DRAFT REPORT

Hazard and Fluvial Assessment.

UNDP/Dolphin Head Trust

A Technical Component of the Dolphin Head Proposed National Park Project

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Prepared for: UNDP/Dolphin Head Trust

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EXECUTIVE SUMMARY

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1. INTRODUCTION

1.1. PREAMBLE

UNDP/Dolphin Head Trust contracted Dr. Ravidya Maharaj to provide technical consulting services with respect to the occurrence of hazards and fluvial dynamics in the proposed 3000-acre Dolphin Head Park, in Lucea, Hanover. The team executing the terms of reference comprised Dr. Maharaj, Dr. Simon Mitchell (both of the Department of Geography and Geology) and Ms. Sherene James. The fieldwork was done in two successive visits by the team during the month of February 2001.

1.2. PURPOSE

The purpose of the study is:

- To avoid using vulnerable areas for development of the nature trail, base camp or any other community-based activity that may come out of this whole process.
- To inform existing land use patterns and any changes that need to be made to present land use.

1.3. SCOPE OF WORK AND PROJECT ACTIVITIES

- The assessment of the landslip related hazards in terms of its incidence, magnitude and frequency, as well as the likelihood of occurrence in the study area (i.e., both spatial and temporal variability).
- Examination of the potential impacts of the hazard in areas where they are likely to occur (human and environmental vulnerability of the area).
- Recommendation of broad interventions that may be possible, and which may be considered and prioritised by stakeholders, thus allowing for the later development of a mitigation plan.

1.4. ASSUMPTIONS AND LIMITATIONS

- Data will be freely available from Forestry Department, WRA, ODPEM, Earthquake Unit, MGD, ICENS and the Meteorological Office.
- Socio-economic data will be available.
- Data on the watershed boundaries (sub-basins and drainage network map) land use and vegetative cover will be available at no cost and in time to meet objectives of the hazard study.
- Data will be available (at no cost and in time for to meet objectives of this study) on biological and other potentially vulnerable watershed resources.
- Maps (1:12,500 and 1:50,000) and aerial photographs are available.
- Fair copy maps (geology, geomorphology, hazards etc.) will be prepared for digitisation, but actual digitisation will be done otherwise by the Dolphin Head project.
- Direct costs (field accommodation, transportation costs, report production) are not included in the professional fees estimate.
- Digital photographs will be taken to inventory hazards in the field. Production of these onto film is not included in the professional fees estimate.

2. FACTORS AFFECTING DRAINAGE & HAZARD

2.1. LOCATION

The proposed Dolphin Head national park is situated on the border of the parishes of Hanover and Westmoreland. It is located approximately 10 km from Lucea in the north, 25 km from Montego Bay in the northeast, and 15 km from Savanna-la-Mar in the south as the crow flies.

The exact coordinates of the Dolphin Head study area are marked by the following planar coordinates: 220000E – 350000E and 840000N – 930000N (Figure 1). The designated area for the park is shown in Figure 1.

For the purposes of this study, we have also considered the communities (such as Askenish, Dias, Flamstead and Glasgow) around the proposed park and these are also shown on Figure 1. This is because we are primarily concerned with the hazards that may affect these communities, and may affect the development of the Dolphin Head park itself.

2.2. CLIMATE

Jamaica experiences a tropical maritime climate with mean daily temperatures ranging from a high of 28°C to a low of 26°C in August and February respectively (Evans, 1973 from UWA, 1990).

Rainfall and Evaporation. Figure 2 shows the rainfall and evaporation stations closest to the Dolphin Head area. The records from the Meteorological Division show the mean rainfall in millimetres per month over a thirty-year period (1951-1980). Rainfall stations in Westmoreland and Hanover indicate that the Dolphin Head area has a marked wet season during the months April to November (Appendix #). In Westmoreland the annual rainfall total for Barham, Frome, and Mint were 2308 mm, 2176 mm, and 2561 mm respectively. The data for Hanover indicate generally higher annual totals: for stations located at Askenish, Kendal, Mount Peto, and Smithfield, amounts were 3108, 2547, 2878, and 2790 mm, respectively. Askenish is the nearest station to Dolphin Head with the highest rainfall (447 mm) for the month of June (wet season) and a minimum of 87 mm for the month of December. Most of this precipitation is experienced in the wet season.

The evaporation data were collected at two of the rain gauge stations, Smithfield and Frome. The values obtained at Smithfield are an average collected between 1971 and 1972. The annual evaporation was calculated to be 1528.2 mm. The annual evaporation value for Frome was estimated to be 1813.6 mm. These values were collected between 1968 and 1971.

2.3. GEOMORPHOLOGY

2.3.1. Drainage

Part of the proposed Dolphin Head Park is situated in the Quasheba Mountains, and forms the upper catchment of the Lucea West River. The Dolphin Head and Retirement sections of the proposed park similarly form part of the Lucea East River catchment. The Cretaceous rocks found in the lowlands are very well drained by the Lucea East and Lucea West Rivers, which are north-draining streams that empty into the Lucea Harbour.

On southern and south-western side of the proposed park, the main drainage system is the Morgan’s River/Cabarita river system, which consists of south draining streams, traversing across extensive alluvial plains. The Flamstead and Cessnock rivers (together with an unnamed tributary) feed into Morgan’s River towards the south-western end of the study area.

In general, the higher lands to the north (Dolphin Head itself and its environs) are located on limestone terrain, where there is mainly conduit karst drainage (underground). Three springs were identified in the study area (Figure 3). These springs currently supplement the water supply for the Askenish area. Very localised ponding of water (at the surface) may occur at the base of blocked sinkholes within the karstic terrain. Ponding tends to be more common in the alluvial plains to the south, where localized clay lenses may result in perched aquifers.

