CEMEX UK Operations Ltd

Raynes Quarry: Hydrogeological Impact Assessment

Report prepared by:

T Sibanda BSc MSc CEnv CSci MCIWEM

Principal Hydrogeologist

Geological Services Department

CEMEX UK Operations Ltd

Wolverhampton Road

Oldbury

West Midlands

B69 4RJ

Report prepared for:

CEMEX UK Materials Limited

Raynes Quarry

Abergele Road

Llysfaen

Colwyn Bay.

LL29 9YW.

Signed:

Date: July 2011

Report Reference:

SH8878 TS 220711

CONTENTS

FIGURES

TABLES

PHOTOGRAPHS

APPENDICES

Front cover photograph

The photograph shows the north-western face of the quarry. Water which accumulates at the quarry floor mainly result from direct rainfall contribution and surface runoff from the surrounding high ground. Some of the water comes from seepage along bedding planes on the quarry face.

1. INTRODUCTION

CEMEX UK Materials Ltd. is required under the auspices of the Environment Act 1995 to Review its planning permission for the winning and working of minerals for Raynes Quarry (often known as a ROMP). A hydrological and hydrogeological impact assessment is to feed into an Environmental Impact Assessment (EIA) of the Company's submission pursuant to the Review process. The report addresses the potential impacts on the local hydrogeological and hydrological environment of working the mineral for the proposed five year development plan.

1.1 Regulatory Correspondence

Following on to the submission of the Environment Statement in support of the ROMP application in August 2009, the Environment Agency Wales (EAW) in their letter to CEMEX (Appendix D) recommended that a groundwater level monitoring scheme be established for the site to support the Hydrogeological Impact Assessment. CEMEX acknowledged that a groundwater monitoring scheme would be required to provide hydrogeological data in support of any future deepening or lateral extension proposals for the quarry. CEMEX submitted a groundwater monitoring proposal (Appendix E) to the Environment Agency Wales in December 2009 for their comments. The EAW approved the monitoring scheme in an email to CEMEX dated 18th December 2009. The approved groundwater level monitoring scheme was implemented in March 2010. In response to further comments provided by the Environment Agency Wales on the dewatering pumping rates, a telemetry flow meter was installed on the dewatering pump to accurately monitor the pumping rates. Information on private water supplies was obtained from the Conwy County Borough Council.

2. SITE LOCATION AND DESCRIPTION

Raynes Quarry is located approximately 1.5km to the east of the centre of Old Colwyn and approximately 1.5km to the west of Llanddulas, in Conwy County Borough, as shown in Figure 1. The village of Llysfaen is located approximately 1.0km to the south. The A547 runs east-west through the quarry area separating the main excavation area to the south from the main plant area to the north. A tunnel passes under the A547 linking the two areas. The new A55 dual carriageway lies immediately to the north of the plant area and separates the plant area from the coast. The National Grid Reference for the centre of the quarry is SH 889781.

A detailed topographical survey and the principal features of the quarry are shown on Drawing *Site BH 1110.*

The quarry exploits Carboniferous Limestone, processing of which is undertaken on site. The limestone is excavated by drill and blast, and transferred to the processing area using loading shovels or hydraulic excavators and dump-trucks. End uses include aggregates and ready mixed concrete.

The quarry comprises two excavations, one on either side of the A547 road. The oldest part of the quarry, understood to date back to the 19^{th} century, is located to the north. This area measures approximately 500m long in an east-west direction and up to 140m wide in a north-south direction and presently houses the main processing plant area. The maximum depth of this part of the quarry is approximately 35m. The main excavation area is located to the south, measures approximately 1.2km long in an east-west direction and up to 600m wide in a north-south direction and has benched limestone slopes. The maximum depth of this part of the quarry is presently some 110m below the natural surrounding surface level.

3. GEOLOGY

Extract from the BGS geological map, (1:50 000 sheet 95) shown on Figure 2 indicate that the site is underlain by Lower Carboniferous (Dinantian) strata belonging to the Dyserth Limestone Group. Superficial Glacial Till (Boulder Clay) deposits overlie the limestone over the majority of the site as shown on the Drift Geological map (Ref. 1) on Figure 2A.

The quarry is located within the lower part of the Dyserth Limestone Group, known as the Llysfaen Limestone Formation, and comprises grey, brown and pink limestones. The bedding is shown to dip regionally between 11^{o} and 19^{o} towards the northeast, see photograph 1.

