17 Durham Avenue · P.O. Box 5185 · Kingston 6 · Jamaica · West Indies
Telephone: +876.898.3442 · website: www.asi-ja.net · email: brichardson@asi-ja.net

GORE DEVELOPMENTS LTD., CORAL SPRINGS PROJECT, TRELAWNY

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Sinkhole Evaluation

Contents

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GORE Developments Ltd., CORAL SPRINGS Project, TRELAWNY

SINKHOLE EVALUATION

INTRODUCTION AND SCOPE

The main objectives of the report will be to identify the main hydrogeological controls at the site especially the function of the depression/sinkhole and its impacts on site hydrology. This wide objective will include specifics such as:

- Evaluate the dimensional extent and genesis of the depression/sinkhole and discuss, based on the data available, its ability to repeatedly accommodate surface flows from the proposed development;
- Identify the factors controlling runoff at the site, from soil conditions, geology to karst landforms (i.e. sinkholes);
- Identify any other depressions that form part of the depression/sinkhole drainage system;
- Identify depth to groundwater from published data and outline any impacts to groundwater from proposed development; and,
- Outline any constraints imposed by the depression/sinkhole or geologically.

The conclusions are based on limited site reconnaissance, review of site contour maps, a review of the published maps, Water Resources Authority (WRA) records, NEPA records and ODPEM database of developments near the site that are applicable and other published data and technical documents available on the internet.

BACKGROUND AND PROJECT OVERVIEW

The site is a subset of either the former 18th century Roslin Castle sugar plantation, or more likely the smaller Spring Hill Estate (known later as Spring Estate). The property is currently being considered for development by Gore Developments Ltd. (GDL) and is outlined in Figure 1 below. The proposed site comprise over 700,000m^2 (~173 acres) with approximately 500-550 lots being developed along with a school and sewage treatment plant.

The historical documents indicate that springs were likely to emerge at the base of the hill to the immediate east of the beach road, hence the term “Spring Hill”. And the name “Coral Springs” suggests that emergent springs are a feature of the area as historic place names in Jamaica are typically related to manifestations in the vicinity of the area and impart their name to the location. Of particular note is the historic name of “Water Valley” for what is currently known as Dry Valley on the south-side of the highway.

FIGURE 1 – ANNOTATED GOOGLE EARTH IMAGE SHOWING THE PROPOSED SITE (DASHED RED POLYGON). NORTH IS AT THE TOP OF THE FIGURE. IMAGE DATE JULY 3, 2009.

DATA COLLATION AND SITE VISIT

The assessment is based on the review of published material, plus consultations with statutory bodies (e.g. WRA, NEPA, and ODPEM etc), brief site walkover, aerial photography and historical maps relating to the local and wider hydrological environment. The data and other sources of information collected are listed in Table 1.

A brief site walkover, through areas that allowed foot-traffic, was carried out on 19 August 2011 to confirm the geology of the sinkhole and the wider site, identify any surface water features, dominant soil types and other land use characteristics likely to influence hydrological processes.

Topic	Source of Information
Geology Solid and Surficial	Mines and Geology Division Sheet 8 (Imperial Series) 1:50,000; WRA data.
Hydrogeology, Surface Waters & Abstractions Wells, Rivers, Springs	WRA Well Logs and Data Report (August 2011)

Topic	Source of Information
Groundwater	WRA (August 2011)
Soils & Land Use	
Soil Type	Soil Survey and Research Dept, UWI, c1970 1:50,000
Land Use	Forestry Department Land Use Maps, 1998

TABLE 1 - SOURCES OF GEOLOGICAL AND HYDROLOGICAL INFORMATION

ASSESSMENT METHODOLOGY AND LIMITATIONS

The assessment has been undertaken primarily using existing quantitative equations based on professional judgment and sinkhole management best-practice ordinances used in the United States and the United Kingdom on karst landscapes. The hydrogeological hazards were identified by overlaying the proposed development layout on the physical elements (such as soils, faults/earthquakes, depressions/sinkholes) that are known to exist at the site. From these essential strategic choices that need to be made as part of the decision-making process based experience and professional judgment are outlined.

The conclusions and recommendations contained in this report are based in part upon the conclusions of others and are contingent upon their validity. These data have been reviewed and interpretations made in the report. No new data was gathered for this evaluation. Some of these data and predictions are preliminary "screening" opinions, and should be confirmed with intrusive and detailed quantitative analyses if more accurate and time specific predictions are necessary.