2.3.2. Landforms

The geomorphology of the study area is largely governed by climate and the underlying geology, which control the types of landform and rates of weathering that may occur. In general, the highest mountain peaks (including much of the proposed park, and Dolphin Head itself, which is the highest point at 688 m) are found at elevations above 460 m and are comprised of limestone. The lower lying areas to the north, west and east of the study area comprises older Cretaceous clastic rocks, whereas the flat low-lying lands to the south mainly consist of alluvium. The fact that the limestone highland area is generally surrounded on all sides by non-limestone terrain, makes this area somewhat isolated, forming a 'limestone island'. In general the geomorphology can be divided along lines of lithology:

a) **The limestone highland** consists of a suite of landforms typically associated with limestone dissolution (karst), including abundant sinkholes, towers, conical hills, and caves. The development of these features is closely tied to the progression from surface drainage to predominantly underground drainage. This occurs because limestone (calcium carbonate) is soluble in rainwater, and gradually develops cavities along joints, fractures and bedding planes. These cavities develop into conduits, and underground cave systems. In general, surface drainage is absent. Hillslopes tend to be jagged, and very steep. In many cases fault escarpments control the more continuous linear slopes. Rock falls and topples are common on these steep slopes, and produce talus aprons at the toes of larger escarpments. Scree derived from higher on the slopes usually becomes cemented lower on the slope by tufa-type deposits.

b) **The Cretaceous terrain** to the north, east and west of the 'limestone island' is characterised by steep, long slopes, surface drainage, including first-order streams (fed by springs emerging from the limestone island), and deeply incised valleys with flat bottoms. The steep slopes and deep valleys are formed as a result of surface water down-cutting into the sandstones and mudrocks. Unlike the limestone area, drainage is predominantly on the surface. At one locality, where the bedding in the sandstones and shales dipped towards the road, water was seen to preferentially flow along the bedding planes producing erosion (Plate 1). Here at least 1 m of roadway was undermined by water backing up along the bedding surface.

c) **Low-lying alluvial plains** to the south. The landforms here include wide alluvial plains, meandering third-order streams, poljes (enclosed alluvial basins), and tower karst. This is important in slope stability in that the slope weakens as sliding planes are created along joints and the boundaries between hard rock and the weathered material. The weathered material is more susceptible to sliding, as the blocks are now loose.

2.3.3. Aspect

Aspect describes the orientation of slopes with respect to the passage of the overhead sun. This is particularly important to hill-slope hydrology, and stability as it effects the length of time the slope remains wet. Moisture levels on a slope directly affect the load on the slope (and its likelihood to succumb to gravity), the rate of weathering, and the amount of vegetation (biomass/load, type). Slopes with greater moisture contents that do not dry out readily (i.e., north and south facing slopes) tend to have more deeply weathered profiles, and are more prone to failure, particularly after heavy rains, when water loading destabilizes the slope.

Thirty-eight percent of the slopes are either east or west facing (17% are east facing, and 21% are west facing). Eighteen percent of the slopes were either north or south facing (5% and 13% are north and south facing respectively). It was observed that the east facing slopes had a wider variety of flora, the west facing slopes had taller trees, and the north and south facing slopes had shade-loving plants such as ferns. The east and west facing slopes were less weathered than the north and south facing slopes seen in the field.

2.4. LAND-USE AND VEGETATIVE COVER

The proposed park area mainly consists of lowland sub-montane seasonal evergreen forest (Figure 3). This forest is located on the White Limestone bedrock; localised areas where bauxitic cover dominates leads to the growth of non-limestone vegetation. This area has remained relatively untouched mainly due to inaccessibility; however, removal of logwood from the area has been observed.

Vegetation generally has a positive effect on slopes as it removes moisture from the soil (through evapotranspiration), and the roots bind the soil. Foliage decreases the terminal velocity of impacting raindrops, and can thereby increase the amount of water infiltrating a slope. However, vegetation can have negative impacts on slope stability:

- Larger roots assist in the channelisation of surface flows, leading to deep incision, and allowing infiltration of water into the soil. This increases the lubrication between the soil particles.
- Trees that do not form part of a continuous canopy act as levers, allowing wind action to cause swaying of trees, which can make soil loose, hence making it unstable. A discontinuous canopy is one of the major effects of logging.

2.5. SOILS

Like the geomorphology, soils are strongly controlled by climate and the underlying bedrock. In the study area, they can be classified as:

a) **Residual soils forming over Cretaceous sediments**. These generally are clays and loams. These are found on the northern, eastern and western periphery of the proposed park area. In the study area, they are represented by the Nonsuch Clay, Lucky Hill Clay, Union Hill Stony Clay and Killancholly Clay. These soils have variable moisture retention. The internal drainage is slow in the Nonsuch Clay and very slow in the subsoil of the Lucky Hill clay loam. The Union Hill Stony Clay and the Killancholly Clay tend to have moderate internal drainage.

b) **Residual soils forming over limestone.** These are thin stony lateritic soils. These soils are generally poor for agricultural purposes. The Bonny Gate Stony Loam is extensive developed over the White Limestone, and is found in association smaller pockets of Lucky Hill clay loam and Carron Hall clay. The Bonny Gate stony loam is generally poor for agricultural purposes, with fairly rapid internal drainage.

c) **Bauxitic soils**, generally found associated with the limestone terrain, but are genetically unrelated. In the study are these are represented mainly by the St. Ann Clay Loam and the

Chudleigh Clay Loam. These red soils tend to be acidic and clayey. Internal drainage is extremely rapid in the St. Ann Clay Loam and the Chudleigh clay loam

d) **Alluvial (transported) soils** associated with large river systems. These contain a wide range of soil types including stony loams, sandy soils and clays.

