7. SAND AND GRAVEL RESERVES OF THE RIBBLE REGION

7.1 EXISTING KNOWLEDGE BASE

7.1.1 Three reports are available to Lancashire County Council (LCC) Minerals and Waste Group about the sand and gravel reserves in the county (*Section 3.3.2;* Allot and Lomax 1990; Entec UK Ltd 2005; Geoplan Ltd 2006). The latest of these reports had a relatively wide brief to look in greater detail at areas defined in previous reports and to target new areas for which there was extant geological data. Whilst the Geoplan Ltd and Entec UK Ltd reports are the best available assessment of sand and gravel aggregate reserves, there remains a paucity of high-quality published information relating to Lancashire's sand and gravel geology and resources.

7.1.2 *The Lancashire Minerals and Waste Local Plan* (2006) set out a policy to release additional land to provide 3.2 million tons of high-grade sand (defined as sand washed to British Standard (BSI) before sale) before 2006. This will be achieved by:

- extraction from existing sites and small-scale extensions to existing sites;
- new small-scale sites operated (briefly) in conjunction with existing plant;
- sites to be worked prior to development for other purposes (avoiding sterilisation of deposit);
- new sites in three main areas of search: north and west of Preston; Leyland-Chorley area; and the Lower Ribble Valley;
- new sites in areas outside these areas of search, but outside and not in the periphery of the Forest of Bowland AONB.

7.1.3 The Geoplan Ltd report, *The Lancashire Minerals and Waste Local Plan,* and the draft *Regional Aggregate Working Party* report (RAWP 2006) show that in Lancashire high-quality sand and gravel with planning permission are currently available from Lydiate Lane (2.01 million tonnes (mt)) and Sharples Quarry (1.45mt) (Fig 144). Achieving the BSI grade for high-quality sands can be facilitated by switching plant processing from dry to washed screening of the sand and gravel, as has been the case at Lydiate Lane. Low-quality sands are extracted at Bradley's Sand Pit and from St Anne's Foreshore (Fig 144). Inactive and dormant permissions exist for German Lane and Lundsfield, with further dormant workings with very little materials remaining at Sale Wheel and Ashton and Lea Marshes (Fig 144). The Higher Brockholes Quarry has now ceased operations (2005) and is being restored. Future provision may be enhanced subject to planning applications at Lower Brockholes (0.95mt), Runshaw (4.3mt) and Sandons Farms (0.6mt).

7.1.4 The mineral assessment by Geoplan Ltd (2006) calculates the probable available reserves, their likely quality and degree to which extraction would be constrained. In calculating the mineral quantities, they have used a 20m buffer around rivers, roads, canals and property, and used an estimated average mineral thickness to calculate volumes. The volumes are moderated by a wastage factor of 15% and converted from cubic metres to tonnes using the following factors: 1.6 for sand; 1.7 for sand with some gravel; and 1.8 for sand and gravel. Geoplan Ltd then examined the degree to which Resource Blocks were constrained by higher tier planning constraints, which include AONBs, national and internationally designated ecological and geological sites (for example ~ SSSIs, NNRs, RAMSARs). From this the sites were divided into four categories using a matrix of criteria underpinned by sand quality and potential mineral volume compared against the degree of planning constraint. This assessment was based on greater detail being available about the mineral resources and so represents an improvement on previous sand and gravel surveys. Throughout the report the caveat is made that prior to any extraction a comprehensive survey should be undertaken to prove the nature of the deposits, and the findings and the predicted aggregate quantities must therefore be regarded as indicative estimates. The responsibility for acquiring new geological knowledge of this type via borehole and test pit survey must rest with the industry rather than local authority planning departments.

7.1.5 The main limitation to the Geoplan Ltd and all previous sand and gravel surveys in Lancashire is that the primary source of information on distribution of sand and gravel is the BGS mapping and knowledge acquired from the aggregate industries. This limitation makes the statement in the report that new areas '…are unlikely to be identified by any county wide sand and gravel study' (Geoplan Ltd 2006, 15) seem extremely naive. County-wide surveys underpinned by extensive borehole survey are not realistic and unlikely to be funded by local government, but the preliminary examination of the Kirkham moraine complex (*Section 5.1.9*), using remotely sensed elevation models with some field survey and use of available borehole records, allows geomorphologists to understand sediment~landform relationships. This can identify and refine our understanding of the likely distribution of usable sand and gravel within complicated former glacial environments. Furthermore, a programme of geomorphic mapping for the Holocene river terraces of the Ribble shows the BGS mapping of the distribution of these features was at best a first approximation, and given that particular terraces form the aggregate Resource Blocks in this region, an improved understanding of the geomorphology can improve the assessment and quantification of fluvially derived aggregates. The value of using a geomorphological approach to sand and gravel assessment is demonstrated when focusing on the Ribble Valley and its environs. The work programme entailed in obtaining these data was neither expensive nor time-consuming, but must be underpinned by expert geomorphological knowledge (Crimes *et al* 1992).