BASELINE

This section describes the existing geological and hydrological conditions at the proposed site and its immediate surroundings.

Climate

The long term (1951-1980) mean annual parish rainfall for Trelawny is just over 1600mm. Rainfall in the parish is bimodal, like much of the island, with initial peak in May (avg. 181mm) and a later peak in October (avg. 222mm). The 30-year monthly mean ranges between 69 (min.) – 222 (max.) mm. The drier period is December to March where the long term average rarely exceeds 130mm.

The information held by the Meteorological Service of Jamaica indicates that Trelawny has been experiencing higher than average rainfall as recently as June 2011. This pattern is to be expected given the likely scenario that Jamaica will experience wetter and more intense rainfall events in the coming years. Dry periods will also be more extreme.

Topography and Surface Hydrology

The site is located within the north-eastern subdivision of the larger Martha Brae Watershed Basin. The property is largely unremarkable, being a part of the larger karst hills on the fringes of the Cockpit limestone. From the topographic maps the elevation ranges from 76m at its highest point along the eastern boundary (Spring Hill) to 9m at its lowest. The landscape is heavily fault-controlled with several steep slopes (>30°) particularly along the eastern perimeter of the sinkhole.

The site's principal drainage direction is completely controlled by the sinkhole with all temporal drainage lines discharging to it. Fractures in limestone bedrock will also affect drainage in its immediate vicinity. The sinkhole also provides runoff outlet to Dry Valley to the south and portions of the North Coast Highway, in total the sinkhole drains an area of approximately 315 hectares. The North Coast Highway separates the southern catchment (Dry Valley side) from the sinkhole and acts as a physical barrier to surface flow. The southern flows are channeled via culvert beneath the highway to the sinkhole. Deep flooding on the south side of the highway is known to be historic and discussed below.

An unnamed spring emerges from the base of the hill south of the highway at about the 50m elevation and drains to the sinkhole through a concrete conveyance beneath the highway. This spring is perennial, but it is understood that there are several temporal springs that emerge at the base of the hills and drain to the sinkhole during significant rainfall events. This is confirmed by concrete entombments along the access road to the beach.

Soils and Geology

The site walkover indicates that there are significant fractures and evidence of mature karstification of the limestone with a central well-defined sinkhole/depressions on the property. The engineering karst classification is a Type **kIII** karst; see Figure 2). The diagnostic karst landform is determined by "the closed depression formed where the ground surface has eroded around an internal drainage point into the underlying limestone"[i]. The type of sinkhole is classified as a dissolution sinkhole formed by the slow dissolutional erosion of the heavily faulted Montpelier Limestone aided by small scale collapse to the water table. The surrounding landscape is dominated by repetitive conical limestone hills surrounded by smaller enclosed depressions, typical of tropical Cockpit Karst.

Published geological information (Geological Sheet 08, 1:50,000 Imperial Series; see Figure 3) indicates that the majority of the site underlain by the Miocene aged Montpelier Limestone Formation (Mm). The Montpelier Formation is the youngest member of the larger White Limestone Group and comprises well bedded white chalks with abundant flint nodules with some grey silty limestone clay in the lower portions. It is up to 460m (1500ft) thick. The Montpelier Limestone has extensive secondary openings (i.e. caves) due to the enlargement of fissures over time by percolating waters. These secondary solution fissures are likely to occupy the upper 5m of the bedrock and result in a significant increase in porosity in the upper zones of the bedrock.

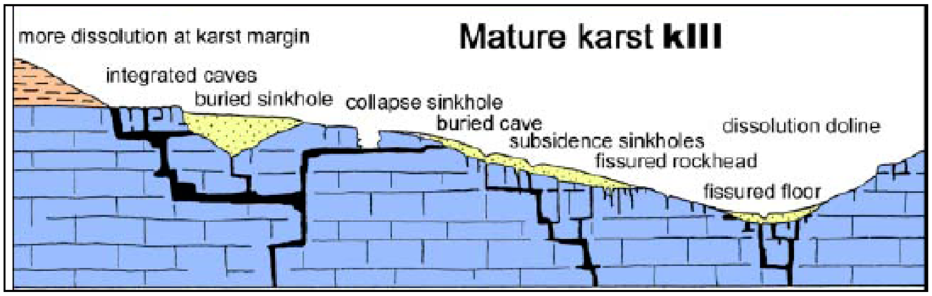

FIGURE 2 - TYPICAL MORPHOLOGICAL FEATURES OF KARST CONDITIONS ASSOCIATED WITH MATURE KARSTS.

