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River Mining: sand and gravel resources of the lower Rio Minho and Yallahs fan-delta, Jamaica

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Extraction of First Terrace sands and gravels, Water Lane, Rio Minho, Jamaica

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Preface

Throughout the developing world river sand and gravel is widely exploited as aggregate for construction. Aggregate is often mined directly from the river channel as well as from floodplain and adjacent river terrace deposits. Depending on the geological setting, in-stream mining can create serious environmental impacts, particularly if the river being mined is erosional. The impacts of such mining on farmland, river stability, flood risk, road and bridge structures and ecology are typically severe. The environmental degradation may make it difficult to provide for the basic needs (water, food, fuelwood, communications) of communities naturally located in the river valleys.

Despite the importance of this extractive industry in most developing countries, the details of its economic and environmental geology are not fully understood and therefore do not adequately inform existing regulatory strategies. The main problem is therefore a need to strengthen the general approach to planning and managing these resources. Compounding the problem is the upsurge of illegal extractions along many river systems. There is therefore a need to foster public awareness and community stewardship of the resource.

The project 'Effective Development of River Mining' aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. This project (Project R7814) has been funded by the UK's Department for International Development (DFID) as part of their Knowledge and Research (KAR) programme. This programme constitutes a key element in the UK's provision of aid and assistance to less developed nations. The project started in October 2000 and terminates late in 2004.

Specific objectives of the project include:

- Resource exploration and resource mapping at the project's field study sites (Rio Minho and Yallahs rivers in Jamaica)
- Analysis of technical and economic issues in aggregate mining, particularly river mining
- Determination and evaluation of the environmental impacts of river mining
- Evaluation of social/community issues in the context of river mining
- Investigation of alternative land and marine aggregate resources
- Review of the regulatory and management framework dealing with river mining; establishment of guidelines for managing these resources and development of a code of practice for sustainable sand and gravel mining.

The 'Effective Development of River Mining' project is multidisciplinary, involving a team of UK specialists. It has been led by a team at the British Geological Survey comprising David Harrison, Andrew Bloodworth, Ellie Steadman, Stephen Mathers and Andrew Farrant. The other UK-based collaborators are Professor Peter Scott and John Eyre from the Camborne School of Mines (University of Exeter), Dr Magnus Macfarlane and Dr Paul Mitchell from the Corporate Citizenship Unit at the University of Warwick, Steven Fidgett from Alliance Environment and Planning Ltd and Dr Jason Weeks from WRc-NSF Ltd. The research project is generic and applicable to developing countries worldwide, but field studies of selected river systems have been carried out in Jamaica and review studies have been undertaken in Costa Rica. Key participants in these countries have included Carlton Baxter, Coy Roache and Larry Henry (Mines and Geology Division, Ministry of Land and Environment, Jamaica), Paul Manning (formerly Mines and Geology Division, Ministry of Land and Environment, Jamaica) and Fernando Alvarado (Instituto Costarricense de Electricidad, Costa Rica).

The authors would like to thank the many organisations in Jamaica and Costa Rica who have contributed to the project. In addition to the collection of data, many individuals have freely given their time and advice and provided the local knowledge so important to the field investigations.

This report forms one of a series of Technical Project Output Reports listed below:

- *Geology and resources of the lower Rio Minho valley and Yallahs Fan-delta, Jamaica, 2003*. AR Farrant, SJ Mathers and DJ Harrison, British Geological Survey.
- *Aggregate production and supply in developing countries with particular reference to Jamaica, 2003*. PW Scott, JM Eyre (Camborne School of Mines), DJ Harrison and EJ Steadman, British Geological Survey.
- *Assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica, 2003.* J Weeks, WRc-NSF Ltd.
- *Scoping and assessment of the environmental and social impacts of river mining in Jamaica, 2003*. M Macfarlane and P Mitchell, Warwick Business School, University of Warwick.
- *Alternative sources of aggregates, 2003*. DJ Harrison and EJ Steadman, British Geological Survey.
- *Alluvial mining of aggregates in Costa Rica, 2003*. Fernando Alvarado-Villalon (Costa Rican Institute of Electricity), DJ Harrison and EJ Steadman, British Geological Survey.
- *Planning guidelines for management of river mining, 2003*. S Fidgett, Alliance Environment and Planning Ltd.

Details of how to obtain these reports and more information about the 'Effective Development of River Mining' project can be obtained from contacting the Project Manager, David Harrison at the British Geological Survey, Keyworth, Nottingham, UK, email: djha@bgs.ac.uk

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Summary

Sand and gravel aggregates are extracted from many rivers in Jamaica but little information is available on the distribution of resources and of the volumes extracted. Resource mapping studies were therefore carried out on two major river systems, the lower Rio Minho and the Yallahs, which were the field study areas for the River Mining project. A combination of walk-over surveys and studies of aerial photographs were used to rapidly produce aggregate resource maps, showing the distribution and relationships of the major sand and gravel bodies. Ground-truth data were provided by a suite of trial pits dug into the river sediments by the Mines and Geology Division of the Ministry of Lands and Environment. All pits were logged and samples taken for particle size analysis.