7.2 REVISED SAND AND GRAVEL MAPPING FOR THE RIBBLE

7.2.1 From consideration of the distribution, origin and character of glacial and fluvial deposits in the Ribble basin, and the wider environs of Lancashire and the Craven District of North Yorkshire, the following general conclusions regarding potential areas of search for sand and gravel aggregates may be drawn. The upland areas, including the majority of the Yorkshire Dales National Park and the Forest of Bowland AONB, are predominantly erosional, and glacial deposits are limited in extent and thickness, highly localised, mostly thin and discontinuous, and predominantly composed of diamict or coarse-grained gravel, largely unsuitable for mineral extraction. This essentially precludes any realistic potential sand and gravel aggregate extraction from the Craven District of North Yorkshire. The National Park and AONB are also so heavily constrained on environmental and aesthetic grounds that an expansion of existing crushed rock aggregate quarries within these regions is discouraged in the *Minerals Plans* of the respective counties. The consideration of crushed rock sources is outside the scope of the current project; this is, however, the subject of a variation to the funded contract that focused on the Craven District (OA North and University of Liverpool 2007), but this has not as yet been commissioned.

7.2.2 Whilst reviewing the results of the present project, a focus is maintained on the defined study area (*Section 1.3.2*), consideration of the resources is extended to the other Resource Blocks in lowland Lancashire, particularly in the Kirkham End Moraine complex, which contains the thickest sequence of Pleistocene deposits in the county (*Section 5.1.9*). To facilitate a discussion of the sand and gravel aggregate reserves, the region has been divided into three provinces on the basis of mode of deposition and distribution.

- The Ribble fluvial terraces (1), which have sustained the only recent sand and gravel workings within the study area (Higher Brockholes) and includes a zone subject to a current planning application (Lower Brockholes). The history of extraction demonstrates substantial quantities of gravel and particularly sand, but the Resource Blocks become increasingly constrained by poor access and environmental controls progressing upstream from the M6 crossing of the Ribble.
- The glacigenic landforms that flank the Lower Ribble (2) between just upstream of Clitheroe and Preston, formed in or around the Ribble ice-dammed lake (*Section 5.1.14*). These extensive benches on both sides of the valley comprise a range of glacial landforms, which, over historical timescales, have been utilised for sand and gravel aggregates (Hurst Green). These Resource Blocks are on the margins of the Forest of Bowland AONB and its fringe, environmental constraints which, when combined with their ice proximal fairly coarse-grained nature, renders the deposits unlikely targets for future extraction.
- The extensive end moraine complex of the Kirkham ridge (3) is composed of significant quantities of sand and gravel, but conventionally this has been regarded as difficult to extract owing to surface diamict. Sand and gravel has, and is, extracted within the moraine complex, with the workings at Bradley's Sand Pit. In addition, the borehole records reveal the presence of large sand reserves. Part of the problem with assessing the sand and gravel potential of the Kirkham moraine has been the lack of detailed geomorphological investigation to provide a process-based reconstruction of the palaeogeography that draws upon both geomorphology and the available data on exposures and from boreholes. This has been rectified to some extent in this project.

- The remainder of lowland Lancashire is largely composed of sub-glacial deposits, with either drumlins composed of thick diamict or by ice-moulded diamict plain and bedrock, and so are largely devoid of potential mineral. Small areas of sub-glacial fluviatile sedimentation, in the form of sub-glacial esker systems, could potentially yield usable aggregates. The other river systems of the Wyre and Lune are zones likely to yield sand and gravel mineral, with a long history of extraction along the Wyre exploiting flanking sandur deposits and higher river terraces. These fall outside the scope of this project and are only mentioned for completeness here.
- Coastal sands, including dune and beach sand, form another potentially good mineral resource and are exploited at St Anne's foreshore. These zones are also subject to considerable environmental controls and so future utilisation of these reserves must be regarded as uncertain. Marine-won aggregates, almost entirely sands, also form an increasing proportion of the mineral supplied to Lancashire, with materials landed in Liverpool and at Heysham. Both marine and coastal sands are beyond the scope of this project and are only mentioned for completeness here.

7.2.3 ***Ribble fluvial terraces:*** the 35km reach from the Ribble, Calder and Hodder confluences downstream to the estuary has been comprehensively mapped by a combination of field survey and the use of Nextmap and LiDAR elevation datasets (Figs 145, 146). Upstream of this point, available borehole data and river bank exposures show that the thicknesses of sand and gravel thin to uneconomic proportions. The mapping, the borehole data and the history of aggregate extraction show that it is Terraces T1 and T2 that provide good-quality sands and gravels, with finer grained alluvium typifying the lower terraces. Combining this understanding with a substantially more accurate assessment of the distribution and dimensions of these features completely alters the extent and distribution of Resource Blocks identified and used in the Entec UK Ltd (2005) and Geoplan Ltd (2006) surveys. It also shows the problems implicit in using outdated BGS data to underpin aggregate assessments; the modern series of maps produced by the BGS (1974; 1975; 1982; 1990; 1991) are less susceptible to this problem because the expansion of geomorphological and Quaternary expertise involved with the mapping programmes.