Structurally, there are several parallel NE trending regional faults with one such fault bisecting the site (Figure 3). This fault gives rise to the steep slopes along the base of the eastern conical hill and is likely to be the main factor in the formation of the site's dissolution sinkhole by increasing the permeability of the limestone via percolating water along the fault plane and stress-relief fractures. Limestone bedding typically dips to the SW at about 25° toward the sinkhole.

The site is overlain by a thin veneer of soil on the steep slopes and hills with a greater depth of soil accumulating within the sinkholes. The soils are classified as Bonnygate Stony Loam and are is described as a "rapidly" internal draining soil.

Intrusive soil borings performed in February 2012 advanced six of seven intended boreholes to depths of up to 15m (50ft). Figure 3 shows the approximate locations of the borings. Please refer to the "Soil Investigation Report: Proposed Housing Development Project, Coral Spring, Trelawny, Jamaica" prepared by NHL Engineering Ltd and dated March 13, 2012 for borehole details and piezometer construction. In summary, the boring encountered weather soils (silty clays and gravels) in the vicinity of the existing pond up to 20m depth in BH#3 and up to 5m (15ft) in BH#4. The balance of the boreholes encountered heavily, fractured limestone from surface requiring coring either at surface or with 1.5m (5ft) of surface. The borings indicate, based on the weather materials in BH's 3 and 4, that the depression extends beyond the two existing ponds and probably occupies the flat, low-lying land surrounding the ponds.

Piezometers were installed in only BH#3 and the soils report indicates that no groundwater was encountered during drilling of the borehole. However, groundwater was measured at approximately 26m ASL (17ft below ground level) in BH#3 on 29 April 2012 after rainfall the previous night. It is also recorded in the soils report that groundwater was "observed flowing into the pond from an apparent aquifer on the southern hills of the site". This accords well with both the historic name of the area, "Spring Hill Estate", and local anecdotal information that during heavy rainfall springs appear at the base of the hill in the area. No groundwater level data was reported outside of the observation of 29 April 2012.

Percolation tests were carried out in BH#2, 4 and 7 and results observed show percolation rates ranging between 0.000015cm/s to 0.0045cm/s, approximately 10-6 to 10-5 m/s, which is within the expected permeability range of fractured limestone.