2.6. GEOLOGY

2.6.1. Background

Previous work. Two editions of the 1:250,000 scale maps of Jamaica have been published. The 1958 edition (Geological Map of Jamaica, 1959) shows the Tertiary geology of the Dolphin Head area mapped as Yellow Limestone (mE) and White Limestone (EΦM). These are briefly described in the accompanying synopsis (Zans *et al*., 1963). The 1977 version (McFarlane, 1977) shows the Tertiary succession mapped as Ech (Chapelton Formation), Ewl (Troy/Claremont, Swanswick and Somerset formations) and Mm (Montpelier Formation). The latter, although appearing to show much finer divisions, was largely based on recognisance mapping of ‘larger foraminifera zones’ and does not represent a lithostratigraphic subdivision. Grippi (1980) undertook a study of the Lucea Inlier and published a geological map of the area. He recognised a complex succession of deep-water clastics up to 4 km thick. Structurally, 2 fault zones were recognised, the Fat Hog Quarter fault zone in the north and the Maryland fault zone in the south. The stratigraphy was revised by Schmidt (1988), who suggested that some of the units recognised by Grippi (1980) should be amalgamated.

Methodology. We undertook a recognisance mapping programme of the area around Dolphin Head defined by Jamaican imperial grid lines 520,000 N to 545,000 N and 130,000 E to 160,000 E (1:12,500 series maps). Our aim was to map the main solid geological features and the superficial features with a view to producing a geological map of value to the other teams working on the project, and to enable hazard assessment in the communities close to Dolphin Head. Eight field days were spent collecting geological information.

2.6.2. Sedimentary Succession

The area of Jamaica exposed above the sea is divided in several tectono-sedimentary units, which relate to the Tertiary sedimentary succession present and the syndepositional and post-depositional tectonic deformation (Fig. 4). In central and western Jamaica, five units are recognised: the Hanover Block, the Negril–Savanna-la-Mar Belt, the Montpelier–Newmarket Belt, the Clarendon Block and the North Coast Belt (Meyerhoff and Krieg, 1977; Robinson and Mitchell, 1999). The blocks are characterised by shallow-water limestone deposits containing abundant larger benthic foraminifera, molluscs and echinoderms, while the belts are characterised by deep-water chalks that contain abundant planktic foraminifera. The area mapped around Dolphin Head falls largely within the Hanover Block.

The geological map is shown in Figure 5. We recognise four formations in the solid geology: these are the 'Undivided Cretaceous Succession', the Yellow Limestone Formation, the Moneague Formation, and the Montpelier Formation.

2.6.2.1. Undivided Cretaceous Succession

The Lucea Inlier contains a thick succession of Cretaceous conglomerates, sandstones and shales with minor units of limestone and intrusive igneous rocks. Only the southern margin of the inlier is in the area of investigation. In view of the relatively monotonous lithology, we mapped the Cretaceous succession as a single unit, which we call the 'Undivided Cretaceous Succession'. This unit consists of interbedded sandstones, shales and minor conglomerates. The sandstones range in thickness from a few centimetres up to several tens of centimetres, while locally thicker sandstone units up to several metres thick are present. Pebbly sandstones and pebble conglomerates ranging in thickness from a few tens of centimetres up to several metres are also locally present in the succession. Spectacular soft sediment deformation features are well developed in some areas and might be worthy of description for tourist guidebooks.

The Cretaceous rocks are exposed in northernmost part of the Dolphin Head Area. The communities of Askenish, Kingsvale and Dias are built on these Cretaceous Rocks. The Cretaceous rocks are deeply dissected by streams and rivers producing a well-defined dendritic drainage pattern, with extensive ridge and valley topography. Many of the roads and paths in the area are constructed on the ridges. Grippi (1980) suggested a thickness of 4 km for the Cretaceous.

The boundaries with the Yellow Limestone and Moneague formations are faulted in the northern and eastern exposures. An unconformable boundary with the Yellow Limestone is interpreted on the eastern side of the map. The formation has yielded several fossil groups of biostratigraphic importance: an ammonite, rudist bivalves and inoceramids (Wiedmann and Schmidt, 1993); and calcareous nannofossils (Jiang and Robinson, 1987). These suggest an age range from Santonian? to Early Campanian. The sedimentary succession of interbedded sandstones and shales is consistent with deposition in a deep-water basinal environment. Reports of abundant planktic foraminifera in these rocks would corroborate this. During the Cretaceous, Jamaica formed part of an island arc system (Robinson and Mitchell, 1999). The Cretaceous sediments found in the Lucea Inlier were probably deposited in a back-arc basin (Schmidt, 1988).

2.6.2.2. Yellow Limestone Formation

The Yellow Limestone Formation is exposed as a fringe between the 'Undivided Cretaceous Succession' and the Moneague Formation along the eastern, northern and western margins of the main Moneague Limestone plateau of Dolphin Head. This formation consists of fossiliferous limestones with variable quantities of clay-grade impurities. This causes the limestone to weather to a yellowish or brownish colour, the colour allowing the formation to be easily distinguished. The lithology ranges from foraminiferal wackestones and packstones to molluscan wackestones and packstones. Foraminifera are dominated by larger benthic species. Molluscs are common and include large oysters and undetermined gastropods. Locally 'patches' of dolostone are found within the Yellow Limestone Formation. On the Clarendon Block, the basal part of the Moneague Formation, the Troy Formation, shows extensive dolomitisation (Zans *et al*., 1963). Because the dolostones in the Dolphin area are clearly within foraminiferal-yielding impure carbonates, they are included in the Yellow Limestone Formation and not with the overlying Moneague Formation here.