7.2.4 The meander loops for the upper half of the reach between the estuary and the Ribble, Calder and Hodder confluences (Fig 145) are annotated with the Sub-Resource Areas codes used in the description of Resource Block 1H by Geoplan Ltd (2006). For the lower reaches down the estuary, Geoplan did not assign codes and there is only a partial overlap with Resource Blocks 2B and 2A (Fig 144). There are three sequences of boreholes (Figs 147, 149) that traverse the Ribble floodplain at the inner estuary west of Preston, along the M6 and slightly further upstream across Elston Old Hall Farm. Boreholes taken for the M6, the M6 widening and for Tilcon to assess the aggregate at Higher Brockholes reveal the sand and gravel deposit thicknesses associated with Terrace T2 at Brockholes as varying between 10m and 5m, and show that the thicker accumulations of overburden are in the more substantial palaeochannels. This aggregate thickness is confirmed by the proposed extraction at Lower Brockholes (Geoplan Ltd 2006). The deposit thicknesses are also similar at the estuary transect; however, it must be stressed that this sequence does not extend to the extensive Terrace T1 sub resource area (LIV 7: Fig 146) to the north of the river, where deposit thickness may be much greater. At the Old Elston Hall Farm, the borehole sequence drilled during pipeline preparation in the area also shows aggregate thicknesses for Terraces T1 and T2 to be 5-7 m, and this is supported by data obtained by Redlands Ltd in 1971 for a planning application to develop this site for aggregates (Geoplan Ltd 2006). Geoplan Ltd indicate that the Old Elston Hall Farm deposit may extend down some 13m, although it is possible this may incorporate some misidentified weathered-top to the underlying Permian sandstone bedrock. In their assessment of the aggregate quantities, Geoplan Ltd used wastage ratios of 15%, an average mineral thickness of 5m and a 1.8 volume to tonnage conversion factor for high gravel content.

7.2.5 For assessment and comparison in the present project, a wastage ratio of 15% and 1.8 volume to tonnage conversion factor was used. The calculations that follow use the redefined resource block mapped outlines. However, the thicker extractable mineral is associated with Terrace T1 which is some 2-3m higher than Terrace T2; the altitude relative to the river level for both terraces is c. 8.5-9.5 m above river for Terrace T1 and *c* 6.5-7m above the river for terrace T2. The borehole evidence and drilling suggest the deposit thickness is greater for Terrace T1, and so a deposit average thickness of ~6m for Terrace T1 was used, and the deposit thickness of areas of Terrace T2 was used to ~3.5m. Any areas of Terraces T3 and T4 have been relieved from the analysis because they comprise fine-grained flood-laminated alluvium.

7.2.6 ***Mineral Assessment for the Ribble between the M6 and Calder tributary:*** of the 15 Resource Blocks (Fig 150), 11 are identified as having mineral present in workable quantities (Table 46). These 11 blocks contain an estimated 24 million tonnes of mineral. According to our reliability index, with the exception of sub-resource areas A1, B, C and G (Fig 145), where borehole data are available and so have a high reliability, the reliability of the remainder of the assessment is medium (*Section 3.11.30*). In terms of constraints (Table 47), the majority of Resource Blocks are unaffected by ‘Urban’, ‘HER sites, ‘Listed Buildings’, ‘Scheduled Monuments’, AONB and the AONB fringe environmental controls. Resource Block A1 is on the margins of ancient woodland, but this has not precluded the mineral extraction at Higher Brockholes. Resource Blocks G, H and I contain either scheduled monuments or listed buildings, with H reflecting the concentration of archaeology around Ribchester. There is a high degree of urban area in Resource Block H (Ribchester), and Resource Block P is within the zone defined as the (Forest of Bowland) AONB fringe, where mineral extraction is discouraged in the county *Minerals and Waste Plan* (2006). However, one of the main constraints to mineral extraction in the Lower Ribble Valley is poor access. Table 47 highlights the problem by recording the distance to the nearest A-road, and whilst Resource Blocks A1, A and C are reasonably close to either the M6 junction or the A59, all other resource areas would have to connect either south to the A59 or north to the B6244 or B6243. Throughout this area, the B and minor road network is covered under ‘quiet road’ planning. The totals have been summed to provide an overall total for adjacent areas within each sub-Resource Area.

7.2.7 The distances to roads listed for Resource Blocks B, D, F and P are misleading because access would have to be from the north, and for H and I access would either be north to Longridge or across the bridge, connecting to the A59. It is feasible that bridge construction could connect Resource Blocks A and B with previous extraction at Higher Brockholes, providing easier access to major road networks, but this would be subject to a cost-benefit analysis. In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 150), which shows that the best prospects within the Lower Ribble Valley are A1, A, B, C, D and J/K, with the other subject to substantial constraint.

