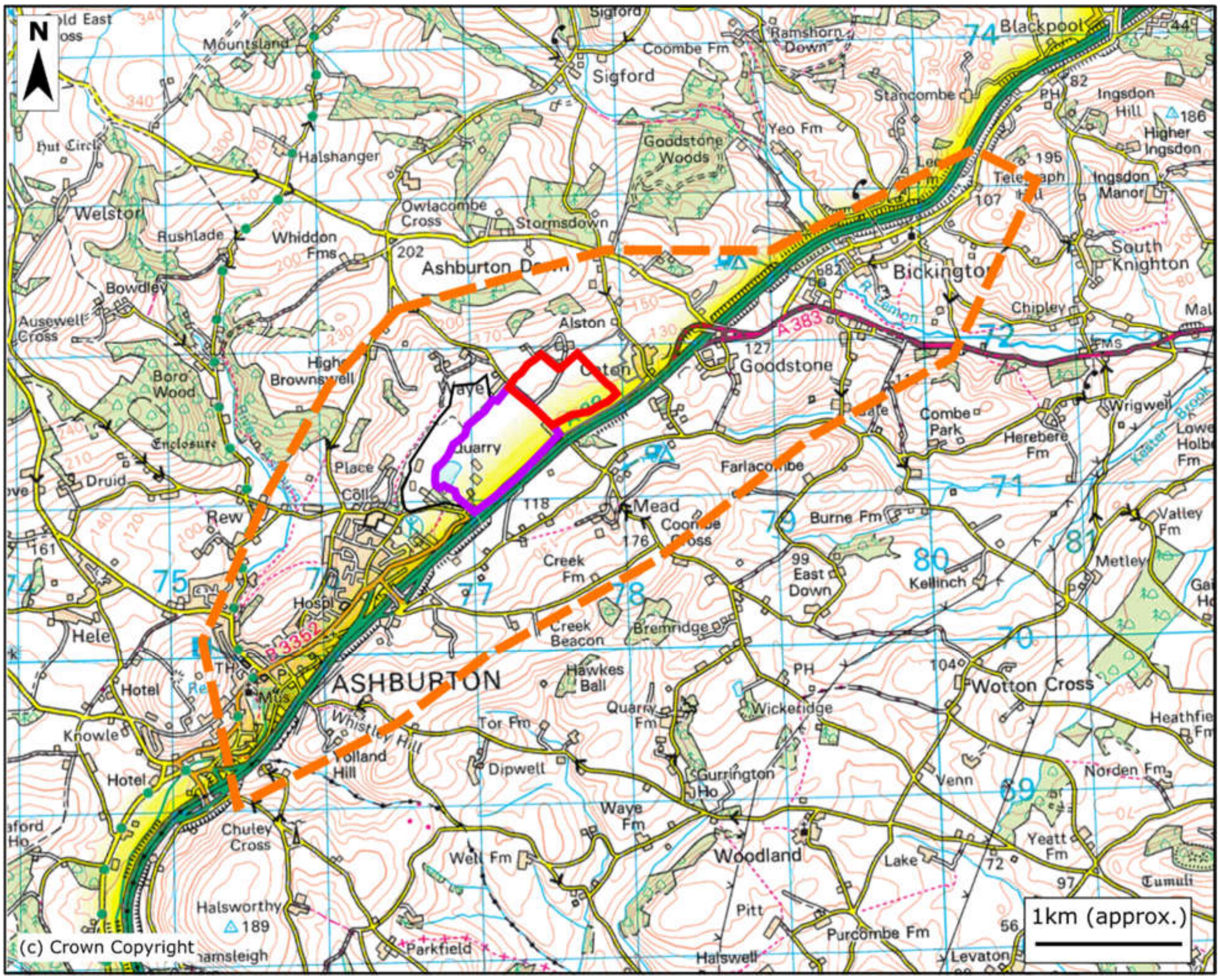
1.3. Objectives

The focus of this LSRA is the effect on land stability risk from the impacts of deepening Linhay Hill Quarry and extending the quarry progressively to the northeast into Alston Farm fields. The extension will require deepening and dewatering of the quarry during its operation and the construction of bunds for overburden on land at Alston Farm, with the attendant drainage including the diversion of an unnamed seasonal watercourse (referred to here as the Alston stream) which flows across the farmland from springs in Alston Wood.

The aim of the LSRA is to identify and assess land stability hazards to determine the current situation and the potential effects of the quarry proposals on land stability risk. For the LSRA, a Land Stability Study Area (Figure 1-1) has been defined by reference to the extent of the Chercombe Bridge Limestone Formation and the surrounding topography.

[1] See https://www.bgs.ac.uk/research/engineeringGeology/shallowGeohazardsAndRisks/sinkholes/catonKarst.html [Accessed January 2019].

Figure 1-1 Excerpt from Ordnance Survey topographic map overlain with the existing Linhay Hill Quarry extent (purple), the proposed quarry extension area (red), and the approximate extent of Atkins' Land Stability Study Area (orange dashed). Crown Copyright and Database right 2016 Ordnance Survey 100018595.



1.4. Scope

The approach adopted for assessing the current situation in the Land Stability Study Area, and the likely effects of the proposed quarry deepening and extension follows the relevant planning and legislative framework applicable to providing a land stability risk assessment as set out in Planning Practice Guidance.

In the entry on land stability assessment, the Planning Practice Guidance states the following regarding methodology and reporting[2]:

> "*Preparation of a land stability risk assessment will normally comprise a comprehensive desk-study and site inspections, but in some circumstances this may require additional intrusive site investigations. The land stability risk assessment report should include:*
>
> - *a review of existing sources of geological and/or mining information;*
> - *site history;*
> - *site inspection;*
> - *intrusive site investigation (if necessary);*
> - *assessment of land instability risks; and*
> - *mitigation measures*"

[2] Planning Practice Guidance (March 2014). Chapter on land stability assessment: paragraph 008 Reference ID: 45-008-20140306 revision date 06 06 2014. https://www.gov.uk/guidance/land-stability

Hence the scope of work for this study has been as follows:

1. Review the Engineering Geology Desk Study of Linhay Hill Quarry and its surroundings carried out for the previous risk assessments, including the findings of project-specific ground investigations and walkovers, to ascertain the ground conditions and sources of potential land stability risk with a particular focus on the karst and sinkhole formation process in the local limestone outcrop (see Appendix A).

2. Review the interpretation of aerial photography and satellite imagery, followed by targeted on-site visual inspection of the working quarry and by engineering geomorphological field walkovers of specific parts of the Land Stability Study Area. Field walkovers included the identification, mapping, and classification of sinkholes according to a project-specific classification scheme (see Appendices B and C, also E).

3. Incorporate the findings from Atkins' hydrogeological conceptual model and associated groundwater monitoring and testing presented in HIA 2020, and the updated ES Chapter 12.

4. Identify potential land stability hazards, receptors, impacts, and effects, and develop the previous risk assessment methodologies prepared by Frederick Sherrell Ltd in 2016 [3] and LSRA 2018 [4].

5. Present an updated Karst Management Plan that proposes mitigation measures and a proposed approach to monitoring of land stability. The proposed mitigation includes drainage control, monitoring, implementation of the Karst Management Plan, and sinkhole repair.

6. Assess the residual risks, taking the proposed mitigation measures into account (including monitoring) to ensure land stability hazards, if any develop, are identified at an early stage.

Permission to undertake walkover surveys was given by several neighbouring landowners, and Atkins gratefully acknowledges their assistance for the study.

Consideration of the stability of the faces of the current and proposed extension to Linhay Hill Quarry is not included within the scope of this Land Stability Risk Assessment. It is provided in the Environmental Statement Appendix 3A.

1.5. Existing Quarry Operation and Layout

E & JW Glendinning Ltd. (the applicant) is an independent family business which has operated quarries in Devon since 1958 and has a long history of supplying limestone building products to key sectors of the regional economy. The main site in the company's business is Linhay Hill Quarry, which has grown from a modest operation to become one of the most important sources of limestone in the South West England, being one of just four major quarries in Devon producing limestone. E & JW Glendinning Ltd. now employs around 240 staff, most of whom are based at the quarry and head office in Ashburton.

The quarry comprises a large void, with surrounding rock reserves, with primary and secondary aggregate processing plant located within it, and further associated workshops, plant and storage areas located on its western and northwestern side. Limestone aggregate, speed screed, black sand, ground limestone, and concrete masonry blocks are all produced at the quarry. A tip for overburden and quarry spoil is located north of the void and is being progressively restored to agricultural use. The quarry is enclosed by vegetated bunds, high tree screens, hedges, or fences, which help to screen it from view from many public viewpoints.

The existing quarry has planning permission for extraction down to an elevation of 28 m above Ordnance Datum (AOD), which will be achieved by the completion of eight 13-15 m deep benches (at the time of writing, the base of the quarry lies within Level 7):

- Level 1: 125-120 mAOD
- Level 2: 120-110 mAOD
- Level 3: 110-97 mAOD
- Level 4: 97-83 mAOD
- Level 5: 83-68 mAOD
- Level 6: 68-54 mAOD

- Level 7: 54-41 mAOD
- Level 8: 41-28 mAOD

A settlement pond lies close to the existing quarry's western boundary, in the Balland Pit, from which limestone was extracted down to approximately 54 mAOD in the early 1990s. The Balland Pit is now a permanent water body with a surface water area of approximately 2 ha and water level at about 78 to 80 mAOD. The Balland Pit provides attenuation water storage and acts as a settlement pond to remove suspended solids before the water is recycled in the quarry, with excess pumped to discharge to the Balland Stream. The quarry utilises a submersible pump to lift water from the quarry's lowest level to the Balland Pit. The sump is now within the top of Level 8, i.e. below the base of the quarry.

1.6. Proposed Extension

The proposal is to extend Linhay Hill Quarry in a north-easterly direction across Alston Lane and into agricultural land south of Alston Farmhouse. The extension is required because as from the end of 2020 the remaining limestone reserves in the existing quarry are only sufficient for a further five years at the current rate of extraction.

The proposal will extend the quarry extraction area by about 21 ha and will be carried out in stages with the year in which stage 0 commences being Year 1 (Table 1-1). The extension will enable extraction of limestone to continue beyond the estimated five years remaining, and assuming the current extraction rate would provide for about an additional sixty years of extraction. The extension area will be quarried progressively in a northeasterly direction from the existing quarry at Linhay Hill, with the adjacent land within the application site being used for bunds that would be created by tipping of the overburden from the earlier stages of the extended quarry area. The extension will be preceded by changes to infrastructure surrounding the quarry, as detailed in Table 1-1.

In parallel, the application seeks to allow the existing quarry to be deepened to extract limestone below the current limit of 28 mAOD, to a maximum of 0 mAOD. This will yield about three years of further reserves from within the existing footprint of the quarry and minimise subsequent negative impacts on the landscape by allowing the overburden from the later stages of the quarry extension area to be backfilled into the base of the quarry. This will reduce the extent of the bunds and return the base elevation of the quarry to 28 mAOD.

As extraction progresses, the capacity of the settling pond in the Balland Pit will need to be increased by bunding around its lowest side. Subsequently, a replacement settling pond can be created in the base of the quarry. The existing pond will have become full of sediment and will be partially capped to provide a competent surface which can be restored and utilised.

Table 1-1 Summary of stages for proposed extension of Linhay Hill Quarry

<table>
<tr><th>Stage</th><th>Indicative timescale (years)</th><th>Extension area (ha)</th><th>Quarry base (mAOD)</th><th>Alston Farm fields – southern bund footprint (ha)</th><th>Alston Farm fields – eastern bund footprint (ha)</th></tr>
<tr><td>Stage 0</td><td>1-2</td><td>0</td><td colspan="3">Infrastructure changes comprising: widening of Balland Lane and construction of a new public road (Waye Lane) and public footpath diversion from Balland Lane to Alston Lane at Lower Waye; construction of a new private access route from Lower Waye to Alston Farm; diversion of existing electricity and water supply along Alston Lane; improvements to Caton Cross.
Monitoring of baseline hydrological, hydrogeological and land stability conditions.</td></tr>
<tr><td rowspan="2">Stage 1</td><td rowspan="2">2-13</td><td>Infrastructure</td><td colspan="3">Removal of Alston Lane and closure of the junction with the A38.
Monitoring of baseline hydrological and hydrogeological and land stability conditions.</td></tr>
<tr><td>5.25</td><td>28</td><td>2.66</td><td>4.27</td></tr>
<tr><td>Stage 2</td><td>14-31</td><td>12.22</td><td>0</td><td>2.66</td><td>7.86</td></tr>
<tr><td>Stage 3</td><td>32-40</td><td>16.31</td><td>14</td><td></td><td></td></tr>
</table>

Stage	Indicative timescale (years)	Extension area (ha)	Quarry base (mAOD)	Alston Farm fields – southern bund footprint (ha)	Alston Farm fields – eastern bund footprint (ha)
Stage 4	41-46	21.47	28		
Stage 5	47-60+	21.47	28 in existing quarry, 0 in extension area		
Stage 6	when Stage 5 complete	21.47 Restoration; no extraction	Fills with water to a controlled level, expected to be around 96 m AOD		

There will be no foreseeable change to the quarry's existing rates of rock extraction as a result of the extension proposals; the quarry's output will continue to depend on the level of demand for quarry products from customers in the surrounding market area.

The proposed layout of the quarry and adjacent bunds is shown in the Planning Application drawings (LINHAY-ATK-S0-Z-PL-001, S1-Z-PL-1000, S2-Z-PL-2000, S3-Z-PL-3000, S4-PL-4000, S5-Z-PL-5000, S6-Z-PL-6000).

New surface water drainage will be formed around the quarry extension area, with bunds to manage the surface water runoff. The only existing watercourse that needs to be diverted is the Alston stream, which flows through Alston Farm. Due to the proposed construction of bunds to the east of the proposed quarry extension area, in Stage 2 a section of the Alston stream will need to be diverted but will continue to flow towards the Kester Brook to the south.

Once the extraction is complete and dewatering ceases, the quarry will infill with groundwater and rainfall to form a lake. The formation of a lake is what would happen for the existing quarry void in the 'Do Nothing' scenario, that is if the proposed quarry extension did not take place. The resulting lake level to the Balland Stream will be controlled, thereby also reducing the stream's flood risk to Ashburton.

2. Existing Situation

2.1. Introduction

The following sections provide an overview of baseline information relevant to land stability risk within the Land Stability Study Area, based on the work that Atkins has carried out, which includes:

- Engineering Geological Desk Study of publicly available information (see Appendix A).
- Inspection of the existing quarry (see Appendix A).
- Engineering geomorphological walkover surveys of the quarry and surrounding land (see Appendix C).
- Interpretation of aerial photographs (see Appendices A and B).
- Ground investigation boreholes (see Appendices A and C).

The conceptual model of the hydrogeology of the study area is provided in HIA 2020.

2.2. Current Topography

The existing quarry is about 1 km northeast of Ashburton. It is approximately rectangular in outline, with its longest axis aligned roughly northeast-southwest, parallel to the alignment of the A38 dual carriageway and the outcrop of the Chercombe Bridge Limestone Formation. It lies at the top of the catchment of the Balland Stream, which flows southwest to the River Ashburn, a tributary of the River Dart.

The existing quarry, the proposed extension area, and the headwaters of the Kester Brook all lie within a topographically low area that is approximately 1 km wide, running in a southwest to northeast orientation alongside the A38 and adjoined by ridges of higher ground to the northwest and southeast.

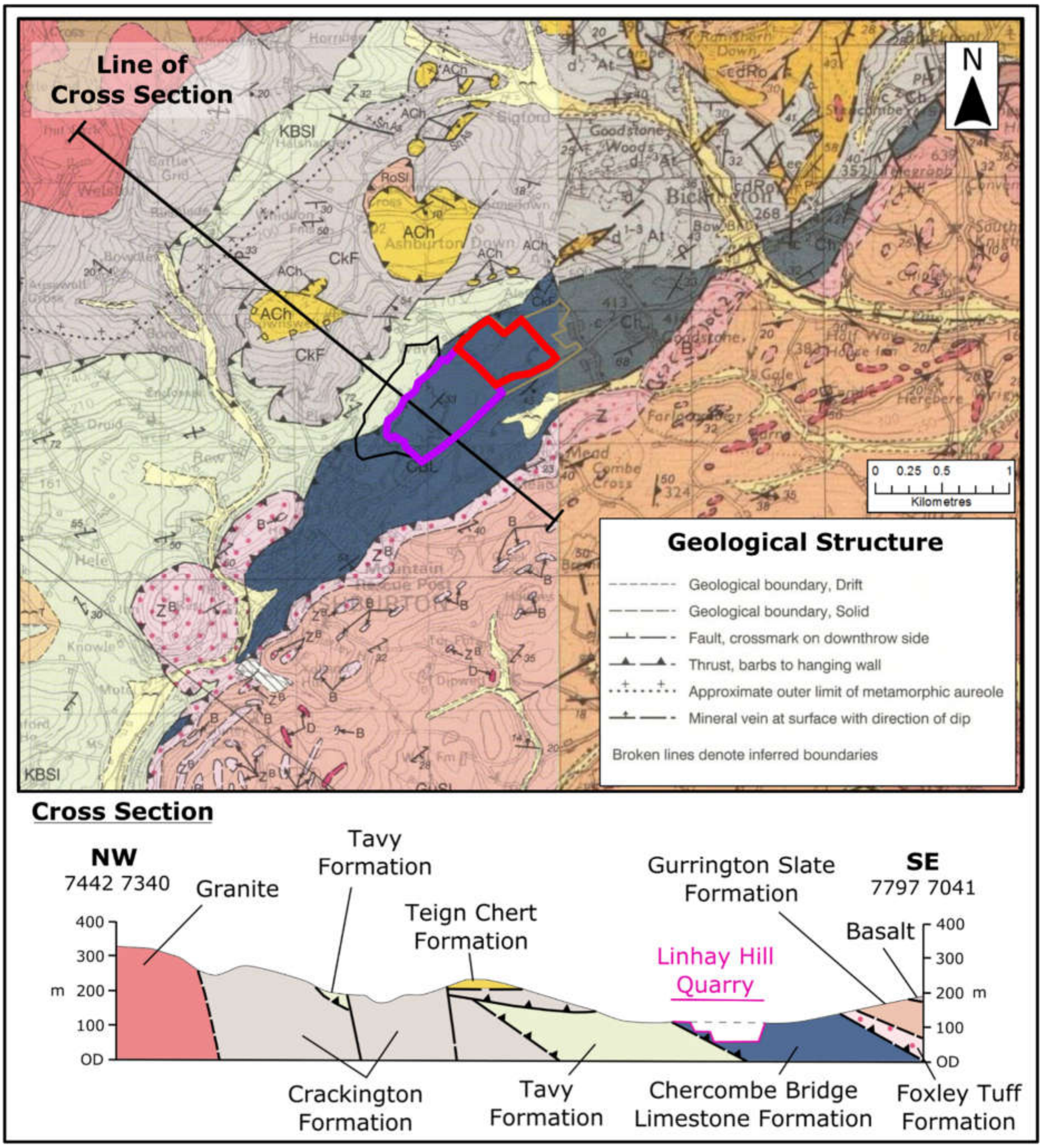
The proposed extension spans the watershed between the Balland Stream and the Kester Brook, the latter flowing west to the River Ashburn at Ashburton and the latter flowing east to join the River Lemon 3 km east of Bickington (Figure 1-1).

The area of the proposed extension, including the area of the proposed overburden bunds, lies to the northeast of the existing quarry and is agricultural land that slopes gently towards the south and east. The current ground elevation of the proposed extension area ranges from approximately 115 mAOD in the south to approximately 145 mAOD in the north, near Alston Farm. The proposed extension area is bounded to the southeast by the A38 dual carriageway, which is partly situated on an embankment and partly in a shallow (approx. 2m) cutting. It is proposed that the southwestern part of the extension area will be excavated (the ‘proposed extraction area’), whereas the northeastern part and a strip alongside the A38 will be used for bunds of overburden.

2.3. Geological Overview

Linhay Hill Quarry works a southwest to northeast trending outcrop of the Chercombe Bridge Limestone Formation (as shown by Figure 2-1), which is Middle to Upper Devonian in age, having been deposited approximately 393 to 383 million years ago in a tropical marine environment. It is described in the 1912 geological survey memoir on the Geology of Dartmoor as: “*It is a bedded dark-coloured, or reddish marble, taking a good polish, and it is often much veined with white calcite. Occasionally it is dolomitized.*” (Reid et al., 1912 [5]). On BGS Map Sheet 338 (1995) it is described as “*medium to dark grey limestone beds*”, and on BGS Map Sheet 339 (1997) it is described simply as “Grey limestone”.

Figure 2-1 Geological map of the area around Linhay Hill Quarry and simplified geological cross section showing the existing quarry excavation (purple outline) and the proposed quarry extension (red outline). Map and cross section adapted from BGS Map sheet 338 [6] and sheet 339 [7]. The cross section shown on BGS map sheet 338 has been re-drawn by Atkins to show the extent of Linhay Hill Quarry in the context of the bedrock geology.



Over geological time, the limestone has been subject to karst weathering (dissolution) processes forming solution features (BGS webpage on the Caton karst [8]), with the karstic rockhead topography buried under superficial deposits. This is discussed further later in this Land Stability Risk Assessment report and its Appendix A (Engineering Geology Desk Study) and in HIA 2020.

A summary of the bedrock formations present in the area around Linhay Hill Quarry is provided in Table 2-1. More detailed descriptions of the bedrock formations are included in the Engineering Geology Desk Study in Appendix A.

Table 2-1 Summary of bedrock formations in the area around Linhay Hill Quarry, and shown on the geological map (Figure 2.1), listed in stratigraphic order (youngest at the top, oldest at the bottom).

Bedrock Formation and geological code on map (Figure 2.1)		Geological age	Thickness (Approx.)	Material type
CkF	Crackington Formation (Including St Mellion Formation)	Lower Carboniferous	>1000m	Mudstone, sandstone, and siltstone
ACh, $d^{1\text{-}3}$Te, and $d^{1\text{-}3}$At	Teign Chert and Codden Hill Chert Formations	Carboniferous	>70m	Chert, shale, and mudstone
edRo	Rora Mudstone Formation	Upper Devonian to Carboniferous	Unknown	Mudstone
GuSl and cdGU	Gurrington Slate	Upper Devonian to Carboniferous	Unknown	Slate
KBSl	Tavy Formation	Upper Devonian	Unknown	Slate and mudstone
CBL	Chercombe Bridge Limestone Formation	Middle to Upper Devonian	>250m	Limestone
Z and Z^B	Foxley Tuff Formation (part of the Kingsteignton Volcanic Group)	Middle Devonian	<30m locally. Up to 195m elsewhere.	Lava flows and volcanic ash, with beds of limestone

The outcrop of the Chercombe Bridge Limestone Formation within which Linhay Hill Quarry is developed covers an area of some 300 ha, extending from Ashburton to Bickington (Figure 2.1). The quarry is located where the outcrop is at its widest (some 1000 metres northwest to southeast), but the quarry footprint is narrower, lying between the A38 dual carriageway to the southeast and the geological boundary with the Tavy Formation to the north.

BGS Map Sheets 338 [6] and 339 [7] show that the bedding within the Chercombe Bridge Limestone Formation dips between approximately 33 and 68 degrees from the horizontal towards the southeast.

Several thrust faults are indicated near Linhay Hill Quarry on BGS Map Sheet 338, showing older rocks to have been thrust over younger rocks. A major thrust fault is located immediately north of the quarry, aligned southwest to northeast, which is probably a continuation of the Bickington Thrust. As a consequence of this thrust, the Chercombe Bridge Limestone Formation has been thrust over the younger slates of the Tavy Formation, which outcrop in the hills to the northwest.

A second thrust fault is shown on Geological Map Sheet 338 at the western and southern extent of the limestone outcrop, where it marks the contact between the limestone and the Foxley Tuff Formation. These extrusive igneous rocks have been thrust over the Chercombe Bridge Limestone and outcrop as a narrow (less than 500 m wide) strip along the entire southern edge of the Limestone outcrop, extending to Bickington (approximately 2.3 km northeast of the existing quarry).

The southwest-northeast trending thrust faults that bound the Chercombe Bridge Limestone outcrop are mapped by the BGS as dipping towards the southeast at angles broadly consistent with the bedding in the limestone (approximately 33 to 43 degrees near Linhay Hill Quarry).

In addition, a north to south trending fault is shown by the BGS near the alignment of the Caton stream, as described further in HIA 2020 (see also Figure 2-8 below).