The Dyserth Limestone Group is underlain to the southwest by the unproductive (Carboniferous) Basement Beds, which in turn overlie Silurian aged strata of the Flwy Group. It is understood that the quarry will be worked down to the top of the ‘siliceous beds’ which constitutes an abrasive horizon of approximately 5m thick at the base of the Dyserth Limestone Group.

The Dyserth Limestone Group is sub-divided into three units comprising the Llanddulas limestone (youngest) followed by the Dulas limestone and finally the Llysfaen limestone (oldest). The Llysfaen limestone being worked at Raynes Quarry has thin bands of shaley partings. Vertical and sub-vertical jointing (photograph 2) of the limestone is common throughout the quarry. This jointing has a wide range of trends and locally develops into clay filled zones in the upper levels of the quarry.

Faulting is reported to be unimportant at Raynes Quarry. However, a major fault trending north-south is identified to the east of the quarry with a downthrow to the west. The limestone is regularly jointed with two predominant joint sets.

3.1 Site Investigations

CEMEX UK Ltd drilled groundwater monitoring boreholes in the vicinity of Raynes Quarry in March 2010. Three deep groundwater observation boreholes (BH1, 2 & 3) were strategically positioned (Figure 3) in consultation with the Environment Agency Wales with the aim of providing baseline groundwater level data around the quarry. The groundwater monitoring boreholes provided a significant body of data on the geology and hydrogeology of the site which has been analysed and reviewed enabling the refinement of the conceptual understanding of the local groundwater flow systems around the site. The collated data is used to support any future deepening or lateral extension developments of the quarry. The site investigations also included down the hole geophysical logging using calliper, temperature, conductivity and natural gamma probes. The geological and geophysical logs from this investigation are included in Appendix A and the installations details are summarised in Table 3.

4. HYDROLOGY

4.1 Rainfall

Long term daily rainfall data were acquired from the Environment Agency for Pensarn rainfall station (NGR SH 95147 78859) which lies approximately 6km to the west of the site. The rainfall was measured using the tipping bucket method with an automatic recorder.

A total of 3654 daily rainfall records were available for the 1999 to 2008 time series for the Pensarn monitoring station. Daily records for 2004 were not used in the in the analysis as several gaps were identified in the records. A maximum annual rainfall of 815.6 mm/yr was recorded in 2008 and a minimum of 665.2 mm/yr recorded in 2003. The mean annual rainfall computed from daily rainfall records for this period is 761.7 mm/yr.

Daily rainfall records were summed up for each month and the summary statistics are presented in Table 1.

Table 1: Rainfall data statistics from Daily records (1999 to 2008)

Month	Average (mm)	Min (mm)	Max (mm)
January	63.2	16.6	116.6
February	53.6	20.2	125.8
March	44.0	26.0	83.4
April	50.8	1.4	86.8
May	49.5	21.2	80.6
June	47.4	17.8	117.6
July	44.3	5.2	101.0
August	69.5	1.4	120.0
September	77.6	4.0	320.4
October	104.1	31.8	169.0
November	80.3	46.4	196.0
December	77.4	45.4	139.2
TOTAL (mm/yr)	761.7		

The graphs of the daily, monthly and annual rainfall distribution are shown on Figures 5, 5A and 5B respectively.

4.2 Surface water features

There are no surface water courses intersected by the quarry. The main water feature close to the quarry area is the Irish Sea. The Sea is situated about 500m north of the main quarry void. River Dulas which is about 1.5km to the east of the quarry is another surface water feature of the area. The River flows from south to north and discharges into the Irish Sea. There is a reservoir (photograph 6) situated on a plateau about 200m to the east of the quarry. All the surface water features are shown on Figure 3A.

4.3 Flood Risk

The Flood Map shown on the Environment Agency's website indicates the quarry lies within Flood Zone 1, with a probability of fluvial flooding of less than 0.1% in any year. The quarry lies on elevated ground and historically there has been no flooding problems reported from rainfall or the nearby Irish Sea ever since the 1940's.

The FEH CD-ROM 1999 (Ref. 2) indicates that the site is located on the northern edge of a surface water catchment associated with River Dulas. The standardised average annual rainfall (SAAR) for the site is 810mm. Rainfall data in the form of the depth of rainfall for return periods between 1:2 year and 1:100 years for periods between 30 minutes and 48 hours was obtained from the FEH CD-ROM. This multiplied by the excavation area and the area from which run-off would enter the excavation gives the volumes of water (Table 2) that might be expected to enter the entire quarry. For the purpose of the calculations the quarry excavation area of 48ha, runoff contribution area of 3ha and run-off coefficient of 0.4 have been used. For the five year development plan the south-eastern corner of the quarry will be worked and an area of 7ha has been used to calculate the volume of water expected to enter the excavation.