The lower Rio Minho flows from the Central Highlands across a broad coastal plain where it has cut a series of terraces into former deposits. The mapping has identified a number of river terrace and floodplain deposits of varying resource potential. The First Terrace deposits are a major sand and gravel resource but the upper parts of the Second Terrace deposits are mostly of clay or silt and have no resource potential. Large amounts of sand and gravel are extracted from the Rio Minho and total production since 1980 when extraction started, is estimated to be about 5.25 million tonnes. Most extraction has been by instream mining, but the mapping has shown that alternative resources of good quality sand and gravel exist in the First Terrace deposits which flank the current river channel.

The Yallahs river drains the southern flank of the Blue Mountains and the river sediments form a lobate fan-delta covering over 10 square kilometres. The delta sediments are composed of coarse sandy gravels, ranging in size from small pebbles to large boulders. The sediments thicken rapidly downstream and are over 150 m thick near the coast. Large amounts of sand and gravel have been extracted from the fan-delta in recent years. It is estimated that about 4.4 million tonnes of aggregate has been produced since 1990. Extraction is concentrated in the main channel which is now incised up to 6 m below the level of the fan-delta surface.

This report is one of a series of Technical Reports on alluvial mining in developing countries, most of which relate to Jamaica (see Preface for details). They are the output from the 'Effective Development of River Mining' project which aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. The work was carried out under the Department for International Development Knowledge and Research programme, as part of the British Government's programme of aid to developing countries. The project was undertaken in collaboration with key organisations in Jamaica and Costa Rica, who provided field guidance and local support.

1 Introduction

The location of aggregate materials requires the collation of data from many sources, but an essential requirement for prospecting is a reliable geological map. Detailed geological maps specifically for sand and gravel resources did not exist in the Rio Minho and Yallahs river valleys in Jamaica (which are the field study areas for the River Mining project) and, therefore, in 2001-2002 a programme of geological surveying with supporting sedimentological studies, was carried out by BGS in the lower Rio Minho and Yallahs fan-delta.

Mapping was undertaken using 1:12,500 scale topographic maps and involved thorough walk-over surveys, including the examination of natural exposures and extraction sites and the mapping of geomorphological features. Several suites of aerial photographs were used to define resource boundaries, to map major depositional landforms and to record channel migrations over time. Borehole and well records (from the Water Resources Authority) were also examined to determine the presence and thickness of sand and gravel bearing deposits. A supporting campaign of trial pitting was carried out in the Rio Minho valley by the Mines and Geology Division (MGD). A total of 52 pits were dug within the MGD designated Rio Minho Quarry Zone. Pits were dug by backhoe to a depth of around 3 to 5 m on a 400 m grid. Lithological logs of the exposures were recorded and samples of aggregate were taken for laboratory grading analysis at the MGD.

The field surveys also aimed to review the scale of current sand and gravel extraction in the Rio Minho and Yallahs rivers by mapping the boundaries of extraction, the depths of extraction, the worked out and restored areas and by gathering information on extraction rates. Estimates could then be made of the volumes extracted in recent years.