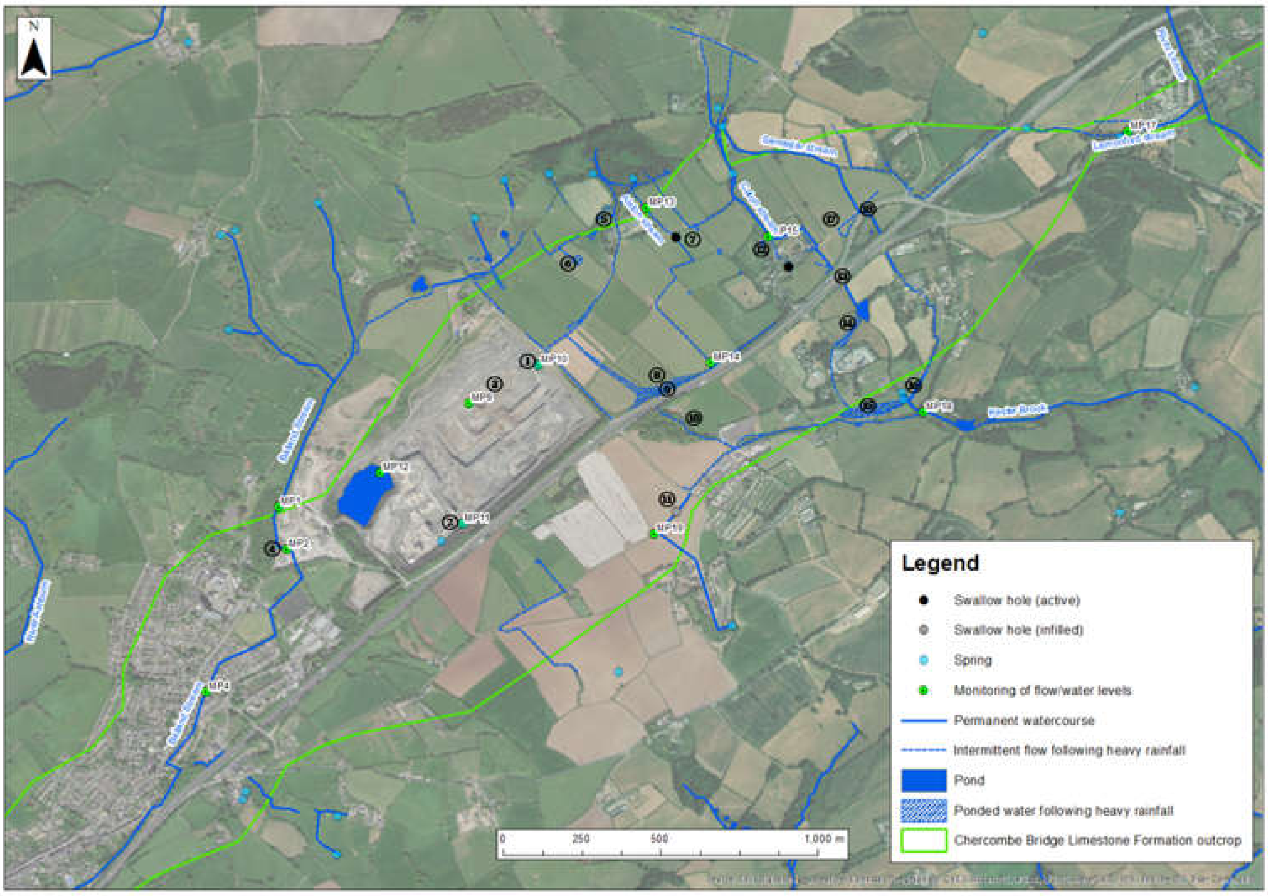
The tectonic history of the area, including faulting and folding, has resulted in fracturing (jointing) of the limestone, as can be observed in the quarry where the joints have acted as preferential zones of karst dissolution.

2.4. Hydrological and Hydrogeological Overview

Hydrology and hydrogeology, including a conceptual hydrogeological model, are addressed in detail in the Hydrogeological Impact Assessment 2020 (HIA 2020) [9]. The following is an overview of the main findings and conclusions that are relevant for land stability.

Surface water

Figure 2-2, which is reproduced from HIA 2020, shows hydrological features in the vicinity of Linhay Hill Quarry.



NOTES

1) Northeast face fracture (Figure 4-25 and Figure 4-26)
2) Southeast face conduit (Figure 4-27)
3) Level 7 conduits (Figure 4-28 and Figure 4-29)
4) Quarry discharge to the Balland Stream (Figure 4-30)
5) Historical alignment of Alston stream towards former mill (Figure 4-31)
6) Ponding in sinkholes to the west of Alston Farm (Figure 4-32)
7) Overflow of Alston stream swallow hole (Figure 4-33)
8) Ponding of water on the northern edge of A38 (Figure 4-34)
9) 300 mm pipe under A38 (Figure 4-35)
10) Inferred intermittent flow within Mead Cross Unconfirmed Wildlife Site (Figure 4-36)
11) Infilled swallow hole in the Mead Farm stream (Figure 4-37)
12) Partial diversion of Caton stream (Figure 4-39)
13) Cattle creep underbridge under the A38 (Figure 4-40)
14) Inundation following heavy rainfall (Figure 4-41)
15) Inundation following heavy rainfall (Figure 4-42)
16) Goodstone Springs (Figure 4-43 and Figure 4-44)
17) Runoff through field towards A38 off-slip following heavy rainfall (Figure 4-45)
18) Pipe under A38 off-slip (Figure 4-46)

Figure 2-2 Hydrological features in the vicinity of Linhay Hill Quarry (Figure 4-26 from HIA 2020). Note that the figures referred to in the notes are Figures within HIA 2020.

The main surface water features near to the quarry are:

- The River Ashburn and its tributary the Balland Stream.
- The River Lemon and its tributary, the Kester Brook and its tributaries which are unnamed watercourses (referred to as the Alston stream, the Mead Farm stream, the Caton stream and the Samaster stream). There is also drainage from east of the A38 Goodstone junction which leads to the River Lemon the final section being referred to as the Lemonford stream where it receives water from a spring near an old quarry west of Lemonford Lane and the property Higher Lemonford.

The River Ashburn flows north to south from the north of the quarry and passing through the town of Ashburton. It passes closest to the quarry at Cuddyford Cross (approximately 1 km west of the quarry), where the river is at an elevation of around 95 mAOD.

The Balland Stream flows southwest, passing through the west side of the quarry workshop area and then roughly parallel to the A38, before joining the River Ashburn in the town of Ashburton. It is fed by several springs, as shown in Figure 2-2, and by water pumped from the Balland Pit (marked as 'MP12' in Figure 2-2) which acts as a settlement pond for water intercepted by the quarry. The upper reach of the Balland Stream flows over the Tavy Formation approximately along the north and northeast boundary of the quarry. It is partly culverted and in places in the quarry runs in an open concrete block lined channel.

The River Lemon is located to the northeast of the quarry, where it flows roughly northwest to southeast. At its closest, the river is approximately 2.3 km northeast of the quarry, near to where it passes under the A38 at Bickington.

The Kester Brook is a tributary of the River Lemon. It is to the southeast of the quarry and the A38. The major input of the Kester Brook is referred to in HIA 2020 as the Goodstone Springs, which are located approximately 1km east of the quarry. The Goodstone Springs and the upper reaches of the Kester Brook do not flow during periods of low rainfall.

The Goodstone Springs are close to the area marked by '16' on Figure 2-2. The geology at the Goodstone Springs comprises Alluvium over the Foxley Tuff Formation, close to the boundary between the Foxley Tuff Formation and the CBLF. The origin of the Goodstone Springs may be groundwater flowing into the Alluvium at the contact between the CBLF and the Foxley Tuff, making the Springs the most notable known spring outflow from the CBLF in the Study Area.

During periods of high rainfall, springs to the north of Alston Farmhouse flow overland to the south, past the Farmhouse and onwards to form the Alston stream. The Alston stream loses water to the CBLF; its flow is highly seasonal and has been modified by various human activities, having been diverted in the past. The previous alignment of the Alston stream is discussed in more detail below. On its current alignment, the stream flows towards a swallow hole which has formed since its diversion (the Alston stream swallow hole, marked as '7' in Figure 2-2). Under low-flow conditions, the Alston stream wholly infiltrates to ground at this swallow hole; during wet periods, water levels in the swallow hole reach the ground surface and the stream continues to flow along a series of hedge lines, southwards towards the A38. This flow during wet periods generally infiltrates to ground but at times vegetation debris collecting in the channel or blocking the grill can cause it to temporarily pond along the northern edge of the A38 (marked as '8' in Figure 2-2 above). The ponded water is able to flow under the A38 towards the Mead Cross Unconfirmed Wildlife Site, by means of a drainage pipe (marked as '9' in Figure 2-2 above). As flow in the Alston stream is ephemeral, the drainage pipe is dry for much of the year.

Flow within the Mead Cross Unconfirmed Wildlife Site has not been observed, even during winter, although local landforms and vegetation in this area indicate the presence of ephemeral drainage channels (marked as '10' in Figure 2-2).

Flow at the Mead Farm stream originates at a spring to the southeast of MP19 (Figure 2-2), discharging from the Foxley Tuff. It then flows northwest across the CBLF to MP19, before flowing in a northeasterly direction in a channel adjacent to Gale Road. At the point marked '11' on Figure 2-2, a swallow hole, when not blocked with sediment, historically received flows from the Mead Farm stream. The swallow hole was infilled in 2020 with concrete by a local farmer, increasing the flow of surface water beyond point '11' on Figure 2-2 towards the Kester Brook.

Prior to infilling, the swallow hole would become periodically blocked with vegetation, exerting a major control on the partitioning of flow between the swallow hole and the channel of the Mead Farm stream and Kester Brook downstream of this point. When cleared of vegetation, the swallow hole would typically accept all flow within the Mead Farm stream, and the channel downstream of this point would be dry, even towards the end of winter, when groundwater and surface water levels are commonly at their seasonal maxima. This indicates that this stretch of the watercourse does not receive baseflow from groundwater and hence, that groundwater levels are consistently below the level of the stream bed.

Springs on the boundary of the CBLF to the north of the hamlet of Caton discharge to the Caton stream and the Samastar Stream. The Caton stream flows southwards across the CBLF towards the point marked '12' on Figure 2-2. At '12', the flow, which historically followed Caton Lane to a swallow hole behind Caton Farmhouse, is now mainly diverted into the field to the northeast of Caton hamlet.

The Caton stream either disappears underground south of Caton Farmhouse before the A38 underbridge (marked as '13' in Figure 2-2), or when flow is sufficient, flows through the underbridge. For most of the year, the stream ceases approximately 100 m to the southeast of the underbridge, presumably at a swallow hole. In high flow periods, water can flow overland across a field to the southwest (marked as '14' in Figure 2-2). During these period of high flow, the overland flow contributes to inundation in a field to the west of Kester Brook, observed during periods of high rainfall (marked as '15' in Figure 2-2).

The Samastar stream flows in a southeasterly direction from the springs to the north. It follows field boundaries, flowing towards a pipe under the A38 off-slip. Following heavy rainfall and debris hindering flow to the pipe, water overtops the stream's channel and flows overland across a field (marked as '17' in Figure 2-2) both westwards across a track and southwestwards along the margins of the A38 off-slip. Although the intersection of the Samastar Stream and the A38 off-slip has previously been identified as a stream sink by Smart [10], the stream crosses beneath the slip-road via the pipe. It then crosses the A38 and, during wet conditions, the Samastar Stream flows into the Kester Brook, via a series of field boundaries. During drier conditions, the Samaster stream typically infiltrates along this route before it reaches the Kester Brook.

At its closest point, the River Dart is approximately 4 km to the west of the quarry, near Shere Wood, where the river is at an elevation of around 42 mAOD. In the vicinity of the Hydrogeological Study Area, the River Dart flows through alluvial deposits, overlying the Tavy and Foxley Tuff Formations, intersecting the edge of the CBLF outcrop at its southernmost end.

Groundwater

Groundwater levels in the vicinity of the quarry were recorded in March 2020 following the installation of several additional monitoring boreholes. These data, taken only from boreholes with screened sections within 30 m of the ground surface, indicate:

- A steep cone of depression focused on the quarry sump with limited drawdown around the Balland Pit. The steepness of the hydraulic gradient around the quarry is also evident in the SW-NE cross-section drawn through the quarry (line of section mapped in Figure 2-3 with associated cross-section in Figure 2-4).

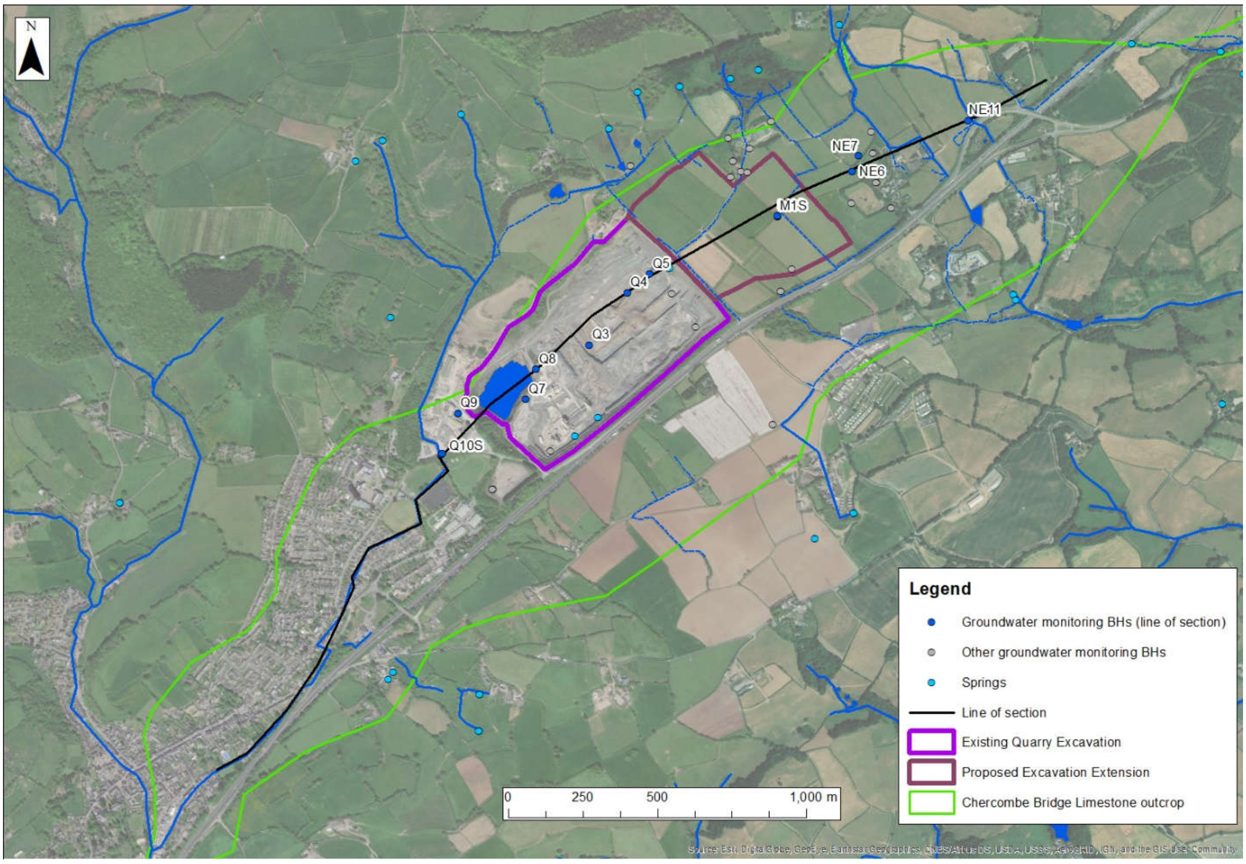


Figure 2-3 Line of SW-NE section through quarry with boreholes screened to depths greater than 30 m below ground level omitted (Figure 4-55 from HIA 2020).

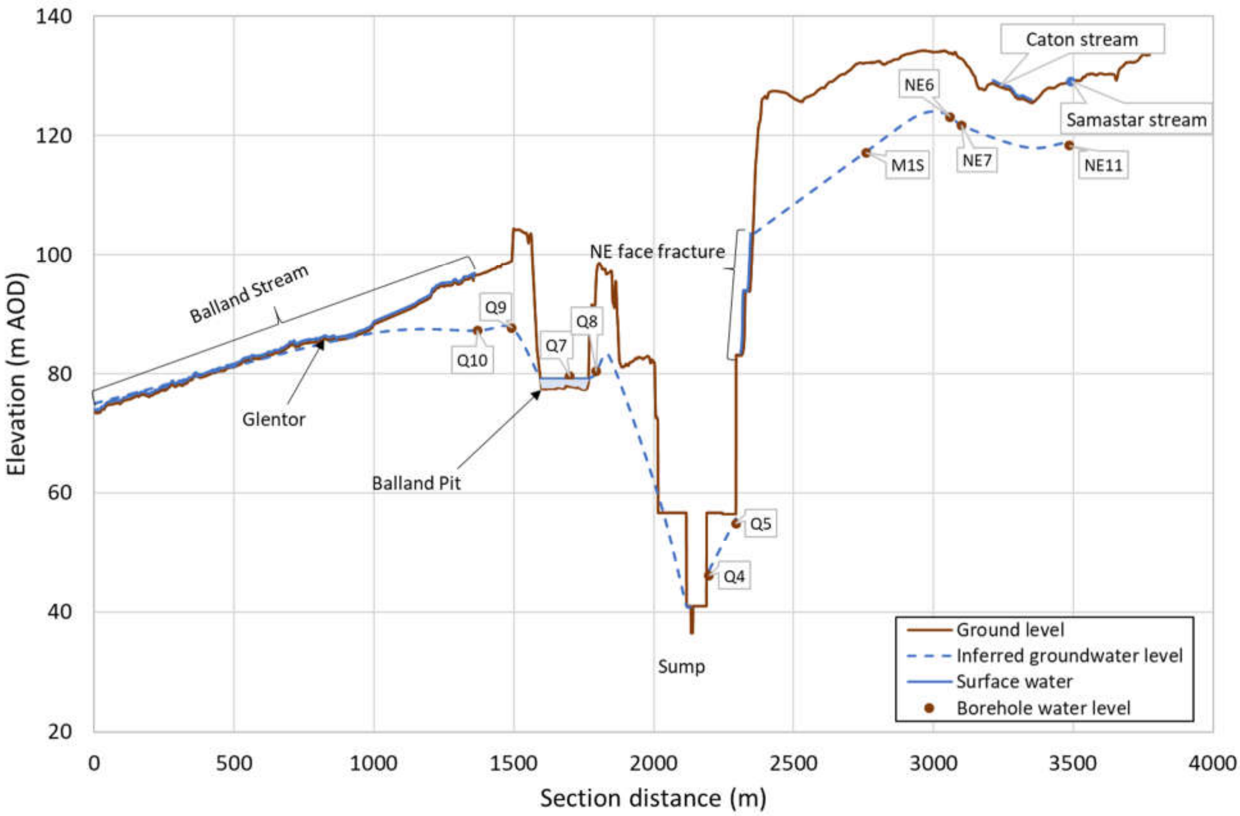


Figure 2-4 SW-NE cross-section through quarry and surrounding area showing observed and inferred groundwater levels (Figure 4-56 from HIA 2020).

- The presence of a groundwater divide close to the quarry's southwestern boundary. Groundwater to the southwest of Q9 flows away from the quarry, to the southwest, while groundwater to the northeast of this point flows northeastwards, either to the Balland Pit or the quarry sump.
- Relatively high groundwater levels immediately to the north of the CBLF and substantially lower groundwater levels throughout the proposed extension area and the area to the northeast. Whilst this difference is most notable at the quarry, it can also be seen beyond the quarry's apparent zone of influence, to the southwest and northeast.
- A dominant southerly or southeasterly hydraulic gradient to the east of the current quarry and an area of southwesterly flow, towards the quarry, within the western part of the proposed extension area. A groundwater divide, delineating the extent of the quarry's groundwater catchment, is likely to be present near the eastern part of the proposed extension area.
- Swallow holes in the Alston and Caton streams that lie several metres above nearby groundwater levels. The overflowing of the Alston stream at the Alston stream swallow hole during winter indicates the presence of a substantial groundwater mound at this location.
- A northwesterly hydraulic gradient near the southern margin of the CBLF, to the southeast of the quarry. Based on the recorded groundwater elevation in Borehole SE3 and surrounding groundwater levels in boreholes and quarry seepages, it is unclear whether a groundwater divide exists between SE3 and the quarry and, hence, whether SE3 lies within the quarry groundwater catchment, or whether groundwater at this location flows southwestwards, towards the Balland Stream and the River Ashburn.

Cross-sections, showing the inferred water table elevation relative to the ground surface in March 2020 provide further insights into the factors that control these hydraulic gradients. Along the line of section in Figure 2-3, groundwater levels at the southwestern edge of the quarry exceed the ground surface elevation to the southwest (Figure 2-4). It is apparent that groundwater levels to the southwest of Borehole Q10S are controlled by the elevation of the Balland Stream.

In the central part of the section, the quarry sump represents the main control on groundwater levels, inducing apparent drawdown of more than 60 m. Drawdown from the sump appears to be superimposed on a natural hydraulic gradient to the southwest, with a groundwater divide close to the eastern edge of the proposed extension area. The results of tracer tests suggest that the groundwater divide is likely to coincide with the location of the Alston stream and, and this has been used to define the water table surface in Figure 2-4. The connection of the Alston stream swallow hole with the quarry to the southwest, as well as the alignment of the groundwater divide with a topographic divide in Figure 2-4 suggests that the groundwater divide is a natural feature of the groundwater system and that the Alston stream lay within the catchment of the Balland Stream prior to establishment of the quarry. The location of the water wheel at Alston Farm, to the west of the Alston stream's current alignment supports this hypothesis.

Towards the east of the line of section, the lower groundwater level at Borehole NE11 appears to be driven by the elevations of the Goodstone Springs to the south, although the two springs near the source of the Lemonford stream are also likely to lower groundwater levels in this area.

Given the length of operation of the quarry, no data are available on pre-existing groundwater levels in the surrounding area. However, data obtained from the east of the line of section in Figure 2-4 suggest that groundwater levels naturally lie approximately 10 m below the surface at this time of year (March 2020). This in turn suggests drawdown of 5-10 m at the quarry's northeastern boundary (at around x = 2520 m in Figure 2-4), whilst natural ground elevations to the southwest of the quarry constrain drawdown in this area to less than 10 m.

The cross-section in Figure 2-6 (line of section mapped in Figure 2-5) shows a steep hydraulic gradient behind the quarry's northwestern face and indicates negligible drawdown within the Tavy Formation. The cone of depression around the quarry may be shallower to the southeast, although precise definition of the quarry's groundwater catchment is hindered by the lower density of monitoring boreholes in this area. The shape of the water table between the quarry and SE3 remains subject to uncertainty, although the possible presence of a groundwater divide in this area is informed by the following:

- the inferred areal extent of the quarry's groundwater catchment, based on estimated recharge and measurements of groundwater inflow; and
- the steepness of the cone of depression behind the other faces of the quarry, as constrained by observed groundwater levels in these areas.

If present, the groundwater divide in this area is likely to vary seasonally, and is expected to be absent during summer, when there is less recharge to the CBLF.

Figure 2-5 - Line of NW-SE section through quarry (Figure 4-57 from HIA 2020).

