A PRELIMINARY REPORT ON THE SABANA WATERSHED/TALAKHAYA SPRINGS SYSTEM ROTA (LUTA), CNMI

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by

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ABSTRACT

Keywords: Mariana Islands, Rota, island karst, caves, spring, watershed, hydrology, contact

Rota in the Mariana Islands is unique in that chain, because it gets its municipal water from high elevation contact springs (Water Cave and As Onan Spring), not from the freshwater lens. These springs, located near the top of an area known as the Talakhaya, are fed by recharge from the Sabana. Very little spring discharge has been found on the other flanks of the Sabana, leading to the hypothesis that most of the water recharged on the Sabana discharges along the Talakhaya. This relationship would be better understood with the application of a water budget, which will require a rain gage on the Sabana and a recording stream gage at least at Water Cave and possibly at As Onan Spring and other springs. The majority of the surface of the Sabana is highly permeable limestone with very fast, autogenic recharge. The summit of the Sabana is an outcrop of weathered volcanics that feed ephemeral streams during rain events. These streams provide allogenic recharge at the contact between the volcanics and the overlying limestone. These streams were instrumental in locating insurges along the contact, particularly north and west of the Peace Memorial. Much of the contact can be located by the presence of a “moat”. South of the Sabana summit, Summit Cave is located on the contact and also captures a stream from the volcanics. On the east side of the Sabana volcanic outcrop, the contact is more difficult to locate, possibly because of human disturbance.
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ROTA (LUTA), CNMI

INTRODUCTION

This report documents the preliminary investigation of the relationship between the Sabana Watershed and the Talakhaya Springs (Water Cave a.k.a. Matan Hanum, and As Onan Spring) from which Rota collects its municipal water. The results reported here reflect insights from an initial, exploratory field investigation, which will provide the basis for designing and carrying out future detailed hydrologic studies when instrumentation can be put in place to obtain quantitative data on the relationship between the hydrological behavior of the springs and the watershed.

SETTING

Geographic and Geologic Setting

The Marianas Islands (Figure 1), in the western Pacific Ocean, are composed of fourteen islands that are the exposed parts of the Mariana Ridge. The ridge lies just west and north of the Mariana Trench, which includes the Challenger Deep, at about 11 km the deepest point in the ocean. The Mariana Trench-Ridge system is a product of the subduction of the Pacific Plate under the Philippine plate.

Figure 1. Location of the Mariana Islands
Figure 2 shows that the Mariana Islands are composed of two concentric island arcs on top of the Mariana Ridge (Karig, 1971). The eastern, paleo-volcanic chain is expressed at the surface as the islands of Guam, Rota, Aguijan, Tinian, Saipan and Medinilla. Karig (1971) reports that the eastern arc continues northward from Medinilla as a series of sea mounts along the eastern edge of the Mariana Ridge to its intersection with the Bonin Arc. Dickinson (2000) states that the volcanoes that formed the basement rock of Guam, Rota, Aguijan, Tinian, Saipan and Medinilla were primarily active during the Late Eocene to Early Oligocene (45 –30 Ma) but that Guam and Saipan have volcanic deposits from as late as the mid-Miocene (15 - 12 Ma). The chain on the western edge of the Mariana Ridge is expressed at the surface as the nine, volcanically active, northern islands of the CNMI, which have probably been active since the Pliocene (Dickinson, 2000). Anatahan, on the eastern arc, is currently active. Karig (1971) reports that the eastern arc on the Mariana Ridge continues as far south as Guam as active submarine volcanoes and states that thrusting as well as island arc volcanism was likely involved in the development of the Mariana Arc (Figure 2). To the west of the Mariana Ridge lies the Mariana Trough, which Karig (1971) described as an extensional back arc basin. To the west of the Mariana Trough is the West Mariana Ridge, a remnant volcanic arc that was part of the Mariana arc-trench system prior to the opening of the Mariana Trough during the Eocene (Reagan and Meijer, 1984). Dickinson (2000) notes that the paleo-volcanic islands of the Mariana Island Arc (Guam, Rota, Aguijan, Tinian, Saipan and Medinilla) are mantled by Miocene, Pliocene, Pleistocene and Holocene limestones.
Rota (Figure 3) is located on the Marianas Ridge about 80 km north of Guam, the southernmost island in the arc, about 100 km south of Tinian and about 3000 km east of Asia at E 145° 12’, N 14° 10’. Rota has a surface area of ~85 km² and a coastal perimeter of ~52 km. Sugawara (1939 [1949]) described Rota as having six distinct terrace levels (see Previous Investigation section below). While Rota can be described as “terraced”, focusing on the terrace levels tends to oversimplify the shape of the island. Rota is oriented roughly east-west with the elevations on the north side of the island generally lower. The western end of Rota is dominated by the Sabana Region. The top of the Sabana is an irregular plateau (400+ m) that spans 4 km east-west and 2.5 km north-south. There are two prominent peaks on the Sabana. One reaches 491 m and the other, Mt. Sabana, reaches 496 m, Rota’s highest elevation and the highest point in the southern part of the Mariana Arc. To the east, north and west of the Sabana, the land drops in a series of irregular terraces. To the south, the Sabana is bounded by a steep scarp above the Talakhaya region. The Talakhaya is characterized by a large, relatively steep exposure of weathered volcaniclastic material. The Talakhaya contains the only surface streams on Rota. It has a discontinuous band of limestone at about 100 m elevation, and a continuous band of limestone from sea-level up to about 40 m elevation. There are many springs of various sizes along the contact of the volcanics with the overlying limestone, at the top of the Talakhaya. The springs of particular interest are the Water Cave a.k.a Matan Hanum and As Onan Spring. In this report, these two springs will be referred to collectively as the Talakhaya Springs. This term is meant to exclude the other numerous smaller springs along the same contact that do not provide water for Rota’s municipal system.