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Usable (tons)	Reliability	Workable
A	Liverpool Group 2006	1	6	1,085,048	1,953,086	1,660,123	M	Y
A	Liverpool Group 2006	2	3.5	922,977	1,661,359	1,412,155	M	Y
A (total)	Liverpool Group 2006			2,008,025	3,614,445	3,072,278	M	Y
A1*	Liverpool Group 2006	2	3.5	852,443	1,534,397	1,304,238	H	Y
A1**	Liverpool Group 2006	2	3.5	2,886,584	5,195,852	4,416,474	H	E
B	Liverpool Group 2006	1	6	852,525	1,534,546	1,304,364	H	Y
B	Liverpool Group 2006	2	3.5	902,888	1,625,198	1,381,418	H	Y
B (total)	Liverpool Group 2006			1,755,413	3,159,744	2,685,782	H	Y
C	Liverpool Group 2006	1	6	895,201	1,611,362	1,369,658	H	Y
C	Liverpool Group 2006	2	3.5	435,861	784,549	666,867	H	Y
C (total)	Liverpool Group 2006			1,331,062	2,395,911	2,036,524	H	Y
D	Liverpool Group 2006	1	6	239,699	431,458	366,740	M	Y
D	Liverpool Group 2006	1	6	302,112	543,802	462,232	M	Y
D	Liverpool Group 2006	2	3.5	394,998	710,997	604,347	M	Y
D (total)	Liverpool Group 2006			936,810	1,686,257	1,433,319	M	Y
F	Liverpool Group 2006	1	6	1,483,525	2,670,345	2,269,793	M	Y
F	Liverpool Group 2006	2	3.5	318,621	573,517	487,490	M	Y
F (total)	Liverpool Group 2006			1,802,146	3,243,863	2,757,283	M	Y
G	Liverpool Group 2006	2	3.5	795,054	1,431,097	1,216,432	H	Y
H	Liverpool Group 2006	1	6	38,572	69,430	59,015	M	Y
H	Liverpool Group 2006	1	6	129,144	232,460	197,591	M	Y
H	Liverpool Group	1	6	1,609,909	2,897,836	2,463,161	M	Y

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Usable (tons)	Reliability	Workable
	2006							
H	Liverpool Group 2006	2	3.5	133,333	240,000	204,000	M	Y
H	Liverpool Group 2006	2	3.5	417,995	752,391	639,532	M	Y
H (total)	Liverpool Group 2007			2,328,953	4,192,116	3,563,299	M	Y
I	Liverpool Group 2006	1	6	322,698	580,857	493,728	M	Y
I	Liverpool Group 2006	2	3.5	488,316	878,969	747,123	M	Y
I	Liverpool Group 2006	2	3.5	650,490	1,170,882	995,250	M	Y
J/K	Liverpool Group 2006	2	3.5	1,912,622	3,442,719	2,926,311	M	Y
P	Liverpool Group 2006	2	3.5	475,360	855,648	727,301	M	Y

*Table 46: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 145. Workable Resource Blocks have to exceed 500,000 tons usable mineral. A1** denotes the exhausted reserves at Higher Brockholes. A1* denote Resource Blocks subject to planning application*

Resource	Road (m)	Name	Urban	Designated sites	AONB	Fringe	HER	Listed Buildings
A	671	A59	0	0	0	0	0	0
A	915	A59	0	0	0	0	0	0
A (total)								
A1**	293	A59	0	1	0	0	0	0
A1*	293	A59	0	1	0	0	0	0
B	1,684	A59	0	0	0	0	0	0
B	1,241	A59	0	0	0	0	0	0
B (total)								
C	1,466	A59	0	0	0	0	0	0
C	1,574	A59	0	0	0	0	0	0
C (total)								
D	1,853	A59	0	0	0	0	0	0
D	1,789	A59	0	0	0	0	0	0
D	1,514	A59	0	0	0	0	0	0
D (total)								
F	2,302	A59	0	0	0	0	0	0
F	2,078	A59	0	0	0	0	0	0
F (total)								
G	2,201	A59	0	0	0	0	0	1
H	2,394	A59	0	0	0	0	0	0
H	2,358	A59	0	0	0	0	0	0
H	2,281	A59	51	0	0	0	3	12
H	2,289	A59	0	0	0	0	0	0
H	2,021	A59	0	0	0	0	0	0
H (total)								
I	2,178	A59	0	0	0	0	0	0
I	2,386	A59	0	0	0	0	0	0
I	2,087	A59	0	0	0	0	0	1
J/K	1,571	A59	0	0	0	0	0	0
P	2,551	A59	0	3	0	83	0	0

*Table 47: Environmental constraints for the workable Resource Blocks identified on Figure 145. Workable Resource Block have to exceed 500,000 tons usable mineral. A1** denotes the exhausted reserves at Higher Brockholes. A1* denote Resource Block subject to planning application for Lower Brockholes. Urban refers to the % of urban area in the Resource Block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and scheduled monuments from the HER are counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road.*