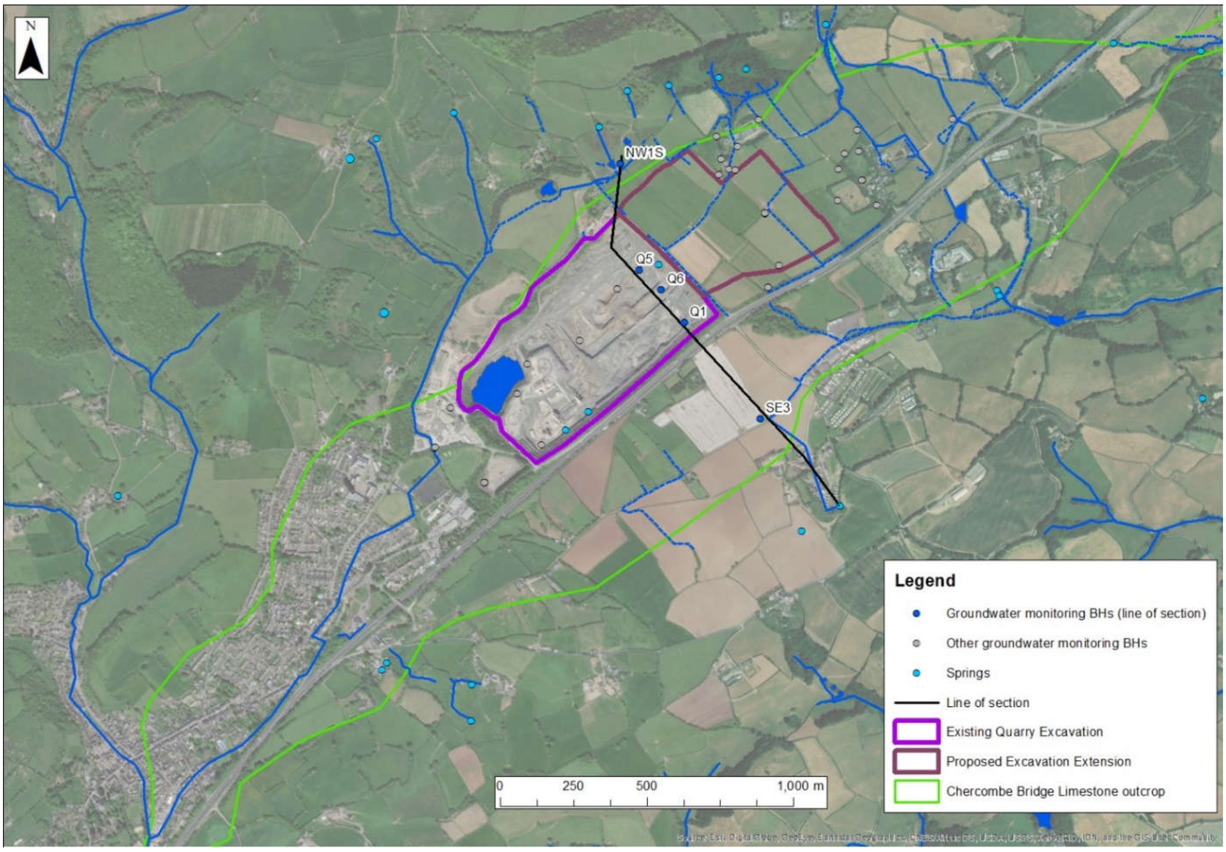
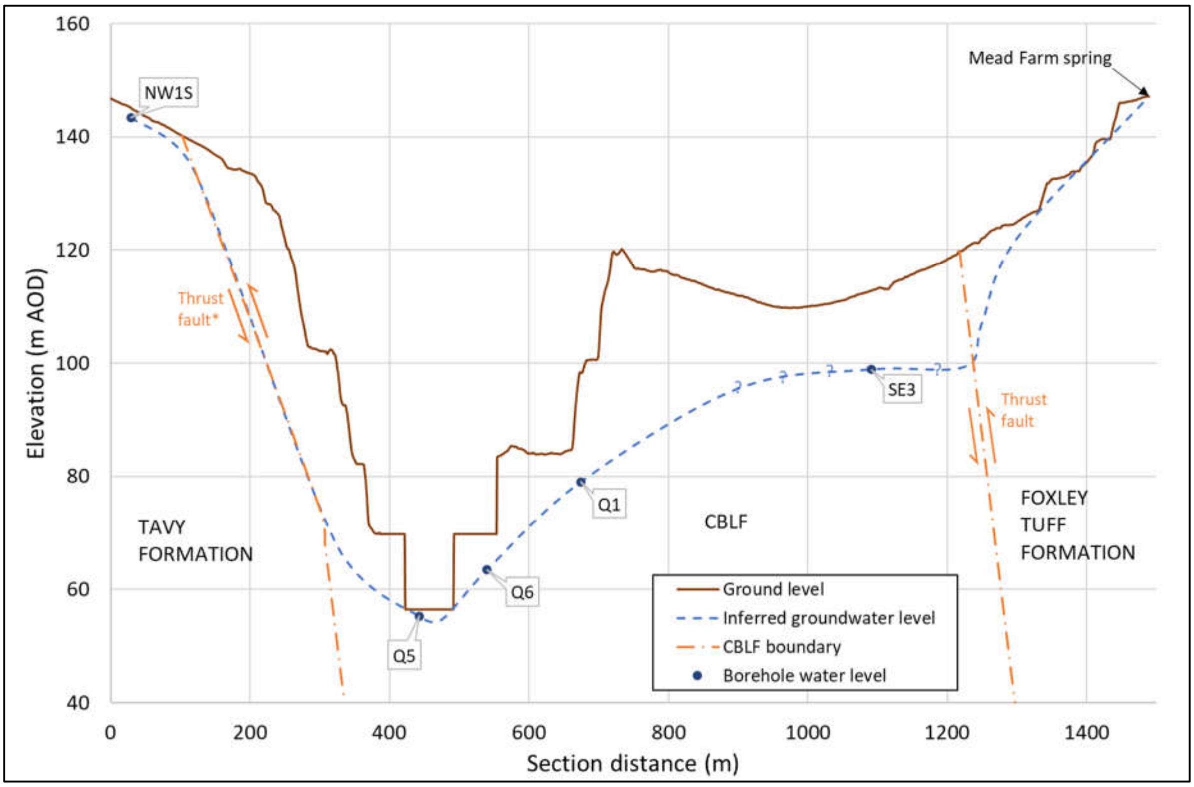


Figure 2-6 NW-SE cross-section through quarry and surrounding area showing observed and inferred groundwater levels (Figure 4-58 from HIA 2020).



*apparent angle of thrust fault reflects the line of section intersecting this fault at an oblique angle

The impacts of recharge are apparent from the hydrographs in Figure 2-7, which show annual variations in groundwater level of up to 20 m in 27 groundwater monitoring boreholes. An additional borehole, SE3, was installed in late March 2020, although there are insufficient data at present to produce meaningful hydrographs. Analysis of the hydrographs in Figure 2-7 indicates the following:

- Annual variations in groundwater levels are lowest in the boreholes that intercept the Tavy Formation (i.e. NW1S and NW1D), reflecting the low permeability of this formation in comparison to the CBLF. The slow recovery of water levels in NW1D following a slug test in August 2018 further highlights this.
- Groundwater levels are substantially higher in the Tavy Formation than in the CBLF throughout the year and lie close to or exceed the local ground surface elevation. The consistent vertical hydraulic gradient between NW1D and NW1S, driving upwards flow, as well as the number of springs to the north of the CBLF, indicates that the nearby ground elevation, rather than quarry dewatering, controls groundwater levels in this area.
- Annual variations are greatest in boreholes within the CBLF and at distance from the quarry (e.g. NE9), away from the influence of hydraulic boundaries, such as springs, the quarry sump and the Balland Pit, that maintain hydraulic head at a relatively constant elevation.
- Outside of the quarry, individual boreholes show a relatively constant trend from one year to another and the groundwater system appears to be in a dynamic equilibrium, despite ongoing dewatering from the quarry. The slight increase in the elevation of summer minimum and winter maximum groundwater levels in 2019 points to an increase in annual rainfall.
- Despite the limited period of data collection since they were installed in December 2019, boreholes Q7, Q8 and Q9 show relatively stable water level trends in comparison to other boreholes and this highlights the moderating influence of the Balland Pit on the surrounding water table.
- Nearby deep and shallow borehole pairs to the east of the quarry (M1D/S and SE2S/D) show a strong vertical gradient, indicating upward flow of groundwater and limited vertical connectivity within the CBLF. A similar phenomenon can be seen by comparing water levels in NE7, which

extends only 18 m below ground level, with those in NE9 nearby, which is screened to the base of the CBLF. This vertical gradient, which is evident throughout the CBLF to the east of the quarry, is consistent with the vertical gradient observed between NW1S and NW1D in the Tavy Formation. It is apparent that the groundwater regime in this area is influenced by the sub-artesian conditions within the adjacent Tavy Formation, with no clear evidence of drawdown from the quarry in the deeper part of the CBLF.

- The vertical hydraulic gradient between SW1S and SW1D, to the southwest of the quarry, is relatively small by comparison. Although SW1S is far more responsive to recharge events than SW1D, this additional water drains away rapidly. The longer-term pattern of water level variations is similar in both boreholes, indicating a greater degree of hydraulic connection than is apparent to the northeast of the quarry.

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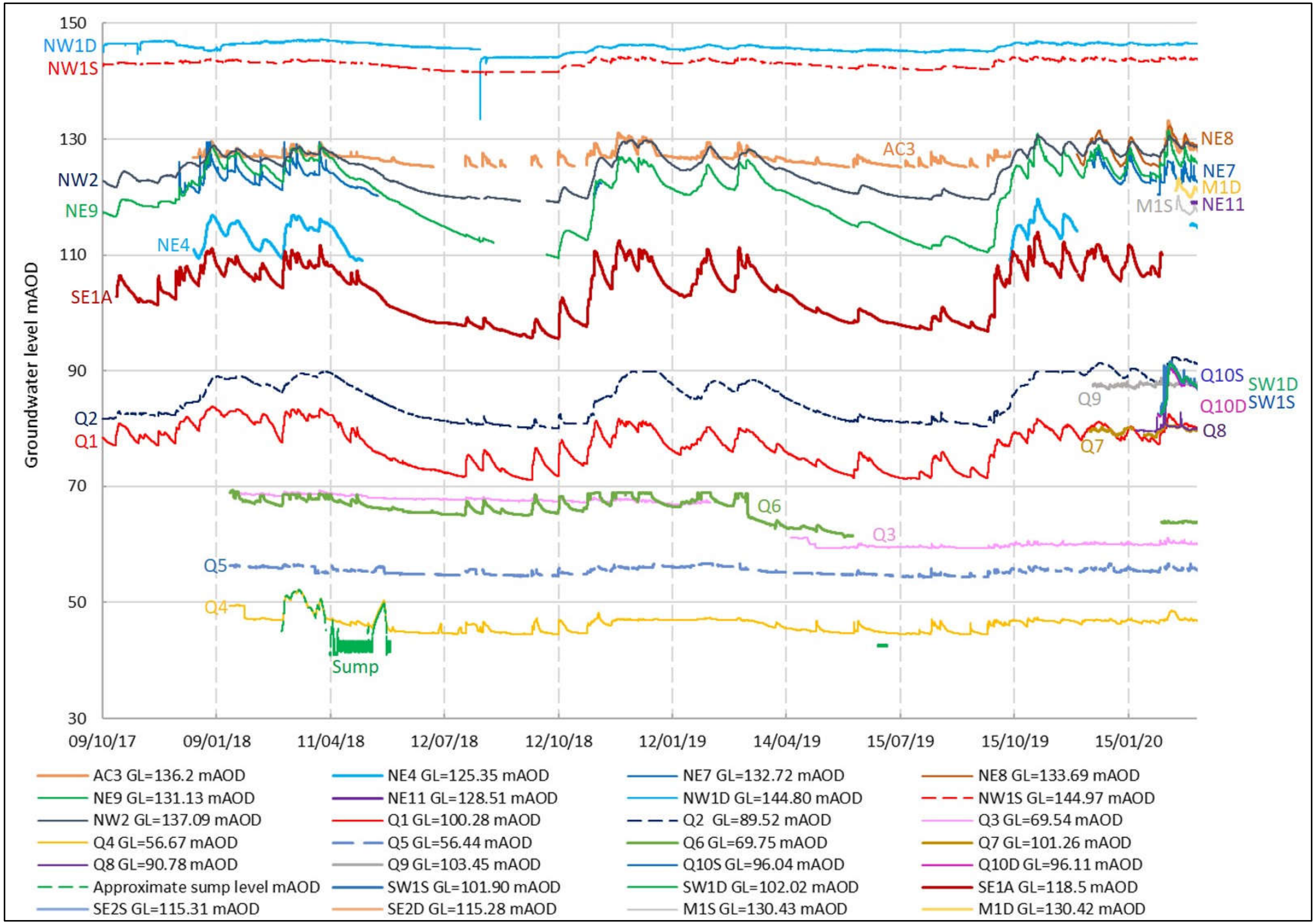


Figure 2-7 **Groundwater level hydrographs (Figure 4-59 from HIA 2020; GL = ground level).**

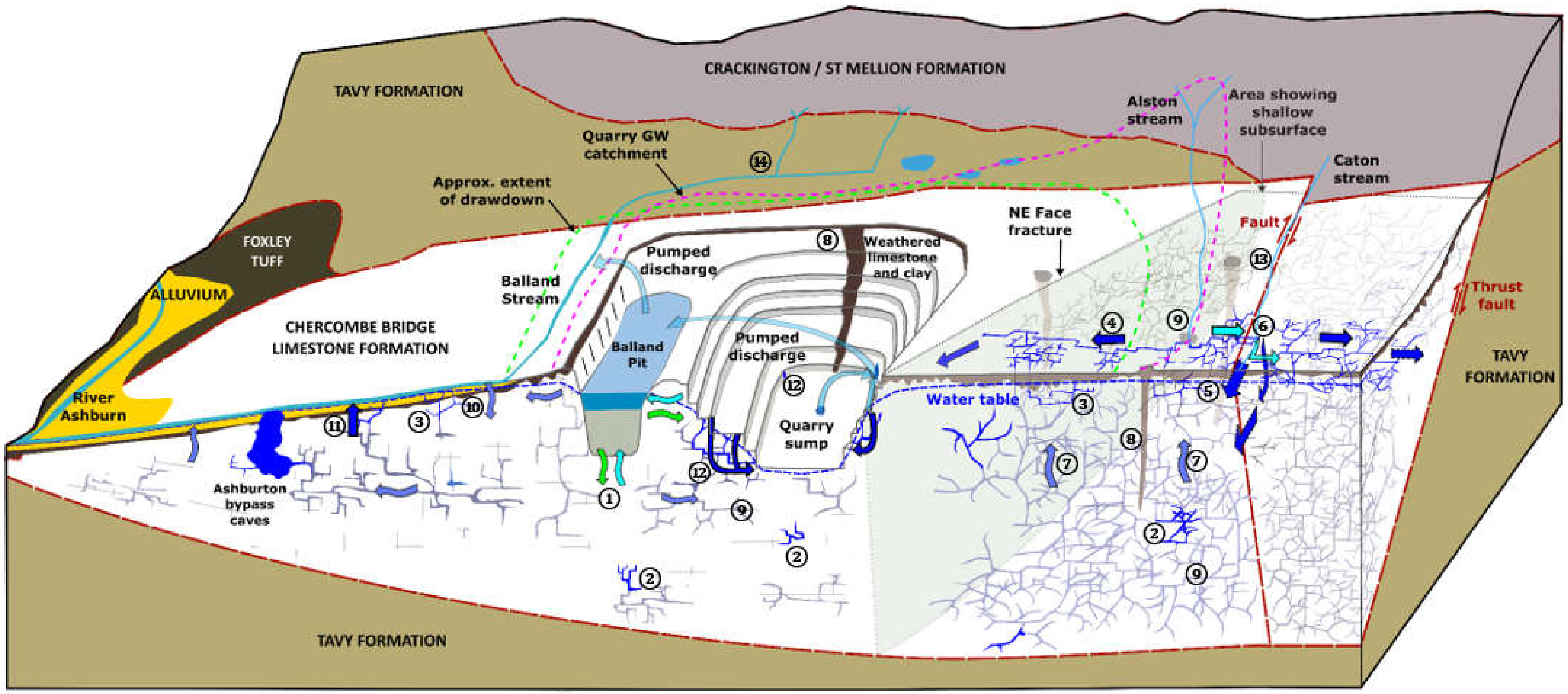
Groundwater flow and preferential flow paths

Groundwater flow is described in detail in Section 4.4.6. of HIA 2020. In summary:

- Water enters the CBLF via subsurface flow from the adjacent formations via allogenic recharge through losing streams and swallow holes, and via diffuse autogenic recharge through the overlying clayey superficial deposits and within the excavated area of the quarry. These flow components are described in further detail below:
    - Sub-artesian conditions within the Tavy Formation, coupled with the presence of a thrust fault that forms its upper boundary beneath the quarry and proposed extension area, drive diffuse flow upwards and into the overlying CBLF. An upward hydraulic gradient is apparent within the CBLF throughout much of the proposed extension area, with recharge only able to infiltrate to the deeper parts of the formation in the immediate vicinity of the quarry itself.
    - The majority of recharge to the CBLF occurs via diffuse, allogenic recharge, as evidenced by the marked response to rainfall events during winter. Recharge by rainfall occurs at a more rapid rate within the excavated area of the quarry, due to the absence of low permeability clay cover, which inhibits infiltration elsewhere.
    - Focussed, allogenic recharge via the Alston and Caton stream swallow holes to influence groundwater levels locally, and in the case of the Alston stream, the associated swallow hole contributes to a natural groundwater divide.
- A natural groundwater divide associated with the Alston stream aligns with the crest of higher ground within the CBLF’s outcrop. To the southwest of the Alston stream, groundwater flows towards the Balland Stream under natural conditions and into the quarry as a result of ongoing dewatering. Water intercepted by the quarry is transferred to the Balland Pit, before being discharged to the Balland Stream. To the northeast of the Alston stream, groundwater flows southwards, towards the Kester Brook.
- The Balland Stream to the southwest, the Goodstone Springs to the southeast and the springs near to the Lemonford stream constitute the principal discharge locations from the main outcrop of the CBLF, which extends from Ashburton in the southwest to an area immediately to the northeast of Bickington.

Conceptual model of the hydrology and hydrogeology

The conceptual model is provided in HIA 2020. The paragraphs below summarise the principal conclusions that can be drawn regarding the current hydrology and hydrogeology of the Study Area and, in particular, on the influence of the quarry. The model is illustrated in three dimensions in Figure 2-8 below, in which key components are numbered. Explanations for the numbered features are provided in the sections of the HIA 2020 listed in the Figure notes.



Legend

- Rapid flow through open conduits/fractures (year-round)
- Limited flow through clay-filled conduits (year-round)
- Rapid flow through open conduits/fractures (winter/summer)
- Limited flow through clay-filled conduits (winter/summer)

1) Seasonally varying in/outflows from/to Balland Pit (Sections 4.5.7 and 0)
2) Deep conduit network, predominantly clay-filled, with localised areas of conduit flow (Sections 4.2 and 4.5.7)
3) Epikarst with clay-filled conduits and areas of greater connectivity (Sections 4.2 and 4.5.7)
4) Connection between Alston stream swallow hole and NE face fracture (Section 4.4.5)
5) Connection between Caton stream swallow hole and Kester Brook (Section 4.4.5)
6) Seasonal connection between Alston stream swallow hole and Kester Brook/Lemonford stream (Section 4.4.5)
7) Upward flow of groundwater, with limited vertical hydraulic connectivity (Sections 4.4.4 and 4.4.5)
8) Deep vertical/sub-vertical clay-filled features (Section 4.2)
9) Shallow groundwater divide/mounding around Alston swallow hole (Section 4.4.5)
10) Recharge to CBLF from Balland Stream beyond quarry groundwater catchment (Sections 4.4.4.2 and 0)
11) Baseflow from CBLF to Balland Stream between quarry and Glentor (Section 0)
12) Flowing conduit networks of limited extent, fed by local recharge within quarry (Section 4.3.4)
13) Continuation of fault across CBLF outcrop (Sections 4.2.4 and 4.4.3)
14) Limited drawdown in Tavy Formation, with groundwater flow to Balland Stream beyond groundwater catchment (Section 0)

Figure 2-8 Conceptual 3-dimensional model through the quarry and surrounding area with supporting evidence. Section references in the notes refer to sections in HIA 2020. (Figure 4-93 from HIA 2020)

The quarry lies within the CBLF, whose outcrop extends in a southwest-northeast orientation from Buckfastleigh to just beyond Bickington. Although its mapped outcrop is discontinuous, it is assumed the various portions of the CBLF are connected via thin subcrops of limestone, which may be only a few metres thick in places.

Although its mapped outcrop is discontinuous, the various parts of the CBLF are connected hydrogeologically at depth throughout its length. The sub-surface connections are elongate bodies of limestone that are narrow when compared with the width of the outcrops.

In the vicinity of the quarry, the CBLF lies within a topographically low area, and is flanked on either side by relatively low permeability formations, which lie on higher ground and are characterised by groundwater levels that lie close to the ground surface. Numerous springs emerge from these low permeability formations and flow onto the CBLF, where groundwater levels are typically several metres below the level of drainage channels, both in the vicinity of the quarry and further to the east, beyond the quarry's groundwater catchment.

The CBLF is a buried karst aquifer, characterised by the infill of pre-existing discontinuities, such as fractures, conduits and dolines, with clayey material. The relatively low hydraulic conductivity of the CBLF relative to other carbonate aquifers reflects the influence of this clayey infill, although several active karst features are evident in the Study Area. The majority of hydraulically significant karst features, including numerous springs and caves, are located at the downstream edges of the CBLF outcrop, although three swallow holes (one of which has been recently backfilled) are located close to the quarry. The quarry intersects several flowing sub-surface conduits, as well as the northeast face fracture, which itself contains several conduits

The natural groundwater divide associated with the Alston stream aligns with the crest of the surface water catchment (topographic) divide within the CBLF's outcrop. To the southwest of the Alston stream groundwater flows towards the Balland Stream under natural conditions and into the quarry as a result of ongoing dewatering. Water intercepted by the quarry is transferred to the Balland Pit, before being discharged to the Balland Stream. To the northeast of the Alston stream, groundwater flows southwards, towards the Kester Brook.

The Balland Stream to the southwest, the Goodstone Springs to the southeast, and the springs near to the Lemonford stream constitute the principal discharge locations from the main outcrop of the CBLF.

The quarry intercepts groundwater from the following sources:

- Flowing conduits near the quarry sump, which account for 55% of all inflows to the quarry.
- Seasonal inflow to the Balland Pit through its base and sides, which occurs predominantly in winter and spring and, during periods of exceptionally high groundwater levels in winter, groundwater seepages in the topographic catchment of the Balland Pit within the quarry. Together, these contribute 25% of annual inflows to the quarry, although during summer the flow direction is reversed and the Balland Pit provides water to the underlying CBLF.
- The northeast face fracture; an extensive, sub-vertical feature that flows throughout the year and accounts for 13% of all inflows to the quarry.
- The southeast face conduit; a localised feature in Level 4 of the quarry that flows during winter and early spring and accounts for nearly 4% of all inflows to the quarry.
- The remaining inflows to the quarry (about 3%) are derived from rain falling on topographic catchment the Balland Pit within the quarry.

Dewatering leads to a steep cone of depression within the quarry, with drawdown of more than 60 m at the quarry sump. Despite ongoing dewatering from the quarry sump, relatively shallow groundwater levels are apparent near the Balland Pit (as evidenced by the predominance of inflows to this feature in the water balance and water levels in nearby boreholes), along much of the southeast face (as evidenced by groundwater flooding in this area and artesian conditions in borehole Q2) and within the northeast face fracture. Drawdown of less than 10 m is apparent at the quarry boundaries.

Deep and shallow borehole pairs to the east of the quarry (M1D/S and SE2S/D) show a strong vertical gradient, indicating upward flow of groundwater and limited vertical connectivity within the CBLF. A similar phenomenon can be seen by comparing water levels in NE7, which extends only 18 m below ground level, with those in NE9 nearby, which is screened to the base of the CBLF. This vertical gradient, which is evident throughout the CBLF to the east of the quarry, is consistent with the vertical gradient observed between NW1S and NW1D in the Tavy Formation. It is apparent that the groundwater regime in this area is influenced by the sub-artesian conditions within the adjacent Tavy Formation, and that the vertical gradient to the east of the quarry persists, despite the interception of deep, flowing conduits in the Level 7 southeast face above the quarry sump.

Groundwater level variations to the southwest of the quarry are moderated by the maintenance of relatively constant water levels in the Balland Pit, leading to seasonally varying flow directions. Absolute groundwater levels between the quarry and Ashburton are controlled by the elevation of the ground surface, which falls steadily to the southwest, driving the discharge of groundwater into the Balland Stream. In the immediate vicinity of the quarry, a component of the water discharged to the Balland Stream infiltrates to the CBLF, where groundwater levels lie below the stream bed elevation.

Water levels in the Tavy Formation, to the north of the quarry, are controlled by the elevation of the ground surface, as evidenced by the shallow water levels in Borehole NW1S and the presence of numerous springs. The difference in groundwater levels between the Tavy Formation and the CBLF, the relatively low permeability of the Tavy Formation, and the pervasive upward hydraulic gradient in the Tavy Formation and the CBLF within the proposed extension area suggest that quarry dewatering exerts a negligible influence on groundwater levels to the north of the CBLF.

There is likely to be a groundwater divide beneath the bunds to the north of the Balland Pit, separating the quarry's groundwater catchment from that of the Balland Stream. Further to the east, near Alston Farm, there is no clear groundwater divide and all groundwater to the south of the line of springs above the farm flows naturally southwards, towards the quarry's zone of influence.

Water levels to the northeast of the quarry are largely controlled by dewatering from the quarry and recharge to the CBLF, both via diffuse, autogenic recharge through the overlying superficial deposits and focussed autogenic recharge via the Alston stream, where there is a groundwater divide. The distance from the quarry to this natural groundwater divide leads to a relatively large groundwater catchment in this direction.

Water levels to the southeast of the quarry are poorly constrained by hydraulic boundaries at present, and, based on estimated recharge and quarry inflows, the quarry's groundwater catchment does not extend as far as the low-permeability Foxley Tuff Formation or the springs that emerge within it.

Dewatering rates within the quarry are subject to substantial seasonal variations, with 79% of all groundwater inflows occurring from October to March and only 8% of groundwater inflows occurring between June and September. The dramatic reduction in dewatering rates during summer, when groundwater levels are at their lowest, demonstrates that the majority of groundwater flow outside the quarry occurs in permeable features (i.e. conduits and fractures) within the shallow parts of the CBLF. These permeable features require seasonal recharge to sustain flow within them and their flow is greatly reduced during summer.

Deeper conduits within the quarry transmit groundwater during winter, but the reduction in flow from these features during summer demonstrates that they are not well-connected hydraulically to the rest of the CBLF. Recharge within the footprint of the quarry accounts for the majority of groundwater flowing to both the sump and the Balland Pit, although just over a third of groundwater inflows to these features comes from beyond the quarry boundary, predominantly via shallow fractures and conduits, which dry out in summer.

The similarity in dewatering rates on an interannual basis indicates that, at current rates of deepening and extraction, the quarry is in a dynamic equilibrium with the surrounding groundwater system.

2.5. Potential Sources of Land Instability

Land instability due to subsidence can lead to damage to buildings or property, or risk to people. Causes of such subsidence include the shrinkage of clay soils, the escape of water causing a loss of soil, and the presence of weak natural ground (e.g. peat), fill materials, mine workings, and karst features. The Engineering Geology Desk Study identified the latter two (mining and karst features) as potential causes of subsidence that could be relevant to the proposals for Linhay Hill Quarry. Historical mine workings and karst are discussed in the following subsections.