The Yellow Limestone Formation is found as a fringe on the western, northern and eastern margins of the Moneague Limestone plateau of Dolphin Head. It forms highland areas with moderate relief, which develop enclosed basins (dolines) with rounded residual hills between. In the western area of outcrop, the community of Glasgow is built on rocks of the Yellow Limestone Formation. The eastern outcrop gives rise to highland that is largely unpopulated. The formation is also present below Dolphin Head lying stratigraphically below the Moneague Formation – loose blocks of Yellow Limestone being found in talus slopes below Dolphin Head.

Cross sections suggest a minimum thickness of about 50 to 60 m.

In the northern and eastern outcrops, the boundary with the underlying Cretaceous mudstones and sandstones is faulted. In the western area of outcrop, the base was mapped as an unconformity, with an angular discordance between the basal beds of the Yellow Limestone Formation and the steeply dipping sandstones and shales of the 'Undivided Cretaceous Succession'. The boundary with the overlying Moneague Formation is interpreted as a normal stratigraphic contact.

The formation yields a wealth of benthic molluscs and foraminifera. The foraminifera include *Eulinderina subplana* (Barker & Grimsdale) together with a new genus/species (Edward Robinson, person. commun. to SFM, 2001) indicating a Middle Eocene age (?Assemblage 3 of Robinson and Mitchell, 1999).

The abundance of benthic molluscs including oysters and complex larger benthic foraminifera (suggesting the presence of photosynthetic symbionts) indicates a shallow-water marine depositional environment. The presence of impurities in the limestone indicates the presence of a nearby emergent land area from which the detrital impurities were derived. The environment at the time can be envisaged as a shallow water shelf adjacent to an emergent land area.

2.6.2.3. Moneague Formation

Robinson and Mitchell (1999) discussed the nomenclature of the White Limestone and suggested recognising two formations, a shallow water Moneague Formation and a deep water Montpelier

Formation. We follow this suggestion here. The Moneague Formation is widely exposed in the Dolphin Head area and the strongly karstified landscape to the south stretching towards Grange. The greater majority of the proposed Park lies on rocks belonging to the Moneague Formation.

The Moneague Formation consists of very pure white-coloured limestones with poorly defined bedding planes. In hand specimens picked up in the field the formation is largely composed of a fine-grained white-coloured limestone in which identifiable fossils are absent or rare. Thin section analysis indicates that this rock consists of foraminiferal carbonate mudstones and wackestones that contain scattered larger foraminifera including *Lepidocyclina* spp. and *Miogypsina* spp. In the northwestern area of outcrop, south of the community of Georges Plain, two distinctive units of foraminiferal grainstones and packstones are present. The lower unit contains abundant examples of the foraminifera *Eulinderina* spp. indicating a Mid Eocene age, while the overlying limestone contains *Lepidocylina undosa* Cushman indicating an Early Oligocene age. In addition the presence of *Miogypsina* higher in the succession indicates that the Moneague Formation ranges in age from the Mid Eocene to the Early Miocene. This is a similar age range to the Moneague Formation developed on the Clarendon Block to the east.

The Moneague Formation is widespread in the Dolphin Head area, and forms the well-defined rugged countryside between Grange and Dolphin Head. Well-developed tower karst is characteristically developed and makes the area difficult to access. The karstic features include towers and enclosed depressions. The towers have flat or weakly convex tops and steep cliffs on their margins that expose extensive thickness of the Moneague Formation. The enclosed depressions are generally elongated. No communities are developed on the karstic topography of the Moneague Formation.

We estimate that the Moneague Formation has a thickness of about 120 m from cross-sectional analysis. The formation has a normal stratigraphic contact with the underlying Yellow Limestone Formation. Although not seen in the area, elsewhere in Jamaica such contacts are relatively sharp, but diachronous (i.e., the lower part of the Moneague Formation is locally the same age as the top of the Yellow Limestone Formation). This relationship is due to local supply of impurities that produce the impure limestones of the Yellow Limestone Formation.

The larger benthic foraminifera present in the Moneague Formation include *Eulinderina*, *L. undosa* and *Miogypsina*, which indicate an age range from Mid Eocene to Early Miocene. The presence of larger benthic foraminifera and the absence of planktic foraminifera indicate the Moneague Formation was deposited in a shallow marine setting. The absence of impurities in the limestone suggests that by this time, the previously emergent land area had be submerged and was no longer a source area for clastic sediments.

2.6.2.4. Montpelier Formation

The Montpelier Formation has a very restricted distribution in the area mapped and is only found at a single outcrop to the NW of Grange. The formation consists of white-coloured limestones with moderately well defined bedding planes spaced at intervals of between 0.5 and 1.0 m. In hand specimens picked up in the field the formation is largely composed of a fine-grained white-coloured limestone in which identifiable fossils are absent. Thin section analysis indicates that this rock consists of biomicrite with abundant planktic foraminifera. The Montpelier Formation is only found in a single outcrop situated in the SW corner of the mapped area. Further exposures of probable Montpelier Formation are sited to the south of this exposure, but off the mapped area. They have not been studied.