The eastern end of the island, the Sinapalo region, is dominated by a relatively high plateau (100 – 200 m). Along the north side of the Sinapalo region, the terrain slopes gradually down to sea-level. At the eastern end of the island and all along the southern side of the Sinapalo region, the plateau is bounded by steep, terraced cliffs that drop to a variable width coastal terrace. The Taipingot Peninsula (Wedding Cake) is connected to the west end of Rota, at Songsong Village, by an isthmus about 0.5 km wide. The Taipingot reaches an elevation of 143 m (USGS, 1999).
Figure 3. Rota Island, Commonwealth of the Northern Mariana Islands
Historical and Political Background

Rota was settled by the Chamorro people around 1500 BCE. Ferdinand Magellan landed somewhere in the Marianas (probably Guam) in 1521 and named them Islas de los Ladrones. In the early 1600’s the name was changed to Islas de las Marianas. Spanish missionaries began the “reduction” of the islands in 1668 (Coomans, 1997). For almost four hundred years, the Marianas remained under Spanish control, during which a considerable number of people immigrated from the Caroline Islands. In 1898, during the Spanish–American war, the United States took control of Guam, which today is an unincorporated US Territory. Since 1898, Guam has thus been politically separate from the remainder of the islands in the Mariana Island Arc. In 1899, Spain sold the northern Marianas, along with Palau and the Caroline Islands, to Germany. Germany maintained control of the northern Marianas until World War I, when Japan occupied the islands in 1914. In 1920, the League of Nations granted Japan a mandate to administer the northern Marianas, and it maintained possession until World War II. Under Japanese administration, large tracts of Rota were cleared for sugar cane production and a sugar mill was built in Songsong Village. During this time, an area near the summit of the island, on the Sabana, was mined for phosphate-rich soil which was transported to the coast using an aerial tramway that ended east of Songsong Village at Sagua (Rodgers, 1948). During World War II, the United States took Saipan and Tinian from Japan, but Rota was left untaken until after the Japanese surrender. In 1947, the United Nations created the Trust Territory of the Pacific Islands under which the United States Department of the Interior administered the northern Mariana Islands, as well as the Marshall Islands and Caroline Islands. After being approved in a plebiscite in the northern Mariana Islands, the United States ratified the Covenant to Establish the Commonwealth of the Northern Marianas Islands in Political Union with the United States of America in 1978. This agreement created the Commonwealth of the Northern Mariana Islands (CNMI) and established a unique relationship. The CNMI is self-governing with regard to taxation, immigration, and labor laws, yet is part of the United States. Several federal agencies, including the US Postal Service, National Park Service, USGS and USDA operate in the CNMI. Permanent residents of the CNMI became citizens of the United States in 1986. Rota, the southernmost island in the CNMI, is one of its three municipalities, along with Saipan and Tinian. In the 2000 United States Census, Rota reported about 3,200 inhabitants.