Historical Mine Workings

Historical mine workings were identified during the desk study and are shown on the map in Figure 2.9 below.

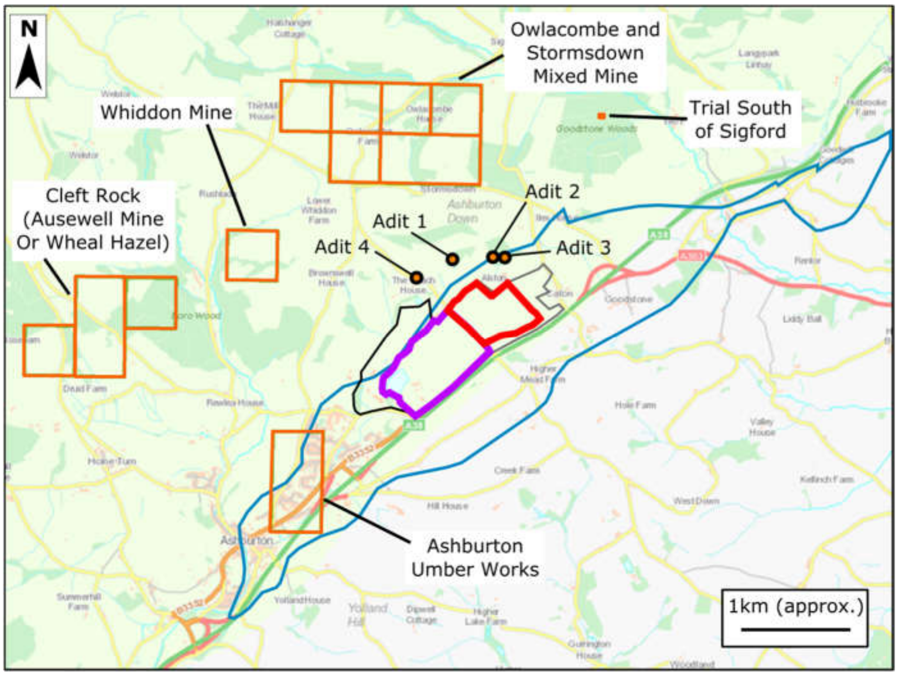
> The nearest historical mine workings to the quarry are four entrances to mine adits located within 700 m to the north and northwest of Alston Farmhouse, and which appear to extend into the hills to the northwest of the limestone outcrop (i.e. away from properties to the south). The adit nearest to properties, Adit 4, is approximately 60 m north of properties at Waye. Mine adits cause groundwater to flow towards them, which can then flow from the adit entrances at the ground surface. This occurs at Adits 1, 2 and 3, which are at a similar elevation to the natural spring line in the hillside (see Figure 2.9). Adit 4, however, is at a higher elevation and water outflow has not been observed from its entrance.

A review of historical mining records indicates that underground mining for tin, copper, and arsenic was carried out at Owlacombe and Stormsdown on the north side of Ashburton Down, approximately 1 km north of the quarry. Deposits of umber were also worked at a location approximately 1 km to the southwest of the existing quarry during the 19th and early 20th centuries.

We have made enquiries with Teignbridge District Council (TDC) as to their records of subsidence within the area underlain by the CBLF. TDC have stated that the only areas of known settlement in Ashburton are Miners Close, Higher Roborough, Emmetts Park and Kellett Close. The records from TDC do not comment on the cause of the subsidence, however the locations show that are all associated with former umber workings as shown on the map in Figure 2.9.below, and we note that their database has not been updated since 2016.

The ES Appendix 15 Historic Environment Assessment identifies more than a dozen other past quarrying locations in the limestone nearby, some of which have now been incorporated into Linhay Hill Quarry itself. However there is no record of underground mining within the proposed extension area or elsewhere in the Chercombe Bridge Limestone Formation.

Figure 2-9 Known areas of historical mining activity in the vicinity of Linhay Hill Quarry [11]& [12]. Adits shown are not marked on the Coal Authority or BGS online maps but have been observed by Atkins during field walkovers. Existing Linhay Hill Quarry shown in purple, proposed quarry extension shown in red, and extent of Chercombe Bridge Limestone outcrop shown in blue.



Karst

Local Context

Extensive karstification, including the presence of caves, is widely observable in south Devon, for example:

- Chercombe Bridge Limestone: the Pridhamsleigh, Buckfastleigh and Ashburton areas.

- East Ogwell Limestone: the upper levels of Stoneycombe Quarry.
- Plymouth Limestone: Worth's Cattedown Bone Cave (150m north of Cattedown Wharves) and Moorcroft Quarry[3].

The karstic dissolution has produced secondary porosity in the limestones, which are otherwise dense and highly crystalline (Jones et al [13]), as described further in the Engineering Geology Desk Study in Appendix A). Karst features in the Chercombe Bridge Limestone Formation (CBLF) are observable in Linhay Hill Quarry and the surrounding land, and have also been indicated by past ground investigations as described in the Engineering Geology Desk Study in Appendix A and in HIA 2020 in section 4.4.2.

Many of the karst locations in south Devon also have statutory designation for protection [14], such as Pridhamsleigh Caves SSSI, Buckfastleigh Caves SSSI, Torbryan Caves SSSI, Chudleigh Caves and Woods SSSI, Kents Cavern SSSI and Scheduled Ancient Monument, Berry Head to Sharkham Point SSSI, Ash Hole Cavern and Brixham Cavern Scheduled Ancient Monuments, and Worth's Cattedown Bone Cave Scheduled Ancient Monument.

In karst areas, ground subsidence over karst features can be triggered by heavy rainstorms, with other potential contributory causes being the introduction into the ground of excessive concentrations of surface water via field drains or soakaways, leaking water supply pipes or drains, groundwater lowering, or active or static surface loading (Edmonds [15] [16]). Hence buildings and infrastructure founded within the soil profile over karstic limestone may be vulnerable to subsidence associated with the development of sinkholes.

The presence of karst features near a site may also be important to the overall understanding of the subsurface geology of the site itself (Fookes & Hawkins [17]). Additionally, historical information is important for assessing cave and sinkhole hazards (Benson and Yuhr [18], and Waltham [19]).

Atkins' experience of karst hazards accords with the published views cited above, and the Land Stability Risk Assessment aims to place relevant historical information in geological and geomorphological context. Considerable importance has therefore been placed on the desk study information and observations made during Atkins' engineering geomorphological field walkovers.

Examples of karst features and formation processes, together with implications for engineering and suggested engineering responses, are shown in Table 2-2.

Table 2-2 Selected features and processes of karst terrain that are considered to be widespread and significant to civil engineering and which may be present in the vicinity of Linhay Hill Quarry (copied from Table 1 in Waltham [2]). Right-hand column added by Atkins. Note that the quarry extension proposals do not include new buildings.

Relevant extracts from Table 1 of Waltham [2]			**Relevance to the proposed quarry extension (see Section 3 below: Site Inspections and Investigations)**
Karst feature or process	**Implications for civil engineering**	**Civil engineering response**	
New dropout sinkholes in the soil cover.	Rapid ground failure, mostly induced by drainage change.	Compaction grouting within soil; minimize by control of drainage.	Potential for formation of Class B and Class C sinkholes (0.5 to 2.0 m in diameter), importance of drainage control to mitigate risk.
Ground subsidence by soil loss into fissures.	Slow settlement, commonly induced by drainage change, may precede dropout failure.	Compaction grouting within soil; minimize by control of drainage.	Potential for formation of Class B and Class C sinkholes (0.5 to 2.0 m in diameter), importance of drainage control to mitigate risk.

[3] As reported within the Aggregate Industries UK Ltd. Moorcroft Quarry ROMP Water Environment Impact Assessment, April 2015. ROMP is an abbreviation of Review of Old Mineral Permissions.

Relevant extracts from Table 1 of Waltham [2]			Relevance to the proposed quarry extension (see Section 3 below: Site Inspections and Investigations)
Karst feature or process	**Implications for civil engineering**	**Civil engineering response**	
Pinnacled rockhead.	Huge variations in depth to rock, and in the stability and shape of pinnacles, for solid founding of structures.	Anticipate large variations; remove soil and fill and replace with crushed rock, or prove every footing.	Anticipated in quarry extension area, but not relevant to extension proposals as no new buildings are proposed.
Buried sinkhole filled with soil.	Large rockhead depression filled with weak and/or soft soil, which may compact under load and/or be lost by suffosion in drainage.	Budget for deeper foundations; control the drainage.	Anticipated in quarry extension area, but not relevant to extension proposals as no new buildings are proposed.
Unexpected cavity in bedrock.	Size, shape and depth of a cave are almost totally unpredictable in strong limestone.	May need to relocate structure, or fill cave with lean concrete, or pile through to solid floor.	May be present in quarry extension area, but not relevant to extension proposals as no new buildings are proposed.
Bedrock collapse under structural load.	Potential roof collapse over large or small cavities with totally random distribution.	Prove sound rock beneath every pile tip and structural element.	The effects of ground loading are in Section 4.3 below.
Subsidence over a breccia pipe.	Effectively a deep buried sinkhole, with fill that may be dense or weak.	May need to relocate to avoid.	May be present in quarry extension area, but not relevant to extension proposals as no new buildings are proposed.
Solution depression.	Large surface basin with soil floor and internal drainage.	Best avoided, as soil floor is prone to subsidence sinkholes.	Class A sinkholes. importance of drainage control to mitigate risk of Class B and Class C sinkholes forming within these topographic lows.

For engineering purposes, karst may be classified on the basis of the severity or complexity of morphological features present, as outlined in the Engineering Geology Desk Study in Appendix A. Following the classification system developed by Waltham and Fookes [20], the predominant karst terrain expected to be present at and in the vicinity of the proposed extension to the Linhay Hill Quarry is buried Mature Karst kIII. This includes the possibility of open conduits associated with continuing karst activity, and irregular rockhead of the type that might be expected from Complex Karst kIV, although elements of Youthful Karst kII are also expected. Although no superficial deposits are indicated on the BGS maps, other than alluvium along the Kester Brook, it is known from the local geomorphology and from ground investigations that the karst in the Land Stability Study Area is buried by a variable thickness of superficial deposits.

Cavities

The size, shape, depth and infilling of cavities (including caves) in karstic limestone are difficult to predict in detail but are known to exist in the CBLF because of the caves at Pridhamsleigh and Buckfastleigh, for example.

Caves, as identified by the Devon and Cornwall Cave Registry (DCUC, 2020), are present in the downstream (western) parts of the CBLF and increase in frequency with distance from the quarry. This is a common feature of karst aquifers: as noted by Kresic (2013), cave systems often comprise "*progressively larger passages in the down-gradient direction toward the locations of aquifer discharge such as springs*". In the upstream (eastern) part of the CBLF, to the east of Linhay Hill Quarry, Jackdaw's Hole lies near the location of the

Goodstone Springs and the Lemonford Cave lies adjacent to the spring source of the Lemonford stream (see Figure 2-2). Given the relative elevations of these features, it is likely that any water flowing through the Lemonford Cave discharges further downstream, to the River Lemon. To the southwest of the quarry, the Ashburton Bypass Caves lie close to the Balland Stream near to the A38 Dual Carriageway.

A small cave was also encountered to the south of Linhay Hill Quarry during the construction of the A38 Dual Carriageway in the early 1970s. The cave opening was identified within the road cutting following a collapse at foundation level during construction (Malkin & Wood, [21]).

In 2016, the BGS produced a report [8] following its visit to subsidence that occurred in 2014 within a pre-existing sinkhole adjacent to the A38 off-slip road at Goodstone Cross. The BGS report includes a map (reproduced in the Engineering Geology Desk Study in Appendix A) showing the locations of five 'cavity entry points'. The BGS 'cavity entry points' are listed below in order from southwest to northeast:

- Adjacent to the A38, south of the quarry, which relates to the cavity encountered during construction of the A38 (presumably that described by Malkin & Wood, [21]).
- In a bench in the southeast face of the quarry; a bridge has been built across this cavity entry point to maintain access along the quarry bench.
- Adjacent the A38 off slip road at Goodstone Cross (presumably that described in the BGS report [8]).
- Lemonford Cave, which is in a small disused quarry in a copse at Higher Lemonford, Bickington. Lemonford Stream originates from the east of the quarry. Oldham et al. [22] describe "*two short tunnels excavated by Walter Chesseman (sic) who found remains of woolly rhinoceros*" and state that the total cave length is 20 feet (approximately 6m).
- Bickington Pot is described by Oldham et al. [22]) as being 400 feet long (approximately 120m), with a vertical range of 120 feet (approximately 37m). It is in the southeast corner of the disused Bickington Barton Quarry, which is northeast of the River Lemon. Oldham et al. [22] state that the first recorded exploration was in 1942. The quarry was used as a local authority tip and the cavity entry point area has been filled but has a protected entrance by way of an extended manhole, with an original aim of also providing an access point for bats.

Filled, or partially filled, karst features that may have once been empty cavities, are also occasionally exposed or encountered within the quarry.

3. Site Inspections and Investigations

3.1. Introduction

Atkins undertook a systematic study of sinkholes in LSRA 2018, which has been updated in the present LSRA 2020. The study included walkover surveys in December 2016, August 2017, October 2019 and March 2020, examination of historical aerial photographs held by Historic England and the Dartmoor National Park Authority, and regular monitoring visits, all complemented by the borehole and hydrogeological testing and monitoring investigations undertaken between 2015 and 2020.

Summary details of the aerial photographs are provided in the Engineering Geology Desk Study, Appendix A, with further details and interpretation of the photographs provided in Appendix B.

The walkover surveys entailed the inspection of Linhay Hill Quarry, the geomorphological walkover of accessible land, and the observation of surrounding land. Their objective was to identify and assess possible karst features, including those interpreted by Atkins from remote sensing (satellite imagery and historical aerial photographs).

Appendices D and E provide the locations of features that were mapped as sinkholes by Atkins, with the assigned confidence level. The confidence levels are as follows: sinkhole features that Atkins has identified in the field ('high confidence' sinkholes); those that Atkins has identified from aerial photographs but were not able to confirm in the field ('low confidence sinkholes'); and those that were identified from aerial photographs and satellite imagery, but were inconclusive when visited in the field ('medium confidence sinkholes'), for example because of ploughing or other modification to the ground surface since the date of the aerial or satellite imagery.

During Atkins' engineering geomorphological walkovers, it became apparent that suspected or potential sinkholes in the land around Linhay Hill Quarry may be classified according to their surface expression. From that observation, a project-specific classification has been produced, with the aim that it informs the LSRA.

It is important to understand that the mapping of sinkholes within the Land Stability Study Area is subject to observational bias, as the study area has been examined more closely than other parts of the CBLF, and more closely than many other limestone outcrops, including those from which other limestone quarries in Devon extract. Also, differences in the frequency of aerial photographs and their resolution mean that the smaller sinkholes (Classes B and C in Atkins' project-specific classification below) are more difficult to identify from these sources. The temporal distribution of the sinkholes Atkins has identified is therefore unavoidably biased towards the period after 1970. Therefore, the spatial and temporal distribution of identified sinkholes is a function of the availability and quality of the data; it does not necessarily mean that the occurrence of sinkholes is more prevalent in this part of the CBLF outcrop or has increased since 1970.

3.2. Project-specific Sinkhole Classification

Atkins' project-specific classification of sinkholes is based on surface morphology, meaning it can be applied readily through visual inspection of a sinkhole or suspected sinkhole, aided by knowledge of surface water management. The three project-specific classes of sinkhole are described below (see also Figure 3-1).

The locations of the Class A, B, and C sinkholes identified by Atkins within the Land Stability Study Area are shown in Appendix D and listed in Appendix E.

The majority of the Class A and B sinkholes in the Land Stability Study Area are believed to have originally developed in association with surface water flow, even where water was not apparent during field walkover inspections.

Class A

Large bowl-shaped depressions. Probably developed in ancient geological time hence Class A sinkholes are likely to be long-term features of the landscape. The 'type' locality for this class of sinkhole is at the A38 off-slip road sinkhole at Goodstone Cross. Highways England has advised that this sinkhole was present when the slip road was constructed.

Class A sinkholes may be an example of Waltham's [2] Type 4 sinkhole (i.e. a 'buried sinkhole') the morphology of which he describes as "*Surface feature from a past environment, which is now filled with weak soils or loose debris. Typically less than 100m wide and 20m deep*".

In March 2014 new Class B and C sinkholes developed within the Class A sinkhole at the A38 slip road at Goodstone Cross. The likely trigger for the Class B sinkhole was excess surface water collecting in the pre-existing depression in the ditch adjacent to the slip road, resulting in a concentration of surface water. A further Class C sinkhole formed in the field adjacent to the foot of the slip road embankment, most likely triggered by the same concentration of surface water, but also by surface water runoff from the higher parts of the field collecting within the pre-existing Class A depression. This demonstrates that Class A sinkholes present a ground stability risk in that they can act as a focal point for the formation of Class B and C sinkholes.

Class B

Small steep-sided depressions, with no evidence of influence from surface water flow or infiltration. Generally 0.5 to 3 m in diameter, which develop over engineering timescales (in contrast to Class A sinkholes). May form within a Class A sinkhole. The 'type' locality for this class of sinkhole is near the centre of a field approximately 300 m to the southeast of Alston Farmhouse, denoted as feature 18 in Figure 3-3 below.

This class may be an example Waltham's [2] Type 1a sinkhole (i.e. 'a dropout sinkhole'), which he describes as "In the soil profile. Collapse of soil arch in cohesive soil over void. Instant failure, then widens as sides degrade. Typically less than 40m wide and 20m deep and limited by soil depth". However, the depressions observed by Atkins are only a few tens of centimetres deep at the ground surface, up to a maximum of approximately 0.5m deep.

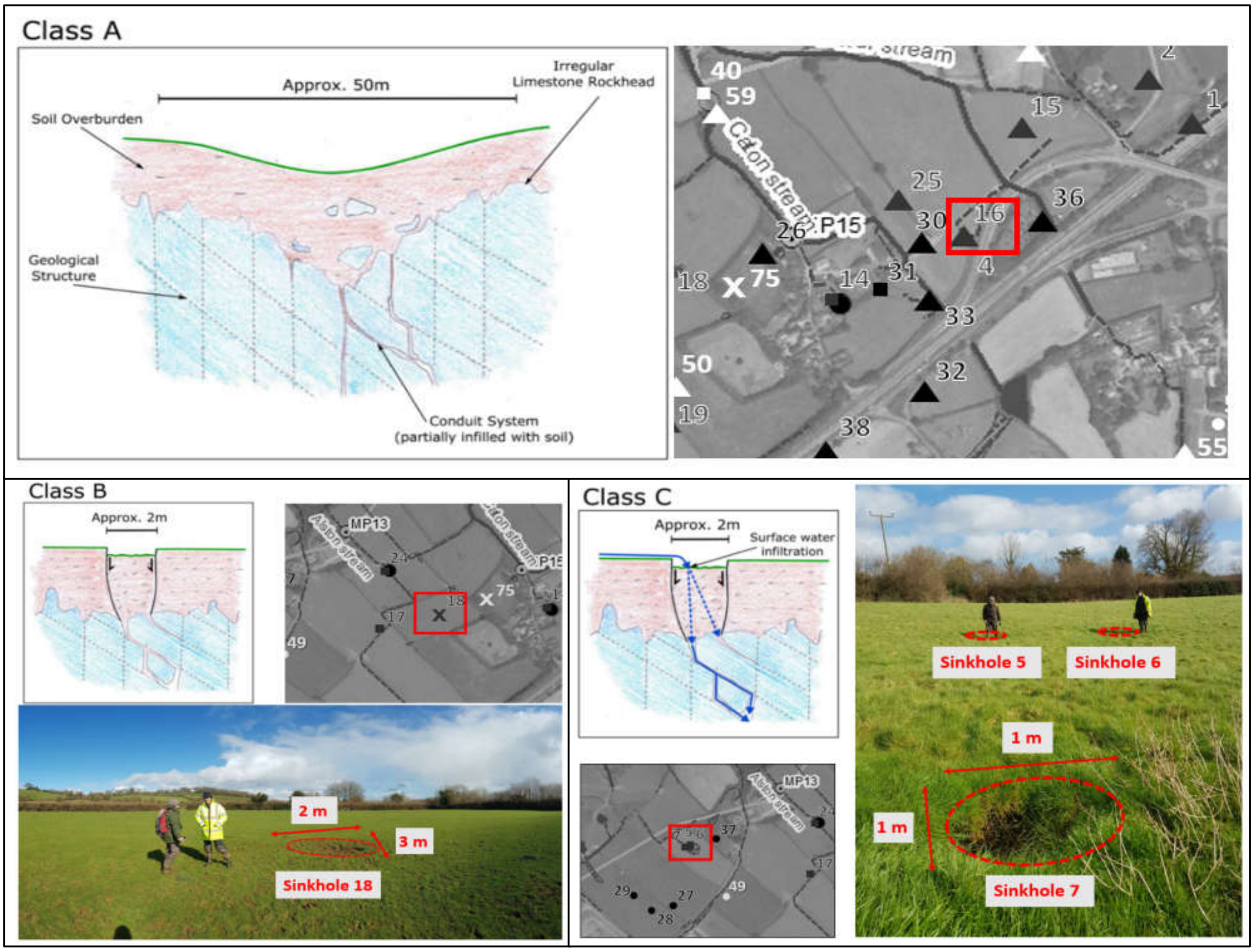
The few Class B sinkholes that have been mapped in the Land Stability Study Area may have formed as Class C sinkholes historically under different hydrological or hydrogeological conditions, but at the time of Atkins' inspections there was no evidence to suggest recent water inflow. That is despite inspections having been carried out during winter. It is possible that these sinkhole depressions might become wet seasonally or after heavy rain. Class B boreholes may also have formed as 'dropout sinkholes' as a result of the migration of water and the erosion of sediment-filled conduits or cavities beneath the ground surface, with the subsequent collapse of the overlying soil into the void.

Class C

Small steep-sided depressions, generally 0.5 to 3 m in diameter, which develop over engineering timescales (in contrast to Class A sinkholes). May form within a Class A sinkhole. Formed only in association with surface water flow, such as at field boundary ditches, streams, or where surface water is poorly controlled (i.e. a route of excess overland flow or where ponding commonly occurs, especially during heavy rainfall events). The 'type' location of this class of sinkhole is in a field approximately 200 m southwest of Alston Farmhouse, in which there is a cluster of three Class C sinkholes (denoted as sinkholes 5, 6 and 7 in Figure 3-3 below).

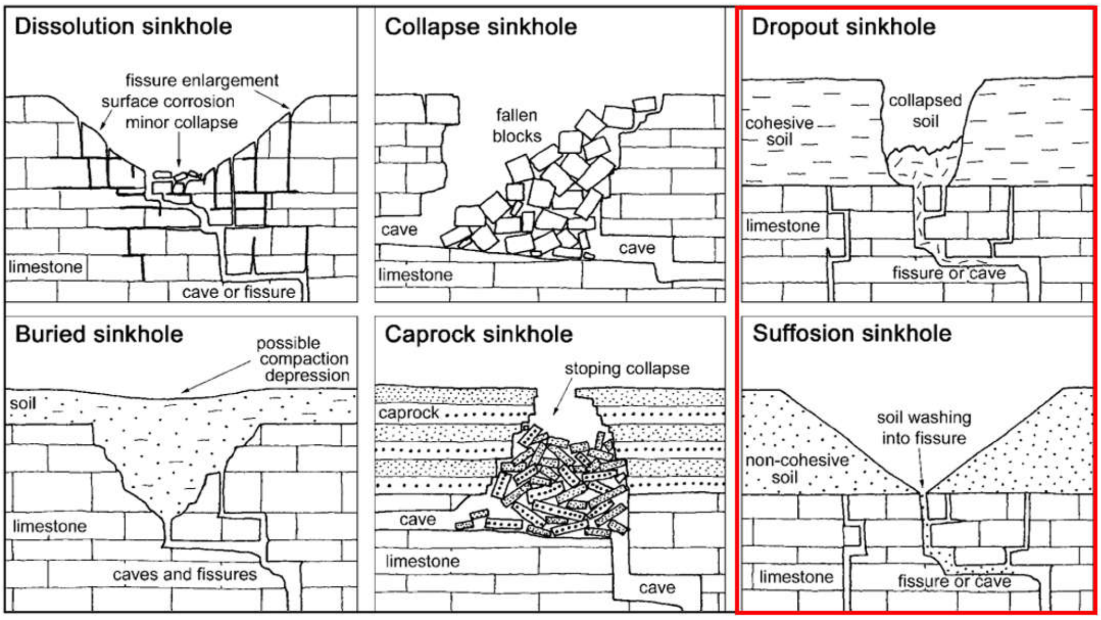
This class may also be an example Waltham's [2] Type 1a sinkhole. Waltham [2] states *"Subsidence sinkholes that are formed by removal of soil cover, without any rock failure, account for almost all new sinkhole events. Locations are virtually unpredictable, except that nearly all are induced by changes in drainage patterns. Caused by water washing soil down into the bedrock cavities, so engineering response is to control the drainage."*

Figure 3-1 Schematic cross sections showing conceptual models for the project-specific sinkhole classification developed by Atkins following the field walkovers, with location maps and examples of Class B and Class C sinkholes.