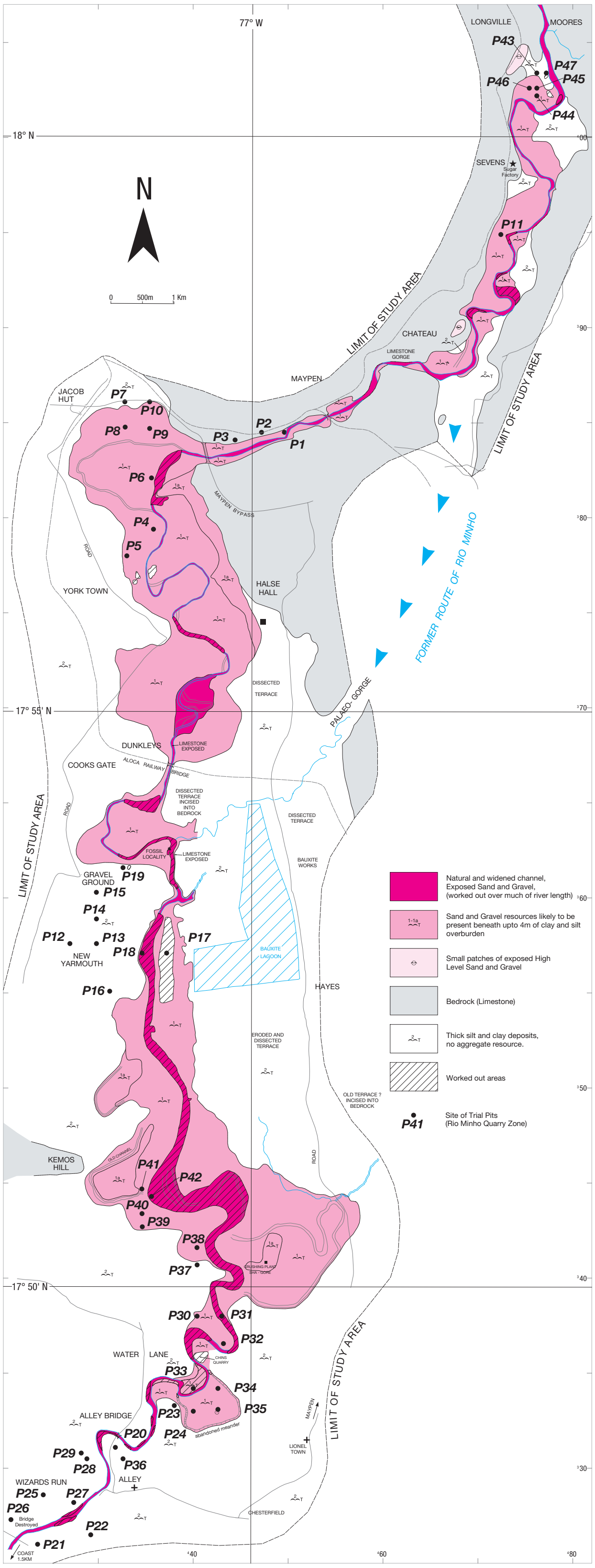
2 Rio Minho – Geology and Resources

The Rio Minho rises in the Central Highlands and flows south via Maypen to the sea near Alley. In its lower reaches south of Maypen, it flows across a broad coastal plain and has incised a series of terraces into a large relict sedimentary fan. This incision is most marked immediately south of Maypen.

2.1 RESOURCE MAPPING

The lower Rio Minho valley can be divided into two study areas: the Longville-Sevens area upstream of the bedrock limestone gorge at Maypen, and the much larger coastal plain south of Maypen. The downstream limit is marked by the position of the former coast-road bridge 2km downstream of Alley Bridge beyond which the river enters the extensive coastal mangrove swamps (see Figure 1).

Figure 1 Alluvial deposits of the lower Rio Minho, Jamaica



2.1.1 Rio Minho: Longville-Sevens Study area

The Longville-Sevens area covers about 6 square km to the northeast of Maypen. The upper boundary of this area is at Moores and the lower limit is at Chateau where the Rio Minho enters a limestone gorge cut as an east-west aligned overflow channel diverting the river from its former, more southerly, route (Figure 1).

The area is wholly underlain by limestone bedrock and the incision of the Rio Minho has created a series of Quaternary fluvial deposits within the valley. Three distinct units can be mapped in this area: **High Level Gravels, Second Terrace** and the **First (floodplain) Terrace**. The distribution of these is shown in Figure 1.

The **High Level Gravels** occur perched on the shoulder of the Rio Minho valley at elevations 20-25 m above the present floodplain. Reworking laterally by small streams results in clasts from these deposits being incorporated as lateral mini-fans into the overbank deposits of the lower terraces. These gravels are predominantly composed of volcanic lavas and tuffs sourced from the Central Inlier with subordinate amounts of more locally derived limestone. The outcrops are small and dissected and these deposits are not thought to constitute a significant aggregate resource.

The **Second Terrace** deposits occur at elevations up to 15 m above the floodplain and abut the bedrock limestone along the sides of the valleys. The natural sections in these deposits show up to 15 m of brown, poorly stratified, silt and clay with subordinate sand beds. These deposits are readily traced on air photos and on the ground due to their diagnostic dissected morphology, which resembles the "badlands" of arid terrains. It is probable that coarser grained sand and gravel deposits occur at depth beneath these fine-grained over-bank deposits but this would be too deeply buried for extraction to be considered. It is also possible that these deposits are composite, as some patches occur at a level (? terrace) 5-8 m above the floodplain whereas others comprise a fine-grained sequence extending up to 15 m above the floodplain. There is no clear bluff enabling the mapping of two levels; rather there is a transition between the two types. This may suggest that the lower 5-8 m above the floodplain is an erosional bench cut into the deposits rather than an aggradational terrace surface. The deposits present in the abandoned valley of the Rio Minho around Paisley are at least 15 m above the modern floodplain and of similar type; they are included in the Second Terrace deposits.