7.2.8 ***Mineral Assessment for the Ribble between Preston and the Estuary:*** between Preston and the estuary, nine resource areas are identified has having mineral present in workable quantities (Fig146; Table 48). These nine blocks contain an estimated 91 million tonnes of mineral, although admittedly, some of this volume is locked beneath major roads and settlements. According to our reliability index, with the exception of sub-resource areas LIV7 and LIV6, where borehole data are available and so have a high reliability, for the remainder the reliability of the assessment is medium. In terms of constraints (Table 49), the majority of resource bocks are unaffected by HER sites, Listed Buildings, Scheduled Monuments and AONB environmental controls. The exception is LIV6, which is within zones designated as SSSI. There is a high degree of urbanisation in Resource Blocks DAR 1 and DAR 3, LIV2-4, and a minor amount of urban area in LIV7. Compared to the Resource Blocks further up the Ribble, this area is less constrained by poor access. Table 48 shows the distance to the nearest A-road, with all the sites within 500m metres of a major road. In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 151), which shows that the best prospects within the Lower Ribble Valley are LIV6 and LIV7, with the other Resource Blocks too heavily constrained by proximity to urban areas for viable mineral extraction. The location of Resource Block LIV7 in relation to the glacial geomorphology is intriguing, because the terrace has formed on the south side of the Kirkham moraine complex at a point where a major former ice-marginal channel system cuts through the moraine. Although there is little borehole data for this location, this feature potentially is a former ice-marginal sandur or a partly eroded ice-marginal sandur, and so the potential for high-grade mineral is high. The Geoplan Ltd (2006) report includes part of this Resource Block in their zone 2B (Fig 144), where, they report, limited borehole data show a deposit of variable thickness, but reaching a thickness of 16.4m. For the present assessment (Tables 48 and 49), a deposit thickness of ~6m has been used consistent with other examples of Ribble Terrace T1. The quantity of mineral associated with this individual prospect is very large, ~35mt, but that will reduce because it includes land-area covered by roads. Nevertheless, it is a large mineral prospect that is serviced by the A583.

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Useable (tons)	Reliability	Workable
DAR1	Liverpool Group 2006	1	6	573,577	1,032,438	877,573	M	Y
DAR3	Liverpool Group 2006	1	6	953,823	1,716,882	1,459,350	M	Y
LIV 1	Liverpool Group 2006	1	6	1,437,138	2,586,848	2,198,820	M	Y

Resource area	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Useable (tons)	Reliability	Workable
LIV 2	Liverpool Group 2006	1	6	1,649,825	2,969,686	2,524,233	M	Y
LIV 2	Liverpool Group 2006	2	3.5	1,071,845	1,929,321	1,639,922	M	Y
LIV 3	Liverpool Group 2006	2	3.5	6,953,596	12,516,472	10,639,001	M	Y
LIV 4	Liverpool Group 2006	2	3.5	2,444,641	4,400,354	3,740,301	M	Y
LIV 5	Liverpool Group 2006	1	6	6,264,539	11,276,170	9,584,744	M	Y
LIV 6	Liverpool Group 2006	2	3.5	15,366,981	27,660,567	23,511,482	H	Y
LIV 7	Liverpool Group 2006	1	6	23,092,130	41,565,834	35,330,959	H	Y

Table 48: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 146. Workable Resource Blocks have to exceed 500,000 tons of usable mineral

Resource	Road (m)	Name	Urban	Environ	AONB	Fringe	HER	Listed Buildings
DAR1	0	A675	72	0	0	0	0	0
DAR3	238	A675	11	0	0	0	0	0
LIV 1	0	A6	0	1	0	0	0	1
LIV 2	121	A582	54	0	0	0	0	1
LIV 2	220	A582	68	0	0	0	0	0
LIV 3	0	A59	87	0	0	0	0	2
LIV 4	596	A583	0	0	0	0	0	0
LIV 5	490	A59	0	0	0	0	0	0
LIV 6	0	A583	0	15	0	0	0	0
LIV 7	0	A584	5	0	0	0	0	0

Table 49: Environmental constraints for the workable Resource Blocks identified on Figure 146. Workable Resource Block have to exceed 500,000 tons usable mineral. Urban refers to the % of urban area in the resource block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and Scheduled Monuments from the HER are total counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road.