The morphology of Class B and C sinkholes indicates that together they may be a combination of dropout and suffosion sinkholes as described by Waltham and Fookes [20]. Figure 3-2 below shows Waltham and Fookes' classification of sinkholes.

Figure 3-2 Waltham & Fookes (2003) classification of sinkholes with respect to the mechanisms of the ground failure and the nature of the material which fails and subsides. Atkins has added the red box to indicate the classifications which comprise Class B and C sinkholes in the Land Stability Study Area.



3.3. Factors that may influence the occurrence of sinkholes

Water is the most important factor in the development of sinkholes: as the water seeps downward and flows through the superficial deposits that overly the limestone bedrock, or as the groundwater level fluctuates, the superficial deposits can be eroded and then transported through the deposits and into conduits in the bedrock. Soil can also be eroded from the infill in karstic voids (fissures etc.). Changes to surface water management or natural drainage may modify the processes by which sinkholes develop. The ground surface depression that results from sinkhole development will further concentrate surface water towards the sinkhole, thereby exacerbating the situation.

Referring to the void that can form within superficial deposits, Beynen et al. [23] state that *"In general, there are five ways through which water flow may increase the pore pressure gradient around a soil void and/or decrease the shear strength in the soil".* Those processes, which largely reflect the natural hydrological cycle in the Chercombe Bridge Limestone Formation (CBLF), are summarised in the following list (adapted from Beynen et al. [23]):

1. Surface water percolating downward:

   Water sources can include detention basins, reservoirs, irrigated land, construction sites, roof down-pipes that are not connected to a positive drainage system[4], and runoff from impervious surfaces.

2. Near-surface water percolating downward:

   Water sources can include leakages of water lines, storm water drainage system, sewer lines or irrigation systems, and natural water flow within epikarst[5] zones.

3. Groundwater level fluctuations:

   Water sources include mine dewatering, water inflow to quarries and mines, pumping at wells, long durations of dry or wet weather. Extensive dewatering in a thick limestone

[4] Positive drainage: Drainage with sufficient gradient and size to convey water away from the area being drained.
[5] Epikarst: The shallow, superficial part of the karst. The majority of dissolution takes place in the upper layers of bedrock, a zone now known as the epikarst but referred to be some early authors as the subcutaneous zone (Gunn, 1986). As this is a zone of enhanced dissolution it is also the zone of highest porosity in which the majority of groundwater is stored.

aquifer may result in two or more temporary aquifers that have different water levels but are hydraulically connected.

4. Water percolation from a shallow aquifer to a deeper aquifer:
   This occurs in a dual aquifer system where the water level in the shallow aquifer is higher than the potentiometric pressure in the deeper aquifer. It can also occur in a thick aquifer system where perched water is present in the upper section.

5. Water uprising from a deep confined aquifer to a shallow aquifer or to surface:
   This occurs when a confined aquifer is hydrologically connected to a shallow aquifer or to a surface water body.

In addition to the lithology of a soluble rock, Farrant and Cooper [24] indicate that a variety of other geological factors influence the style and severity of karst features likely to be present or develop, and hence the likelihood of a sinkhole occurring where the bedrock is soluble. These factors, which include the geomorphological setting and the thickness of superficial deposits, are considered in the following paragraphs for the CBLF around Linhay Hill Quarry.

Geological and geomorphological setting

In broad terms, flat or gently sloping areas are more susceptible to the development of new sinkholes than is steeper terrain [24]. Within the Land Stability Study Area, the terrain over the CBLF outcrop is generally gently sloping, which suggests that the influence of slope steepness on the formation of new karst features is similar over the entire Study Area.

However, run-off from the surrounding hills north and south of the Study Area, may have affected the development of sinkholes. The likelihood of karst features, including sinkholes, is affected by the relationship between the soluble rock (in this case the limestone) and adjacent less permeable or impermeable strata. The greatest concentrations of sinkholes are commonly associated with margins between impermeable and soluble geological formations, where runoff is directed onto the soluble rock [24]. The Tavy Formation to the north and Foxley Tuff Formation to the south of the CBLF are both less permeable strata from which runoff and surface flow from springs, are likely to be sources of recharge to the limestone. Hence, an increase in karst features would be expected along the northern and southern boundaries of the CBLF. Such an increased likelihood of karst features may be manifest in the greater occurrence of sinkholes. The findings from Atkins' walkover surveys (Figure A-1 in Appendix D) provide some evidence for this expected higher frequency of sinkholes, particularly in the northern Alston Farm fields (east of Alston Lane), though by comparison fewer sinkholes have been observed along the southern border of the limestone.

Karst features also occur where non-karstic rocks overlie a soluble lithology. Karst features such as sinkholes, stream sinks, and dissolution pipes are particularly common where the cover lithology thins towards its boundary with underlying soluble strata [24]. Such a geological condition is present along the southern boundary of the Chercombe Bridge Limestone Formation where the Foxley Tuff Formation has been thrust over the limestone. There might, therefore, be a greater likelihood of karst features along the limestone's southern boundary, though from the walkover survey and monitoring observations that does not seem to have manifested in an increased occurrence of sinkholes.

Karstic drainage systems can also develop in soluble rock that lies below a significant thickness of less permeable or impermeable rock and, though there might be little or no surface expression of the karst, karstic groundwater flow systems, including caves, may be present at depth [24]. Such a geological setting exists along the southern boundary of the CBLF where the Foxley Tuff Formation has been thrust over the limestone, but there is no evidence from Atkins' desk study, walkover surveys or monitoring observations of a high occurrence of sinkholes in this area. Therefore, we do not consider that this geological setting has given rise to an increased occurrence of sinkhole development in the Study Area.

Superficial deposits

Sinkhole size is generally directly related to both the thickness of overlying superficial deposits, and the void space within the rock [18]. Areas with a thin cover of superficial deposits commonly have a greater incidence of near surface karst features. However, when the superficial deposits are thin and voids in the bedrock are small, the sinkholes will generally also be small. Larger dropout sinkholes or cover collapse sinkholes are generally associated with thicker superficial deposits and occur where a well-developed and interconnected open fracture system or open conduit system exists within otherwise massive bedrock. Atkins' Class B and Class C sinkholes are relatively small (not more than a few metres wide), which suggests they are likely to be associated with isolated voids or small conduits in the epikarst, rather than a larger and more open cave system.

Areas with a thin cover of superficial deposits will have a greater likelihood of point recharge and, therefore, of sinkhole development, whereas greater thicknesses have more diffuse infiltration and less propensity for the development of new sinkholes. This factor was considered in LSRA 2016 [3] by making use of information from the ground investigation boreholes and surface geophysical surveys carried out for the design of the quarry extension and overburden bunds.

The surface geophysical surveys were undertaken by Bentham Geoconsulting in 2014 and 2016 [25, 26] to assess the thickness of superficial deposits to the east of the quarry, including the proposed extension area, using resisitivity and electromagnetic methods. The results, which were interpreted with the aid of the borehole data, indicate about 1 to 3 m of superficial deposits near the A38, with thicknesses increasing to more than 10 m in the north of the extension area and more than 6 m in the adjacent land to the east, near Caton Farm.

LSRA 2016 interpreted a broad variation in the depth to rockhead across the extent of the limestone, with generally greater thickness of superficial deposits at, for example, Alston Farm than at Caton Farm. However, considerable local variation is expected in accordance with a predominantly Mature Karst kIII with elements of Complex Karst kIV and Youthful Karst kII.

Ground investigation data obtained since the LSRA 2016 work (principally for hydrogeological purposes) has confirmed the general variation in thickness of superficial deposits within the study area, in addition to which it should be noted that there is an irregular rockhead profile beneath the superficial deposits when an individual smaller area is considered as described in the Engineering Geology Desk Study (Appendix A). The results may be summarised as follows:

- Proposed quarry extension area: Boreholes drilled using rotary open hole techniques encountered superficial deposits that are between 0.5 m and 12.8 m thick.
- Close to the Alston Farm buildings and Alston Cottage: Boreholes encountered superficial deposits thicknesses ranging from approximately 6 m to 17.5 m. Five of the boreholes (AF1, AF2, AC1, AC3 and NW2) encountered the limestone rockhead at between 4.9 and 10.5 depth, but it was encountered at 16 m depth in two other boreholes (AF3 and AC2) confirming the localised variability in thickness of the superficial deposits.
- At and near the proposed overburden bund, in the east of the extension area: The superficial deposits were generally interpreted as being between 6 m and 16 m thick (NE5, NE6, NE7, NE8 and NE9) but were found to be more than 19 m thick in one borehole (NE4).
- Near the A38 off-slip road at Goodstone Cross: Boreholes drilled for Highways England indicate potentially about 40m of superficial deposits below a sinkhole depression north of the off-slip road (Atkins' feature number 16, see Appendix A). At the overbridge itself, boreholes drilled in 1969 indicate superficial deposits to variable depths of up to 6 m, with clay-filled conduits encountered within the limestone to approximately 11 m below ground level [17].

Passive seismic geophysical surveying undertaken by the BGS in 2017 [27] supports the evidence that the superficial deposits thicken substantially to the north of the hamlet of Caton, although the ability of the technique to pick out local variations in depth to rockhead appears limited. Nonetheless, the BGS's east to west orientated geophysical survey line near Alston Farmhouse appears to identify an extensive, sub-vertical feature, corresponding to the approximate alignment of the fracture visible in northeast face of the quarry. In the northeast of the extension area, another BGS survey line appears to identify a similar sub-vertical geophysical feature that is approximately aligned with the position of a fault shown on published BGS map at the northern edge of the CBLF outcrop, suggesting that the fault may extend further south than shown on the published map.

The permeability of the superficial deposits will also affect the likelihood of dissolution features developing in the underling bedrock [24]. Investigations of the superficial deposits for the design of the quarry and the overburden bunds, together with boreholes drilled for groundwater monitoring, indicate that the superficial deposits are mainly clay with gravel and cobbles. Clay-rich deposits would typically be expected to have low permeability. However, from Atkins' observations during wet conditions, including comparisons of runoff between land that does and does not overly the Chercombe Bridge Limestone Formation, suggest that the superficial deposits are moderately permeable, rather than having particularly low or high permeability.

Weather conditions

The Regulation 22 Request 2020 advises that consideration is given to a comparison of sinkhole development with records of weather conditions, to ascertain if particular sinkholes have developed as a result of high rainfall.

Rainfall records are presented in Section 4.3.2. of HIA 2020, including site specific rainfall monitoring data collected from Alston Farm since October 2017.

High rainfall events have the potential to cause sinkhole formation during or soon afterwards [28]. However, Atkins has not been able to establish a rainfall trigger level that results in the formation of sinkholes in the Land Stability Study Area. This is primarily due to the difficulty in dating the formation of sinkholes, as discussed below, though for example the sinkhole activity adjacent the A38 off slip occurred following the very wet winter of 2013 / 2014. Therefore Section 5 of this LSRA proposes an increased frequency in monitoring visits by engineering geomorphologists / geologists in response to high rainfall events to help determine whether a relationship exists between rainfall and sinkhole development within the Land Stability Study Area.

3.4. Current Baseline

Atkins' LSRA begins with establishing the current occurrence of sinkholes, which is known as the current baseline. This has been done using an understanding of the processes by which the sinkholes are formed (as described above) and an assessment of their spatial distribution and an indicative spatial zoning, which are given below.

Spatial distribution of sinkholes

Class A sinkholes are ancient features of the landscape. As such, it is unlikely that there are trigger factors in the present or likely future groundwater and climate conditions that would result in the formation of additional Class A sinkholes in the Land Stability Study Area. In contrast, Class B and Class C sinkholes form over engineering timescales. Class B and Class C sinkholes may form within Class A sinkholes, as Class A sinkholes form topographic lows that can concentrate surface water.

Interpretation of remote sensing (aerial photographs and satellite imagery, presented in Appendix B) forms a source of data from which Atkins has compiled the table of mapped sinkhole features presented in Appendix E. Atkins has drawn a distinction between sinkhole features as follows:

- Visited and confirmed sinkholes: those that Atkins has identified in the field ('high confidence' sinkholes);
- Visited but inconclusive: those that Atkins has identified from aerial photographs but were inconclusive when visited in the field ('medium confidence sinkholes'); and
- Identified from remote sensing only: those that Atkins has identified from aerial photographs but was not able to confirm in the field ('low confidence sinkholes').

Class A sinkholes are more readily identifiable from aerial photographs than are Class B and Class C sinkholes, as Class A sinkholes are significantly larger, and are permanent features in the landscape. Class B and C sinkholes are more difficult to identify from aerial and satellite photographs because they degrade more rapidly than Class A sinkholes and landowners tend to fill them in.

Aerial photographs from before 1970 have a lower resolution and were taken less frequently than aerial photographs after 1970. As a result, and because Class B and Class C sinkholes are more difficult to identify from aerial photographs than are Class A sinkholes, the temporal distribution of the sinkholes Atkins has identified in Appendix E is biased towards the period after 1970. It is important to appreciate that this unavoidable observational bias is a function of the availability and quality of the data; it does not necessarily mean that the occurrence of sinkholes has increased since 1970.

An assessment of the distribution of Class B and Class C sinkholes indicates that they have often formed in clusters. Figure 3-3 below is an extract from Figure 2-2 above, on which the Class B and Class C sinkholes have been superimposed. Clusters of Class B and Class C sinkholes have been identified and are indicated by red dashed lines on Figure 3-3. We have designated the Clusters I, II, III, etc.

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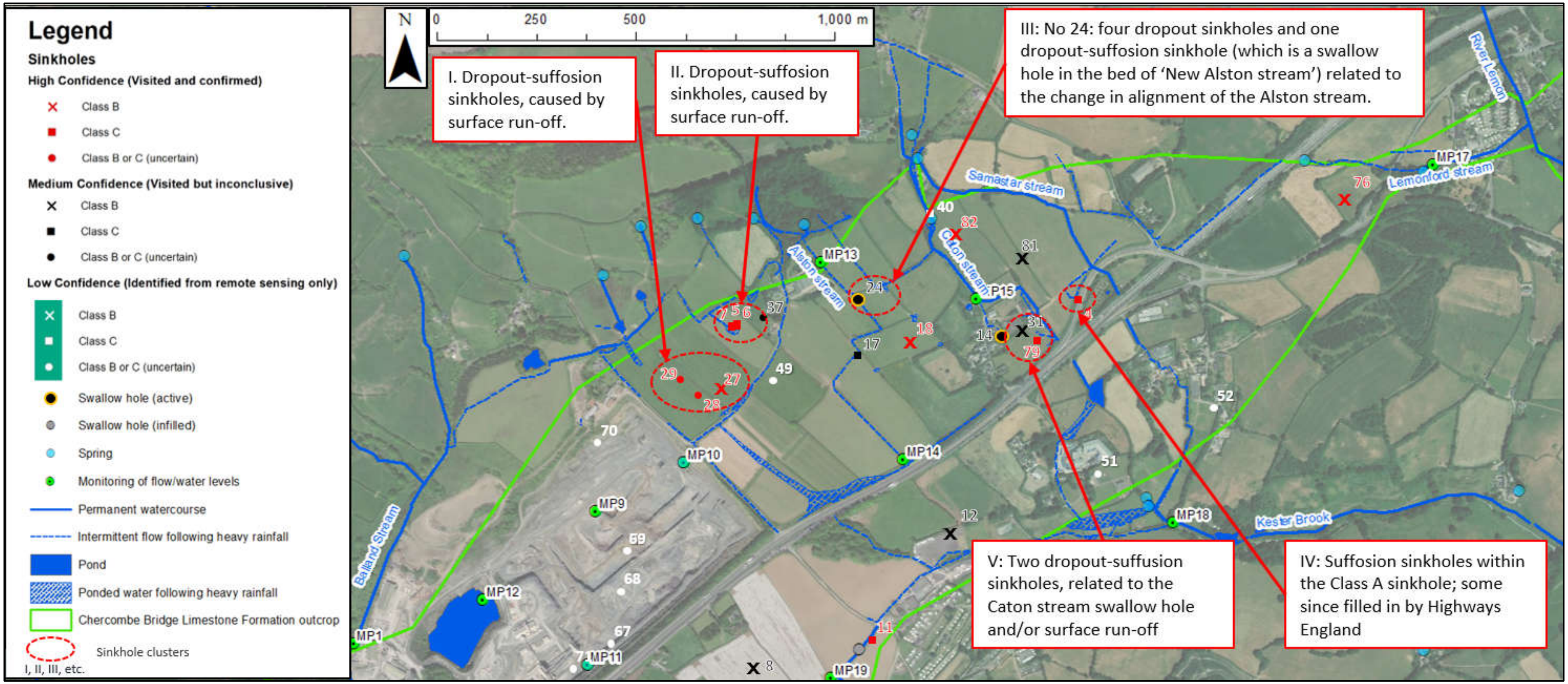
Figure 3-3 Extract from Figure 2-2, with Class B and Class C sinkholes superimposed.



The clusters of Class B and/or C sinkholes correlate with areas of surface water runoff and ponding, although Class B sinkholes may also form as a result of changes to the flow of water underground caused by infiltration of surface water nearby.

Sinkhole Cluster I comprises three dropout-suffosion sinkholes (labelled as feature numbers 27, 28 and 29 in Figure 3-3. They are likely to be related to surface run-off.

Sinkhole Clusters II and III are likely to be related to the change to the alignment of the Alston stream as shown in Figure 3-3 and described in the following paragraphs.

The Alston stream previously flowed via a water wheel at Alston Farm (in Figure 3-4 below) and, although no records are available to show the alignment of the stream downstream of this point, the location and orientation of the water wheel indicates flow across fields to the southwest, which is where there is a cluster of sinkholes (Sinkhole Cluster II, comprising sinkhole Nos. 5, 6 and 7 in Figure 3-3). After heavy or prolonged rainfall some runoff still flows to the water wheel's sump and infiltrates away from there, presumably via this historical flow path.

Figure 3-4 Water wheel at Alston Farm along former alignment of the Alston stream

Following diversion to its current alignment, the Alston stream now flows southeast alongside the hedgerows of the farm fields. Atkins has called the current alignment the 'New Alston stream'. A swallow hole marked as No. 24 on Figure 3-3 formed at or very close to the New Alston stream a few years before 2016. Sinkhole Cluster III comprises five Class B sinkholes that subsequently developed near the swallow hole:

- Nos. 24a, 24b and 24c: Three dropout sinkholes that formed pre-2016, close to the pre-2016 swallow hole (No. 24).
- Nos. 24d and 24e: Two dropout sinkholes approximately 25 m east of the pre-2016 swallow hole (No. 24). These sinkholes were identified by Atkins in early 2020. They had not been observed in previous walkover surveys or visits to the field in October and November 2019, suggesting that they have formed during the winter 2019/2020.

It seems likely that Sinkhole Cluster III formed as a result of suffosion and collapse at depth, due to the flow of water that enters the ground along the route of the New Alston stream via the stream's bed and via the swallow hole. It is also possible that loss of water to ground from the New Alston stream and the movement of that water underground to the limestone may have contributed to the formation of the dropout (Class B) sinkhole in the field to the southeast (No. 18 in Figure 3-3; see also the photograph in Figure 3-1).

The spatial distribution of these Class B and Class C sinkholes therefore suggests a close link to the presence of surface water and its ingress and movement underground. This is further demonstrated by Sinkhole Cluster IV: The development of Class B and C sinkholes within a Class A sinkhole into which surface water draining along the ditch beside the A38 slip road is concentrated (Figure 3-3). The Class B sinkholes have been infilled and currently at this location only one Class C sinkhole is visible.

To the south east of the hamlet of Caton, there may be a cluster of two sinkholes (Cluster V in Figure 3-3) that may be related to the Caton stream swallow hole (No.14): a medium confidence Class B sinkhole (No. 31) and a high confidence Class C sinkhole (No. 79). The latter was observed by Atkins in November 2019, and we understand that it formed during 2019. We further understand that an incident of farmyard runoff occurred during the wet winter of 2015/2016 uphill of the location at which sinkhole No. 79 has formed. The formation of sinkhole No. 79 may be related to the increased surface water runoff during that time, or from part of Caton stream being allowed to flow to the sinkhole behind Caton Farmhouse.

We note that there are roughly equal numbers of mapped Class B and Class C sinkholes within and outside the inferred current extent of the groundwater drawdown from the quarry (see Figure 4-91 of HIA 2020, which we have included as Figure 3-5 below). Therefore, there is nothing to indicate that drawdown from the existing quarry has contributed to the formation of sinkholes to date.

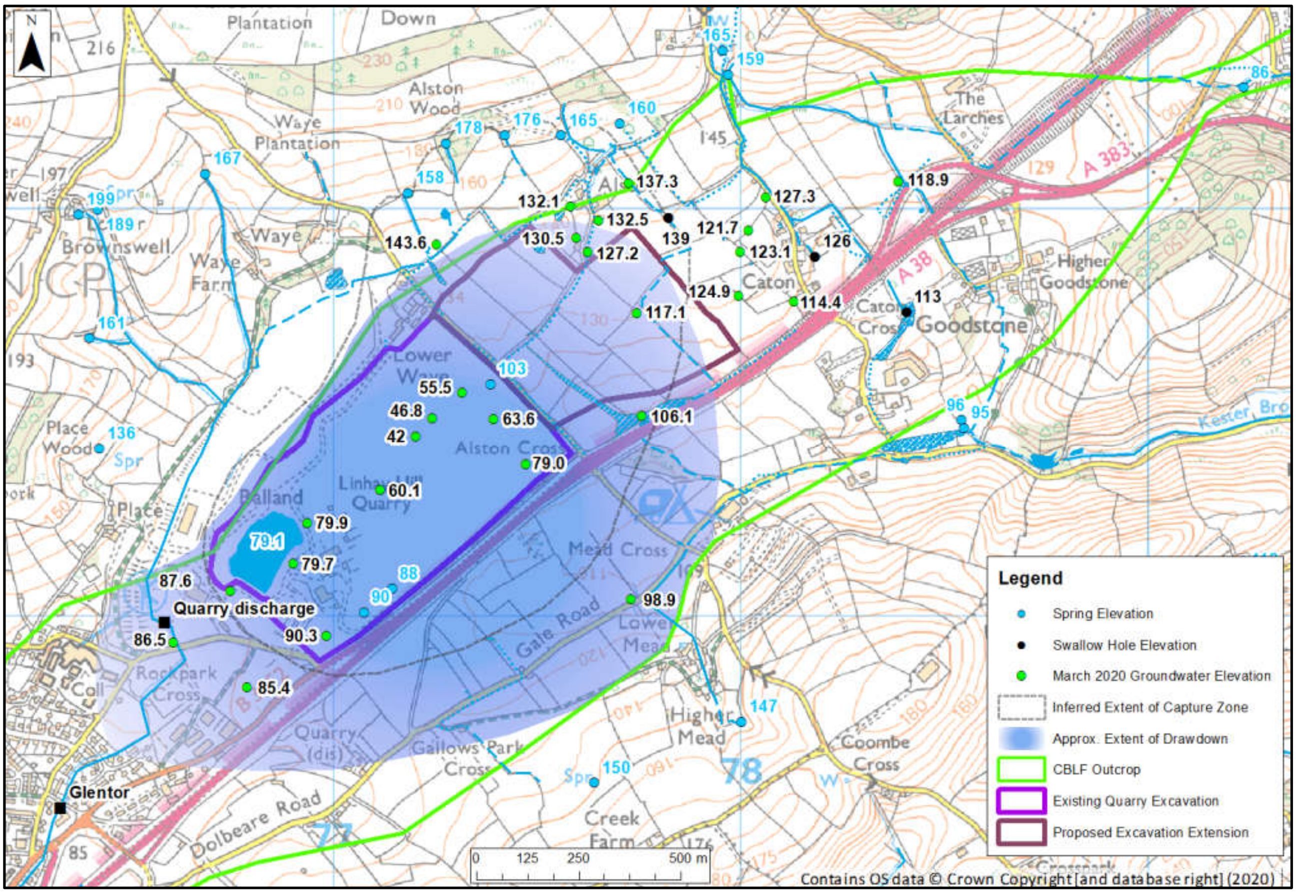


Figure 3-5 Approximate current extent of quarry drawdown (copied from figure 4-91 of HIA 2020)

Indicative zoning of sink holes

In general terms, the factors described above that affect sinkhole occurrence will have resulted in variations in sinkhole density (i.e. number of sinkholes per unit area), which can be used as one of the indicators of the likelihood of sinkhole occurrence. Atkins has produced a zone map to inform the land stability risk assessment (see Appendix D Figure A-2). It combines Atkins' sinkhole observations with general receptor vulnerability for the whole of the area underlain by the CBLF between Ashburton and Bickington.

The zones have been established from the assessed vulnerability of receptors, based on land use: the existing quarry, the proposed extension area including the extraction area, agricultural land, and infrastructure and buildings. The number of mapped sinkholes per zone was then calculated (Table 3-1), which provides an indicative baseline frequency for each zone as shown in Figure A-2, Appendix D.