The thickness exposed in outcrop is only about 2 m. We cannot estimate the thickness of the formation because of its limited outcrop. The boundary between the Moneague and Montpelier formations is covered by alluvium. We suspect it may be fault controlled, but cannot demonstrate this unequivocally with the data available at present.

We have not been able to determine the age of the outcrop of the Montpelier Formation in this area. Elsewhere in Jamaica, the Montpelier Formation ranges in age from Middle Eocene to Early Miocene (Robinson and Mitchell, 1999). The presence of abundant planktic foraminifera in a micritic limestone indicates a deep-water deposit. The Montpelier Formation in the mapped area is interpreted to have formed in a deep-water embayment on the edge of the Negril–Savanna-la-Mar trough.

2.6.2.5. Superficial Deposits

The superficial deposits include: alluvium, bauxitic soils and landslide deposits.

Alluvium.

Alluvium is widely distributed in the southern part of the Dolphin Head area. An extensive wide alluvial valley is developed on the western side of the area extending southwards from Glasgow. This valley is flat floored and widely used for Sugar Cane production. The valley is now occupied by three parallel south flowing tributaries (Cessnock River, Flamstead River, and an unnamed tributary) to Morgans River. At the southern end of the valley, there are several small dolines developed in the alluvial plane. These are developed either, in the Moneague Formation or, more likely, in the Yellow Limestone Formation (judging from their morphology) beneath the Moneague Formation. No exposures of limestone were seen to verify this. The alluvium of Morgans River consists of clasts with lithologies dominated by pebble conglomerate, sandstone and claystone. These lithologies match lithologies present in the 'Undivided Cretaceous Succession' of the Lucea Inlier to the north. The presence of three parallel flowing tributaries suggests significant change in river style. We believe that formerly the valley contained a large southerly flowing river draining the high ground of the Lucea Inlier. As erosion continued the highland area was reduced and, coupled with increasing river capture by north-flowing rivers, the southerly flowing river waned. Subsequently, tributaries were developed in the relatively wide river valley.

Two small enclosed, flat-floored valleys (poljes) are present on the southeastern margin of the mapped area. They are used for the growth of sugar cane. These valleys are clearly interior valleys surrounded by hills in the Moneague Formation and contain an alluvial fill. The fill undoubtedly was also derived from the Lucea Inlier to the north.

Bauxite.

The Moneague Formation contains deep sinkholes, some of which have extensive fills of bauxite and bauxitic soils. These have not been mapped separately, largely because of the difficulty of access to the area. These bauxite-filled areas give rise to non-calcareous soils, and associated vegetation.

Landslide Deposits.

Landslide deposits are widespread along the fault scarp separating the limestones of Dolphin Head from the 'Undivided Cretaceous Succession' of the Lucea Inlier. These landslide deposits are largely composed of large and small blocks derived from the Yellow Limestone and Moneague formations. The material forms an apron deposit along the foot of the fault scarp, and is now heavily vegetated. This suggests that this talus apron is probably largely inactive, and that it formed under different climatic conditions. Minor small-scale rotational sides are now occurring in the talus deposits themselves. These give rise to lobe-shaped hummocky topography, particularly to the south of Askenish.

Failures also occur in the Cretaceous shales at Askenish. This appears to be a result of SW facing topography interacting with SW dipping mudstones in the 'Undivided Cretaceous Succession'. The result is an active landslip area that has destroyed four houses and caused the abandonment of the Askenish Health Centre. The close proximity of this failure to the Maryland Fault Zone (Grippi, 1980) suggests that this failure may also be related to faults, although not necessary recent fault activity.

2.6.3. Structural Geology

The main structural features developed in the area mapped are faults. The Maryland Fault Zone (Grippi, 1980) runs through the northern area of the mapped area. The fault zone consists of near-vertical east-west faults that offset features in the 'Undivided Cretaceous Succession' (Grippi, 1980). Several other faults are also developed in the area (Fig. 5), the most important are in the northeast part of the map and separate the high ground of the Yellow Limestone and Moneague formations of the Dolphin Head plateau from the lower ground of the 'Undivided Cretaceous Succession' to the NE.

We did not map any folds in the area. In the 'Undivided Cretaceous Succession', bedding generally strikes north and dips gently towards the west. Bedding is more difficult to measure in the Yellow Limestone Formation and particularly in the Moneague Formation. Our measurements suggest a strike towards the WNW and a gentle dip towards the SSW. Grippi

(1980) mapped an anticline in the 'Undivided Cretaceous Succession' to the east of Askenish; this is to the east of the area mapped for this project.