The calculated volumes of water entering the excavation are very low to cause any flooding problems onsite. The large storage volume in the quarry ponds and lagoons can easily accommodate the highest 1:100yr return period volume which is unlikely to occur during the operation of the quarry. The flood flows are likely to be even less than the predicted flows due to the increased infiltration and lateral outflows along the carboniferous limestone's bedding planes and the mudstone/shaley beds which dip in a southerly direction.

Table 2: Volumes of water expected to enter the excavation for different return periods

Rainfall Event	Return Period	Rainfall (mm)	Volume entering entire quarry (m3)	Volume entering the south-eastern excavation (m3)
30 mins	1: 2 yr	9	4512	651
	1:5 yr	13	6480	935
	1: 10 yr	17	8231	1188
	1: 20 yr	21	10357	1495
	1: 50 yr	28	13943	2012
	1: 100 yr	35	17422	2514
	1: 2 yr	12	5874	848
	1:5 yr	17	8241	1189
	1: 10 yr	21	10317	1489
	1: 20 yr	42	20713	2989
	1: 50 yr	34	16900	2439
1 hr	1: 100 yr	42	20826	3005
	1: 2 yr	15	7621	1100
	1:5 yr	21	10455	1509
	1: 10 yr	26	12890	1860
	1: 20 yr	32	15759	2274
	1: 50 yr	42	20433	2949
2 hrs	1: 100 yr	50	24826	3583
	1: 2 yr	41	20074	2897
	1:5 yr	52	25372	3661
	1: 10 yr	60	29633	4276
	1: 20 yr	70	34391	4963
	1: 50 yr	85	41702	6018
24 hrs	1: 100 yr	98	48182	6953
	1: 2 yr	55	27139	3916
	1:5 yr	67	33062	4771
	1: 10 yr	78	38583	5568
	1: 20 yr	90	44132	6369
	1: 50 yr	107	52521	7579
48 hrs	1: 100 yr	122	59832	8634

4.4 Water Abstractions

The Environment Agency records (Appendix A) indicate that there are no licensed groundwater abstractions within 3km of the site.

4.4.1 Unlicensed abstractions

Details of private water supplies in the vicinity of the quarry were obtained from Conwy County Borough Council. Only one private water supply was identified which is marginally within the 3km radius of the quarry. The water supply is at Cefn Y Ffynnon which is situated about 3km to the south west of the quarry. The water supply is sourced from shallow groundwater. The location of the abstraction is shown in Figure 6.

4.5 Water Management

Water currently enters the quarry operations via three main routes which include:

- Direct rainfall
- Surface runoff from the adjacent high land which lies to the south of the quarry
- Lateral subsurface flow which has become perched upon the Carboniferous Limestone's bedding planes and the mudstone/shaley beds which dip in a southerly direction.

Once water is on the quarry floor it will either flow as runoff and collects in the large pond or infiltrates into the ground. Surface water within the quarry which has failed to infiltrate into the quarry floor and cannot be accommodated within the balancing pond due to it being full will be discharged off site. This only occurs during prolonged wet periods when pond water levels are very high.

4.5.1 Water quality monitoring

The sediment content from the quarry discharge water is regulated by the conditions of a discharge permit (Discharge Permit N^{o} CG0362301) issued by the Environment Agency Wales which stipulates a limit of 100mg/l.

CEMEX UK Ltd currently monitors suspended solids consent at the consented discharge point. Monitoring results are available from September 2009 to June 2011. Monitoring takes place on a monthly basis and the samples are analysed by Severn Trent Laboratories. The test results are summarised in Table 3, the trend in suspended solids content is shown on Figure 10.

Table 3: Suspended solids content for discharge water

Sampling Date	Suspended Solids @105C (mg/l)
25/09/2009	15
23/12/2009	9
27/01/2010	16

Sampling Date	Suspended Solids
15/02/2010	21
15/03/2010	12
24/04/2010	17
28/05/2010	59
29/06/2010	56
29/07/2010	18
03/09/2010	188
05/10/2010	14
12/11/2010	7
09/12/2010	5
12/01/2011	13
14/02/2011	25
14/03/2011	9
12/04/2011	7
04/05/2011	9
15/06/2011	6

Only one measurement was recorded above the consent limit on 13th September 2010. This was due to an operational problem at the jetty where a small amount of fine material fell from the conveyor belt which runs above the discharge trench. The problem has now been resolved by covering the discharge trench (photograph 8) and installing additional weir plates on the trench to enhance settling out of silt before reaching the final discharge point.