STATEMENT OF PROBLEM

The hydrology of Rota has had very little systematic examination. The only known hydrologic investigation was conducted by the US Geological Survey (USGS) in 1997. In conjunction with the Commonwealth Utilities Corporation (CUC), the USGS drilled 6 exploratory wells on the Sinapalo plateau. The USGS report of that project is forthcoming. That project resulted in three reserve production wells that are maintained by CUC. The total of the sustainable yields of these three wells is less than half the typical demand for municipal water on Rota (pers. comm., Charles Manglona, CUC).

The municipal water on Rota is collected at two high-elevation contact springs on the Talakhaya; Water Cave and As Onan Spring; the Talakhaya Springs are driven by
gravity flow to consumers. This makes Rota unique in the CNMI, as all of the municipal water for Tinian and Saipan is from freshwater lenses. This means that the knowledge gained by investigations on Tinian and Saipan (see Investigation) has limited applicability to the present fresh water supply on Rota. Under normal climatic conditions, the Talakhaya Springs produce water in excess of the demand. During the wet season, water overflowing from the storage tank at Kaan, near Songsong Village, can be seen spilling down the cliff face. In normal dry seasons, the water collected at the Talakhaya Springs is adequate for the demand. However, the islands of the Marianas typically experience drought conditions during the year immediately following the end of an El Nino-Southern Oscillation (ENSO) event (Ropelewski and Halpert, 1987). These drought events are known to lead to significantly reduced discharge at the Talakhaya Springs. In 1998 the amount of water captured at the Talakhaya Springs was inadequate, and water rationing was instituted.

Parts of the Sabana have been used for agriculture at least since the Japanese era, and some parts are still farmed today. Any agricultural chemicals used on the Sabana could possibly enter the municipal water supply via the Talakhaya Springs. An understanding of the surface and sub-surface hydrology of the Sabana should lead to better decisions regarding where and whether agriculture is continued on the Sabana.

The present investigation of the relationship between the Sabana Watershed and the Talakhaya Springs is needed in order to establish a basic understanding of hydrology of this system and should be part of the basis for decisions regarding use of the Sabana and decisions regarding municipal water use, especially during drought conditions. The results of this study will also provide useful initial information for more general studies of the hydrology or geology of Rota.

PREVIOUS INVESTIGATIONS

Climatology of Rota

Since rainfall records for Rota are incomplete and have not been sufficiently analyzed, the recent work of Lander (2004) on the climatology of Saipan, along with unpublished rainfall data from the Rota Municipal Airport will be used to make inferences about rainfall on Rota. Rota, like the other islands in the southern Marianas, has a wet-dry tropical climate with a distinct rainy season (July – December) and dry season (January – June) with the potential for significant drought in post-ENSO years (Lander, 2004) (See Previous Investigation below). Rainfall typically totals ~260 cm per year. Temperature on Rota is quite uniform and averages 27°C (USDA, 1994). About 70% of the annual rainfall occurs in the wet season with significant variability from year to year. Ropelewski and Halpert (1987) have shown that the western Pacific region usually experiences substantially reduced rainfall in the year immediately following an ENSO event. Figure 4 (after Lander, 2004) shows Saipan rainfall from 1954 to 1999. Post-ENSO years, shown in red, clearly tend to be dryer. The drought in these years is typically distributed across the year, being dryer than normal in the wet season and

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1 All maps of Rota in this report are on WGS 1984, UTM projection. Except where noted, contour lines are derived from the US Geological Survey digital elevation model.
extremely dry in the dry season. Lander (2004) also showed that on Saipan, higher elevations tend to receive more rainfall. Based on this knowledge, it is expected that rainfall on the Sabana is greater than at the Rota Airport, but the magnitude of this difference is not known. Previous plans by the US Geological Survey to install a rain gauge in the Sabana and a stream gauge at the water cave to replace the ones previously destroyed by typhoons have not materialized because of lack funding. The older gauges were not in place long enough for significant rainfall and discharge records to be collected.