7.2.9 ***Ribble Valley Glacigenic Deposits:*** during deglaciation, the Lower Ribble Valley and the Bowland Fells became free of ice relatively early and returned to local ice-stream control, through the south Lake District Icestream and a Ribble Glacier. It appears that the Lower Ribble glaciolacustrine environments extended from just east of Preston, upstream in the Lower Ribble and Calder, in the Vale of Chipping, and throughout much of the Hodder, but the lake probably varied considerably both in size and water depth throughout its existence. Critical to the existence of the lake is the damming mechanism across the Lower Ribble Valley near Preston. A glaciolacustrine depositional environment for the Lower Ribble provides a different context in which to interpret the extensive glacial mounds and flats that diversify the marked topographic bench between 50m and 75m OD in the Lower Ribble Valley. Some of the mounds between the Hodder confluence and Longridge (Fig 65), have been interpreted as esker/kame mounds (Aitkenhead *et al* 1992). The ice-marginal delta sequence in a former gravel pit at Hurst Green and other exposures of sands suggest a different depositional setting and highlight this area as a potential source of well-sorted sand and gravel (GLA1-10: Fig 152). The gravel exposures show a deposit thickness in excess of 15m locally at the Hurst Green pit, and thick deposits of sand-rich gravels are shown in gully sections at GLA1, Hothersall Hall. Further upstream (Fig 152), the landform types likely to yield quality mineral are esker ridges (ESK1-12) which are extend between 80m and 150m OD along the bench between the Ribble and the Hodder north of Clitheroe. The ridges have a relief of 25-19m above the diamict bench and so comprise reasonable volumes of aggregate. It is possible that these ridges were a mixture of pro-glacial, sub-aqueous fan and sub-glacial esker forms which were produced as the margin of the Ribble glacier retreated eastwards, in which case the potential for good-quality mineral increases.

7.2.10 Twenty-six resource areas are identified as having mineral present in workable quantities (Fig 152; Table 50). The volume calculations are underpinned by estimated average deposit thickness of 8m for the deltaic features and 5m for the eskers. Eskers are linear ridges and so the deposit thickness is very much an estimate. The potential errors inherent in volumetric estimation for irregular landforms from an average deposit thickness have been highlighted (*Section 3.11.31*) and are exemplified here for ESK5, for which two volumetric estimations are shown (Table 50); one was derived using an average thickness method and the second, much higher and probably realistic, by cut-and-fill calculations using the ground surface DEM and a deposit-base surface. If borehole data were more widespread within this esker field, this DEM-based approach would improve the assessment of aggregate volumes, although admittedly some of the volumes shown (Table 50) are locked beneath roads and settlements. According to our reliability index, with the exception of sub-Resource Blocks GLA1, GLA6-8 and ESK5, where exposures are available and so have a high reliability, the remainder are inferred resources and the reliability of the assessment is medium to low. Prior to any extraction, a comprehensive survey must be undertaken to prove the nature of the deposits, and the predicted aggregate quantities shown here must be regarded as indicative estimates.

Resource Block	**Source**	**Terrace**	**Depth (m)**	**Volume (m^3)**	**Weight (tons)**	**Usable (tons)**	**Reliability**	**Workable**
ESK11	Liverpool mapping	Esker	5	854,827	1,538,689	1,307,886	M	Y
ESK10	Liverpool mapping	Esker	5	1,258,838	2,265,909	1,926,023	M	Y
ESK9	Liverpool mapping	Esker	5	724,154	1,303,477	1,107,956	M	Y
ESK8	Liverpool mapping	Esker	5	705,437	1,269,786	1,079,318	M	Y
ESK7	Liverpool mapping	Esker	5	618,093	1,112,567	945,682	M	Y
ESK6	Liverpool mapping	Esker	5	830,696	1,495,253	1,270,965	M	Y
ESK5	Liverpool mapping	Esker	5	2,426,520	4,367,736	3,712,576	M	Y
ESK5**	Liverpool mapping	Esker	DEM	4,777,560	8,599,608	7,309,667	M	Y

Resource Block	Source	Terrace	Depth (m)	Volume (m^3)	Weight (tons)	Usable (tons)	Reliability	Workable
ESK4	Liverpool mapping	Esker	5	821,528	1,478,750	1,256,938	M	Y
GLA14	Liverpool mapping	LG Delta	5	829,237	1,492,626	1,268,732	L	Y
GLA13	Liverpool mapping	LG Delta	5	850,547	1,530,985	1,301,337	L	Y
GLA12	Liverpool mapping	LG Delta	5	7,564,124	13,615,423	11,573,110	L	Y
GLA11	Liverpool mapping	LG Delta	5	3,168,081	5,702,546	4,847,164	L	Y
GLA10	Liverpool mapping	LG Delta	5	2,429,310	4,372,757	3,716,844	L	Y
GLA9	Liverpool mapping	LG Delta	8	9,830,533	17,694,959	15,040,715	M	Y
GLA8	Liverpool mapping	LG Delta	8	3,664,161	6,595,489	5,606,166	M	Y
GLA7	Liverpool mapping	LG Delta	8	1,020,666	1,837,198	1,561,619	M	Y
GLA6	Liverpool mapping	LG Delta	8	5,190,229	9,342,413	7,941,051	M	Y
GLA5	Liverpool mapping	LG Delta	8	9,023,226	16,241,807	13,805,536	M	Y
GLA4	Liverpool mapping	LG Delta	5	1,806,485	3,251,673	2,763,922	M	Y
GLA3	Liverpool mapping	LG Delta	5	2,467,625	4,441,724	3,775,466	M	Y
GLA2	Liverpool mapping	LG Delta	5	4,094,263	7,369,674	6,264,223	M	Y
GLA1	Liverpool mapping	LG Delta	5	5,442,886	9,797,196	8,327,616	M	Y