Following on to the successful implementation of some mitigation measures and upgrading the site water management infrastructure in October 2010, the suspended solids content has gradually gone down ranging between 6mg/l and 25mg/l.

4.6 Flowmeter installations

CEMEX UK Materials Ltd has recently installed two flowmeters at Raynes Quarry to monitor dewatering volumes and amount of water discharged off site. The flowmeters are linked to telemetry where real time data is available remotely, accessed via online database. The data is recorded every 15 minutes for both flowmeters. The data from the flowmeters has been used in conjunction with groundwater level fluctuation to delineate the zone of influence and the drawdown from the sump dewatering.

4.7 Designated sites

The Environment Agency Wales provided information on designated sites within 3km radius of the quarry. The Mynydd Marian SSSI (see Figure 3B) lies at about 515 metres to the south of Raynes Quarry. The SSSI has been designated due to its wide range of limestone grassland communities as well as its population of the dwarf race of silver studded blue butterfly.

The Llanddulas Limestone, Gwrych Castle Wood SSSI is approximately 1.6km to the east of Raynes Quarry. It is of special interest due to its limestone grassland, heath and woodland communities, the first two of which comprise some of the largest examples in Clwyd. It is also has a population of vascular plants, bryophytes, butterflies and moths and a winter roost of the lesser horseshoe bat. Details of the designated sites from the Environment Agency Wales are included in Appendix C.

5. HYDROGEOLOGY

5.1 Aquifer Characteristics

According to the Environment Agency (EA, Groundwater Vulnerability Maps), the Dyserth Limestone Group is classified as a major aquifer with medium to high permeability capable of supporting large abstractions, see Figure 6. The Basement Beds (Siltstone) is classified as a non-aquifer with low permeability (aquiclude). Limestone typically has minimal primary porosity/permeability and high secondary permeability. Groundwater is contained in and moves within enlarged fissures and fractures. These are often fault controlled and run parallel to the direction of faulting and jointing. The fissures are generally better developed in the zone of water level fluctuations.

5.2 Limestone groundwater flow mechanism

There are three conceptual types of flow in carbonate aquifers which include free flow, confined flow and diffuse flow (Ref. 3). In free flow carbonate aquifers, groundwater movement is concentrated in a limited number of well developed channels. These groundwater conduits form by dissolution of limestone. Flow is typically turbulent and rapid. Confined flow aquifers are also characterised by large solution conduits but flow directions are controlled by surrounding impermeable strata. Diffuse flow occurs in aquifers that have undergone negligible solution activity, often due to high argillaceous or dolomitic content of the rock. Groundwater flow is not concentrated in zones but rather spread throughout the rock mass discontinuities. There are no solution features found in Raynes Quarry (see Photographs 1 & 2) and there are no known records of caves in the area, it may be that the Dyserth Limestone in Clwyd area could be treated as a diffuse aquifer.

5.3 Groundwater level monitoring

Groundwater level monitoring network comprising three deep observation boreholes (BH1, BH2 & BH3) was implemented in May 2010 around the quarry. Each observation borehole was installed with dual standpipes (photograph 7) for monitoring shallow perched groundwater and deep seated groundwater. The three observation boreholes were strategically positioned around the quarry forming a triangular configuration as shown on Figure 3. The boreholes were drilled to a maximum depth of 111.5m below ground level at a nominal diameter of 150mm through the carboniferous limestone using the rotary down-the-hole hammer method with air as the flushing medium. Each borehole was installed with dual standpipes comprising 50mm and 19mm ID uPVC standpipes. The annulus around the slotted section of the standpipe was filled with 10mm pea gravel and the section around the plain standpipe was sealed with bentonite.

5.4 Groundwater levels

Groundwater levels are currently monitored on a 30 minutes interval basis using automatic dataloggers. The automatic dataloggers were installed in

August 2010 in all the three observation boreholes. Continuous groundwater level data is available from August 2010 to present, there are some gaps in between when the water levels fell below the logger levels. In addition, manual dip measurements are taken on a monthly basis for the calibration of dataloggers. Monthly groundwater level data is available from March 2010 to June 2011 completing a full hydrological cycle. The statistics of recorded monthly groundwater levels are summarised in Table 4 and detailed data is presented in Appendix B.