2.6.4. Geological History

During the Cretaceous (Santonian to Early Campanian), the Dolphin Head area formed part of a large deep-water basin, probably situated in a back-arc setting (Grippi, 1980; Schmidt, 1988). Large quantities of clay, sand, and pebble-grade detritus were supplied to the basin from the active volcanoes and a 4-km thick pile of volcaniclastic sediments accumulated. After the extinction of the arc in the ?Late Cretaceous (Maastrichtian), the area was extensively deformed and uplifted creating an emergent highland region. During the early Tertiary (?Paleocene to Early Eocene), rifting occurred and a trough was established between the Clarendon and Hanover Blocks (Meyerhoff and Krieg, 1977). By Middle Eocene time, the block and trough structure of western Jamaica (Fig. 4) was established. In the troughs a deep-water succession of marls and chalks (e.g., the Montpelier Formation) accumulated containing abundant planktic foraminifera. In contrast, the blocks initially (Middle Eocene time) had islands of uplifted Cretaceous rocks supplying impurities to the shallow water limestones (Yellow Limestone Formation) in which a variety of molluscs and larger benthic foraminifera lived. As these land areas became submerged sedimentation changed from the impure limestones of the Yellow Limestone Formation to the pure limestones (Middle Eocene to Early Miocene) of the Moneague Formation. Renewed uplift began in the Miocene (may be 10 million years ago) with the Clarendon and Hanover Blocks undergoing extensive uplift. In contrast, the intervening Montpelier-Newmarket Trough was not strongly uplifted and still retains a cover of deep water Montpelier Limestones of Oligocene to Miocene age. It is at this time that the isolated upland area of the Hanover Block came into existence. With progressive uplift, the limestone cover succession originally developed over the Lucea Inlier was stripped off, and the Cretaceous rocks became a source of detritus for the rivers draining off the highland areas. Initially, large amounts of detritus were delivered to the south coast, where extensive low marine terraces were built out by river deltas. Over time, however, the rivers draining south have been captured by northward draining rivers. Consequently, the modern river systems draining the Lucea Inlier now drain north.

2.7. HYDROLOGY

2.7.1. Surface Water Resources

The Cabarita River Basin supplies surface water in Hanover. It was estimated in 1990 (WRA, 1990) that the use in non-agricultural sectors of water from the Cabarita Catchment was 11 MCM/yr (million cubic metres per year), while the agricultural sector used 24 MCM/yr. It was projected then that the expected demand by the year 2015 would be 16 and 84 MCM/yr for non-agricultural and agricultural sectors, respectively.

2.7.2. Groundwater

Three springs were actually identified in the area however only one was entombed. This spring provides gravity fed water to the community of Askenish. The Parish Council did this entombment in order to provide water to the homes below. The standpipes that were seen in the area are a part of the Parish Council's effort to meet the social needs of the people as far as possible. It is likely that there are other smaller, more seasonal springs emerging on the fringes of the 'limestone island'. These springs tend to be located along the line of contact between the pervious strata (limestones and scree) and the less permeable Cretaceous mudrocks.

2.7.3. Supply and Demand

The Rapid Response Unit (RRU) carries out water supply in the communities in the study area. This unit was set up by the Ministry of Water to quickly attend to the people in areas where there is no potable water or water distribution network by the National Water Commission (NWC). Under this programme 3-5 million gallons of water are trucked within the Parishes of Hanover and Westmoreland. The Household Black Tank Programme is another facility set up to provide potable water for the citizens of Westmoreland and Hanover. This facility involves the sale of 650-gallon tanks. This sale is done on a community basis and requires a minimum of 12 persons to be affected. These tanks are offered at two options (1) buying the tanks at $5,000 and (2) buying the tanks at $2,500 with 6 monthly instalments of $470. Meetings are held with the citizens as to the fittings and other requirements for the installation of the tanks. The first delivery of water is delivered for free after the purchase of the tanks.

The water is trucked to accessible areas (i.e., areas where the roads are in relatively good condition and where the trucks can actually go). The NWC as well as the Parish Council buys water from this programme as well, as most of the communities within the study area do not have a water administration network. The schools in the area are also serviced by the RRU, a document, signed by the principal of the school, is sent to the Ministry of Education, which pays the money over to the Ministry of Water.

The water is supplied to individual customers, customers of the Household Black Tank Programme, hotels, schools and farms. The coupons are bought at the Post Office at $1 per gallon for schools and general customers, $1.50 per gallon for hotels, and 60 cents per gallon for farms. Distribution of the water is done by a truck provided by the Ministry of Housing. The coupons are collected by the truck driver and delivered to the RRU from which they are sent to the office at the Ministry of Water.

Few of the communities within the study area are on this programme. The RRU trucks water in the study area, but some parts are inaccessible to these trucks. The communities of Kingsvale and Dias are a part of the Household Black Tank Programme; while Raglan, Hampton or Baulk Pen, Quasheba, Bath Mountain, Geneva Mountain and Patrick Archer are inaccessible. As a result, water is not administered in these areas; similarly areas with low population densities are not served. Retirement, Riverside, and Middlesex obtain trucked water.

3. HAZARD ASSESSMENT

3.1. INTRODUCTION

The purpose of this document is to report on the "hazard susceptibility and fluvial survey" in order to "assess the high landslip potential of the area". The immediate concern with assessing landslip potential and its relationship to fluvial systems arises from the major rotational failures that have occurred historically along the road at Askenish. The data and analyses presented here feed into recommendations, ultimately geared towards the broader aims of:

- Avoidance of the use of hazardous areas for development of the nature trail, base camp or any other community based activity

- Providing information that will allow for the reduction of vulnerability with respect to existing land uses within the immediate environs of the proposed Dolphin Head forestry reserve.

Vulnerability associated with hazards was beyond the scope of the present study. However, we note that access roads into the proposed management area are particularly vulnerable to the worst effects of improper drainage and land slippage. These routes are lifelines upon which critical flows people (to and from work and markets), goods and services depend. Settlements tend to be linear along these main access routes. Major lifelines such as water, electricity and telephone services also run along these routes.

There are communities within the park area, which are not currently under the Rapid Response Unit (RRU) programme. These areas are in the hilly interior of the study area i.e. within the Park area and could be accessible by the RRU trucks, and do not have piped water. Some of the communities along the fringes of the park and those located along the access roads to the park area that are a part of this programme are not served by this programme because the access roads are damaged.