The **First (floodplain) Terrace** deposits comprise a classic fining-upward sequence as revealed in numerous exposures in the riverbanks. The active channel contains gravel deposits and is incised about 6-8 m into the floodplain. Sections in the banks consistently show 2-3 m of silt and clay overlying a similar thickness of sand resting on 1-2 m of coarse gravel of similar composition to the higher level deposits. Sections in the trial pits show 1-2 m of silt overlying up to 3 m of sand and gravel. The clasts are commonly cobbles, and at maximum, boulders. This is the classic fining upward sequence of a meandering river. Boreholes prove up to 35 m of Quaternary fluvial deposits are present in the area infilling a deeply incised palaeovalley.

2.1.2 Rio Minho: South of Maypen

At Maypen, the Rio Minho debouches from a gorge cut into limestone bedrock onto an extensive coastal plain. The study area extends south for 16 km from Maypen to the former coast road bridge some 2 km downstream of Alley Bridge, in a 2 km wide strip straddling the Rio Minho.

Two principal levels of Quaternary deposits are recognised: those forming the broad coastal plain, classified as the Second Terrace and those related to the meander belt of the Rio Minho which is incised into the coastal plain and here termed the First (floodplain) Terrace. These levels are tentatively correlated with the deposits upstream of the gorge in the Longville-Sevens area.

The coastal plain surface falls consistently southwards at 2-3 m per km from Maypen to the coast. At its inland margin around Maypen, the plain has an average elevation of c. 50 m, descending to 12 m around Water Lane near the coast. Away from the Rio Minho, smaller streams and gullies dissect the surface of the plain. The depth of this incision is greatest in the north, where the active channel of the Rio Minho is now about 15 m below the coastal plain, this decreasing to about 4-5 m around Water Lane. This is primarily because the channel gradient is less than the regional slope of the coastal plain. Extensive meander scrolls, apparent on air photographs as bundles of curved lines, mark successive positions in the lateral migration of the channel across the coastal plain (Second Terrace), these are especially well developed on the west bank. Sections in riverbanks and the trial pits cut into the coastal plain **Second Terrace** deposits show 5-6 m of predominantly silts and clays with sands, no gravel was seen.

The **First (floodplain) Terrace** is present throughout the study area. Around Maypen, it is well developed and lies at 6-8 m above the active channel, and is incised 10-12 m into the coastal plain, forming a significant bluff feature. Downstream, the relative elevation between the two terrace levels decreases. So at Water Lane, the active channel is cut 4-5 m into the First (floodplain) Terrace which is itself only incised 3 m into the coastal plain (Second Terrace). Farther downstream beyond Alley Bridge, the First (floodplain) Terrace disappears, and the channel is entrenched within the Second Terrace deposits. Here the river probably adopts an anastomosing style and progressively passes into the coastal mangrove swamps. Slightly higher (+2 to 3 m) patches of the First (floodplain) Terrace have been labelled on the map as Terrace 1a. Just upstream of the Aloca Minerals railway bridge there is a small patch of incipient floodplain forming below the level of the First (floodplain) Terrace, this is likely to develop with time as another phase in the incision process.

The channel of the Rio Minho is still actively migrating. Avulsion resulted in a large meander cut-off during the 1980s northwest of Water Lane. Whilst it is possible that this event could relate to the onset of river mining upstream it is more probable that it is a natural event. A similar cut-off occurred in the late 1980s to early 1990s just downstream of the Maypen by-pass. This cut-off is clearly unrelated to any river mining activity.

Sections in the First (floodplain) Terrace in riverbanks reveal 2-3 m of silts overlying sands and gravels (Figure 2), a fining upward sequence typical of the meandering style of the river at this point. In general, the sediment appears to fine downstream. Trial pit exposures (eg P4, 5, 6, 24, 34, 38, 40, 41) show up to 2 m of silt overlying at least 2 m of sand and gravel (see Appendix 1).

Locally, the active river channel is incising into bedrock. This occurs where the Aloca mineral railway crosses the Rio Minho west of Cooks Gate, and again a kilometre downstream east of Gravel Ground. This has effectively prevented the river channel from meandering laterally and explains why the meander belt of the First (floodplain) Terrace is so narrow in these locations.

Immediately below Maypen about 25 m of Quaternary deposits are present resting on limestone bedrock, but in the Bowens – Cooks Gate area several well logs show only c. 10 m of Quaternary sediments on limestone bedrock suggesting a buried karstic or faulted surface of high relief below parts of the drift deposits. This is confirmed by the observation of limestone bedrock in the river channel noted above. Farther south limestone is only encountered in well logs at considerable depth (60-95 m) in the Water Lane and Alley area. It is overlain by a clastic sequence of sands, clays and thin gravels and in one log shelly ?marine deposits were encountered. There are two possibilities here:

- Limestone forms the pre-Quaternary bedrock throughout and the drift reaches 95 m in places close to the coast.
- Late Tertiary ?marine and fluvial, clastic sediments are present beneath the Quaternary deposits in the south of the area and the Quaternary thickness is 20-40 m.