Table 4: Summary details of observation boreholes around the quarry

Borehole	Ground Elevation (mAOD)	Base of Piezometer (mAOD)	Water level (mAOD)			Range (m)
			Min.	Mean	Max.	
BH1P1	102.95	8.95	18.06	24.55	35.45	17.39
BH1P2	102.95	83.95	-	-	Dry	-
BH2	177.63	66.13	91.893	93.24	94.18	2.29
BH2P2	177.63	157.63	-	-	Dry	-
BH3P1	119.69	19.69	52.79	53.69	55.42	2.62
BH3P2	119.69	99.69	-	-	Dry	-

Groundwater levels vary significantly across the site ranging from a maximum of 94.18mAOD (BH2) to the south of the quarry to a minimum of 18.06mAOD (BH1) on the north western corner of the quarry. Groundwater level range is very high in BH1, a maximum water level fluctuation of 17.39m has been recorded in this borehole. The geological and geophysical records indicate a very permeable sandy layer at 15.15mAOD, see borehole and geophysical logs in Appendix A. The identified permeable zone in the limestone seems to be acting as a groundwater conduit transmitting a significant amount of water from the quarry sump to the surrounding aquifer as lateral subsurface flow.

The low storage coefficient of the limestone results in a rapid response to groundwater recharge from rainfall and the quarry sump in BH1. Groundwater level fluctuation in BH1 shows a correlation between the quarry dewatering pumping regimes and the water table fluctuations. However, groundwater levels in BH2 and BH3 do not show any response to quarry dewatering. The maximum radius of influence from quarry dewatering has been calculated as 51m (section 7.1.1), only BH1 falls within this radius.

Groundwater level monitoring records show seasonal fluctuations in all the three boreholes with generally higher levels recorded in winter and lower levels recorded in summer, see composite groundwater hydrograph on Figure 9. The groundwater level hydrographs show that there is a good correlation between water levels and rainfall. Groundwater recharge from rainfall is noted in all the three hydrographs with a significant response observed in BH1 and subdued response in BH2 and BH3.

The sinking in the north-western corner, which requires constant pumping (Photograph 3) to maintain ‘dry’ working conditions, has intersected groundwater. However, recent site walk over indicated that most of the water accumulated on the quarry sump comes from direct rainfall and some from the quarry face seepage (Photograph 4). A notable flow of approximately 1l/s was observed on the south-eastern corner of the quarry (Photograph 4a). The topographic survey for March 2010 indicates a standing water level of 42.35mAOD on the north- western corner of the quarry.

The water level in the freshwater supply lagoon (Photograph 5) located within the north-eastern part of the main excavation area is artificially maintained. This lagoon was created many years ago by damming of the tunnel which formerly provided access to the then lowest level of the main quarry (floor level of about 43mAOD). The portal of this tunnel, which is still accessible up to the dam, is located near the lorry sheeting area in the plant site. The pond water level recorded on the topographical survey for September 2007 was 54.40mAOD. However, it is understood that the water level within the pond may vary over the year in the order of 5m.

The 5 year development plan for the quarry will concentrate on the south eastern corner of the quarry. This will be terraced from 120mAOD down to 65mAOD. The maximum groundwater level on the south-eastern part of the quarry is about 62mAOD. Consequently, the 5 year development plan will not intersect groundwater and as such no major dewatering will be required. Only minor dewatering will be required to cope with direct rainfall and surface water inflows into the quarry void from the surrounding catchment.

5.5 Groundwater flow

The groundwater level monitoring data indicate that groundwater generally flows from the south to the north. Local groundwater flow system in this area generally mimics the surface topography which drops from south to north towards the Irish Sea. The groundwater flow map for the site shows that the maximum groundwater levels drop from about 94mAOD around the southern boundary of the quarry to about 35mAOD on the northern boundary of the quarry, see Figures 6A and 6B. Some of the groundwater would discharge to the Irish Sea where the carboniferous limestone aquifer is in continuity with the Sea.

6. PROPOSED DEVELOPMENT

6.1 Current Development

CEMEX (UK) Limited currently operates Raynes Quarry for the production of limestone aggregates. The quarry has reached its maximum lateral extent and future developments will involve deepening the quarry base to lower levels. Limestone will be recovered from the working faces by blasting with explosives. The excavated rock is processed on site to produce the required product. Primary blasted material is hauled by quarry dumper to the primary crusher. The crushed material is fed by conveyor under Abergele Road to the secondary processing plant, where it is subject to further crushing and screening. There is an internal road link between the quarry and the plant area which passes under Abergele Road. A marine jetty has been developed in association with the quarry for the purpose of transporting the material by ship. The ships are loaded by means of a conveyor system which carries the processed material from the plant area across the railway line and under the A55 Road.

