A Technical Analysis of Suriname for Tropical Testing of Army Materiel and Systems

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13. ABSTRACT *(Maximum 200 words)* This report presents the findings of a scientific panel assembled by the U.S. Army Research Office (ARO) at the request of the Technical Director, U.S. Army Yuma Proving Ground (YPG), for the purpose of evaluating the suitability of the Moengo area of Suriname in northern South America for tropical testing for the Army. The evaluation panel addressed this tasking through the utilization of an ideal tropic test site model and a hierarchical decision tree process to prioritize critical environmental parameters developed in previous studies in Puerto Rico, Hawai'i, and Queensland, Australia.			
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A Scientific Analysis of Suriname for Tropical Testing of Army Materiel, Equipment, and Systems

This analysis was conducted by a scientific panel assembled by the Army Research Office and Yuma Proving Ground of the U.S. Army Developmental Test Command.

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EXECUTIVE SUMMARY

The U.S. Army has long recognized the significance of military operations in tropical climates. First, conflicts will continue to occur in these geographic areas; since 1960 more than 75 percent of regional conflicts have their roots in countries located within the tropics. Secondly, successful operations require troops and equipment capable of sustained operation in the heat, humidity, and variable environmental conditions presented by tropical landscapes. To achieve the latter, military equipment must be tested in harsh tropical conditions and soldiers must be trained within this demanding environmental setting. Under the terms of the Carter-Torrijos Treaty of 1977, the military mission in Panama was required to vacate the country by December 31, 1999. The U.S. Army lost important capabilities with the closure of both the Army tropic testing facilities and Jungle Operations Training Center (JOTC) in Panama and the Army should not delay further to restore these essential activities. To this end, the U.S. Army Test and Evaluation Command (ATEC), through its sub-element at U.S. Army Yuma Proving Ground (YPG), is developing a suite of alternative sites to support the tropical testing mission.

In 1998, YPG requested the assistance of the U.S. Army Research Office (ARO) to convene an expert panel to undertake two related studies. The first study, “A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems” (King et al., 1998), examined the Army tropical test mission to define the conditions that best provide the environmental challenges needed for tropical testing, today and into the 21st century. This study identified the climatic, physical, and biological characteristics defining the ideal tropical test environment and identified regions of the world that best fit the composite specifications of an ideal tropical test environment. Sixteen regions of the world were identified that provide the requisite conditions of an ideal environment for tropical testing and training.

As a consequence of the initial study, follow-on studies examined locations in Hawai’i, Puerto Rico (King et al., 1999), and Northeast Queensland, Australia (King et al., 2001). The specific charter for these two follow-on studies was to identify areas of the Hawai’ian Islands, Puerto Rico, and the NE Queensland region of Australia that best provide a combination of environmental conditions as defined in the initial study panel report requisite to the testing and evaluation of Army materiel, equipment, vehicles, and weapon systems (King et al., 1999). The results included a regional analysis of the environmental setting for the three areas, an environmental characterization of specific sites within each area, the rating of each site’s capacity to support each component of the testing mission, and finally, conclusions as to the capacity to conduct tropical testing and training in these three regions. Based on the findings, from the three previous studies, the Yuma Proving Ground Tropic Regions Test Center (YPG-TRTC) has developed and is operating a testing facility at Schofield Barracks in Hawai’i.

Previously, the tropic test study panel concluded that a suite of sites would offer the best technical approach to replace the testing capacity lost with the closure of testing facilities in Panama (King et al., 1998, 1999, 2001). This conclusion was based on the absence of an ideal test site at any single location examined, where ideal is defined as a single accessible location possessing all of the requisite environmental conditions. Suriname is being considered because it was identified in the initial study (King et al., 1998) as containing areas possessing the requisite environmental conditions and preliminary assessment by staff of the YPG-TRTC had recognized possibilities for vehicle mobility testing there.

The overarching conclusion of this study is that **access to the Moengo region of Suriname would significantly enhance the capability of the United States Army to test military equipment and systems in a tropical environment**. Detailed analysis completed in this study fully confirms previous work (King et. al., 1998; 2004), which found that the northern coast of South America possesses the requisite conditions of physical setting, climate and biologic diversity for effective tropical testing. The Moengo region of northeastern Suriname offers a range and diversity of tropical environments and potential testing conditions not observed in Hawai'i or at any of the other candidate sites examined to date.