Figure 2 Fining-upward sequence of the First (floodplain) Terrace at Chin's Quarry north of Water Lane.

Figure 3 **Extensive in-channel mining near Water Lane**

2.2 EXTRACTION HISTORY AND RESOURCES

River sand and gravel mining has taken place throughout much of the Rio Minho valley (Figures 1 and 3). Upstream of Maypen, in the Longville-Sevens area extraction has been undertaken at three main points, in each case mainly exploiting the river channel deposits and point bars where little or no silt overburden is present. The total estimated volume extracted at the 3 sites is about 125,000 cubic metres, equivalent to around 250,000 tonnes. Most has occurred in the last 10 years.

Between Maypen and Hayes mining has been confined to areas with easy access to the river. A large quarry with crushing plant occurs just south of the Maypen bypass. A small, single person, operation extracts sand from the First (floodplain) Terrace 1km southwest of Maypen. South of Hayes, extraction has taken place from the active channel along virtually the whole river course. In this area the channel has been considerably widened over long stretches.

A first order estimate of the amount of aggregate extracted from the river channel is 2.1 million cubic metres. This is based on a quarried channel 14km long, averaging 50 m wide and 3 m thick, yielding around 4.2 million tonnes.

Additional minor extraction from the First (floodplain) Terrace occurs at Chin's Quarry (Water Lane) where an area averaging 200 m long and 150 m wide with an average depth of 3 m has yielded some 90 000 cubic metres, equivalent to around 180 000 tonnes. Near Hayes an area 800 m long by 100 m wide and 4 m deep, yielded 320 000 cubic metres, or 640 000 tonnes. Nowhere has the higher Second Terrace been worked.

A total estimate (up to 2001) for the lower Rio Minho valley is about 5.25 million tonnes with over 75% from in-channel mining and the balance from quarrying or cutting back into the First (floodplain) Terrace, widening the channel in the process. All this extraction has occurred since 1980 and much of it in the 1990s. Much of the gravel fraction that is too coarse for sale is taken to the crushing plant owned by Messrs Sha-Gore (which has a reported capacity of 3,000 tonnes a day) and crushed to produce fine gravel and manufactured sand.

There is only limited transport of sand and gravel in the river channel at present and major flood events which would be required for significant replenishment have not occurred for at least the last 30 - 40 years. The last major hurricanes in Jamaica were Flora in the 1970s and Gilbert in 1986. Both created substantial wind damage but rainfall was only modest. Heavy rains, however, in May, September and October 2002, did result in extensive terrace erosion, generating considerable amounts of sediment into the river system. River channels were seen to migrate, but reverted to their original course after the flooding receded.

In summary, in terms of aggregate resources, sand and gravel is now only available at a few points in the active channel due to extensive extraction. However, significant inferred sand and gravel resources are present beneath 2-4 m of silt-clay overburden beneath the First (floodplain) Terrace. The Second Terrace deposits in most localities are capped by up to 15 m of silts and clays making extraction of any sand and gravel beneath impractical.

2.3 HYDROLOGICAL DATA

The Water Resources Authority has provided river discharge data for the Rio Minho in 1969 and 1971. The gauging stations are located at Suttons near Chapelton, nearby at Pindars in the left bank tributary Rock River (both upstream of the study area); at Maypen and at Alley Bridge. The datasets are incomplete and there is no 1971 data for Maypen. Nevertheless the data allows several general conclusions to be drawn.

The Rio Minho has a highly variable discharge over an order of magnitude of 1,500. Daily fluctuations of an order of magnitude of 100 are apparent. The river flowed continually throughout the year, albeit a trickle at times, in the upper reaches (Suttons, Pindars) and at Alley Bridge. At Maypen however no flow was recorded at times in the dry season (1969).

A significant fall in discharge occurs between Suttons and Maypen in major flood events (c.50%) which suggests loss of water into the underlying limestone aquifer above Maypen; this also explains the absence of flow at Maypen in the dry season although modest flow is maintained at Suttons.

The dry season for 1969-1971 was from December to mid-May and also parts of June-August. Major flood events occurred in both years in late May and early June and more sporadically in August to October. The two years (1969 & 1971) differs to some degree, suggesting some variability from year to year.

There is a 24hr lag time between Suttons and Alley Bridge for major discharge events.