The quarry waste material resulting from the processing of the stone is currently disposed of in the tip in the south western part of the site to the south of the Abergele Road. The tip is in effect part of the extant and proposed restoration, forming a grassed and treed slope against the quarried face.

6.2 Proposed Development

The proposed five year development plan for the site will concentrate working in the south eastern corner of the site (see Figure 7), pushing forward existing faces to their maximum extent before working the face beneath. This will involve working the mineral from 120mAOD down to 65mAOD. No soil or overburden stripping is necessary in this period.

As a continuation of current operating practice, the extracted mineral will be passed through a primary crusher positioned in the quarry and then conveyed in a tunnel beneath Abergele Road to the main processing plant for further processing and screening.

The quarry waste will continue to be disposed of in the tip on the south western part of the site until the proposed restoration contours are achieved. The silt lagoons will be dug out when full and dispose of the material generated into the quarry waste disposal area, and replacement lagoons will be established.

6.2.1 Future Development

In view of the substantial reserves at Raynes Quarry, and at current outputs, activities would continue until, and beyond, the current end date of the mineral permission at the site of 28th September 2028. The quarry would continue to be worked using conventional quarrying techniques, creating a series of levels whose height is typically 15 m, with near-vertical faces. The proposed maximum extraction depth is 10 mAOD, as shown on the indicative development proposal on Figure 11.

6.3 Proposed Restoration

The 5 year restoration plan includes the planting of blocks of trees on the completed quarry waste tip on the south western corner of the quarry. The detailed restoration master plan is shown on Figure 8.

7. POTENTIAL IMPACTS AND MITIGATION

An assessment is made of the potential impacts on surface water bodies around the site. The assessment also takes account of any consequent impacts on the environment and flood risk resulting from the following two stages of the development:

- Extraction
- Restoration

7.1 Extraction

The proposed 5 year development plan does not require any groundwater dewatering during quarrying operations. Only minor dewatering will be required to cope with direct rainfall and surface water inflows into the quarry void from the surrounding catchment. The proposed workings on the south-eastern corner of the site will be above the groundwater levels. This restricts the number of receptors that are appropriate to consider as part of the EIA. Therefore it is considered that there will be no impact on surface water, groundwater sources and surface water flows due to quarry dewatering.

The following short term potential impacts of the extraction operation were identified:

- Water ingress resulting in quarry floor flooding risk
- Sea water intrusion
- High suspended solids in discharge water which may exceed the consent limit

7.1.1 Groundwater ingress volumes

The north western corner which has been worked out intercepted winter groundwater levels at about 35mAOD. Water which has accumulated on the north western quarry void will need regular pumping to avoid flooding the quarry floor. Groundwater seepage into the north western corner of the quarry excavation is estimated to be very small and the overall dewatering volumes from the quarry may be accounted for by incedent rainfall.

Estimates of potential groundwater inflow under steady-state conditions have been made using the Dupuit-Thiem formula for a range of potential hydraulic conductivities. For the purposes of the assessment the groundwater level is taken as the maximum groundwater level recorded at borehole 1 (BH1) which is in the vicinity of the dewatering sump, the maximum groundwater level coincides with the current quarry floor of 35mAOD.

A conservative, steady state groundwater inflow to the quarry was calculated using the Thiem-Dupuit equation for steady flow in an unconfined aquifer as specified by the Environment Agency, 2007 (Ref. 4).

$$Q = \pi k[(h_o^2 - h_w^2)/\ln(r_o/r_w)]$$

Where Q = groundwater ingress rate (m^3/d)

k = hydraulic conductivity (m/d) [0.001, 0.01, 0.1, 1]

h_o = saturated aquifer thickness before drawdown (m) [5]

h_w = saturated aquifer thickness after drawdown + h_s

(h_s = nominal value of 0.5 to represent height of seepage face in workings (m))

r_w = radius of working area (m) [190]

r_o = r_w+ radius of influence, r_i (m)

The radius of influence of the drawdown to be imposed is required as an input to the Dupuit-Thiem equation. The radius of influence of dewatering was estimated using an approximation method detailed in the CIRIA report on control of groundwater for temporary works (Ref. 6). The method relates radius of influence of drawdown to hydraulic conductivity:

$r_i = C.s\sqrt{(k)}$

Where r_i = radius of influence of dewatering (m)

s = Drawdown (m)

k = hydraulic conductivity (m/s)

C is usually taken as 3000 for radial flow. The drawdown is estimated as the maximum drawdown that would be observed at 30 mAOD, and a pre-development water level of 35 mAOD, which yields 5 m drawdown. The hydraulic conductivity (k) for a non karstic limestone is estimated to be between 10^{-5} and 1 m/d (Ref. 5). A range of hydraulic conductivity values were used for this assessment.