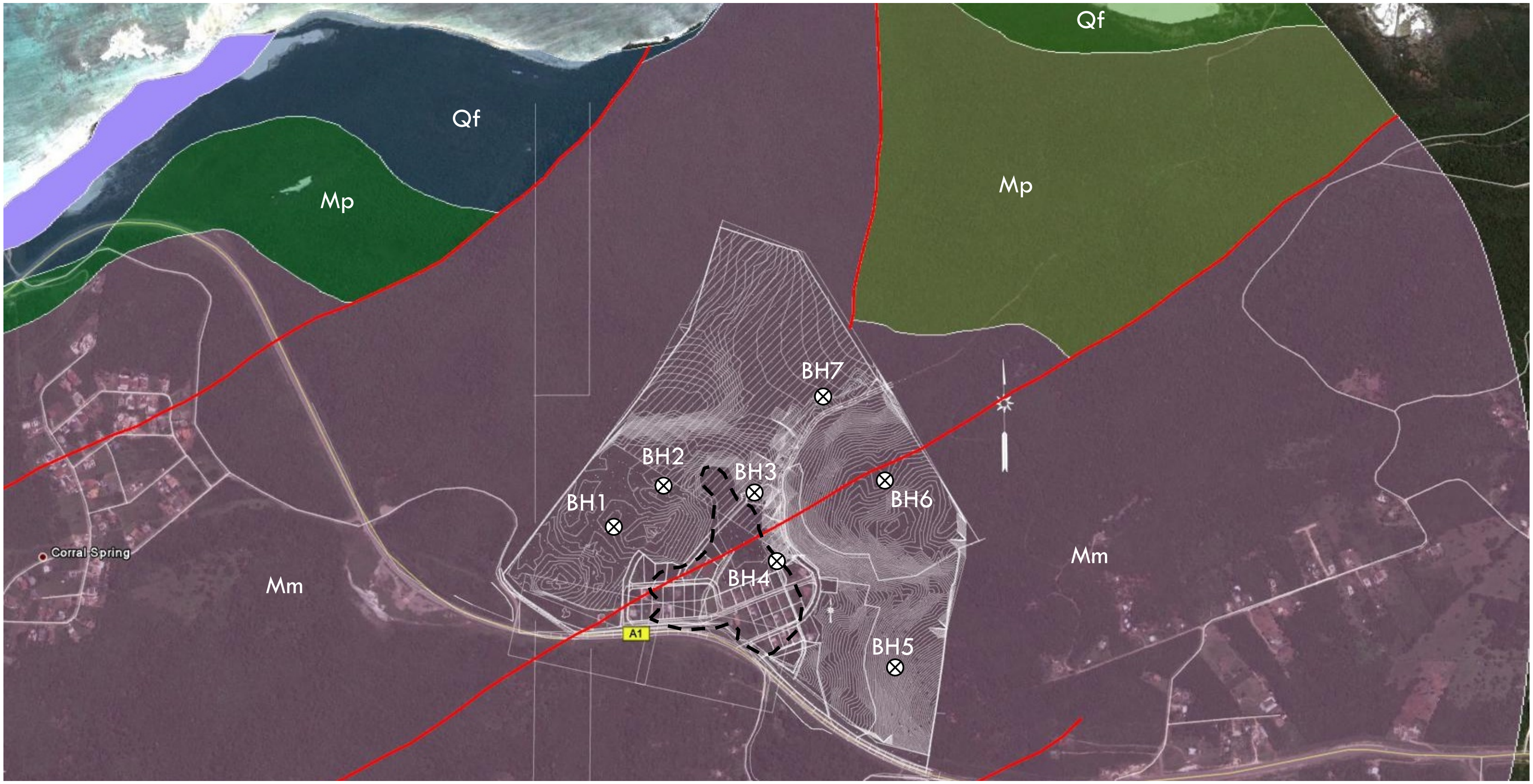

FIGURE 3 – EXTRACT OF GEOLOGICAL MAP NO.8 SHOWING THE BEDROCK GEOLOGY UNDERLYING THE SITE AND ITS IMMEDIATE SURROUNDINGS. Mm – MONTPELIER LIMESTONE FORMATION; Mp – OLDER REEFS, MARLS & LIMESTONE; Qf – FALMOUTH FORMATION. RED LINES DENOTE FAULTS. BLACK DASHED LINES DENOTE SINKHOLE 50FT CONTOUR LIP FROM THE 1:12,500 TOPOGRAPHIC SHEET 51D. BOREHOLE LOCATIONS ARE INDICATED, BH6 WAS NOT ADVANCED BY TO SITE ACCESS ISSUES. IMAGE ADAPTED FROM GOOGLE EARTH. IMAGE DATE JULY 03, 2009.

Hydrogeology

The Water Resources Authority (WRA) classifies the geology underlying the site a Limestone Aquiclude. The Limestone Aquiclude underlies the entire site. Groundwater levels based on a well sunk at Stewart Castle averages about 6m ±1.7m above sea level (asl) based on readings from 1965-1967. Historical records indicate that other temporal springs emerge from the base of the hills at Coral Springs. These temporal springs are likely to discharge to the sinkhole as this is the lowest spot within the catchment. The groundwater level taken from BH#3 suggest that subsurface flows are present within the area and may be typified by temporal and perennial springs at the base of hills, with static groundwater at depth, possibly at or around depths similar to those encountered at Stewart Castle. Groundwater level taken at BH#3 is approximately 17m above the lowest level of the existing pond surface.

There is one such perennial spring and it provides constant baseflow to the sinkhole. This unnamed spring results from groundwater emerging at the surface. Flow measured at the concrete U-drain during site walkover ranges between 0.005 - 0.007 m3/s. Figure 4 shows several images of standing water within the sinkhole along with views of the developed spring-channel leading to the sinkhole. Surveyor spot heights record the lowest point in the sinkhole at 8.7m asl. This places the base elevation of the sinkhole at, or just above, the average groundwater table as measured from Stewart Castle in the mid 1960's. If the regional groundwater levels still holds true then this will result in standing groundwater being permanently present within the depression at the site. However, from the borelogs in the soils report, only BH#2 extends beneath the surveyor's elevation of 8.7m asl and no groundwater is recorded within BH#2 at all. This suggests that static groundwater may well be below 4m asl. Extending from the findings of the soils report, the ponds at Coral Springs are present due to low-permeability clays and silts.