Geology and Hydrology

The primary work on the geology of Rota was published in Japanese by Sugawara (1939 [1949]) and translated into English by the United States military. Sugawara’s approach was primarily to define the physiography of Rota based on the prominent series of terrace levels that are obvious almost all the way around the island. He also defined a series of depositional units based on his understanding of depositional facies, and presented exhaustive lists for fossil fusulinids and corals found in the various units. These units essentially followed the visible terraces, which he described as constructional. The positions of the terraces are probably the product of interaction between glacio-eustasy and local tectonics. Sugawara identified a number of faults on

Figure 4. Constructed Saipan Rainfall (after Lander, 2004)
Rota, particularly around *Poña Point*, and reports that the Water Cave was even then being used as a source of municipal water.

Rota is fringed for much of its perimeter by Holocene reef limestone that was exposed by tectonic uplift. Estimates of the of Holocene uplift range from 2.4 - 3.1 m (Dickinson, 2000), to 3 - 4 m (Kayanne et al., 1993). Weathering and erosion of this currently exposed Recent limestone has produced a jagged, rugged coast around most of the island.

Bell (1988) and Wietrzychowski (1989) published MS theses documenting diagenetic change of the lower elevation limestones around the perimeter of Rota. While important to the geologic knowledge of Rota, the work of these authors is not directly applicable to the present project since neither included hydrology in their research.

In their ethnographic study of water use customs on Rota, Stephenson and Moore (1980) mention the gravity fed systems built during the Japanese era for piping water from the Water Cave to *Songsong Village* and from *As Onan* Spring to *Sinapalo*. Rogers and Legge (1992) report that they visited the Water Cave during their brief investigation of the caves of Rota. Stafford et al. (2002) also report on their visit to the Water Cave during a reconnaissance visit to Rota. In the inventory of the caves and karst of Rota, Keel et al. (2004) include maps and descriptions of the Water Cave and *As Onan* Spring. Maps of Water Cave and *As Onan* Spring are included here as Figures 6 & 7, below. Keel et al. (2004) also report the discovery of Summit Cave, near the summit of *Mt. Sabana*, at the contact of the outcropping volcanics with the overlying limestone (Figure 5, below). The entrances to Summit Cave are located in a closed depression that acts as an insurgence for some of the water that collects on the topographically higher volcanic outcrop.

There are no published studies of the hydrology of Rota in general or the *Sabana Watershed/Talakhaya Springs* in particular. The known geographic and geologic relationships are considered to be overwhelming evidence that the recharge area for the *Talakhaya Springs* is the *Sabana*. Stafford et al. (2002) report on the large volcanic outcrop on the *Sabana* and report two caves on the *Sabana* that were thought to act as insurgences. These caves have proven to not act as insurgences even though they are located on or near the contact.

The other limestone islands in the Mariana arc have received considerably more hydrologic investigation than Rota. Examples of such investigations are those of Gingerich (2003), Jenson et al. (1997), Jocson et al. (2002), and Mink and Vacher (1997) on Guam; Borman (1992), and Gingerich and Yeatts (2000) on Tinian; Wexel (2001) on Saipan. Because of the unique nature of the *Sabana Watershed/Talakhaya Spring System*, the knowledge gained through investigations of the hydrology of the other islands in the archipelago is not particularly applicable to Rota. For a general summary of the known and inferred geology of Rota, please refer to Keel et al. (2004).

**METHODS OF INVESTIGATION**

**Data Collection**

The primary method of collecting data during this study was extensive and intensive field investigation of the areas in question. The most productive investigation was conducted during rain events. A Global Positioning System receiver (GPS) was used
to record to locations of contacts, outcrop, insurgences, springs, etc. in UTM coordinates with WGS 84 Datum. Field notes and map notations were used to record the nature and relationships of features whose location was determined by GPS.

**Data Processing**

To generate the maps that are the most essential record of this project, UTM coordinates collected by GPS were entered into databases so that the points could be applied to a georeferenced image of the USGS topographic map of Rota (1999). The geologic contacts on the maps were drawn by connecting known contact points. The inferred geologic contact was drawn based on the known location of the contact and on field observation. Ephemeral stream channels were drawn based on observation of stream flow during rain events.