The north-western corner of the quarry is the only part which will intercept winter groundwater levels during the 5 year development plan. The maximum radius of the north western part of the quarry which intercepts groundwater has been estimated at 190m, this value has been used in the flow computations. The estimated groundwater inflows have been calculated for a range of hydraulic conductivity values. Results of the calculations are presented in table 5.

Table 5: Groundwater ingress volumes (NW corner)

	Hydraulic conductivity (m/d)			
	0.001	0.01	0.1	1
Quarry floor at 30mAOD				
Radius of influence (m)	2	5	16	51
Groundwater inflow (m^3/d)	7	30	96	327

7.1.2 Total dewatering requirements (5 year Development)

The total dewatering requirement is a summation of rainfall and groundwater ingress. Assuming a relatively conservative (high) value for bulk hydraulic conductivity in the Limestone of 1m/d, the maximum winter daily pumping rates may increase by 327 m^3/d from the north western corner sump of the quarry.

Assuming that all rainfall falling within the excavation is hydrologically effective and applying the standardise average annual rainfall (SAAR) of 810 mm/a over the operational quarry area of 48 ha equates to rainfall inflow of 1065 m^3/day. During the summer, much of this would be lost to evaporation from the sump.

The quarry water management scheme has been designed incorporating landscaping and drainage systems which minimise the risk of local flooding.

7.1.3 Future working projections

In the long term (beyond 5 year plan), the quarry will be worked to a minimum level of 10mAOD on the central part of the quarry (Figure 11). The minimum level is unlikely to be reached during the current minerals permission, however, for completeness this assessment has been extended to include the full quarry development. Future deepening of the quarry will require groundwater dewatering to enable dry working conditions. The maximum projected groundwater level for central part of the main quarry void is 58mAOD, this has been assumed to be the pre-development groundwater level for the calculations. The maximum radius of the central main quarry void has been estimated at 315m, this value has been used in the flow computations. The radius of the quarry working decreases with depth. The quarry radius used in the calculation remained at 315m, therefore the estimated groundwater inflows are considered conservative for the deeper workings. Quarry levels have been taken as 50mAOD, 35mAOD, 20mAOD and 10mAOD for the calculations.

Applying the same principles as above, estimates of potential groundwater inflow and radius of influence have been calculated for a range of potential hydraulic conductivities. Results of the calculations are presented in table 6.

Table 6: Groundwater ingress volumes (Main Void)

	Hydraulic conductivity (m/d)			
	0.001	0.01	0.1	1
Quarry floor at 50 mAOD				
Radius of influence (m)	3	8	25	81
Groundwater inflow (m^3/d)	21	80	190	875
Quarry floor at 35 mAOD				
Radius of influence (m)	7	24	74	255
Groundwater inflow (m^3/d)	76	226	787	2801
Quarry floor at 20 mAOD				
Radius of influence (m)	12	39	122	387
Groundwater inflow (m^3/d)	121	389	1386	5660
Quarry floor at 10 mAOD				
Radius of influence (m)	16	49	154	489
Groundwater inflow (m^3/d)	146	501	1818	7724

7.1.4 Water abstractions

One shallow groundwater fed abstraction has been identified within a 3km radius of the site. The abstraction is located approximately 3km upstream of the quarry. The abstraction is located sufficiently far from the quarry boundary such that it is not considered to be at risk of any potential impacts from the quarry workings or the proposed extension. The maximum calculated radius of influence due to dewatering is only 489m from the quarry sump at full quarry development.

7.1.5 Sea water intrusion

Dewatering the quarry could potentially reverse the groundwater flow systems around the quarry resulting in sea water intrusion into the quarry void from the nearby Irish Sea. Enlarged fissures may act as pathways for saline water from the sea resulting in flooding of the quarry void.

However, the calculated maximum radius of influence induced by dewatering at full development does not extend to the sea which is down the hydraulic gradient of the quarry. The quarry will not be lowered to sea level at full development. In addition, the site investigations including geophysical logging did not indicate any fissures which could act as pathways for sea water. Electrical conductivity data indicated fresh groundwater, this is not expected to change throughout the quarry development.