The geometry of the sinkhole suggests there are two, maybe three, base levels to the sinkhole. The significance of this is not presently clear, but suggests the collapse process to groundwater level developed three distinct "floors" to the sinkhole over time with its ultimate rim being defined by the 15m (50ft) contour. This sinkhole is water-table dominated and geologically controlled and classified as a hybrid structural/baselevel poljes. It is a sinkhole where in effect the karst surface is being progressively lowered toward the regional water-table and forced by geological controls (faulting). Such sinkholes develop on the outlet side of karst systems with the sea forming the ultimate output boundary threshold, with the system gradually lowering over centuries until the regional groundwater level is encountered. This progressive denudation towards the static water-table is likely what caused the once subterranean, unnamed stream being exposed and flowing at the surface. Seasonal and major storm inundation is characteristic of such outlet sinkholes. Temporal springs are also typical of such outlet systems, as the outlets act as the lowest discharge points for all subsurface groundwater flow conduits.

Further evaluation of the karst landscape during the site walkover indicates several fractures and fissures that form the larger network of secondary porosity within the White Limestone that surrounds the sinkhole Fissure/fracture spacing taken on-site ranges between 0.5m to 10m with apertures (opening of the fissures/fractures) between 5mm to over 10cm. This suggests that groundwater flow within the limestone is a combination of fracture flow in the upper zones and possibly conduit flow within the deeper zones. Typically in fractured limestone these upper fractures are not well connected to each other but are well connected to the larger and deeper conduits (or tubes) through which groundwater flows. Based on Kiraly's nomograpghs[ii] for determining hydraulic conductivity using aperture spacing and fracture density for various fracture networks the estimated hydraulic conductivity of the upper limestone is between 10-4m/s to 10-3m/s (360mm/hr to 3600mm/hr). However, natural conditions are more complex than these modeled figures because of uneven openness, roughness of fractures and infilling of fissures/fractures with roots and soil detritus etc. Based on information from the ODPEM Regional Officer, Mr. Haye (pers. comm.)[iii], that the sinkhole drains after heavy flooding within 1-2days , scoping calculations suggest a hydraulic conductivity of between 10-5m/s to 10-4 m/s (36mm/hr to 360mm/hr). Detritus infilled fractures will tend to skew fracture flow performance towards lower hydraulic conductivities. On-site percolation tests within the boreholes sampled this sub-surface complexity and indicates that average fracture flows are an order of magnitude lower at 10-6 to 10-5 m/s.

The ODPEM's historical, albeit anecdotal, flood information indicates that both the north and south side of the highway is inundated during significant storm events. On the south side (Dry Valley) the indicated depth of flooding covers the first floor of a two storey structure in Dry Valley, approximately 1.5m to 2.5m (5-8ft) and remains flooded for weeks to months. On the north side (Coral Springs) the flooding reaches onto the verandah and into rooms of the homes adjacent the sinkhole and lasts 1-2 days.

The sinkhole is the main control on surface drainage and acts at output control on the catchment system for Coral Springs and Dry Valley. The working conceptual model of the site suggests that site runoff, from Coral Springs and Dry Valley, are directed into this sinkhole and transmitted through the groundwater system through a network of interconnected conduits that finally discharges at sea. And when stormwater runoff exceeds the capacity of the sinkhole flooding occurs. The output efficiency of the sinkhole is controlled by the intersected water-table and the flow parameters within the subsurface conduit network. Maintaining the outlet efficiency of this sinkhole will be critical to stormwater management within the catchment.

As this sinkhole is the only drainage outlet for the catchment, developments that drain to this sinkhole will increase the volume of runoff that the sinkhole must handle. Additionally, construction practices such as inadvertent sinkhole infilling, blasting and inadequate erosion control and sediment control may alter the karst terrain and increase the potential for flooding. Encroachment within the sinkhole rim will also reduce the storage volume available to contain stormwater runoff. Blasting can change the geometry of the sinkhole throats and underground caves, blocking outflow pathways. Lack of erosion and sediment control measures can increase the potential for silt and other debris to accumulate within fissures/fractures and effectively reduce outflow efficiency. Once output efficiency is reduced in sinkholes it is normally difficult to rectify or regain.