Table 50: Mineral volumes expressed as total estimated sand and gravel for the workable Resource Blocks identified on Figure 152. Workable Resource Blocks have to exceed 1,000,000mt usable mineral

7.2.11 In terms of constraints (Table 50), because these resource areas border the Forest of Bowland AONB all the esker Resource Blocks are affected by being within the AONB or the AONB fringe zone. The deltaic deposits in Resource Blocks GLA1 -GLA14 are also affected by AONB, urban area, Scheduled Monument and Listed Building constraints. Like the upstream parts of the Ribble between the M6 and Calder tributary, this area is also constrained by poor access. The ESK1-12 and GLA11-13 traffic would have to pass via Clitheroe, although Resource Blocks GLA1-10 could be accessed via the B6244 or B6243 to Longridge (Table 51). In summary, combining the information on the quantity of mineral available with limitations to use by constraint produces a relative viability index (Fig 153) which shows that most of the Resource Blocks are of low viability for future use. The Geoplan Ltd (2006) report does not touch upon these areas and they are included here for completeness. The quantity of mineral associated with these prospects is, however, large, potentially of the order of ~100mt. A growth area in terms of development within National Parks and AONBs is the use of local stone and mortar in building projects for aesthetic reasons, for instance colour matching of mortar and stone. In other regions, such as North Wales, this has seen an interest in the possibility of creating local permissions for mineral extraction to service this specialised market. The prospects fringing the Forest of Bowland may be valuable in that regard.

Resource	Road (m)	Name	Urban	Environ	AONB	Fringe	HER	Listed Buildings
ESK11	1,509	A671	0	0	0	100	0	0
ESK10	1,598	A671	0	0	0	100	0	0
ESK9	1,947	A671	0	0	0	100	0	1
ESK8	2,237	A671	0	0	0	100	0	1
ESK7	2,868	A671	0	0	0	100	0	0
ESK6	2,378	A671	9	0	77	23	0	0
ESK5	2,562	A671	33	0	59	41	0	3
ESK4	3,117	A671	0	0	34	66	0	0
GLA14	0	A671	39	18	0	0	0	0
GLA13	3,036	A671	15	0	100	0	0	5
GLA12	3,319	A671	1	0	100	0	0	2
GLA11	2,700	A671	0	1	77	23	0	0
GLA10	2,510	A59	0	5	0	100	0	1
GLA9	2,961	A59	0	5	61	39	0	2
GLA8	2,551	A59	18	3	0	83	0	0
GLA7	2,283	A59	0	12	0	0	0	0
GLA6	2,615	A59	3	2	0	35	1	4
GLA5	2,065	A59	0	5	0	0	0	4
GLA4	2,816	A59	0	5	0	0	0	0
GLA3	3,252	A59	4	1	0	0	0	0
GLA2	3,132	A59	0	2	0	0	0	0
GLA1	2,924	A59	0	5	0	0	0	0

Table 51: Environmental constraints for the workable Resource Blocks identified on Figure 152. Workable Resource Block have to exceed 500,000 mt usable mineral. Urban refers to the % of urban area in the resource block, with equivalent % area calculations for designated sites (SSSI, NNR, LNR, Ramsar). Listed buildings and Scheduled Monuments from the HER are total counts within the Resource Block. Connectivity to the road network is based on distance in metres to the nearest A-road

7.2.12 ***The Kirkham End Moraine Complex:*** although not part of the current study area, arguably one of the best prospects for finding significant quantities of sand and gravel in Lancashire lies in the low ridges that extend from east of Preston to the coast north of Blackpool, collectively termed the Kirkham End Moraine (*Section 5.1.19).* It is an area of considerable archaeological potential, reflecting that is raised dry land, edged by the wetlands of the Fylde to the north, and consequently has attracted settlement since the early prehistoric period (Middleton *et al* 1995). The Romans built a military installation on the Kirkham End Moraine, and nearby a medieval town developed around a parochial centre (Howard-Davis and Buxton 2000; White 1996).