3.2. HAZARDS

3.2.1. Earthquake History

Because of its tectonic location, the whole island of Jamaica is susceptible to the occurrence of a damaging earthquake, although some areas are higher risk than others due to the presence of active faults (e.g. Kingston). In areas of relatively equal risk (likelihood of the occurrence of a damaging earthquake), particular locations may be impacted more by earthquakes of a given magnitude, because of the risk of liquefaction. Liquefaction is most likely to occur on saturated or wet, sandy soils. Therefore, soils developing over Cretaceous sandstone-mudrock successions and sandy transported alluvial deposits are the most susceptible to liquefaction, particularly where soil moisture is high (e.g. near rivers, or during the rainy season).

Earthquakes also act as trigger mechanisms for land slides, slumps and rock falls, and may even result in the collapse of subterranean cavities. These related hazards are discussed below.

Information obtained from the UWI Earthquake Unit online database shows that the earthquake epicentres have not been recorded within the study area, although there are recorded epicentres several approximately 10 km away (Fig. 6). Between 1997 and 2000, the earthquake magnitudes recorded in the parishes of Westmoreland and Hanover ranged between zero and 3.5 (Fig. 6). Three stations are required for relatively accurate measurements to be made (Wiggins-Grandison, pers comm., 2001) and at times only two readings were recorded, resulting in the fact earthquake occurrence may be underrepresented on the map.

3.2.2. Flooding and Drainage

The study area is generally characterised by steep slopes. Therefore, in times of high rainfall, surface floods take the form of sheet flows over these steep slopes, and impermeable surfaces. The Askenish All-Age school playing field appears to have undergone some lowering as a result of sheet flows removing the topsoil and exposing the bedrock. Exposed roots of the trees on the playing field are evidence of this lowering. The amount of erosion is estimated to be about 18 inches.

Such surface flows are unlikely in the limestone terrain, due to the presence of a well-developed subterranean drainage system. Ponding of water may also occur within blocked sinkholes found on the limestone uplands of Dolphin Head and its immediate environs. Blockage of the sinkhole central shafts is typically the result of infilling by bauxite, lateritic soil and rock debris from slopes. Water sinking underground in the limestone area re-emerges as springs where there is a major change in the transmissivity and permeability of the bedrock.

In general, because of its steep topography, much of the area surrounding the limestone parts of Dolphin Head is not subject to significant flooding. However, there may be localised instances of ponding of water occurring over clay lenses in alluviums, limestone detrital soils or mudrock layers within Cretaceous sedimentary succession. These impermeable layers result in the development of perched water tables, above the normally expected water table, and may result in surface ponding during rainy periods. Flooding associated with perched water tables are most likely to occur in heavily weathered Cretaceous rocks and associated soils which occur on the northern and western periphery of the Dolphin Head study area, and in the alluvial polje deposits which occur on the southern periphery of the area.

The main access road to Askenish from Lucea runs parallel to the Lucea West River. The banks as well as along the gorge face of the Lucea West River were vegetated, that the river has not overflowed its banks for some time now. The debris observed in the vegetation on the banks and in the river shows the river however has the potential to flood its banks, which is about 10 m above the riverbed. During the heavy rains of June 12, 1979 the Dolphin Head region received between 16 and 20 inches (40-50 mm) of rainfall (Blake, 1982).

Various points along the Middlesex main road towards Askenish show the result of inadequate surface drainage. As a result of inadequate provision of drainage, water flowing off the surface of the road tends to incise the softer sediments downslope, and undercut the road surface itself. Where the dip of the strata appears to dip towards the road (into the slope), surface water tends to collect and result in the further undermining of the road. At point C on Figure 7 approximately 1 m of the road surface has been eroded. This trend is likely to continue unless proper road drainage is put in place.

At point D (see Fig. 7), large potholes in the road surface suggested deterioration. This also seemed to have been caused by improper drainage as incipient rills were noted. The junction (alternative route to Askenish through Dolphin Head) at McLaren Gate showed some signs of road deterioration, allegedly due to the fact that the road surface was dug up for repairs on a water main, this road was not subsequently restored. This road is being further undercut by surface flows. Primary channels developing from these flows are incising the adjacent slopes.

The residents at point G have compounded the road degradation problem in that a trench has been dug, resulting in further incision of the road.

3.2.3. Land slippage

Land slippage is a very general term that refers to a range of types of earth movements. The important ones that are found in the study area are:

- Soil creeps;
- Landslide;
- Land slumps, and,
- Rock falls, topples and collapses.

3.2.3.1. Soil Creeps

Soil creeps are earth movements where weathered or transported materials slowly move down slope, resulting in a toe bulge on the slope, and gradually thinning of the soil upslope. Vertical structures such as trees, posts etc. on a slope where this is occurring show a marked tilting. Soil creeps tend to occur on long moderately steep slopes that are covered by deeply weathered rock or detrital soils. No clear evidence for this was observed in the study area, but the slopes most prone to creep occur along the Askenish main road.

3.2.3.2. Slides

Earth movements where movement is translational along a linear failure plane are called landslides. These typically occur along well-bedded strata where lubrication of bedding planes provides the basis for failure. The slopes most prone to slides include poorly weathered bedded Cretaceous sandstones or conglomerates overlying mudrocks, particularly where the angle of dip of the strata is parallel or sub-parallel to the slope dip. At point E, the beds dip into the slope, these beds were thought to be relatively stable as there was no sign of significant erosion and the beds seemed well cemented.