3 Yallahs fan-delta – geology and resources

3.1 RESOURCE MAPPING

The Yallahs river near its mouth is a classic example of a fan-delta (Westcott and Ethridge, 1980). The river drains the southern flank of the Blue Mountains to the east of Kingston. Where it debouches from the mountains at Easington Bridge, it has built a lobate fan-delta covering 10.5 square km, extending 2km out into the Caribbean Sea (Figure 4).

Prior to levée construction and sand and gravel mining on the fan-delta, the Yallahs river channel displayed a braided morphology. Channel bed forms are dominated by low relief longitudinal gravel bars separated by low flow channels. These bars consist of poorly sorted, well imbricated coarse gravels and sands. The channels are armoured with coarse clast-supported gravel with a coarse sand matrix. Clast composition is predominantly volcanic and metamorphic lithologies from the Blue Mountains Inlier plus more locally derived limestones (Wescott and Ethridge, 1983). The fan-delta is wave dominated at its mouth.

Quarrying has significantly changed the channel morphology. Whereas previously the river displayed a braided morphology, the channel is now incised up to 6 m below the level of the fan-delta surface. This is partly as a direct result of gravel extraction in the channel, but also due to the fluvial system adjusting to the decrease in available bed-load and the change in channel gradient. Most incision occurs during flood events, when rapid headward erosion of the fluvial deposits occurs, creating a series of knick points that migrate upstream. This has caused the undermining of the causeway for the coast road (Figure 5). During floods following heavy rains in September/October 2002, the causeway was washed away, severing the main road. It has recently been replaced with a temporary bailey bridge structure.

Boreholes indicate that the Quaternary sediments thicken rapidly downstream. Limestone bedrock is exposed in the channel at Easington Bridge, yet less than a kilometre downstream, the sediment thickness reaches 92 m, by the ford. Near the coast the sediment is in excess of 150 m thick.

Extraction below the ford has provided excellent, almost continuous exposures of the fluvial gravels on both sides of the river. Immediately upstream of the ford, exposures are limited to disused quarries on the west bank, but farther upstream, recent incision by the river has provided superb continuous sections for almost a kilometre.

The principal deposits are fluvial interbedded coarse to very coarse, poorly sorted, sandy gravels and sands (Figure 6). The gravel units have crude indistinct planar bedding and occasional well developed imbrication. These gravels are generally clast supported with a medium-coarse sand matrix.