**RESULTS AND DISCUSSION**

Since this study was primarily directed at field investigation, the results reported here are primarily descriptive, with maps used for illustration. That the Sabana is the recharge area for the Talakhaya Springs is obvious given the geography and known geologic relationships. Over the majority of the Sabana the surface is limestone or soil-mantled limestone, thus most of the recharge is autogenic. Near the north edge of the Sabana, however, there is a volcanic outcrop that extends over ~1/3 km² and includes the summit of Rota at 496 m (USGS, 1999). The summit is about 300 m south of the Peace Memorial, which is also located on the volcanic outcrop. The other prominent peak on the Sabana (491 m) is northeast of the true summit and is composed of limestone. The highest part of the volcanic outcrop at the summit of Rota is covered with scattered trees and a thick undergrowth of grass and fern. The lower part of the outcrop contains no significant trees. Ephemeral streams on the summit volcanic outcrop provide alloogenic recharge to the overlying limestone.

**Topography**

Except for the area around the summit volcanic outcrop, the 491-meter peak, and along the northeastern edge, the Sabana is relatively subdued terrain, particularly to the south and east. The Sabana is bounded along the south and for part of the north by steep scarps. The contact of the volcanics and the overlying limestone is exposed along the base of most of the south scarp (Talakhaya) and along parts of the north scarp. To the east and west, the Sabana is bounded by irregular terraces and slopes. The roads accessing the Sabana are in these areas.

The limestone surface of the Sabana, like most of Rota, is a true karst terrain, i.e., there are no surface streams. No water leaves the Sabana by flowing over the surface, except for possibly during extreme rain events. A large area (>1 km²) of the limestone terrain southwest of the summit has been significantly modified by human activity. During the Japanese era, large quantities of phosphate-rich soil were mined from natural soil pits (epikarst pits), transported by cable tram to the coast and processed at the Teruson plant, near present day Miigao, before being shipped off the island (Rodgers, 1948). The mined area now consists of a multitude of pits generally <1 m diameter and
ranging from <1 m to >3 m deep (Figure 5). This terrain is impossible to safely cross on foot, unless the original, overgrown mine haul roads are used. Exploration of the area has shown that the mined area is more extensive than depicted on the USGS topographical map (1999). At various places around the mined area there are berms ~2 m high and tens of meters long. These are apparently piles of mined soil that were never transported off the Sabana. The effect, if any, that the extremely convoluted surface of the mined area might have on evapotranspiration and recharge has not been investigated. Vegetation in the mined area is subdued, probably due to there being very little soil present and a significant portion of the surface being “missing”. However, vegetation in the mined area is not dramatically different from the low mixture of grasses and ferns covering much of the un-mined parts of the Sabana. Of the un-mined parts of the Sabana, about half is covered in thickets of pandanus and/or limestone forest (with the limestone forest more dominant toward the perimeter).

It is apparently not very well known, even among residents of Rota, that the original mine haul roads allow relatively easy access to the mined area. The hub for the mine haul roads is an overgrown complex of machinery and ramps that was apparently the loading area for the aerial tram used to haul the soil from the Sabana down to the processing plant at Teruson. The overgrowth of thick grass made the extent and condition of the tram loading machinery impossible to determine.

On the south side of the Sabana, the USGS topographic map (1999) depicts a large, very shallow closed depression. This depression is visible on the ground, but exploration during a light rain event did not reveal an insurgence related to it or any ponding of surface water. The depression is apparently anthropogenic and probably not hydrologically significant. Much of the closed depression and the surrounding area has

Figure 5. Typical Sabana epikarst pits mined for phosphate rich soil.

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very subdued vegetation. The ground surface here has the remnants of agricultural furrows, indicating that this area was farmed relatively recently (Figure 6). The 10-m contour lines in Figure 6 were digitized from an image of the USGS topographic map because the contour lines generated by GIS from the USGS digital elevation model failed to show the subtle topography depicted on the topographic map. Figure 6 also includes some intermediate contours.

Figure 6. Sabana Overview, Rota
West of the Sabana summit, the USGS topographic map depicts another closed depression. This depression was observed pooling water as deep as 0.25 m during a moderate rain event. The road across this depression would probably be impassable during and immediately after a large rain event. Exploration of this depression while it contained standing water did not reveal an insurgence, therefore recharge here is considered to be diffuse.