The following section determines the 100yr floodplain levels and evaluates the storage volumes of the sinkhole under varying development scenarios..

Calculation of 100-yr Flood Elevation

To evaluate the potential of the sinkhole accommodate the predicted runoff from the development, international best-practice requires the determination of the ability of the sinkhole to contain the 100-yr frequency, 24-hour storm assuming pre-development site conditions with a plugged sinkhole outlet (0 outflow), and no evaporation (i.e. all rainfall becomes runoff) without flooding any structures. This defines the 100-yr sinkhole flood elevation for the particular sinkhole. The evaluation of the Coral Spring sinkhole is presented in Table 2 and 3 below:

Watershed Variable	Pre-Dev: Coral Springs & Dry Valley (ML)	Post-Dev: Coral Spring only (ML)	Post-Dev:Coral Springs & Dry Valley (ML)
Total Watershed Runoff 100yr	164	152	221

TABLE 2 - CATCHMENT RUNOFF EVALUATION (FCS CONSULTANTS, MARCH 2012)

The calculated incremental storage volume for the sinkhole presented in Table 3 is determined by using the volume formula for the frustum of a cone. The areas at different elevations, taken from the recent surveyor elevations, are the areas at the top and bottom of the cone frustum and the storage calculated is the incremental volume storage between each elevation. The elevations are determined from the 9m contour up to the "rim", or lip, of the sinkhole as determined from the published 1:12,500 topographic sheet 51D. From the topographic sheet the sinkhole lip is clearly demarked as occupying the 15m (50ft) contour. The site walkover gave no evidence to adjust that determination. It is clear that encroachment into the sinkhole floodplain has occurred previously and is likely to be a contributing factor as to why existing homes are flooded during significant rainfall events.

Elevation (m)	Area Inside Closed Contour (m²)	Incremental Storage Volume (ML)	Cumulative Storage Volume (ML)
9	278	n/a	n/a
10	518	0.4	0.4
11	2370	1.3	1.7
12	7699	4.8	6.5
13	15688	11.5	18.0
14	21855	18.7	36.6
15 (rim of sinkhole)	36905	29.0	65.7
16	58072	47	112.8

TABLE 3 - INCREMENTAL STORAGE OF SINKHOLE BASED ON EXISTING CONTOURS

The 100yr floodplain elevation is determined by the cumulative volume that is equal to, or exceeds, the total pre-watershed runoff of 164 ML considering a no-outflow or plugged scenario. Even at the 16m contour, outside the marked sinkhole lip, the pre-development 100yr runoff is not contained within the sinkhole without overflow. This accords with the known position that even the existing situation floods the existing properties.

Post-development the watershed runoff for Coral Springs only and both Coral Springs and Dry Valley are more than the cumulative storage of the existing 16m contour. This demonstrates clearly that the 100yr pre- and post-development watershed runoff would not be contained within the sinkhole without overflow, infiltration or contour modification (i.e. cut and filling).

To achieve a sustainable stormwater management plan, and through discussions with the consulting engineers, it is understood that volume cuts within the sinkhole footprint between the 13.5m and 17m contour will be necessary and will be implemented by GDL to increase sinkhole storage volume and reduce flood risk. Existing low-permeability soils between 13.5 to 17m contour will be removed and replaced with compacted gravel and crushed limestone to provide an engineered percolation zone. Based on these revised contours the incremental storage volumes, assuming zero outflow, are presented below:

Elevation (m)	Area Inside Closed Contour (m^2)	Incremental Storage Volume (ML)	Cumulative Storage Volume (ML)
11	6614	n/a	n/a
13	16191	22.1	22.1
14	31546	23.4	45.5
15 (rim of sinkhole)	39893	35.6	81.2
16	61045	50.1	131.2
17	92400	76.1	207.4

TABLE 4 - INCREMENTAL VOLUME STORAGE OF SINKHOLE BASED ON GDL VOLUME CUTS TO INCREASE SINKHOLE STORAGE VOLUME BETWEEN 13.5M TO 17M.