Figure 4 Alluvial deposits of the Yallahs fan delta, Jamaica

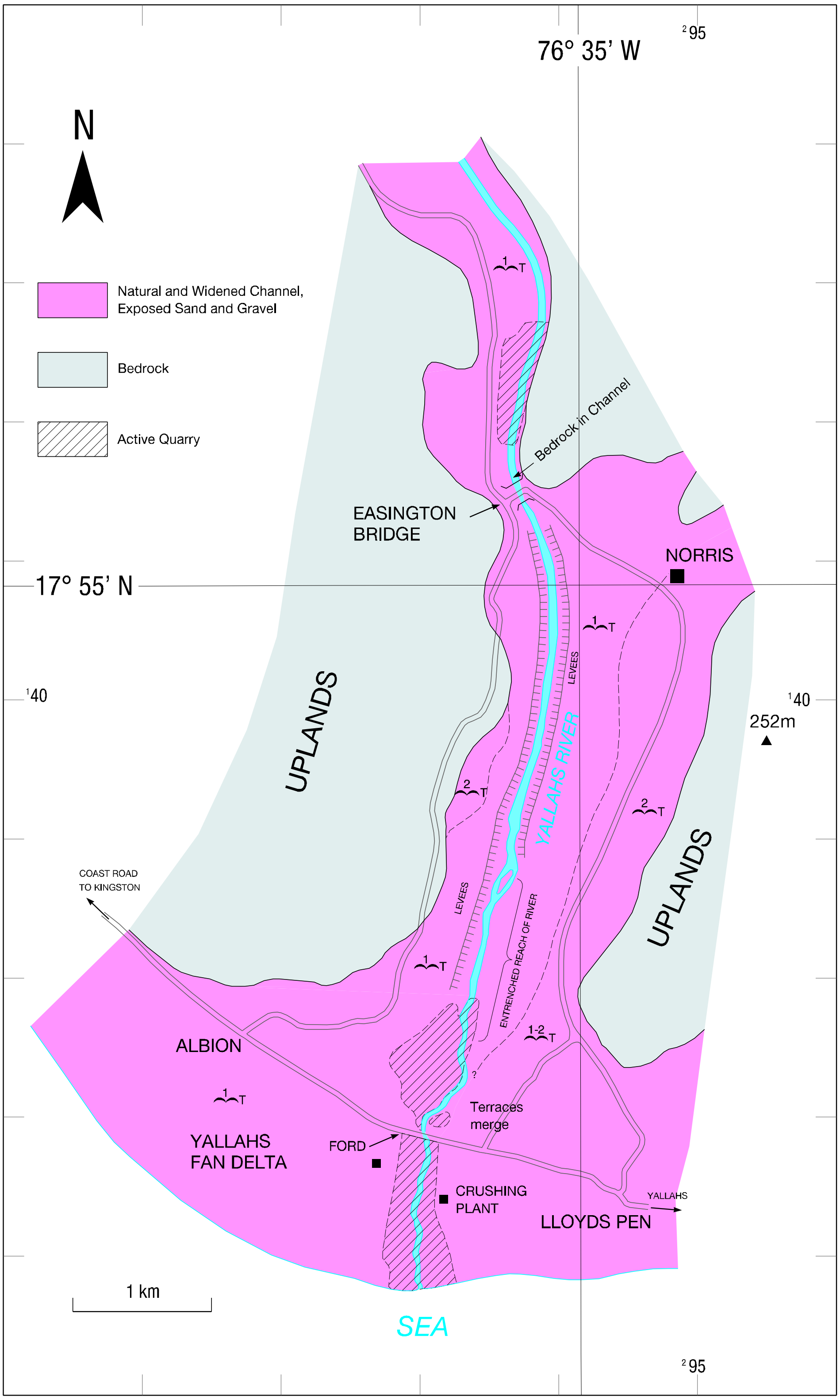


Figure 5 **Undermining of the road causeway, Yallahs ford (January, 2002). The waterfall marks the position of the spillway. Broken pipes can be seen in the foreground.**

Figure 6 **Section downstream of Yallahs ford on the west bank. Cross bedded sandy gravel overlain by crudely bedded coarse gravel channel fill. Note the large size of the boulders.**

Clasts range in size from small pebbles and cobbles to large boulders 2 m in diameter. The gravels grade laterally and vertically into coarse, poorly sorted sands with scattered pebbles. Locally, over bank deposits are preserved. These silty, very fine grained to medium grained sands are characterised by ripple lamination, small scale cut and fill structures and cross-bedding. These are laterally discontinuous, but can be traced for several hundred metres. A superb example can be seen in the sections immediately south of the ford. However, these finer grained lithologies are volumetrically insignificant.

3.2 EXTRACTION HISTORY AND RESOURCES

Extraction of aggregate from the Yallahs fan-delta commenced about 1990. Below the ford extensive extraction of 3 to 6 m of sand and gravel has occurred (Figure 7). Some limited extraction has also taken place just above the ford, especially on the western side of the river and in the channel itself. There is almost no extraction on the east bank upstream. Two quarry operators are actively mining the Yallahs river sands and gravels below the ford. On the east bank is a crushing plant. At the time of survey, active extraction was taking place within 100 m of the seashore. However, the company is said to have plans to move their operations north of the ford. To the west, active mining of the river channel upstream of the ford is taking place. Extraction is also taking place just upstream of Easington Bridge.

Figure 7 View downstream from Yallahs Ford. The recent incision of the channel can be seen.

Below the ford, extraction has taken place over the entire 1.6 km length of the river channel, up to 250 m wide and 4 m deep, yielding approximately 1.6 million cubic metres, or around 3.2 million tonnes of aggregate. Extraction from adjacent quarries in a subsidiary channel has yielded a further 240 000 cubic metres, equivalent to around 480 000 tonnes of aggregate. Upstream of the ford a rough estimate of the area quarried is 120 000 square metres worked to an average depth of 3 m, yielding 360 000 cubic metres (or 720 000 tonnes) of aggregate.

Total aggregate production (up to 2002) from the Yallahs fan-delta is thus approximately 2.2 million cubic metres, equivalent to about 4.4 million tonnes of aggregate. Coarse poorly sorted sand and gravel resources are inferred to be present from surface throughout the fan-delta. Extraction from about 1990 has focussed on the main (artificial) channel and immediately adjacent areas near the river mouth.

3.3 HYDROLOGICAL DATA

The Yallahs river is highly seasonal. Maximum discharges typically occur in November, associated with hurricane discharges and the wet season. Peak measured discharges are 17.5 cum/sec, but are much higher during hurricane events. During the dry season, the river is often dry from the apex of the fan to the sea. Water is diverted into irrigation canals and lost to subsurface flow. Only periodically is the discharge sufficient for surface water to reach the sea. There is extensive abstraction of water from the Yallahs river farther upstream for domestic use in Kingston. When visited on 6th May 2001, there was some flow at Easington Bridge but none apparent at the ford. At low discharge all the water is presumed to pass into the underlying limestone aquifer between the two crossings. However, during the study period in January 2002, flow was continuous from Easington Bridge to the sea.