**The Volcanic-Limestone Contact**

While the investigation of the composition of the exposed volcanics was not a primary objective of this investigation, it was noted that the volcanics that outcrop at the summit of Rota are primarily intact agglomerate and clay derived from the in-place weathering of volcanics. In some places, the clay retains the texture of the original volcanic material. The agglomerate and the clay are considered impermeable relative to the surrounding and overlying limestone. Considering its small size, it is no surprise that there are no perennial or seasonal streams on the Sabana volcanic outcrop. Sheet flow that collects into channels forming ephemeral streams on the volcanics during rain events recharges either at point insurgences along the contact or in areas of diffuse recharge. There are no continuing stream channels leading off the Sabana. Observation of water flow and recharge during and immediately after rain events was instrumental in locating the contact of the summit volcanic outcrop and in beginning the investigation of the Sabana Watershed/Talakhaya Spring System. Figure 7 is a map depicting the observed and inferred ephemeral streams on the Sabana, the point insurgences found by observation during rain events, and the ~20 m diameter sink hole that leads to Summit Cave. Summit Cave is the only significant cave documented along the contact bounding the Sabana outcrop. Summit Cave is directly on the contact and has volcanic rock exposed inside. Figure 8 is a map of Summit Cave.
Figure 7. SABANA EPHEMERAL STREAMS & INSURGENCES

Legend
- Sabana Insurgences
- Sabana_Roads
- Closed Contours*
- 10 m Contours*
- Stream

*Digitized from USGS Topo

Contour Interval:
10 meters, plus
5 m supplementals

0 100 200 400 600
Meters

USGS 1999 & T.M. Keel, 2005

Peace Memorial
Diffuse Recharge Point
Summit Cave

West Sabana Road
East Sabana Road

496 m
The location of Summit Cave, the recharge points of ephemeral streams, direct observation, and vegetation clues were used to determine the location of the contact bounding the summit volcanic outcrop and the surrounding/overlying limestone. On the south, west and north sides of the outcrop, the contact was relatively easy to locate. Since Summit Cave is developed directly on the contact, the sink in which it is located provides a good starting place for a description of the contact. Although Summit Cave Sink is not depicted on the USGS topographic map (1999) it is easy to locate, ~300 m south of the summit. Figure 9 is a photograph of Summit Cave Sink looking northwest.

![Figure 9. Summit Cave Sink, looking west (Photo, Abby and Jay Snow)](image)

From Summit Cave, west to the point where the contact intersects the west Sabana road, the location of the contact was determined from the location of the “moat”, vegetation clues, the behavior of ephemeral streams and direct observation. The “moat” is a trough typically located at the contact. About 200 m south of the west Sabana road there is a closed depression along the contact, immediately adjacent to the mined limestone area, which contained a banana patch during the time of this project. This depression does not normally retain water during dry weather but was observed with water as deep as 1 m during a rain event (Figure 10) and is obviously acting as a collection point for diffuse recharge (Diffuse Recharge Point in Figures 7 & 12). A sufficiently intense rain event would probably cause this depression to overflow directly into to mined limestone area where recharge is expected to be rapid. Exploration of this
depression when it was dry failed to locate an open insurgence. An ephemeral stream rising on the volcanics and discharging several hundred liters per minute into this depression was observed during a rain event. Other smaller ephemeral streams also discharge to the same depression. There are smaller ephemeral streams north of this depression. The discharge from these streams appears to recharge diffusely but no significant depressions are associated with them.

Along the south side of the west Sabana road there is a swale 1-2 m deep that was observed carrying a significant ephemeral stream after rain events. No insurgence could be found associated with this stream. Apparently it begins to recharge diffusely at the contact. However, some of the water from this stream crosses the road and joins the stream that parallels the north side of the road at this point. This combined flow continues for some tens of meters beyond the contact, but is gradually reduced by diffuse recharge. In a sufficiently intense rain event, this combined stream probably flows into the broad closed depression previously described on the west side of the Sabana.