The zone boundaries broadly encompass the receptor land use areas such that the 'infrastructure and buildings' zone, which has the highest relative receptor vulnerability, includes infrastructure such as roads, and buildings, as well as some of the land immediately adjacent to those assets. The indicative sinkhole frequency is, therefore, an over-estimate rather than a precise measure of the coincidence of sinkholes with infrastructure and buildings. Also, for the 'infrastructure and buildings' zone, infrastructure types have not been differentiated (e.g. strategic road versus minor road), nor have building uses (e.g. dwelling, commercial building or farm building). There may also be some sampling and observation bias in the sinkhole frequency mapping. This is because some areas or zones have been studied in more detail than others:

- The most heavily investigated zone is Zone 2, which is the proposed extension area. It is owned by E&JW Glendinning Ltd. and so access is readily available for survey and investigation. That may partly explain the higher mapped frequency of Class B and C sinkholes within Zone 2 (Class A sinkholes are not likely to be related to the quarry because they are long term features of the landscape), although there are also other locally contributing factors such as surface water run-off from the higher land to the north.
- Conversely, an absence of recorded sinkholes in other parts of the map may partly reflect an absence of data as a result of more limited land access, limited geomorphological survey, or land uses that mask the presence of sinkholes, such as existing development in eastern Ashburton and elsewhere, ploughed fields, crops, and woodland. The absence of data in such areas may, therefore, underestimate the actual frequency of sinkholes.

Table 3-1 Sinkhole zoning and current baseline density of sinkholes in the Chercombe Bridge Limestone Formation outcrop (see Figure A-2 in Appendix D).

Receptor Type and Zone		**Baseline**					
Description:	Map Zone	Area (km²)	Number of mapped sinkholes including unverified (low confidence) features				Density of sinkholes (per km²)
			Class A	Class B	Class C	Class B or C (uncertain)	
Existing quarry	1	0.46	2	0	0	5	15.2
Proposed extension area (including proposed extraction area)	2	0.33	11	7	10	3	94.0
Infrastructure and buildings	3	1.54	13	1	4	3	13.6
Agricultural land	4	1.21	18	5	1	1	0.7

Taken together, Atkins' mapping and consideration of the factors affecting sinkhole occurrence helps in the understanding of historical sinkhole formation within the Land Stability Study Area. However, there is no certainty that it has statistical value for future prediction unless it is assumed that the causes and occurrence of land subsidence in the future will be similar to those in the past. Such an assumption could be the case if nothing changes, whereas even in the absence of the extension proposals, there is likely to be climate change (causing longer drier periods and more intense rainfall events resulting in changes to natural drainage), and human activities (such as further building and changes to drainage that are unrelated to the quarry) that could affect the management of surface water over the Chercombe Bridge Limestone.

3.5. Future Baseline

The future baseline is defined as changes to the current baseline that would occur if the proposed quarry extension and deepening did not take place – it is the Do Nothing Scenario.

In the Do Nothing Scenario, extraction of limestone at Linhay Hill Quarry will cease when the current reserves are exhausted or no longer viable to extract. Restoration will proceed in accordance with a scheme to be agreed with the DNPA under the terms of conditions on the existing planning permission(s). The restoration scheme is that, with the cessation of dewatering, the quarry void will fill with water from rainfall and groundwater, allowing the quarry to be restored to a lake. The water level in the lake will recover until the inflows of water equate to outflows, and it is expected that groundwater movement will follow flow paths below the lake level similar to those that existed prior to dewatering of the quarry. Inflows to the quarry are likely to be substantially reduced following the cessation of pumping and establishment of the lake, leading to a much reduced likelihood of effects on the nearby groundwater and surface water system. There would be controlled outflow from the lake to the Balland Stream for flood risk management.

Were the quarry deepening and extension not to go ahead, it is expected the existing land stability situation for the surrounding area will still change over the next 70 years and beyond, because of the nature of buried karst limestone generally, and the way that sinkhole development is affected by natural factors such as seasonal changes in groundwater levels, extreme rainfall events or prolonged wet weather and consequent variance in groundwater levels and movement, and also by human activities such as new buildings and changes to drainage.

In general, surface water will normally be expected to flow toward, and eventually drain into streams, rivers, and lakes. Waltham [2] states that "*Almost any means by which a new or increased flow of water can pass through a soil cover into underlying fissured limestone, and thereby carry away soil, is likely to form a subsidence sinkhole".*

Consequently, where water flow over the ground surface above the Chercombe Bridge Limestone Formation becomes concentrated or diverted, either due to natural events or human intervention, the change in infiltration of surface water to the limestone will affect the subsurface water flow pathways and could alter the likelihood, and hence the risk, of subsidence sinkholes forming in those areas. But the future likelihood and spatial occurrence of sinkholes cannot be easily predicted outside the quarry and its proposed extension area because it will depend closely on human activity and the management of surface water on land that is not managed by the quarry. However, as is the case for the existing situation, the highest risk in the Future Baseline scenario will be along changed drainage routes, and the appearance of subsidence is most likely to occur after periods of high and prolonged rainfall.

4. Potential Sources of Land Stability Risk

The following section provides an assessment of the potential causes of land instability and potential hazard sources associated with the quarry extension proposals. It is important to recognise here that the extension programme is sub-divided into stages and that monitoring both for hydrogeological and land stability purposes will be ongoing, providing recurring opportunities to review the findings and refine the monitoring and mitigation measures.

4.1. Changes to Surface Water Management

The proposed extension to Linhay Hill Quarry and associated infrastructure works will result in some modifications to the existing surface water drainage, together with new surface water drainage provided to convey runoff, increase attenuation storage and prevent runoff off-site. The proposals take account of the need to manage surface water, as stated by Waltham [2]: "*without built drains to carry the runoff away or directly to bedrock, any concentration of drainage input to the soil within a karst terrain becomes a potential site for a new sinkhole*".

The drainage proposals are shown in the Planning Application drawings[6] and described in the Environmental Statement and the Hydrogeological Impact Assessments [29] [9]. They are summarised in the following table with a consideration of the implications in relation to the Chercombe Bridge Limestone Formation (CBLF). The drainage areas and details are as considered in the Flood Risk Assessment (FRA) [30].

Table 4-1 Proposed works and implications for the Chercombe Bridge Limestone Formation

Proposed works and FRA drainage area	Drainage Works	Implications for the Chercombe Bridge Limestone Formation and Drainage Details for Construction
Stage 0		
Balland Lane Widening	Overall the widening will increase surface water runoff along Balland Lane into the Balland Stream, but that increase will be mitigated by upstream catchment attenuation and additionally by storage and diversion of peak flows into the quarry.	Although the Balland Stream downstream of Balland Lane lies on the limestone, there are no implications because there will be no increase in flow due to the Balland Lane Widening. The widening will have positive drainage, and ground investigation for construction design will be carried out pre-construction. Balland Lane is maintained by Devon County Council and hence design and construction of the widening will meet its standards.

[6] Atkins drawings LINHAY-ATK-S0-Z-PL-001, S1-Z-PL-1000, S2-Z-PL-2000, S3-Z-PL-3000, S4-PL-4000, S5-Z-PL-5000, and S6-Z-PL-6000.

Proposed works and FRA drainage area	Drainage Works	Implications for the Chercombe Bridge Limestone Formation and Drainage Details for Construction
Waye Lane Public Road and Footpath Diversion	Surface water runoff will flow along either side of the new impervious tarmac road surface and down the slope of the new road constrained mainly by the hedge banks, with positive drainage to three attenuation storage areas, which will be at Waye Pond, east of Brownswell, and east of Place Wood. Below the lowest attenuation area, at the western end there will be 0.16 hectares of new Waye Lane impermeable tarmac surface which has the potential to increase surface water runoff directly to Balland Lane and the Balland Stream. That potential increase will be mitigated by the upstream catchment attenuation storage and diversion of peak flow to the quarry.	For the majority of the Waye Lane Public Road and Footpath Diversion east of chainage 200 (approximately) there are no implications because the works do not lie on the limestone. For the 0.16ha (<200m^2) at the western end which can runoff directly to Balland Lane and so to the Balland Stream which lies on the limestone there will be no increase in flow because of the upstream catchment attenuation. The new road will have positive drainage, and ground investigation for construction design will be carried out pre-construction, with the road adopted by Devon County Council.
Alston Farm and Alston Cottage New Access Route	The initial 70 m will drain to the existing Alston Lane and so to the quarry via existing drainage. Chainage 90 to 300 will drain positively to the drainage for Waye Lane. Runoff from the remainder i.e. to chainage 643, will flow to existing drainage at Alston Farm until Stage 4 when it will drain to the extended quarry.	The route of the new access is underlain by superficial deposits that are underlain by the limestone from about chainage 350. Uncontrolled runoff from chainage 300 to 643 could cause infiltration through the superficial deposits to the limestone bedrock. To avoid concentrated infiltration forming new subsurface pathways, positive drainage leading to existing drainage routes. The positive drainage will be achieved by dished channel(s) at the edge of the access route, or lined French drains at suitable gradients, or road gullies and underground pipe. The design and construction will reflect the ground conditions as confirmed by ground investigation pre-construction, and for the lifecycle design and maintenance objectives of the landowner (E&JW Glendinning Ltd.).

Proposed works and FRA drainage area	Drainage Works	Implications for the Chercombe Bridge Limestone Formation and Drainage Details for Construction
Stages 1-5		
Quarry Extension and Operation	Direct surface water runoff into the quarry from the surrounding land of the Alston Farm fields will be prevented by the quarry's edge protection safety banks, which will be around the quarry's surface extent. Where necessary, new drainage ditches will be formed to convey runoff around the extended quarry, but with a preference of utilising the existing flow routes, such as along field or hedge boundaries, with check dams in order to reduce the rate of runoff and suspended solids therein.	At present, surface water runoff mainly either infiltrates while it flows over the Alston Farm fields or within a ditch that runs parallel to the A38, located within a vegetated channel on the north side of the A38 embankment, north east of Alston Lane. That situation will continue because existing drainage routes will be mainly utilised where they exist i.e. ditches adjacent to hedges. There will be some localised new drainage within a few metres of the northern perimeter of the extended quarry where water could infiltrate to the limestone, but its slope will promote flow rather than infiltration and it is envisaged that, due to its proximity to the extended quarry, the subsurface pathway would be more likely to be towards the extended quarry than away from the extended quarry. Should it be observed that a potential for localised or concentrated infiltration is likely to cause erosion or subsidence, drainage will be modified accordingly. For example, the route may be adjusted, or the drainage lined.
Overburden Bund Formation and Restoration	New drainage ditches will be formed around the bunds to intercept surface water runoff and divert an existing seasonal spring-fed minor watercourse, which crosses the Alston Farm fields. For structural stability, the bunds will have basal drainage and internal drainage most likely in the form of herringbone gravel drains. The formation of the bunds will be regulated under a Mining Waste Permit to comply with the Mining Waste Directive 2006/21/EC (as transposed to UK legislation).	The limit of the bunds' footprint is mainly the perimeter of the Alston Farm fields. This is where runoff flows to at present, the field boundaries being mainly hedge lines. New linear positive drainage routes around the bunds will be formed as grassed channels over a low-permeability membrane to prevent the concentrated infiltration of storm water to the shallow sub-surface. Suspended solids settlement areas will be lined.
Balancing pond	A balancing pond is proposed to the northeast of the extension area, to minimise the potential for drawdown to the east and into the groundwater catchment of the Kester Brook	Groundwater levels at the balancing pond would be maintained within their natural range, thus avoiding the potential for effects on the CBLF and land stability.

Proposed works and FRA drainage area	Drainage Works	Implications for the Chercombe Bridge Limestone Formation and Drainage Details for Construction
Diversion of the Alston stream	Diversion of the Alston stream will occur at the start of Stage 2, prior to emplacement of overburden material along its current course. The diverted channel, which will run to the west of the bunds via a ditch lined with low-permeability material, and to the east via pipe to an unlined section to be constructed along part of the eastern edge of the stage 1b bund. The rate of flow to the east will be controlled for infiltration along the unlined section to help maintain the groundwater divide in this area and minimise the potential for drawdown to the east and into the groundwater catchment of the Kester Brook.	There will be a risk that this drainage change could alter the local risk of subsidence. However the drainage will be monitored by regular observation and the stream flow controlled and rate of infiltration managed by design of the soil / filter material within the unlined section to mitigate that risk.
Stage 6 Quarry Restoration Completed	Perimeter drainage formed around the extended quarry and bunds will remain, as is the case for the existing quarry. Once rock extraction ceases and pumping of water from the quarry is stopped, the void will begin to fill with water from rainfall and groundwater.	Inflows to the quarry are likely to be substantially reduced once the void is filled with water leading to a much lower likelihood of effects to the nearby groundwater and surface water system. There will be a controlled outflow from the lake to the Balland Stream. The lake level will be at approximately 96 to 97 mAOD, with storage above and the outflow to the Balland Stream subject to flood risk management controls. The groundwater levels would be within their natural range, thus avoiding consequential effects on the CBLF and land stability.

It should be recognised that the localised changes to surface water drainage for the proposed quarry extension are not dissimilar from other development that has taken place locally and coexisted with incremental extension of the quarry since the 1950s, a period of some seventy years. These other developments have included new buildings and associated positive drainage, and most notably the construction of the A38 dual carriageway from the mid-1960s onwards. Ground loading will also have increased, particularly where the road is on embankment (Alston to Goodstone). However, since construction of the A38 dual carriageway, and considering other changes to the land adjacent to the A38 and near Linhay Hill Quarry over the last seventy years, we have found no published accounts of land stability concerns other than of the sinkhole cluster adjacent to the A38 slip road at Goodstone Cross (shown in Figure 3-3 above, No. 4,).

4.2. Operational Dewatering of the Quarry

In Mature (kIII) Karst, such as the CBLF, there is potential for the first few years of dewatering to lead to an increased occurrence of dropout sinkholes (Atkins' Class B or C, or Waltham's [2] Type 1a). That is, if the lowering of groundwater by dewatering increases the flow of water from superficial deposits into bedrock, or if the interception of conduits by the excavation activates groundwater flow, leading to the removal of infilled material from the conduits. Where such karst is buried beneath superficial deposits, and the conduits are filled with clay, as is the case for the CBLF, a greater period of time may be expected to pass for material to be removed from infilled conduits by water erosion and collapse than if the karst were not filled with sediment.

Also, in areas where the groundwater level is usually above rockhead (within the superficial deposits), sinkholes may be triggered when the groundwater level drops below rockhead, such as during dry periods or due to dewatering. A rapid drop in groundwater level will increase the effective stress in the superficial deposits and can cause a loss of buoyant support that the water provides to a cavity7.

The groundwater level data from borehole monitoring reported in HIA 2020 indicates that there are large seasonal variations in groundwater levels in the CBLF, together with rapid response to rainfall and declines thereafter. This occurs both within the current drawdown area, for example at the borehole close to the A38 (SE1A), and outside it, such as those in the northern part of the extension area, for example some of the shallow boreholes near Alston Cottage and the Alston Farm buildings. The groundwater data indicate significant seasonal variation in the northeast of the extension area, with the recorded groundwater levels in borehole NE9 varying between 109 mAOD and 131 mAOD (the ground level at the borehole is 131 mAOD).

The variations in groundwater level further from the quarry are not considered likely to have been caused by the quarry, because they are outside the inferred current extent of drawdown (see Figure 3-5 above), and because the groundwater monitoring results show that individual boreholes have a relatively consistent pattern from one year to another, with the slight increase in the elevation of summer minimum and winter maximum groundwater levels in 2019 pointing to an increase in annual rainfall and occurred despite the quarry being deepened.

HIA 2020 delineates an inferred maximum extent of drawdown following the proposed deepening and extension of the quarry. This is shown in Figure 5-1 below. This inferred maximum extent will be approached gradually as the quarry extension proposals progress. Although it is not possible to quantify at what point in the development a specific risk level may be reached, the maximum extent of drawdown will be in the latter stages, by which time ongoing monitoring and reporting, together with triggers for reassessments detailed in the HIA and Karst Management Plan will assist in the proactive management of the identified residual risk and enable an appropriate response to the assessed risk as it materialises and to possible residual risk elsewhere.

HIA 2020 points out that the likely magnitude of drawdown ranges from about 60 m at the quarry sump, to 10m at the quarry margins, to 0 m at the edge of the drawdown extent. HIA 2020 also highlights the highly seasonal nature of the quarry dewatering regime, with 79% of all groundwater inflows occurring from October to March and only 8% of groundwater inflows occurring between June and September. The drawdown within the inferred maximum drawdown area is therefore anticipated to occur mainly in winter when groundwater levels are notably higher than in summer. The dramatic reduction in dewatering rates during summer, when groundwater levels are at their lowest, means the magnitude of the drawdown in the summer is anticipated to be substantially less than in the winter and therefore less than the pre-existing natural seasonal fall in groundwater levels that occurs in summer. This leads to the conclusion that dewatering causing a change in general groundwater levels is unlikely to add to that source of land stability risk within the inferred maximum extent of groundwater drawdown.

Whilst the projected maximum extent of groundwater drawdown is based on a detailed conceptual model of the site and multiple lines of evidence, it remains subject to residual uncertainty therefore ongoing monitoring of groundwater levels both within and beyond the inferred maximum drawdown area is proposed in HIA 2020 with triggers for reassessment of receptors and update to the adaptive monitoring and mitigation programme, which would be subject to agreement by the Mineral Planning Authority.

The location and geometry of the karst conduits will always be largely unknown. However, based on the available groundwater data and site observations (including the results of the recent tracer testing presented in HIA 2020), the extent of potential effects from shallow dewatering is likely to be limited, with potential for a new sinkhole to form more likely to be triggered by an excess rather than a deficit of surface water.

4.3. Ground Loading

Increasing the load on the ground has the potential to cause instability where the ground is incapable of supporting that load, such as where a void exists below the ground surface. The construction of the overburden bunds will load the ground beneath them. The extent to which the limestone bedrock is required to accommodate the bund loads will depend, in part, on the thickness of the superficial deposits and groundwater therein, if present.

[7] https://www.bgs.ac.uk/research/engineeringGeology/shallowGeohazardsAndRisks/sinkholes/home.html

The Tip Stability Report (Environmental Statement Appendix 3E) refers to the proposed bunds as "*tips/bunds*", and states that *"Construction of the tips on these soils is unlikely to result in deep-seated rotational failure of the tip foundation or basal sliding, provided that all topsoil and any soft or wet soils are removed from the foundation area prior to the start of tip construction".* However, the report does not consider the possibility of instability (i.e. collapse) of the limestone bedrock.

Collapse of the limestone would be classed as a 'collapse sinkhole' (i.e. a Waltham [2] Type 2a sinkhole), but Waltham notes that *"Collapse sinkholes that are formed by natural rock failure of the limestone or a caprock are extremely rare".*

Waltham's [2] Table 4 indicates a stable thickness of rock cover of 3 m for strong limestone (kI to kIII) with an imposed stress of 2000 kPa (i.e. 2 MPa) and cave width of 5 m. Using the CBLF as an example, French [31] carried out finite element analysis which indicated that *"a 6m diameter void of typical karst at 3m depth would require a surface load of 5MPa to induce collapse".* The ground loading (stress) applied by the proposed overburden bunds will be considerably less than the collapse stresses calculated by Waltham [2] and French [31]. For example, it is expected that a 15 m high bund might result in a maximum vertical stress increase of approximately 300 kPa (i.e. 0.3 MPa).

Furthermore, collapse of the limestone bedrock has not occurred at the quarry and it is not known elsewhere within the CBLF's outcrop, including along the A38 dual carriageway.

5. Mitigation Measures for Land Stability

5.1. Introduction

Land stability mitigation measures have been considered by Atkins for the proposed deepening and extension of the quarry in the knowledge that *"controlling the drainage on construction projects is usually the most cost-effective means of minimizing the karst geohazard*", as stated by Waltham [2].

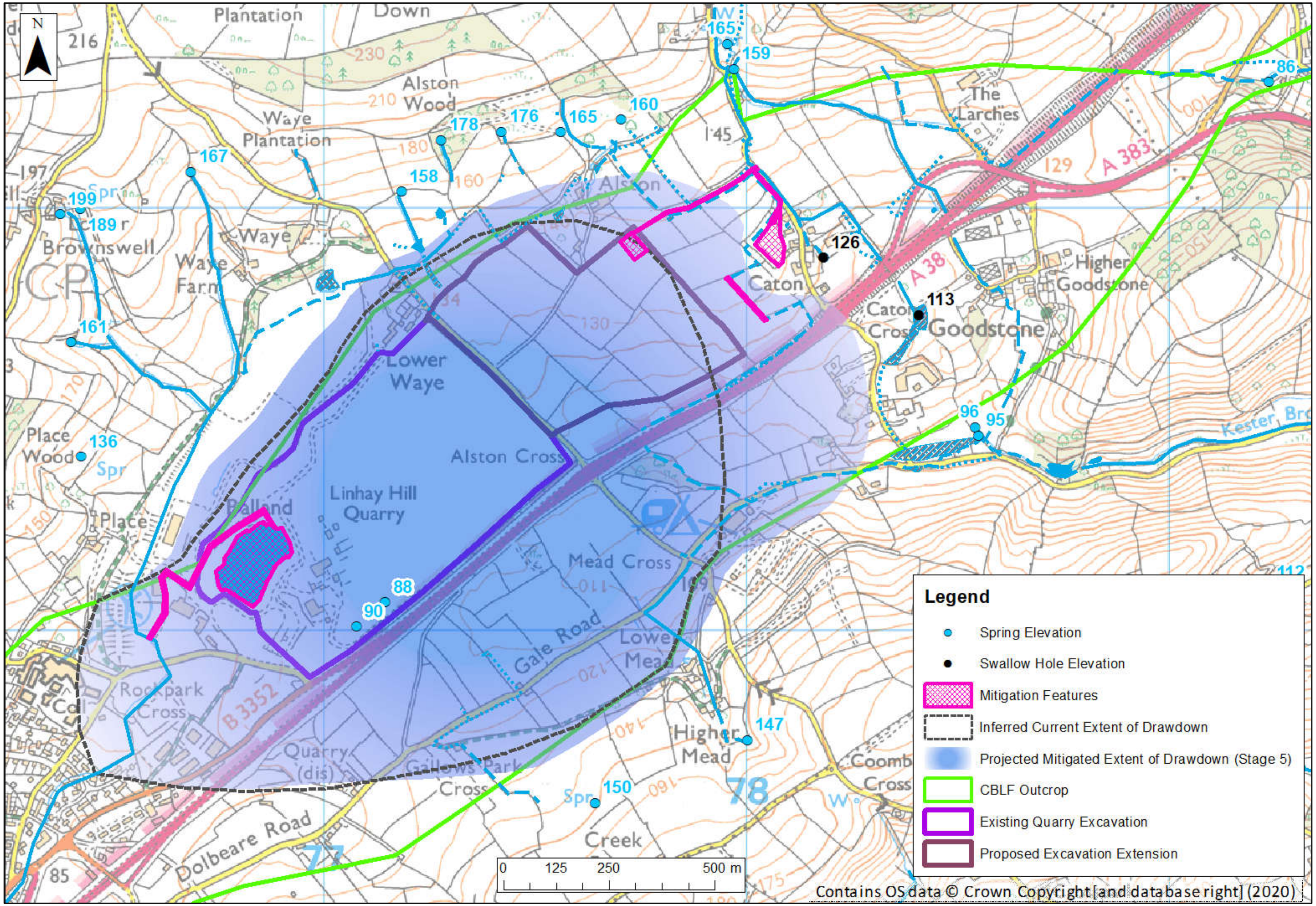
As a general point, we note that E & JW Glendinning Ltd. holds appropriate public liability insurance so that, in the event of claim against them due to damage from a new sinkhole occurring as a result of the quarry operations, the damage would be remediated/repaired or otherwise remedied as deemed appropriate by the insurers.

The land stability mitigation measures are incorporated into a Karst Management Plan (section 5.2 below) comprising drainage control, reviews of monitoring data and triggers for reassessment of land stability risk, and sinkhole repair. Each of these measures is described below. In addition, the measures specific to groundwater management proposed in HIA 2020, in particular the balancing pond and an unlined section of the diverted Alston stream, are complementary to managing the land stability. This is because they will maintain the current groundwater divide in the northeast of the extension area and minimise drawdown to the east of the extension area and into the groundwater catchment of the Kester Brook, whilst limited or negligible additional drawdown is anticipated to the northwest, southeast and southwest of the current drawdown area.

Mitigation measures specific to the management of groundwater are provided in HIA 2020, from which the following points are relevant to ground stability:

- A steep cone of depression (drawdown) of the water table is anticipated around the faces of the extended quarry, with drawdown of less than 10 m at the quarry's boundary, reducing to negligible drawdown at a distance of up to 400 m from the boundary. For context, groundwater levels in the CBLF naturally vary by about 10 m throughout the year in response to variations in rainfall and evaporation.
- Dewatering rates are highly seasonal, with 79% of all groundwater inflows occurring from October to March and only 8% of groundwater inflows occurring between June and September. The drawdown within the inferred maximum drawdown area is therefore anticipated to occur mainly in winter, when groundwater levels are at their highest anyway, and normal summer groundwater levels already some 10m below this. This leads to the conclusion that dewatering causing a change in general groundwater levels is unlikely to add to that source of land stability risk within the inferred maximum extent of groundwater drawdown.
- The proposed balancing pond and unlined portion of the diverted Alston stream on the east side of the proposed stage 1b bund would result in mounding of the groundwater table thus maintaining a groundwater divide in the east of the extension area and thereby marking the eastern extent of the quarry's groundwater catchment, as shown in Figure 7-2 of HIA 2020 and of the mitigated maximum extent of drawdown as in Figure 7-3 of HIA 2020, shown below as Figure 5-1. Whilst the proposed water level of 128 m AOD in the balancing pond is slightly below recorded maximum groundwater levels in this area during winter, it exceeds the long-term average groundwater level by several metres (see Section 7.2.3 of HIA 2020). Due to the slight increase in long-term average groundwater levels in this area, net drawdown from quarry dewatering would only occur some distance west of the balancing pond.