Table 4 shows that the post-development runoff from developing Coral Springs only will be just slightly larger than the expanded 17m contour under plugged conditions (i.e. no outflow allowed). The plugged condition is the most conservative case. However, there is evidence, for historical drawdown for the Coral Springs sinkhole. Modification of the existing ground by replacing low-permeability soils with engineered soils will provide the percolation/infiltration capacity required to maintain the pond level below the 17m contour. FCS Consultants are confident that sinkhole floodplain will not extended beyond the 17m contour under the post-development scenario.

FIGURE 4 – IMAGES FROM AROUND THE SINKHOLE SHOWING STANDING WATER WITHIN SINKHOLE AND SHOWING THE SPRING DISCHARGE LEADING TO SINKHOLE. IMAGES DATED AUGUST 19, 2011.

RECOMMENDATIONS

The recommendations and development guidelines are listed below in Table 5. All are subject to modification by the Water Resources Authority (WRA).

Item	Guidelines/Recommendation
1.	Based on the storage evaluation, the obvious throat of the sinkhole, the history of flooding and the existing encroachment within the sinkhole floodplain, a no-fill zone is recommended to ensure the proper management of the sinkhole and the local stormwater system. For this particular sinkhole the no-cut/fill line shall be the existing 13m contour (Figure 5). The area encompassed by this line shall be the no-fill zone for all development activities. No construction, vegetation removal/modification, stockpiling or storage of any kind shall be allowed in this zone. Any fill added to the sinkhole floodplain outside this no-fill line must be compensated for by an equal volume cut outside of the no-fill zone. .
2.	A water quality buffer should be considered around the perimeter of the 13m no-cut/fill zone. The water quality buffer width shall be measured perpendicular form the 14m topographic contour. These buffer zones are to be one continuous buffer around the sinkhole.
3.	If encroachment beyond the 13m contour is required, then detailed sub-surface testing shall be done to determine the permissible range of outflows under a variety of design conditions and such testing should be performed under the supervision of registered professional hydrogeologist, or registered professional engineer with demonstrated experience in hydrogeology.
4.	Nothing shall be placed, or caused to be placed, any substances or objects, other than stormwater runoff, or any other discharges approved by NEPA into the sinkhole(s) in such a way as to allow such substances of objects to be washed into the sinkhole throat during storm events.
5.	To ensure that the runoff volumes can be accommodated, additional storage shall be preserved or created outside of the non-fill zone to accommodate the retention basin requirements of the stormwater management design.
6.	Disturbance of the immediate area around the sinkhole during construction shall be minimized to as little as possible. The use if mechanized equipment near the sinkhole should be controlled. The underground system of caves and streams is dynamic and explosions in the vicinity can alter or block underground drainage passages changing the output efficiency beyond what is currently understood.
7.	All temporal and perennial spring outlets must remain open and free of obstruction. No spring, or spring entombment, shall be filled over. Any conduits, channels, caves encountered during site development should not be infilled or covered over. As their retention allows the continued percolation of runoff into these systems.

Item	Guidelines/Recommendation
8.	Any approved discharges to the sinkhole must not exceed WRA/NEPA recommended water quality guidelines.

TABLE 5 – DEVELOPMENT GUIDELINES FOR CORAL SPRINGS PROPERTY

In sum, the site has been historically impacted by flood events as are the existing properties and this will persist into the future. The site is situated within the catchment of a critical catchment base-level outlet sinkhole. Any future developments within the other contributing catchments to the south, such as Dry Valley, will have to be very carefully planned to ensure that all generated runoff is kept within the Dry Valley sub-catchment.

FIGURE 5 – 13m CONTOUR NO-FILL ZONE (LIGHT BLUE POLYGON) FOR CORAL SPRING OUTLET SINKHOLE. IMAGE ADAPTED FROM GOOGLE EARTH. PROPOSED POST-DEVELOPMENT CONTOUR MODIFICATIONS ARE SHOWN IN RED. WHITE CONTOURS ARE THE EXISTING SITE CONTOURS

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[i] A.C. Waltham and P.G. Fookes, Engineering classification of karst ground conditions, QJEGH, 2003, vol. 36. pp101-118

[ii] Kiraly, L., Karstification and Groundwater flow in Grabrosvek, F. (Ed.), Evolution of Karst: from Prekarst to Cessation, Postojna-Ljubljana: Institut za raziskkovanje krasa, ZRC SAZU, 2002, pp155-190.

[iii] ODPEM Western Regional Coordinator pers. comm. Sept. 2011