North of the West Sabana Road, arcing north of the Peace Memorial and continuing nearly to the East Sabana Road, there is a series of insurgences that mark the contact (Insurgence #1 through Insurgence #8 in Figures 7 & 12). There is a small insurgence (Insurgence #8) located ~150 m north of the west Sabana road. There are two insurgences located on opposite sides of the large volcanic boulder that is northwest of

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*Figure 10. Diffuse recharge point on west side of Sabana Summit*
the Peace Memorial (Insurgence #7 & Insurgence #6). There is another insurgence located a few tens of meters east of the boulder (Insurgence #5). Insurgences #5 through #8 are located in thick grass and will be difficult to relocate except by sound during a rain event. The most significant insurgence on the north side of the Sabana outcrop is located in a banana patch, adjacent to Rota Rooter Cave (Keel et al., 2004), ~100 m northeast of the Peace Memorial. Insurgence #4 (Figure 11) or the “north banana patch insurgence” (Figures 7 & 12) was observed taking several hundred liters per minute during and after a moderate rain event. Under normal circumstances, Rota Rooter Cave clearly does not act as an insurgence. However, a sufficiently large rain event may cause water to pool up to the level that it spills into Rota Rooter Cave. This very small cave was probably a primary drain for this closed depression in the past.

In the moat between Insurgence #4 and the East Sabana Road there are three other small insurgences (Insurgence #3, 2, &1). Some of these were observed when they had reached their maximum throughput and had water pooled above them. The entire overflow from this series of insurgences flows to the local low point at the Insurgence #4. Although it is not depicted as a closed depression on the USGS topographic map (1999), the area around Insurgence #4 is clearly a closed depression. The moat that leads to this series of insurgences indicates the location of the contact all the way to the East Sabana Road. At the time of this investigation, the location of the contact along the East Sabana Road could be located by the change in lithology exposed on the surface.
From the point where the contact cuts the East Sabana Road to Summit Cave the exact location of the contact is much more difficult to locate and is accordingly shown in Figure 12 as a dashed line. The east side of the Sabana summit shows evidence of human disturbance, although vegetation cover and erosion make a firm determination of human disturbance difficult.

Figure 12. Sabana Outcrop & Insurgences
Talakhaya Springs

As described in SETTING above, the Talakhaya Springs (Water Cave and As Onan Spring) provide water for Rota’s municipal system and are both located at the base of the scarp bounding the south side of the Sabana is the top of the Talakhaya.

Water Cave (Matan Hanum) (Figure 14) is located at 350 m elevation, ~2 km directly south of the Sabana summit. As Onan Spring (Figure 13) is located at about the same elevation, ~1.5 km east of Water Cave. The locations of Water Cave and As Onan Spring are shown on the map in Figure 15. Once again, the term “Talakhaya Springs” is not meant to include the springs along the Talakhaya that are not exploited for municipal water. Based on its morphology, Water Cave might be a flank margin cave, formed by mixing dissolution at the edge of the former freshwater lens, which coincidentally developed at the contact. However, there are no other known flank margin caves at this elevation on Rota (Keel et al., 2004), therefore it seems more probable that Water Cave developed as a result of the very large discharge of water that occurs there. The discharge at Water Cave is far greater than the discharge at any of the other springs along the Talakhaya contact. Most of the water collected into the municipal system at Water Cave, several thousand liters per minute, appears inside the cave from impassable holes along the east wall of the main chamber and along the east wall of the smaller chamber at the rear of the cave. Some water is also collected from small spring just outside the entrance to Water Cave. Water Cave and the small springs adjacent to it normally supply 2.7 to 3.8 million liters per day of water to Rota’s municipal system. During a normal wet season, there is a considerable excess flow of water that is not captured by the municipal system and which flows down its natural channel. During dryer times, most of the discharge from Water Cave is captured by the municipal system. Water from Water Cave is gravity fed, primarily to the storage tank at Kaan above Songsong Village. There is a pipe running east from Water Cave so that water from there can be used to supplement water from As Onan Spring to supply the village at Sinapalo.

Figure 13. Map of As Onan Spring
Figure 14. Map of Water Cave
Figure 15. Sabana Overview with contacts and contact caves
Unlike Water Cave, there is no cave chamber at *As Onan* Spring. *As Onan* is actually a series of springs along a section of contact that is inset relative to the cliff above it. Each of the larger springs has a small concrete catchment feeding a pipe collection system. Although the value is not known, the discharge at *As Onan* Spring is probably less than half the discharge at Water Cave. Water from *As Onan* is gravity fed to the CUC storage tank at Sinapalo.