Figure 5-1 Copy of Figure 7-3 of HIA 2020 - Approximate maximum extent of drawdown for the current quarry and its proposed extension in the presence of mitigation measures



5.2. Karst Management Plan

Control of Surface Water Drainage

In a buried karst setting, water infiltration from the surface into the karst system is particularly detrimental to land stability and the control of surface water drainage is considered to be the most cost-effective means of reducing the sinkhole risk (Waltham [2]). In a buried karst setting, water infiltration from the surface into the karst system is particularly detrimental to land stability. Waltham & Fookes [32] state that *“Drainage control is essential in areas of soil cover on karstic limestones; by appropriate reaction to proper investigation, the hazards of collapsing sinkholes is largely avoidable.”*.

Class C sinkholes are defined by Atkins as those forming only in association with surface water flow, such as at field boundary ditches, streams, or where surface water is poorly controlled (i.e. excess flows or ponds in locations outside of normal drainage routes), especially during heavy rainfall. See Figure 3-1.

To avoid disrupting the natural subsurface flow and recharge to the limestone, the proposed mitigation measures will maintain the current surface drainage pattern as far as possible at all stages of the quarry extension. Positive drainage measures[8] will be utilised to manage surface water over land that is underlain by the CBLF (i.e. the land beyond the perimeter of the quarry from which water may runoff or infiltrate directly to the quarry). The positive drainage will prevent concentrated infiltration of water to the shallow subsurface, which could otherwise result in additional pathways for shallow groundwater flow that could in time lead to ground instability.

During Stages 1 and 2 of the proposed quarry extension, new positive drainage around the overburden bunds will be formed as grassed channels. Beneath the grass, the channels will have a low permeability membrane that will prevent the concentrated infiltration of runoff to the shallow subsurface. The membrane will be at a depth such that sufficient soil is retained to maintain grass growth and to ensure the long-term integrity of the channels, thereby minimising the need for maintenance. Settlement ponds used during construction of the bunds will have a low permeability liner for the same reason.

The Alston stream will be diverted around the northwest corner of the overburden bunds in Stage 2, with control of the flow (i) to the west within a lined ditch and (ii) to the east by using pipe drainage that flows to an unlined section of the diversion (constructed along part of the eastern edge of the stage 1b bund). The unlined section of the ditch would allow infiltration to occur between the proposed extension and the groundwater catchment of the Goodstone springs and Kester Brook to the east and help to maintain the current groundwater divide in this area. Should the flow or infiltration in the unlined section of the ditch be insufficient to maintain the groundwater divide, the flow could be increased or this section of the diversion would be excavated to a depth of 2 m and backfilled with inert, granular material to increase the permeability of the stream bed.

Monitoring of Surface Water, Ground Water and Land Stability

Monitoring before, during and after the deepening and extension of the quarry provides a means of enhancing the hydrogeological conceptual model and the early identification of unexpected changes or effects on drainage, watercourses and potential sinkhole development.

There may be warning signs indicating the initiation and development of a new sinkhole such as tilting fence posts and trees, new depressions and cracks in the ground, new areas of ponding of rain, and in structures there may be visible damage resulting from structural distortion, such as new cracks in walls or around doors or window frames. To assist in gauging damage severity BRE Digest 251 ‘Assessment of damage in low-rise buildings with particular reference to progressive foundation movement’ [33] outlines three broad categories: ‘

- ‘aesthetic’, which affects only the appearance of a property.
- ‘serviceability’, which includes cracking and distortions that impair weathertightness or other functions.

[8] Positive drainage: Drainage with sufficient gradient and size to convey water away from the area being drained.

- 'stability', where there is an unacceptable risk that some part of a structure will collapse unless preventative action is taken.

Ongoing monitoring of surface water flows, inflows to the quarry, groundwater levels, the occurrence of a new sinkhole, or other changes to the surrounding land, (including new development or alterations to hedges/woodland that could affect the hydrological system), will also ensure continued improvement of the understanding of the relationship between surface water, groundwater and sinkhole development within the Land Stability Study Area. It will also further reduce residual uncertainty.

Therefore, in addition to the monitoring proposed by HIA 2020, land stability monitoring is proposed as part of the Karst Management Plan, comprising four sets of information gathering, as follows:

1. Liaison with interested parties: Liaison with local landowners, tenants and occupiers of surrounding agricultural and developed land situated on the CBLF within 1km of the planning application red line, for example via a Liaison Group, so that evidence of potential subsidence can be reported, inspected and documented, with identified sinkholes being classified if they form, prior to remediation if that is found to be required.

2. Ground surface monitoring: Inspection by engineering geologists/ geomorphologists undertaking regular field walkovers, observation, or survey of accessible land, particularly near watercourses, within the predicted maximum unmitigated extent of drawdown (see section 5 of HIA 2020). Field observations and Atkins' three-fold project-specific classification of sinkholes will form the initial basis of the monitoring, with refinement and updating of the map presented in Appendix D and the table presented in Appendix E. It is expected that monitoring will include recording indications of potential subsidence or sinkhole activity and updating Atkins' inventory of karst features and sinkhole occurrences on land near to the quarry. The frequency of inspection will depend in part on the information gained from local liaison, the programme of quarry development works, and observations from other monitoring:

    - An initial planned frequency of twice yearly: once in March to April at the end of winter before seasonal watercourses cease to flow, and once in September to November when seasonal watercourses are flowing again.
    - Atkins has also proposed, in response to the Regulation 22 Request, that an additional monitoring walkover is made between the twice yearly walkovers to specifically inspect the areas around those receptors that are denoted as 'medium' or 'high' risk in Table 6-5 below.
    - In addition, given the current uncertainty concerning the relationship between rainfall and the potential for sinkhole development within the Land Stability Study Area, monitoring visits are proposed after high rainfall events. As an initial guide high rainfall events will be those with a return period of 1 in 2 year or more severe (refer to Table 5-5 in the FRA for predicted rain versus storm duration). If no relationship between high rainfall evens and sinkhole development is established, such monitoring visits could be discontinued.

3. Groundwater monitoring: Ongoing monitoring of relevant groundwater inflows to the quarry during excavation. Changes in the groundwater inflow regime to the quarry may be an indicator of the activation of conduit flow (refer to Section 7 of HIA 2020 [9] for details of proposed hydrological monitoring).

4. Building surveys: As requested in the Regulation 22 Request and as a further precautionary measure, non-intrusive external structural survey of Lower Waye, Alston Farmhouse, Alston Cottage and properties within the hamlet of Caton (subject to landowner permission) will be undertaken prior to the commencement of quarrying in order to provide a record of their baseline structural condition against which to measure detected changes in condition thereafter. The buildings will be checked for visible damage resulting from structural distortion, such as cracks in walls, or around doors and window frames.

Reviews of Monitoring data and triggers for reassessment of land stability risk.

The quarry extension has a long timescale with several stages, which provide opportunities to review the hydrological and hydrogeological conceptual model, the understanding of land stability risk, the effectiveness of monitoring and mitigation, and the design and trigger levels for reassessment of receptors and update to the adaptive monitoring and mitigation programme, which would be subject to agreement by the Mineral Planning Authority before each stage progresses.

The Karst Management Plan proposes an annual integrated review of the ongoing monitoring of surface water flows, water quality, and groundwater levels in order to enhance the hydrological and hydrogeological conceptual model and improve the understanding of likely groundwater flow pathways between surface water (including springs), sinkholes, and the quarry. This can be done as part of the annual summary review proposed in HIA 2020 monitoring plan.

In addition the Karst Management Plan incorporates the monitoring and triggers for reappraisal envisaged in HIA 2020 reflecting the close relationship between hydrological and hydrogeological understanding and the assessment of land stability risk. This is equivalent to the periodic reviews and reassessments in response to a quarry monitoring and reporting planning condition that applies to limestone quarries elsewhere.

This approach means that those potential land stability impacts associated with karst which cannot be closed-out at the time of the decision on the planning application can be monitored and proactively managed. The interim results of ongoing monitoring, together with other mitigation measures if required, may be reviewed at defined stages of the proposed quarry extension as will be set out in the Karst Management Plan.

The proposed approach is broadly equivalent to the Review of Old Mineral Permissions (ROMP) procedure for the periodic review of mineral planning permissions contained in the Environment Act, 1995 [33], but provides the DNPA (as Mineral Planning Authority) with a means to reduce the 15 year interval between Periodic Reviews in the ROMPs regime if considered appropriate.

The periodic review approach mirrors that being taken at numerous limestone quarries elsewhere in the UK, including by Plymouth City Council as Mineral Planning Authority for Moorcroft Quarry, and Devon County Council for Stoneycombe Quarry. It is also incorporated into the adopted Plymouth and South West Devon Joint Local Plan in Policy PLY55[9], 'Hazeldene Quarry Minerals Safeguarding Area and buffer zone', an extract of which is provided below:

> "*Land at and to the north of the existing Hazeldene Quarry shall be safeguarded for the extraction of limestone aggregate… Proposals for extraction of aggregate should provide for:*
>
> *….*
>
> *5. An appropriate method of monitoring and review of the development's long term environmental impacts, which may otherwise be unforeseeable. This will be achieved either through only consenting development proposals for individual phases, the impacts of which are more reasonable to predict, or through a scheme of phasing and environmental review periods to monitor and manage potential environmental impacts which cannot be predicted at the time of granting consent".*

Sinkhole Repair

Currently, Class B or Class C sinkholes that develop on agricultural land are anecdotally understood to be filled in by the landowner, tenant or occupier. The infilling may not be well-planned or well-controlled and so in time further subsidence could reoccur.

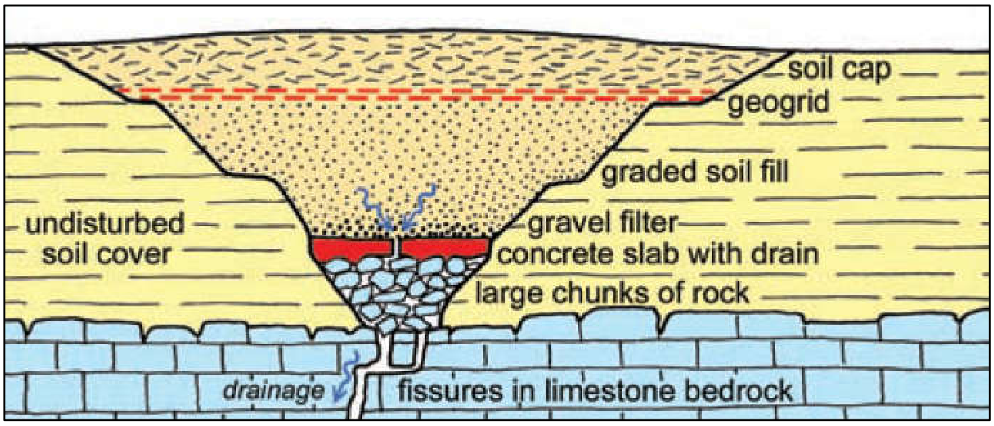
Ideally, if a developing sinkhole is identified, such as by the monitoring, its remediation should be implemented early, planned, controlled, and documented.

Investigation by appropriately experienced engineering geologists and geomorphologists should be carried out before a sinkhole is infilled. Once a sinkhole has been inspected, an appropriate remediation strategy should then be agreed and implemented. Remediation may entail changes to the local surface water drainage, though

[9] https://plymswdevonplan.co.uk/policy/so5/ply55

it may be acceptable simply to infill a sinkhole that is small, stable and located in agricultural or open land (i.e. where the receptor is of low sensitivity). Drainage enhancements and repair of the sinkhole and its effect may be necessary at a receptor of higher sensitivity (e.g. a road or building). A sinkhole located near a more sensitive receptor may require remediation similar to that shown in Figure 5-2. Potential effects on structures are likely to also require inspection by a structural engineer to determine the need for more detailed monitoring or appropriate repair of the structure.

Figure 5-2 Idealised schematic drawing of a sinkhole repair that prevents soil from entering the bedrock fissures, whilst allowing drainage without the diversion of water (Waltham [19])



Remediation of the type shown in Figure 5-2 is unlikely to be necessary in every instance of a new sinkhole. Instead, the approach to sinkhole remediation would be assessed on a case by case basis and will need the permission and cooperation of the landowner where that is possible.

Following restoration of the extended quarry, it is proposed that the water in the quarry will have an outflow route to the Balland Stream, with the outflow level and rate controlled so as to provide flood risk attenuation to Ashburton. HIA 2020 indicates that, for the envisaged control elevation of 96 to 97 mAOD (with storage above that level), the water level in the post-restoration void is close to, or slightly exceeds, late summer groundwater levels at the southern end of the proposed extension area. However, at the end of the winter recharge season the water level in the post-restoration void will be below groundwater level. At all times of the year, the water level in the post-restoration void will be above the base of the northeast face fracture and southeast face conduit. As such, inflows to the quarry are likely to be substantially reduced following restoration, leading to a much lower likelihood of effects on the nearby groundwater and surface water system, and a return to a natural system in dynamic equilibrium. The likelihood of a sinkhole occurring will then be more a function of future changes to either local drainage in the land surrounding the restored quarry or to climate change, for example as a result of more frequent high intensity or prolonged rainfall events.

6. Assessment of Residual Land Stability Risk

6.1. Approach

Risk can be defined as a combination of the likelihood of occurrence of a defined hazard, exposure to the hazard, and the magnitude of the consequences of the occurrence and exposure. A risk assessment evaluates the potential links between the hazard, exposure and receptor, based on the available information. The potential sources of land stability hazard in relation to the proposed quarry deepening and extension, and their mitigation, are described in the preceding sections, with receptor sensitivity and risk evaluated in this section below.

Potential sinkhole risk, (R), is function of the hazard (H), the exposure (E) to or likelihood of a hazard occurring, and the receptor sensitivity or vulnerability (V), and may be evaluated in qualitative terms, or in quantitative terms if suitable data is available (e.g. monetary valuation) from $R = \sum (H \times E \times V)$ [34].

The site-specific risk assessment described below has applied the general strategy outlined by Benson and Yuhr [18] whereby data from desk study and investigation has been obtained and used to identify and understand the main geological, hydrological and hydrogeological, and anthropogenic factors that may lead to surface subsidence or collapse associated with the karstic character of the CBLF and the effects of the quarry extension and deepening proposals. The information evaluated for this risk assessment has been assimilated and interpreted to assign a risk level as defined herein for specific receptors and areas, taking account of the mitigation measures set out in Chapter 5. The site-specific risk assessment has necessarily required professional judgement, which is supported by evaluation of the available information.

The risk assessment presented in Table 6-5 below provides a 'risk level' that in reality is approached incrementally, over a period of many years as the extent of the drawdown progresses outwards to its maximum extent from its current position. Between the start of the quarry expansion and the end of Stage 5, the risk level for individual receptors could gradually rise to the risk level given in Table 6-5. It is not possible to quantify at what point in the development the risk level may be reached. Ongoing monitoring and reporting throughout the proposed quarry extension, together with triggers for reassessments built into the HIA 2020 and Karst Management Plan will ensure proactive management of the identified residual risk and enable an appropriate response to this if it materialises and to residual risk elsewhere.

We have therefore referred to the risk level associated with the 'cumulative' impacts of the quarry extension proposals.

In stage 6, when the quarry is restored, the risk levels associated with the quarry extension proposals will no longer apply.

6.2. Potential Receptors

The focus for the assessment of potential receptors is twofold: those associated with proposed changes to surface water drainage and those within the maximum drawdown area in Figure 5-1 above.

Whilst previous comments from stakeholders have suggested the potential for impacts to more distant receptors, such as the Pridhamsleigh Caverns, 3.7 km to the southwest of the quarry, the available data show that current dewatering impacts are far more localised and that a variety of factors will constrain the extent of future drawdown, following proposed deepening and extension of the quarry (see HIA 2020 Sections 4.7 and 5).

The assessment of land stability risk is based on a detailed conceptual model of the site and multiple lines of evidence, including those set out in HIA 2020, it remains subject to residual uncertainty, therefore as a precautionary approach, the assessment of impacts and the Karst Monitoring Plan also considers potential receptors and includes monitoring in respect of receptors situated on the CBLF within 1km of the planning application red line[10]. This will be done via the Local Liaison Group.

The inclusion of groundwater monitoring locations to identify departures from the projected extent of drawdown (HIA 2020 Sections 6.3 and 7.4) addresses this residual uncertainty and takes a precautionary approach to managing potential impacts. This precautionary approach is reinforced by the proposed timescale for deepening and extension of the quarry which means that drawdown will occur incrementally, over a period of many years, allowing ongoing monitoring periodic reviews and reassessments of receptors and mitigation measures to identify and respond to unexpected increases in drawdown at an early stage.

LSRA 2020 identifies potential receptor locations and assigns an overall risk level for each location based on assessment of the current situation and site specific interpretation of the site data and the existing factors likely to affect sinkhole development together with the cumulative impacts of the quarry extension proposals and relevant mitigation measures.

The potential types of receptor are listed in the following table in order of increasing importance or sensitivity, for which Atkins has assigned relative terms as indicated.

Table 6-1 Receptor Importance/Sensitivity

Receptor / Land Use	Relative Importance / Sensitivity
Existing quarry rock extraction area	Minimal
Land and buildings used for agriculture or forestry, natural and semi-natural land, minerals processing.	Low
Non-residential commercial buildings and local infrastructure, e.g. services and minor roads (B roads or lesser classification).	Medium
Dwellings, A roads / Highways England network, and essential utility infrastructure.	High

6.3. Risk Matrix

This Land Stability Risk Assessment (LSRA 2020) utilises descriptions of relative terms for the consequence of a hazard (i.e. sinkhole subsidence) and the probability of an event occurring. Using a risk assessment matrix, it provides an evaluation of the risks and takes account of the mitigation measures included as part of the quarry extension proposals.

"Predictions of the locations of caves or potential sinkhole sites are next to impossible" (Waltham [2]). However, it might be possible to estimate the probability of a sensitive receptor, such as a dwelling, being within the perimeter of a new sinkhole by considering a range of foreseeable sinkhole diameters and the potential for their occurrence within a property, and then estimating the probability of consequent events such as one of the categories of subsidence damage in the BRE Digest 251, [35] and the probability of harm (i.e. fatal injury). Such an estimation would be likely to indicate a very low probability of occurrence for rural areas with a low density of dwellings compared with more urban areas where the density of dwellings is higher (such as Ashburton). There would, however, be some conjecture regarding sinkhole scale and it would not include spatial prediction, nor would it predict the timing of a potential event or the effect of existing drainage systems.

Therefore, Atkins has applied a simpler approach that combines the hazard and available evidence of likelihood into a single rating, as shown in Table 6-2 (this approach is adapted from that published by Farrant and Cooper [24] of the British Geological Survey).

[10] This incorporates the groundwater monitoring locations proposed in Section 7 of HIA 2020, for potential receptors within 1km of the maximum drawdown extent without mitigation,

Table 6-2 Description of hazard ratings for soluble rocks and indicative implications for end users (based on Farrant and Cooper [24]; Atkins' additions shown in red)

Atkins' modified characteristics for Linhay Hill Quarry and surroundings	Atkins' hazard rating	Hazard rating	General characteristics	Indicative implications for					
				Planners	Developers / Geotechnical Engineers	House holders	Insurance / Financial Institutions	Environmental Health / Waste disposal	Farmers and Estate managers
Areas where significant soluble rocks are present, but no reported subsidence.	A	1 or A	Areas where soluble rocks are present, but unlikely to cause problems except under exceptional conditions	No constraints to land use due to land instability within site.	Normal desk study and walkover survey of site.	No maintenance or use implications due to land instability.	No increased cost due to land instability present.	Possible concern about groundwater contamination.	No restrictions on land use due to land instability, concerns about groundwater contamination.
Areas with significant soluble rocks, but few reported dissolution features and instances of subsidence.	B	2 or B	Areas with significant soluble rocks, but few dissolution features and no subsidence; unlikely to cause problems except with considerable surface or subsurface water flow.	No constraints to land use due to land instability within site.	Normal desk study and walkover survey of site. Consideration of stability of site surroundings	No maintenance or use implications due to land instability	Increased cost due to land instability likely. Slight liability due to groundwater pollution possible.	Concern about groundwater contamination	No restrictions on land use due to land instability, concerns about groundwater contamination.
Areas with significant soluble rocks, where there are some reported dissolution features and instances of subsidence.	C	3 or C	Areas with significant soluble rocks, where there are dissolution features, and no or very little recorded subsidence, but a low possibility of it occurring naturally or in adverse conditions such as high surface or subsurface water flow.	Report on implications for stability should be submitted if changes to surface drainage or new construction are proposed.	Site investigation should consider specifically the land stability of the site and surroundings. Care should be taken with local drainage into the bedrock.	Consideration of implications for stability should be made if changes to surface drainage or new construction are planned.	Increased cost due to land instability possible. Some liability due to groundwater pollution possible	Potential for site integrity to be damaged by minor ground movements Concern about groundwater contamination.	Consider minor changes in land use, surface run- off and drainage to prevent groundwater contamination and reduce the likelihood of subsidence.
Areas with significant soluble rocks, where there are many reported dissolution features and instances of subsidence.	D	4 or D	Areas with very significant soluble rocks, where there are numerous dissolution features and/or some recorded subsidence with a moderate possibility of localized subsidence occurring naturally or in adverse conditions such as high surface or subsurface water flow.	Land use changes involving, loading, infilling, excavation or Changes to surface drainage may affect stability and assessment/mitigation measures should accompany application. Conservation measures should be considered.	Specialist site investigation for stability assessment might be necessary before construction. Construction work might cause subsidence. Surface drainage should not be allowed to affect the karst system or groundwater.	Do not load the land and obtain specialist advice before undertaking building work. Do not dispose of surface drainage to the ground. Maintain drainage infrastructure.	Increased cost due to land instability probable. Liability due to groundwater pollution possible.	Possible damage to contaminative structures, tanks, drainage, sewers, pipelines, etc. Inspection of structures recommended. Areas prone to pollution and groundwater contamination	Consider some changes in land use, surface run- off and drainage to prevent groundwater contamination and reduce the likelihood of subsidence.
Areas with significant soluble rocks, where there are numerous reported dissolution features and instances of subsidence.	E	5 or E	Areas with very significant soluble rocks, where there are numerous dissolution features and/or considerable recorded subsidence with a high possibility of localized subsidence occurring naturally or in adverse conditions such as high surface or subsurface water flow.	Land use changes involving, loading, infilling, excavation or changes to surface drainage may affect stability. Permission for development might require investigation and remedial works as part of development. Permission for development might not be possible. Conservation measures should be considered.	Specialist land stability assessment necessary. Investigation, remediation and/or mitigation works might be necessary to stabilize the area. Construction work might cause subsidence. Surface drainage must not affect the karst system or ground-water.	Consider obtaining specialist advice to advise on need for stabilization work and/or land management plan to maintain stability. Do not dispose of surface drainage into the ground. Maintain drainage infrastructure.	Increased cost due to land instability very probable. Liability due to groundwater pollution probable	Significant possibility of damage to contaminative structures, tanks, drainage, sewers, pipelines, etc. Regular inspection of structures recommended. Areas very prone to pollution and groundwater contamination.	Consider major changes in land use, surface run- off and drainage to prevent groundwater contamination and reduce the likelihood of subsidence.

The hazard consequence of potential subsidence is further defined in Table 6-3 below, which is consistent with that defined in Table 1 of LSRA 2016, and which broadly aligns with the categories of damage outlined in BRE Digest 251 [35], including the Digest's Table 1 '*Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry*'. Vulnerability to damage will depend on a structure's construction, the ground movement, resulting ground slope and horizontal strain. Precise damage prediction is therefore not possible because of uncertainty about actual ground and structure behaviour. Nevertheless, for the low-rise structures present within the study area damage due to sinkhole subsidence (if it occurs) is likely to be repairable. Serviceability effects are considered a more foreseeable consequence based on the data obtained for the LSRA.

Table 6-3 Subsidence Consequences

Consequence of Hazard	Description for Buildings and Infrastructure	Indicative Equivalence to BRE 251
Very Minor	Very slight damage that can be easily treated during normal decoration. No significant damage to services or infrastructure.	BRE 251 Table 1 Category 0 or 1 i.e. 'Aesthetic' effects.
Minor	Easily repairable effects of damage to buildings. Slight damage to services or infrastructure.	BRE 251 Table 1 Category 2 i.e. 'Aesthetic' effects.
Serious	Damage requiring repairs such as brickwork replacement. Service pipes may fracture.	BRE 251 Table 1 Category 3 i.e. 'Serviceability' effects.
Severe	Major damage requiring extensive repair work such as breaking out and replacing sections of buildings and underpinning. Disruption to service pipes.	BRE 251 Table 1 Category 4 i.e. 'Serviceability' effects.
Very Severe	Irreparable damage involving partial or complete rebuilding. Severe damage to services or infrastructure.	BRE 251 Table 1 Category 5 i.e. 'Structural' effects.