The likelihood of landslide is increased by the fact that the general dip of the Cretaceous rocks in the area is westwards hence the west-facing slopes are more at risk to failure. Though west-facing slopes dry out quickly, heating and cooling of these sandstones and shales can cause expansion and contraction of the rocks, which reduces slope stability. This process is relatively slow but it is accelerated by the fact that the water preferentially runs along the dip of the beds hence there is continuous movement of water throughout the rocks especially during the wet season. Water adds weight to the slopes as well as the pore pressure created can induce failure.

Slides can also occur within the White Limestone slopes of the proposed park area, particularly along fault scarps. There is abundant evidence within the limestone area of re-cemented scree deposits. However, the slopes observed in the proposed park seemed to be generally stable at high angles.

3.2.3.3. Slumps

Earth movements where rotational movement occurs along curved failure planes are called slumps. These tend to be large-scale and can involve material at great depth below the slope surface. The plan form scars of these failures tend to be the classic arcuate shape, with evidence of an accumulation of material at the base of the slope. In the study area, slumps occur in deeply weathered sediments, or thick deposits of detrital material. The extent of weathering of the various lithologies found in the area appears to be related to the aspect of the slope, the extent to which it dries out, and the density of vegetation it supports.

The compound failures along the Askenish main road appear to be deep rotational slumps, the most recent being in 1999 (ODPEM, 1999). There are several different landslides in the area around Askenish. Many of these landslide failures have occurred in material forming a part of the limestone talus apron, which was deposited adjacent to the fault scarp. Most of these landslides are not active at the present time.

A significant landslide in Askenish began in September 1999 (ODPEM Report, 1999). The ODPEM report stated that the failure occurred in the “undifferentiated Yellow Limestone Group”, however, the rocks affected are in fact part of the undifferentiated Cretaceous succession. The failure plane as defined by the form of the fissures had an arcuate surface trace. The slide rendered three-quarters of the road impassable, shifted supporting columns of the Post Office to angles ranging between 45 and 50 degrees, created large fissures behind the Post Office of length 20 m, and created small fissures in the walls of the Health Centre.

3.2.3.4. Falls, topples and collapses.

Rock falls and topples are brittle failures, where boulders or large areas of rock lose lateral support and move down slope randomly. The deeply karstified limestone terrain is most prone to these types of failures, where trigger events such as earthquakes may result in the loss of support for overlying burdens. Collapses are the result of loss of underlying support, and typically occur where underground caverns or cavities develop below a “roof” of limestone. Evidence for these are large enclosed depressions with large limestone boulders and dripstones. These failures are likely to occur in the limestone terrain of the main Dolphin Head Park, particularly on the White Limestone area.

4. RECOMMENDATIONS

This section outlines our recommendations for broad interventions that may be possible, and which may be considered and prioritised by stakeholders, thus allowing for the later development of a mitigation plan.

In general, the major hazard affecting the area appears to be the deep rotational failures that occur in the Askenish area. These occur as a result of the combination of poorly consolidated detrital material, a fault scarp and periodic lubrication and loading of the slope by throughflows. Seepages and springs from the limestone area into this area cannot be avoided. Training of gullies associated with springs, and the erection of concrete structures around springs are not recommended, as these locations tend not to be permanent.

We recommend that:

1. More attention should be paid to surface drainage management, particularly storm water and grey water disposal. This is particularly important in relation to drainage associated with roads located on steep slopes made of highly erodeable rocks. Slope failures and the other numerous examples of road degradation are thought to be exacerbated by inadequate provision of surface drainage facilities.

2. There should be no further residential development in the area shown to be affected by the rotational slumps; the use of the area upslope of the Askenish main road for kitchen gardens is not recommended as farmers may not properly manage throughflows of water. Keeping of animals such as goats and pigs may be a more appropriate use for this area.

3. The foundations of any large structures that are to be sited on limestone in the Dolphin Head area need to be carefully checked to ensure that there are no subterranean cavities.

4. Sewage disposal of any tourist resorts to be located in the limestone area should not involve the use of soakaway pits, as this will increase the risk of groundwater contamination, and eventual contamination of the major north-draining rivers, and Lucea Harbour.

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FIGURES

Figure 1 **The proposed park and study areas.**

Figure 2 **Rainfall and Evaporation.**

Figure 3 **Geomorphology of the Dolphin Head Area**

Figure 4 **Block structure of Jamaica**

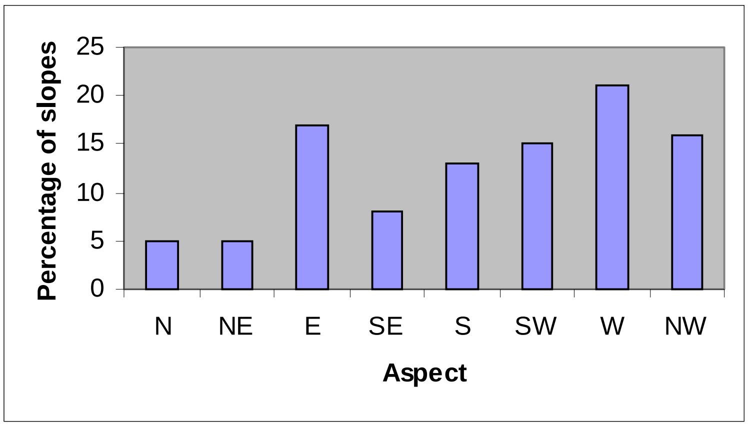

Figure 5 **Geology Map**

Figure 6 **Earthquake epicentres in Hanover and Westmoreland**

Figure 7 **Hazards in the Dolphin Head Area**

<<figures to be included in final document>>