There are other springs along the *Talakhaya* contact that have a large enough discharge during at least part of the year to lead to suggestions that they be exploited for municipal water. However, considering that there is no usable road near most of these springs, the cost of building systems to tap these springs would be very high. Moreover, he largest is these springs is on private land. Probably the most significant reason that using the untapped springs on the *Talakhaya* is not advisable is that they are not needed when flow from the developed springs is sufficient, and they will likely be dry when flow from the developed springs is inadequate; during the drought events they are most likely to have extremely low flows or zero flows.

**Other Springs**

The scarp bounding most of the north side of the *Sabana* is in two sections that meet at an angle ~1 km north-northwest of the summit. The western section of this scarp overlooks *Uyulan Hulo*. The contact of the volcanics and the overlying limestone is exposed across most of the western section of this scarp. There are two small spring caves developed along this section of contact, but remarkably little discharge of water. The locations of North Side Trickle Cave and Reservoir Cave are shown in Figure 15. On 25 May 2004, North Side Trickle Cave had a flow of <1 liter per minute. On 9 July 2004, Reservoir Cave had a measured flow of 1 liter per minute. The areas below both caves do not show evidence of ever having significant water flow. There are no stream channels developed below either cave. These two caves are the largest known springs on the western part of the north scarp of the *Sabana*. The area down slope of this section of contact is primarily a volcanic surface yet, unlike the *Talakhaya*, it is forested. There are scattered “islands” of limestone across this slope. This slope also contains the scar of a large landslide. The slide tongue and scar are visible on the USGS topographic map (1999) and are visible from the air.

**SUMMARY AND TENTATIVE CONCLUSIONS**

The work of this project has yielded a number of important discoveries for the better understanding of the Sabana Watershed/*Talakhaya* Springs relationship.

- A location for most of the volcanic/limestone contact around the summit of the *Sabana*.
- A general characterization of the ephemeral streams of the *Sabana* and the insurgences related to them.
- A better understanding of the historically mined section of the *Sabana* but not the impact that it might have on recharge versus evapotranspiration.
- A characterization of the large contact springs at the top of the *Talakhaya*. 
• The near absence of surface discharge from any other locations around the perimeter of the Sabana.
• Location and characterization of some small springs on the northwest flank of the Talakhaya.
• Documentation that there is normally no surface run off from the Sabana.

As previously stated, that the Sabana is the recharge area for the Talakhaya Springs is not in doubt. Although the lack of Sabana rainfall data and the Talakhaya Spring discharge data precluded calculating a water budget, the extremely large total discharge from all the springs along the Talakhaya contact and the reliability of those springs except in the worst drought years, support a hypothesis that a very large fraction of the recharge on the Sabana makes its way south along the buried contact to be discharged along the Talakhaya. If this hypothesis is true, the subsurface contact between the volcanics and the overlying limestone form a trough that surrounds the Sabana summit volcanic outcrop and funnels the water toward the south. Further work, including dye tracing, water budgets, and subsurface methods, should provide evidence to support or refute this hypothesis. The map in Figure 16 presents a proposed 4.5 km² catchment area for Water Cave. The much thicker surface cover and the relative lack of surface relief made drawing such a proposed catchment impractical for As Onan Spring. However, it is expected that most of the Sabana adjacent to As Onan Spring acts as its recharge area.

Testing this hypothesis about the catchment area of Water Cave will require the reinstallation and maintenance of a rain gage on the Sabana and a stream flow gage at the Water Cave in order that a water budget may be calculated. Measuring the discharge at As Onan Spring should also be explored.

This report presents evidence that a very large fraction of the Sabana acts are recharge for Water Cave and As Onan Spring. This means that agricultural chemicals used anywhere on the Sabana have a high probability of making their way into the municipal water system. While recognizing that the Sabana has some of Rota’s prime farm land, the risk to the water supply posed by continued farming there should be examined.

The springs Water Cave and As Onan Spring are among the most valuable resources to the people of Rota. While this study should help with decisions regarding these resources, we encourage further investigation to continue building knowledge that will help protect of Rota’s water source into the future and help protect the people of Rota.
Figure 16. Hypothesized Water Cave Catchment
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