7.1.6 High suspended solids

Water discharged from the quarry to the Irish Sea via discharge consent no. CG0362301 may contain higher suspended solids exceeding the consent limit especially after heavy storms. Although a set of silt lagoons are in place for the settling out of suspended solids, runoff from the quarry catchment which does not pass through the lagoons may contain elevated levels of suspended solids.

However, the quarry water management scheme (Figure 3) minimises any chances of discharging water with high suspended solids. The scheme is designed in such a way that all the water from the processing plant goes through the silt settling lagoons before being transferred to the clear water lagoon where overflow water is discharged to the sea.

Suspended solids content monitored at the consented discharge point has gone down from October 2010 onwards ranging from 6mg/l to 25mg/l. The sediment content is well within the permitted limit of 100mg/l owing to the successful implementation of the site water management system upgrade which addresses the siltation problems on site on the discharge water.

7.2 Restoration

The quarry waste tip on the south western part of the site which form part of the restoration scheme has the potential to increase surface runoff leading to the erosion of sediments. The eroded sediments could potentially impact on local flooding and ecology. However, the proposed restoration and landscaping works would minimise any surface runoff from the waste tip material. The planting of trees on the slope will increase the rate of infiltration and reduce surface runoff on the restored slopes thus minimising any chances of sediment erosion. The quarry has existing restored waste tips and there is no evidence of sediment erosion from the tip either in their exposed form or when planed with trees.

8. CONCLUSION

The main conclusions of the assessment are:-

- The Carboniferous Limestone is classified as a Major Aquifer and groundwater flow is dominated by secondary permeability characteristics.
- This investigation has produced a clear understanding of the local water environment and the potential impact which the on-going mineral extraction may have upon it.
- As infiltration rates are high in the area, there are few surface water features in the vicinity of the site. The Irish Sea which is about 500m north of the quarry void and River Dulas, 1.5km to the east of the quarry form the main watercourses of the area.
- Current operations have not been observed to have any impact upon the local water environment and the proposed workings are also unlikely to have a significant effect. A programme of continued monitoring of water levels, pumping and discharge rates will indicate any changes that may occur as a result of the on-going operations.
- The maximum radius of influence at full development (10 mAOD) is 489m from the quarry sump. All the identified environmental receptors are beyond this zone of influence.
- The maximum groundwater levels range from about 94mAOD on the southern edge of the main quarry, to about 35mAOD on its northern side.
- The proposed 5 year development plan which involves working the mineral from 120mAOD down to 65mAOD on the south eastern corner of the quarry will remain above the maximum recorded ground water levels. There will be no impact on the water environment due to the proposed development since the mineral will be worked above the water table.
- The calculated maximum winter groundwater ingress of $327m^3/d$ into the quarry sump for the 5 year development plan is quite small compared to the $1065m^3/d$ rainfall contribution. Therefore dewatering from the quarry void is mainly accounted for by incident rainfall.
- The site does not lie within an area at risk of 1: 100 year or more frequent flood events, there will be no loss of floodplain storage or an increase in flood risk.
- The proposed 5 year restoration scheme and landscaping works incorporating tree planting will increase the rate of infiltration.
- The existing quarry water management scheme which includes a set of silt lagoons and a clean water lagoon is quite efficient in the settling out of suspended solids. The scheme has been upgraded recently to include a series of weir plates on the discharge gully to facilitate the settling out of any residual suspended solids. The suspended solids content has significantly gone down owing to the successful implementation of the site water management system upgrade.

References

1. British Geological Survey (BGS) (1973) Rhyl. England and Wales Sheets 95, Drift and Solid Edition, 1:50 000.
2. Institute of Hydrology, 1999. Flood Estimation Handbook, CD-ROM, Version 1.0.
3. WHITE, W. B. 1969. Conceptual models for carbonate aquifers. Groundwater 7, no 3, 15 –22.
4. Environment Agency. 2007. Hydrogeological impact appraisal for dewatering abstractions. Science Report – SC040020/SR1.
5. Nonner, J.C., Introduction to Hydrogeology (2003) IHE delft, AA. Balkema Publishers, Tokyo.
6. Somerville, S.H, 1986. Control of groundwater for temporary works. Construction Industry Research and Information Association (CIRIA) Report 113).

FIGURES

PHOTOGRAPHS

APPENDIX A

BOREHOLE AND GEOPHYSICAL LOGS

APPENDIX B

GROUNDWATER LEVEL MONITORING DATA

APPENDIX C

ENVIRONMENT AGENCY DATA REQUEST

APPENDIX D

ENVIRONMENT AGENCY LETTER TO CEMEX

APPENDIX E

GROUNDWATER MONITORING SCHEME