An overall risk level, as presented in Table 6-4, has then been assigned for receptor locations based on Atkins' assessment of the existing situation, site-specific interpretation of the site data, and the factors likely to affect sinkhole development, together with the cumulative impacts of the quarry deepening and extension proposals and mitigation as described in Table 6-5.

Table 6-4 Risk Level Categories

Risk Level	Risk Description (as a consequence of the proposed quarry expansion, see Figure 5-1 herein)
None	Surface subsidence will not occur because there will be no change from the current (baseline) in the surface water and groundwater conditions.
Negligible	Surface subsidence is very unlikely to occur.
Low	Surface subsidence is unlikely to occur.
Medium	Surface subsidence may occur.
High	Surface subsidence is imminent
Very High	Surface subsidence or collapse is actively occurring

6.4. Risk Assessment with Mitigation

Adopting the approach described above, an assessment of the land stability risk after application of the mitigation measures is provided below for receptors underlain by the buried karst of the CBLF up to 1km beyond the application red line area. Where a potential receptor is very close to a receptor of lower sensitivity, such as a dwelling close to outbuildings or agricultural buildings, only the receptor with the highest sensitivity has been assessed.

The receptors are listed in order beginning with the existing quarry and application site and then receptors situated on the CBLF within 1km of the application red line progressing clockwise from the area in the eastern end of Ashburton, starting with those within the projected maximum mitigated drawdown area and then those beyond it.

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Table 6-5 Assessment of Land Stability Risks

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Existing quarry rock extraction area	Minimal	A	Karst features are observable and encountered but surface water drainage is direct to the bedrock. Operational health and safety management in place. Within the quarry's current drawdown area.	Very Minor	Localised deepening. Mitigation is by operational health and safety management.	Negligible
Existing quarry processing and maintenance areas	Low	A	Karst features are observable and encountered but surface water drainage is direct to the bedrock or to a positive drainage system. Operational health and safety management in place. Within the quarry's current drawdown area.	Minor	No change. Mitigation is by operational health and safety management.	Negligible
Balland Lane widening	Medium	A	The existing lane does not have positive drainage, though some runoff from the existing lane (upstream of the Balland Stream) will flow to the Balland Stream, whereas in high rainfall events excess runoff contributes to flooding in Balland Lane downstream. Based on the ground elevations and on observations of the Balland Stream immediately downstream of Linhay Hill Quarry through Rockpark Cross playing field, water within the stream is more likely to infiltrate to groundwater rather than receive baseflow from groundwater in the limestone, and groundwater levels are likely to reflect the existing quarry operation. Within the quarry's current drawdown area.	Minor	Increased hard surface area. Mitigation will be by upstream catchment attenuation to ensure no increase in flow in the Balland Stream. The widening will have positive drainage and the works will be carried out to Devon County Council standards.	Negligible

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Waye Lane Public Road and Footpath (western edge to approx. chainage 200)	Medium	A	Natural surface water runoff by overland flow occurs at present. The western end to chainage 200 lies within the quarry's current drawdown area. The rest of the Waye Lane route lies beyond and is not on the limestone.	Minor	Introduction of impermeable road surface. Mitigation will be by upstream catchment attenuation to ensure no increase in flow in the Balland Stream. The new road will have positive drainage and the works will be carried out to Devon County Council adoptable standards.	Negligible
New access route to Alston Farm and Alston Cottage from Chainage 350	Low	C / D	Evidence of nearby sinkholes in the farm fields where existing drainage is mainly infiltration and overland flow. Evidence from geophysical survey and boreholes that there is likely to be several metres of superficial deposits. Groundwater levels are variable within the superficial deposits and limestone. From chainage 350 lies within the quarry's current drawdown area. The rest of the access route lies outside and is not on the limestone.	Minor	Introduction of impermeable surface on a new private access route to only two properties, as such vehicle movements are limited. Road design and construction would take account of the local ground conditions. Mitigation will be by positive drainage to existing drainage routes to reduce the potential for concentrated infiltration forming new subsurface pathways.	Medium

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Stage 1 – 5 Quarry extension area and operation	Low	C / D	Evidence of a variable thickness of superficial deposits and a likely irregular rockhead profile. Groundwater levels are variable within the superficial deposits and limestone. Sinkholes have been observed near the northern extent of the limestone, with the low permeability Tavy Formation present to the north. Also associated with surface water drainage, including changes to the route of the Alston stream. Existing drainage is by infiltration, overland flow and ditches adjacent to hedge-lines. Apart from a small part of stage 4, this area is within the quarry's current drawdown area. There is potential for enhanced flow rates through conduits or fractures into the quarry.	Very Minor	Staged removal of superficial deposits and subsequent staged extraction of limestone in benches and dewatering as extraction void deepens. The whole of this area lies within the projected maximum extent of the drawdown area associated with the quarry extension proposals. Mitigation will be by controlling the drainage utilising existing surface water drainage routes, and the monitoring proposed in the Karst Management Plan. .	Low

Overburden bund formation	Low	C	Evidence of a variable thickness of moderately permeable superficial deposits with an irregular rockhead profile and observed sinkholes, including a swallow hole along the route of the watercourse (Alston stream) fed mainly by springs in Alston Wood and a Class A sinkhole exists on the western side of the stage 1b bund. Groundwater levels are variable within the superficial deposits and limestone. Beyond the quarry's current drawdown area.	Minor	Increase in ground loading from placement of the overburden soils to form the bunds. Basal and perimeter drainage and diversion of seasonal Alston stream. The anticipated increase in ground loading is not expected to cause land instability from collapse into a potential void in the limestone bedrock. With the exception of the northeasternmost part of the stage 2a bund, the footprint of the bunds is within the projected maximum extent of the drawdown area associated with the quarry extension proposals. Mitigation will mainly be by controlling the drainage such that infiltration beneath the bund(s) footprint will be plane / diffuse, similar to the existing situation. New linear positive drainage routes around the bunds and settlement ponds used during construction will be lined to prevent concentrated infiltration of surface water. Sinkhole repair will be carried out for the Alston stream swallow hole. The final form of the repair will be dependent on the findings of monitoring carried out until the repair is necessary for the formation of overburden bunds in Stage 2b (year 16).	Low

Diverted Alston stream	Low	C / D	A cluster of sinkholes has been recorded in the vicinity of a swallow hole along the present route of the watercourse. It seems likely that these formed as a result of suffosion and collapse at depth, due water entering the ground along the Alston stream via the stream's bed and via the swallow hole. Groundwater levels are variable within the superficial deposits and limestone. Beyond the quarry's current drawdown area.	Minor	Prior to construction of the stage 2b bund, the Alston stream will be diverted around the west of the bunds via pipe and ditch lined with low-permeability material, and to the east via a pipe to an unlined section to be constructed along part of the eastern edge of the stage 1b bund. The rate of flow to the east will be controlled for infiltration along the unlined section to help maintain the groundwater divide in this area. With the exception of the northeasternmost part of the stage 2a bund, the footprint of the bunds is within the projected maximum extent of the drawdown area associated with the quarry extension proposals. Groundwater levels are variable within the superficial deposits and limestone. Mitigation will be primarily by this drainage control and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan. Regular observation and the stream flow controlled and rate of infiltration managed by design of the soil / filter material within the unlined section. The existing swallow hole and associated sinkholes will be repaired as noted in the row above.	Medium

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Eastern end of Ashburton i.e. Part of Dartmoor Community College and Linhay Business Park and along the B3352 road	Dwellings = high Other receptors = Medium	A	Comprising part of the buildings of the South Dartmoor Community College and its playing fields, together with Linhay Business Park mainly developed since the early 1990s. Some dwellings at the north end of Long Park and opposite the entrance to the Linhay Business Park. Near the northern margin of the limestone and within the quarry's current drawdown area. The area is expected to have positive drainage, though at the college substantial buildings exist some of which use soakaways. Ground investigation in 2014 for new development at the college showed superficial deposits to at least 6.45m below ground level. Surface water conveyed to infiltrate to ground via a large soakaway in west end of the business park and the use of soakaways elsewhere. No known reported subsidence. For the ground elevations and based on observations of the Balland Stream through this area, water in the stream is more likely to infiltrate to groundwater rather than receive baseflow from the limestone; and groundwater levels are likely to reflect the existing quarry operation.	Very Minor	Extended period of dewatering, but the drawdown area is not anticipated to extend further in this direction as a result of the quarry extension proposals. Mitigation will be primarily by controlling the drainage from the Balland Lane Widening and the new Waye Lane Public Road and Footpath and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan.	None

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Dwellings at Lower Waye	High	B	Located on the northern margin of the limestone. Rockhead is expected to be shallow and historical maps show some of the buildings have been present for more than a hundred years. The dwellings at Lower Waye lie within the quarry's current drawdown area. Groundwater levels are variable within the superficial deposits and limestone, and will reflect the existing quarry operation. Current mitigation is by operational health and safety monitoring e.g. of ground vibration due to blasting.	Serious	Extended quarry extraction area with associated dewatering, but the drawdown area is not anticipated to extend further in this direction as a result of the quarry extension proposals. Mitigation will be by drainage control for the new access to Alston Farm and Alston Cottage and the new Waye Lane Road off Alston Lane, combined with the monitoring feedback and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan.	Low

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Alston Farmhouse and Alston Cottage	High	B	Located on the northern margin of the limestone with the lower permeability Tavy Formation to the north. Alston Cottage lies within the quarry's current drawdown area. Alston Farmhouse lies outside the quarry's current drawdown area. Surface water is from springs in Alston Wood and farmland to the north. Geophysical survey and boreholes indicate several metres of superficial deposits and there is evidence of sinkholes nearby in the farmland. Groundwater levels are variable within the superficial deposits and limestone. Infiltration drainage is utilised, but historical maps show the buildings have been present for more than a hundred years. Alston Barn has a waterwheel that extends into a pit, which is anecdotally understood to have pipe drainage to the farm fields south or west of the farmhouse There has been no known subsidence at Alston Cottage and Alston Farmhouse. A cluster of sinkholes (Numbers 5, 6 and 7 on Figure 3-3) are present in a field to the west of the farmhouse.	Serious	New access route provided with slight local increase in impermeable surface area, and extended quarry extraction area with associated dewatering. Alston Cottage will be close to the edge of the quarry void in stages 3 and 4 of the quarry extension. Alston Farmhouse is about 100m from the stage 4 quarry edge, and anticipated to lie close to the edge of, but within, the projected maximum extent of the drawdown area associated with the quarry extension proposals. Drawdown at the edges of the drawdown area are anticipated to be significantly less than existing ongoing naturally occurring seasonal fluctuations. Mitigation will be mainly by drainage control for the new access to Alston Farm and Alston Cottage and the new Waye Lane Road off Alston Lane, and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan.	Alston Cottage = Medium Alston Farmhouse = Low

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
The western side of Caton Lane south of the entrance to Underway	Medium for lane, High for the gardens of dwellings	B	Lies outside the quarry's current drawdown area. Geophysical surveys indicate a generally shallow depth to limestone bedrock, however boreholes indicate more variability with locally thick superficial deposits. Groundwater levels are variable within the superficial deposits and limestone. There is some evidence of sinkholes to the east, possibly related to the Caton stream swallow hole and/or high surface water runoff. There is no positive drainage of the road. Groundwater in this area is below the elevation of the Caton stream, hence stream water is likely to infiltrate to the superficial deposits and the limestone.	Minor	Extended quarry extraction area with associated dewatering and overburden bunds between the extended extraction area and Caton Lane. The edge of the projected extent of drawdown associated with the quarry extension proposals is anticipated to reach the western side of the southernmost part of Caton Lane when it reaches its maximum. Drawdown at the edges of the drawdown area are anticipated to be significantly less than existing naturally occurring seasonal fluctuations. Mitigation comprises the balancing pond and unlined portion of the diverted Alston stream, drainage control around the overburden bunds, and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan.	Low

A38	High	B	The highway traverses the central area of the limestone from southwest to northeast, on embankment from Alston to Caton and in cutting elsewhere. A length of some 1.5 km of the A38 lies within the quarry's current drawdown area. Geophysical surveys, boreholes, observations at the quarry, and records of works at Goodstone Cross indicate that rockhead is likely to be irregular with variable thickness superficial deposits, which are locally more than 10 m thick. There is a cluster of sinkholes within the Class A sinkhole adjacent to the slip road at Goodstone Cross associated with A cavity was encountered south west of the quarry during construction of the A38, and reportedly partially infilled with concrete. Basal embankment layers will have utilised an engineered fill, though the contract drawings also show variation in the sub-base thickness. The highway will have intercepted natural drainage, and mainly uses positive drainage, though infiltration occurs along drainage on the north side of its embankment and through the grassed central reservation between Ashburton and Caton. Following its construction, the A38 dual carriageway has coexisted with that existing infiltration drainage and dewatering of the quarry to its current extraction area. There are no known subsidence effects on the A38 reported as being attributed to the quarry operation.	Serious	Extended quarry extraction area with associated dewatering and overburden bunds between the extended extraction area and Caton. A further 350 m of the A38 eastwards will come within the projected maximum extent of the drawdown area associated with the quarry extension proposals. Mitigation will be by drainage control around the quarry and the overburden bunds, and the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan. Quarry slope construction will adhere to the design within the Environmental Statement Appendix Chapter 3 Appendix 3A Site Investigation and Design Report by Sandybed Geological Services. The quarry extension's south east face will be further from the A38 than the south east face in the existing quarry. For south east faces i.e. parallel to A38, that design utilises parameters based on a report on the slope stability of existing and proposed workings prepared by Engineering Geology Ltd. in 1987. Hence, the stability of the quarry slopes is proven by the existing quarry workings, and will be subject to regular inspections as required by the Quarries Regulations 1999.	Low

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Dwellings south of the A38 along Caton Lane and Gale Road east of Mead Cross	High	B	The dwellings are near the southern margin of the limestone, with the lower permeability Foxley Tuff Formation to the south. Outside the quarry's current drawdown area. There is no positive drainage and some evidence of sinkholes nearby. Some of the buildings have been present for more than a hundred years and there is no reported damage to buildings as a result of sinkhole development.	Minor	Extended quarry extraction area with associated dewatering. The edge of the projected extent of the drawdown area associated with the quarry extension proposals is anticipated to reach the dwellings when it reaches its maximum. Drawdown at the edges of the drawdown area are anticipated to be significantly less than existing ongoing naturally occurring seasonal fluctuations. Mitigation will be by the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan. .	Low
Dwellings on Gale Road, Mead Garage and Mead Storage	High, medium for other buildings	B	Located near the southern margin of the limestone, with the lower permeability Foxley Tuff Formation to the south. Mead Garage, Mead Storage and 1 km of Gale Road lie within the quarry's current drawdown area. The Kester Brook flows seasonally in open drainage north of the road i.e. between the properties, and the A38 and the quarry and its proposed extension.	Minor	Extended quarry extraction area with associated dewatering, but the drawdown area is only anticipated to extend a short further in this direction as a result of the quarry extension proposals. No additional properties are likely to be included. Mitigation will be by the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan.	Low

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Dwellings within the hamlet of Caton	High	B	On the central area of the limestone, generally gently sloping land. Geophysical surveys suggest relatively shallow depth to the limestone bedrock, but boreholes indicate variability with locally thick superficial deposits. Groundwater is below the elevation of the Caton stream hence it is likely to infiltrate to the superficial deposits and the limestone. There is some evidence of sinkholes to the east, possibly related to Caton stream sink and/or high surface water runoff. There is no public drainage for foul or surface water in the hamlet of Caton, and foul and surface water enter the ground via septic tanks and soakaways respectively. It is likely that the proportion of rainfall entering the ground has been increased by the use of soakaways, which concentrate infiltration of rainwater into a smaller area and reduce its evaporation and runoff. Some buildings have been present for more than a hundred years and there is no known reported building subsidence. Outside the current extent of the quarry's drawdown area.	Minor	Extended quarry extraction area with associated dewatering and overburden bunds. Caton lies just beyond the eastern edge of the projected maximum mitigated extent of drawdown associated with the quarry extension proposals. Mitigation comprises the balancing pond and unlined portion of the diverted Alston stream, drainage control around the overburden bunds, and the monitoring, periodic reviews and reassessments proposed in the Karst Management Plan, including external structural surveys.	None

Receptor	Receptor importance / sensitivity	Atkins' hazard rating for existing situation	Existing factors likely to affect the local occurrence of sinkholes	Hazard consequence	Quarry extension proposals and mitigation	Risk Level after mitigation
Other areas on the limestone within 1km of the application red line	High for dwellings, medium for other buildings	A-D	In the built up areas of Ashburton and along the B3352, many buildings have existed for more than a hundred years within the area of the limestone; and since the early 1960s there has been extensive development north of the B3352 (i.e. closer to the northern margin of the limestone). The area is expected to have positive drainage, though there may be use of soakaways but no known reported building subsidence. Elsewhere there is a mixture of longstanding and more recent development, and, apart from roads, there is less likely to be positive drainage. Outside the quarry's current drawdown area.	Minor	No anticipated impact, the area lies outside the projected extent of drawdown associated with the quarry extension proposals. Mitigation will be by the monitoring and periodic reviews and reassessments proposed in the Karst Management Plan to address residual uncertainty.	None

7. Summary and Conclusions

7.1. Overview

Linhay Hill Quarry works a southwest to northeast trending outcrop of the Chercombe Bridge Limestone Formation (CBLF) that has been subject to karst weathering (dissolution) processes forming a variety of karst features in geological time, with the karstic rockhead topography buried under superficial deposits. Buried karst terrain also exists in several other Devonian limestone deposits, including those quarried elsewhere in south Devon.

Desk study and walkover engineering geological and geomorphological surveys have confirmed the presence and indicated the spatial distribution of karst features such as sinkholes. As sinkholes can cause subsidence, Atkins' Land Stability Risk Assessment has considered the likelihood of further sinkholes being caused by the quarry extension as a result of the quarry's operational dewatering in the extension area and in the base of the deepened quarry, as well as by quarry construction activities that require changes to the existing surface water drainage and loading of the ground by bunds of excavated overburden. Potential receptors, such as buildings and roads, have been identified and their land stability risk assessed in the light of the proposed mitigation measures.

7.2. Geological context and study area

The outcrop of the CBLF covers an area of some 350 ha, extending from Ashburton to Bickington, with the quarry located north east of Ashburton where the outcrop is at its widest (some 1000 metres northwest to southeast).

In plan, the quarry's footprint is narrower than the outcrop, lying between the A38 dual carriageway to the southeast and the geological boundary between the CBLF and the Tavy Formation to the north. The Tavy Formation is slate and mudstone of low permeability. South of the CBLF is the Foxley Tuff Formation which also has low permeability. Further to the north is the Crackington Formation and further south is the Gurrington Formation, both of which are more permeable than the strata adjacent the CBLF, and from which springs arise and that water flows overland often to the CBLF. For this study, a Land Stability Study Area has been defined by reference to the extent of the Chercombe Bridge Limestone Formation and the surrounding topography.

7.3. Karst hazards in limestones

In karst terrain, the concentration of drainage input at the ground surface or within the ground is likely to trigger the development of a new sinkhole. For example, Waltham [2] comments that *"almost any means by which a new or increased flow of water can pass through a soil cover into underlying fissured limestone, and thereby carry soil away, is likely to form a subsidence sinkhole".*

The lowering of the ground water level within the karst, such as by pumping from an excavation, can also cause a new sinkhole to develop, as described by the British Geological Survey [8]: "*Karst environments are sensitive to anthropogenic impacts, e.g. as a consequence of groundwater lowering to exploit minerals beneath the water table; by focusing flow through drainage and point discharge, or by diverting flow paths*."

7.4. Hydrogeology and hydrology

Groundwater flow within the CBLF is primarily controlled by karst conduits, with less flow occurring in the network of widened fractures.

As the vertical hydraulic connectivity within the CBLF is low, the deep dewatering from the quarry's sump, which accounts for most of the inflow to the quarry, is unlikely to be a direct, rapid, or primary cause of subsidence.

The available groundwater data and site observations, together with the projected extent of drawdown associated with the quarry extension proposals, show that the extent of potential land stability effects from dewatering is likely to be limited, with a new sinkhole more likely to be triggered by an excess rather than deficit of surface water. Concentrated infiltration of water to the superficial deposits can occur from existing watercourses, ponds and drainage at Alston Farm (the Alston stream) and at Caton (the Caton stream) and water flowing adjacent to and under the A38 dual carriageway. Natural fluctuations in surface water flows, recharge, and shallow groundwater levels may lead to ground subsidence that is not related to the dewatering of the extended or deepened quarry.

As described above and in HIA 2020, within the projected extent of maximum drawdown area, a steep cone of depression is anticipated around the quarry faces, with drawdown of less than 10 m beyond the extended quarry boundaries, reducing to negligible drawdown at the edges of the maximum drawdown area. For context, groundwater levels in the CBLF naturally vary by about 10 m throughout the year in response to variations in rainfall and near-surface evaporation. Drawdown from the quarry extension and deepening is therefore likely to be most in the winter, when groundwater levels are at their highest anyway, and normal summer groundwater levels already some 10m below this.

This leads to the conclusion that dewatering causing a change in general groundwater levels is unlikely to add to that source of land stability risk within the inferred maximum extent of groundwater drawdown.

7.5. Land stability within the study area

As is well-documented in the published literature and is demonstrable on site from the occurrence of sinkholes around the Alston stream swallow hole following the realignment of the stream, and observations of other sinkhole clusters, that unmanaged changes to surface water are the primary trigger for the occurrence of sinkholes.

From evaluation of the load on the ground of the proposed overburden bunds it is concluded that formation of a collapse sinkhole due to failure of the limestone bedrock into an existing cavity is unlikely. Collapse of the limestone bedrock has not occurred at the quarry and it is not known to have caused subsidence of structures elsewhere over the CBLF's outcrop, including along the A38 dual carriageway.

7.6. Proposed mitigation

Mitigation is proposed in a Karst Management Plan comprising drainage design and control, monitoring and reporting and sinkhole repair. In addition, the balancing pond and unlined ditch for infiltration of controlled flow from the Alston stream proposed in HIA 2020 are complementary to managing the land stability, because they are designed to maintain the current groundwater divide in the northeast of the extension area, thus reducing the extent of the maximum drawdown area associated with the cumulative quarry extension and deepening.

The proposed monitoring will help ensure that a developing sinkhole hazard, if one occurs, is identified at an early stage, thereby enabling timely corrective action to be taken as necessary. Whilst being focussed on the application area as a precaution to address residual uncertainty the monitoring proposals will include observing for potential precursors of surface subsidence in the CBLF within 1km of the application red line alongside liaison with interested parties in the Karst Management Plan.

This precautionary approach is reinforced by the proposed timescale for deepening and extension of the quarry which means that drawdown will occur incrementally, over a period of many years, allowing ongoing monitoring periodic reviews and reassessments of receptors and mitigation measures to identify and respond to unexpected increases in drawdown at an early stage.

Should a new sinkhole occur, then the mitigation response could range from no action or its simple infilling where the receptor is of low sensitivity (e.g. agricultural land) to the need for drainage enhancements and repair of the sinkhole and its impact at a receptor of higher sensitivity (e.g. a road or building).

7.7. Residual land stability risk

As the primary trigger for sinkhole subsidence is the drainage of surface water, the development proposals are designed to avoid poorly managed changes to surface water drainage and to maintain the current groundwater divide in the extension area.

Following the implementation of the proposed mitigation measures, the residual land stability risk due to the karstic nature of the CBLF is the uncertainty regarding the likelihood of a new sinkhole occurring, or its location, timing or severity, because the location and geometry of the karst (including its conduit system) will always be largely unknown. There could be localised areas with a higher frequency of buried karst features which will have a greater potential for future sinkhole occurrence may be present., but the development proposal by design can avoid poorly managed changes to surface water drainage that are the primary trigger for sinkhole subsidence.

Receptors where there is some assessed residual risk following implementation of the drainage and drawdown mitigation are:

- Existing quarry extraction and processing areas: Negligible residual risk
- Stages 1 to 5 quarry extension area, and the overburden bund area: low residual risk.
- Balland Lane and Waye Lane; Negligible residual risk
- Diverted Alston stream: Medium residual risk
- Part of the proposed access route to Alston Farm and Alston Cottage: medium residual risk.
- Alston Cottage: Medium residual risk
- Dwellings at Lower Waye, and Alston Farmhouse: Low residual risk.
- Caton Lane, including to the south of the A38: low residual risk.
- The A38: low residual risk.
- Dwellings south of the A38 along Caton Lane and Gale Road: low residual risk.
- Dwellings on Gale Road, Mead Garage and Mead Storage: low residual risk.

The assessment identifies a risk level that will be approached incrementally, over a period of many years as the quarry extension proposals progress. Between the start of the quarry expansion and the end of Stage 5, the risk level for individual receptors may gradually rise to this identified risk level. Although it is not possible to quantify at what point in the development the risk level may be reached, it can be said that it will be in the latter stages of the quarry proposals, by which time ongoing monitoring and reporting, together with triggers for reassessments built into the HIA and Karst Management Plan will assist in the active management of the identified residual risk and enable an appropriate response to this if it materialises and to possible residual risk elsewhere.

In Stage 6, when the quarry is restored, the risk levels associated with the quarry extension proposals will no longer apply.

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Appendices

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