7.2.13 Stratigraphic information on the mineral potential of this region is limited to descriptions of the coastal sections at Blackpool (Fig 64), the M55 borehole sequence (Wilson and Evans 1990; Aitkenhead *et al* 1992); (Fig 66), and the north/south M6 boreholes (Fig 67). The detailed mapping of the geomorphology (Fig 69) and the borehole and section evidence (Figs 64 and 66-7) show that the glaciofluvial sands and gravels thicken in the inter-moraine areas (Figs 64 and 66-7). These deposits provide the best prospect for mineral extraction within the stratigraphic sequence. The moraine ridges show that ice retreat was punctuated by oscillations of the ice margin and between these ridges the depositional model predicts that ice-marginal outwash plains (sandur) would form. These sandur would be wider and comprise thicker deposits near the major through-moraine outwash channels: the Skippool and the Kirkham Channels (Figs 69 and 66). Towards the eastern end of the M55 and southern end of the M6, borehole sequences, the surface diamicts and the thick sequence of glaciolacustrine laminated clays preclude aggregate extraction (Fig 67), but to the west there are clearly thick sequences of glaciofluvial sands and gravels. The surface diamict laid down during the ice-marginal oscillations responsible for the ridges often buries these glaciofluvial sands and gravels, but the diamict drape thins in the inter-moraine areas and can be shallow (1-3m) on the moraine ridges.

7.2.14 Further data on the mineral reserves within the Kirkham moraine are available from past, current and planned mineral extraction sites: Chain Lane; Bradley's Sand Pit; Higher House Farm; Myerscough; and Sharples Quarry (Geoplan Ltd 2006); (Fig 154). Higher House Farm was refused planning permission for mineral extraction in 1983 and the limited information within the Geoplan Ltd report (2006) suggests that a fairly limited deposit of glaciofluvial sand and gravel was the target mineral, with a predominance of sand ~72%. The setting is one of an inter-moraine sandur flat, and so is a zone with high potential for glaciofluvial sands and gravel. Further confirmation of ice-marginal sandur-style deposits associated with this flat that are commercially extractable is gained from mineral reports from nearby exhausted workings at Myerscough (Fig 154) (Geoplan Ltd 2006). Bradley's Sand Pit to the south-east is also within an inter-moraine area, and the mineral reported is some 25m in thickness, buried by 4-4.5m of diamict/clay. The geomorphological setting is intriguing, because the nature of the deposits and inter-moraine setting suggests a sandur depositional environment, but the sandur would have been very restricted in extent between the flanking ridges. However, the total thickness of deposit may relate to the phase of ice retreat formed as pro-glacial outwash, with ridge-forms created by later ice-marginal advance. Further to the west, at Chain Lane, a restored gravel pit was worked glaciofluvial deposits during the 1950s, and again the geomorphic setting is in an inter-moraine flat. In summary, all previous mineral extraction in the Kirkham moraine complex has targeted the inter-moraine areas.

7.2.15 The database of Resource Block reports by Geoplan Ltd (2006) also warrants further scrutiny in comparison with the geomorphological control. Resource Blocks 1F and 1G form an area of raised ground at 35-40m OD, which apparently comprise sands and gravels of *c*5m thickness. These areas of flat ground are raised above the surrounding lowlands and abut against the incline up to the Bowland Fells; they are topographically higher than the sandur system between Myerscough and Higher House (Fig 154). The most logical palaeogeographical interpretation is that an ice-marginal sandur/kame terrace existed between the ice margin and the rising bedrock relief of the Bowland Fells and ice-marginal drainage deposited sand and gravel in a conduit that fed into more extensive sandur to the south. The selection of Resource Block 3H for further analysis (*ibid*) is intriguing, given that the geomorphology shows that it is a moraine ridge and so likely to comprise thicker surface diamicts, as is confirmed by the reported 5-7m of silty-clay sand and gravel (Geoplan Ltd 2006). The zone immediately to the south would have made a more logical block for assessment. Resource Blocks 4C and 4D further highlight the potential resource within the Kirkham moraine, with 8m-thick sand and gravel deposits (Geoplan Ltd 2006), but again differences in borehole records between moraine crests and inter-moraine areas are not made. Examination of the M55 borehole series around the M55-A585 interchange (Fig 66) shows the thickest sand deposits, potentially 15-20m in thickness, that lie in this inter-moraine sandur associated with the Kirkham Channel (Fig 69). The reports for Resource Block 4E (Geoplan Ltd 2006) around Bradley’s Sand Pit confirm this interpretation, that mineral is present but is laterally variable. There probably is sufficient density of boreholes to assess whether the thickest deposit is confined to the inter-moraine area (Fig 155).

7.2.16 In summary, our mapping of the geomorphology and preliminary assessment of published borehole records (Wilson and Evans 1990; Aitkenhead *et al* 1992) shows that there are considerable potential mineral resources in the Kirkham moraine complex. Further detailed examination of the borehole evidence will improve the interpretation, but although local variability from this rule is possible, at present the thickest sand and gravel deposits concentrate in the inter-moraine areas. Conveniently, the surface diamict overburden is also much thinner in the inter-moraine areas, which is more convenient for the extractive industries. Further mineral assessment in this region should be undertaken, but it must be underpinned by a sound understanding of the geomorphology and landform-sediment relationships. This integrated approach should also be extended to other parts of lowland Lancashire, where the geomorphological story is poorly constrained and has a great deal of information to impart.