4 Conclusions

- Geological mapping of the Quaternary sediments of the Rio Minho valley and the Yallahs fan-delta has identified a series of river terrace and floodplain deposits of varying resource potential. The terraces are particularly well developed in the lower Rio Minho valley and here, the First (or Floodplain) Terrace forms a major sand and gravel resource, adjacent to the river channel deposits. Sections and trial pits in the terrace consistently show around 2 m of silt overlying up to 3 m of sand and gravel. The Second Terrace deposits are mantled by a thick (up to 15 m) cover of silt and clay and are not considered to be a sand and gravel resource.

- Large amounts of sand and gravel have been extracted from the Rio Minho in the past 20 years. Most extraction has been by instream mining, although small amounts have been taken from the First Terrace deposits in the Water Lane area. Total production since 1980 when extraction started, is estimated to be about 5.25 million tonnes. Many parts of the active channel have been extensively mined, with considerable widening of the river channel. Significant sand and gravel resources are present within the First Terrace deposits flanking the river channel, and these should be considered as alternative resources.

- Large amounts of sand and gravel have also been extracted in recent years (since about 1990) from the thick accumulations forming the Yallahs fan-delta. Extraction is concentrated in the main channel which is now incised up to 6 m below the level of the fan-delta surface. It is estimated that about 4.4 million tonnes of sand and gravel aggregate has been produced since 1990. The dynamic instability of the river caused by the instream mining results in headward erosion of the fluvial deposits and has led to undermining of the causeway for the coast road.

References

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Appendix 1 Summary logs of trial pits, Rio Minho Quarry Zone.

NOTE: See Figure 1 for locations of P1 to P47

P1. Silt 3 m.

P2. Silt 3 m.

P3. Clay 1.5 m, sand 0.5 m, silt 1.2 m.

P4. Silt 1.2 m, sand and gravel 0.9 m.

P5. Silt 1.8 m, sand 0.9 m, gravel 0.6 m.

P6. Silt 0.2 m, gravel 0.4 m, silt 0.8 m, gravel 0.3 m, sand 1.2 m, gravel, 0.6 m.

P7. Clay 1.2 m, gravel and sand 1.9 m.

P8. Clay 2.4 m, sand and gravel 1.2 m.

P9. Clay 0.9 m, sand and gravel 2.1 m.

P10. Clay 2.0 m, gravel and sand 2.0 m.

P11. Silt 1.4 m, sand 3.1 m.

P12. Clay 3.0 m.

P13. Silt 1.1 m, sand 1.5 m, clay 1.0 m.

P14. Clay 3.0 m.

P15. Clay 3.0 m.

P16. Clay 3.0 m.

P17. Silt 2.0 m, sand 1.1 m, silt 1.4 m, sand 0.9 m, silt 1.0 m, sand and gravel 0.8 m.

P18. Silt 3.0 m.

P19. Clay 3.0 m.

P20. Clay 3.0 m.

P21. Silt 1.4 m, sand 1.9 m, clay 1.1 m.

P22. Clay 3.0 m.

P23. Clay 1.3 m, sand 2.4 m.

P24. Silt 1.7 m, sand and gravel 2.3 m.

P25. Clay 3.0 m.

P26. Clay 3.0 m.

P27. Clay 3.0 m.

P28. Clay 3.0 m.

P29. Clay 1.0 m, gravelly sand 3.3 m.

P30. Clay 2.4 m, sand and gravel 1.2 m, clay 0.4 m.

P31. Clay 3.0 m.

P32. Clay 3.0 m.

P33. Silt 1.0 m, sand and gravel 2.5 m.

P34. Silt 1.9 m, gravelly sand 2.1 m.

P35. Clay 3.0 m.

P36. Clay 3.0 m.

P37. Clay 3.0 m.

P38. Silt 1.0 m, sand and gravel 2.2 m.

P39. Clay 3.0 m.

P40. Silt 1.4 m, sand 0.9 m, gravel and sand 1.2 m.

P41. Silt 0.7 m, gravel and sand 1.7 m, sand 0.6 m.

P42. Silt 1.1 m, gravel and sand 1.0 m.

P43. Silt 1.6 m, gravel and sand 3.2 m.

P44. Silt 0.9 m, sand and gravel 2.9 m.

P45. Silt 3.0 m.

P46. Silt 3.0 m.

P47. Silt 1.1 m, sand 1.8 m, gravel and sand 1.1 m.

P48. Silt 0.3 m on igneous bedrock.

P49. Silt 0.6 m, sand 0.7 m, gravel and sand 1.6 m.

P50. Sand and gravel 2.9 m.

P51. Silt 0.3 m on igneous bedrock.

P52. Silt 1.9 m, gravel and sand 0.8 m.

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