The Moengo region of northeastern Suriname encompasses a very accessible area ~600-km^2 tropical rainforest of diverse character, ranging from recent secondary growth jungle to mature triple-canopy rainforest that rated as very good to ideal for all 14 environmental factors evaluated as part of this study. ***This is the best site for tropical testing the panel has seen outside of Panama, and is suitable for most testing missions.*** The Moengo area is ideal for vehicle mobility testing, exposure testing, all types of human factors testing, and excellent for most types of developmental and operational testing. Sensor and electronics testing could be conducted there in a very acceptable to excellent manner, as a diverse suite of environments is available that would offer a variable set of challenges to sensors and electronic devices. This capability would fill a major shortfall in existing testing capacity in Hawai'i. The Moengo area offers a variety of different environments for exposure testing, but no present ability to fire weapons or detonate explosives. The Moengo area would be an excellent location for testing that requires putting troops into fresh water. Overall, YPG-TRTC access to Moengo would greatly enhance the existing U.S. Army testing capability and offers the potential for an ideal site for Army jungle operations training.

Conclusions from this study are as follows:

- The Moengo area of northeastern Suriname should be added by YPG-TRTC to the suite of sites that can support Army tropical testing.
- The Moengo area is an outstanding location for vehicle mobility testing. It is also an excellent area for developmental and operational testing of material and systems, useful as a site for human factors testing of all types of equipment as the area is expansive and the variable environmental conditions across the area provide a diverse set of challenges. Use of this area would greatly enhance existing capability for sensor and electronics systems testing of all types.
- The panel finds that many types of tests can be more rigorously conducted at sites in Suriname than at sites currently available in Hawai'i or under provisional use in Panama.
- YPG-TRTC should pursue discussions with the government of Suriname to determine the availability of Moengo area for use as sites for US Army tropical testing.
- The panel sees value in developing a cooperative relationship with the Suriname Ministry of Defense.
- Transportation and economics will be an important concern in successfully implementing testing in Suriname. The panel recommends that U.S. Army Developmental Test Command conduct an economic analysis of the cost of testing in Suriname in comparison to Hawai'i and Panama.

CHAPTER I

BACKGROUND HISTORICAL REVIEW

I.1. Introduction.

The major military powers of the world recognize the need for field testing of materiel in the tropics. The U.S. experience in the Pacific in World War II and in Southeast Asia during the Vietnam War clearly demonstrated the need to test the performance of new equipment in the harsh environmental conditions of the tropics. Since 1960, some 75% of all international and internal conflicts have been in countries whose borders are totally or partially within the tropics. Researchers examining past conflicts to better understand the security threats of the future have reached the conclusion that the countries lying within the tropics are the most likely locations for future conflicts (Lee, 1999). Further, studies examining the sources of insecurity posed by global environmental degradation see the tropical regions of Africa, Asia, and the Americas as the most likely locations of instability in the future (King, 2000). Recent operations in Somalia, Rwanda, Haiti, Panama, East Timor, and elsewhere have only reinforced the need to be prepared for tropical conditions. Clearly, the Army must be prepared to deploy and operate successfully in the tropical environment.

As prescribed by AR 70-38 (U.S. Army, 1979a), and guided by requirements in numerous performance standards (MIL STDs), environmental conditions and their effects are to be given realistic consideration in the research, development, test, and evaluation (RDT&E) process for materiel used in combat by the Army. As a result, testing and evaluation in the tropical environment of material, equipment, and systems, as well as human performance, is well established and has a long history. The U.S. and several of its military allies operate testing and/or training facilities in the hot, humid tropics (e.g., the U.K. in Belize, France in French Guiana, and Australia in its state of Queensland). The mission of testing in extreme natural environments for the Army (U.S. Army, 1979b) resides with the Army Test and Evaluation Command (ATEC) and is vested with Yuma Proving Ground (YPG). Presently, this mission is accomplished at desert, arctic and sub-tropical test facilities in the United States (arctic at Fort Greeley, AK (CRTC); desert at Yuma Proving Ground, AZ (YTC), and sub-tropic at Schofield Barracks, HI (TRTC). Temperate environment testing is the responsibility of the Aberdeen Test Center (Aberdeen Proving Ground, MD).

I.2. Study Panel Tasking.

Army testing of materiel, equipment and systems, together with human performance evaluation under tropical conditions took place in the Canal Zone area of the Republic of Panama as far back as WW II. This mission evolved into the Tropic Test Center (TTC) in 1962, which supported specific Army test functions in response to evolving military needs through the 1990's. Under the terms of the Carter-Torrijos Treaty of 1977, the military mission in Panama was required to relocate from the country by December 31, 1999. In 1998, at the request of Yuma Proving Ground (YPG), the Army Research Laboratory's Army Research Office (ARO) convened an expert panel to undertake a study to identify the general areas across the globe that could satisfy the test environment that was being lost as a result of departure from Panama.

That study - *A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems* (King et al., 1998) examined the Army tropical test mission to define the conditions that best provide the environmental challenges needed for tropical testing, today and into the 21st century. The 1998 study defined the climatic, physical and biological characteristics of the “ideal tropical test environment” and identified regions of the world that best provided the combined parameters for such an ideal location. The analysis was based solely on critical environmental parameters defined by the panel, without constraining the analysis by the numerous important, but non-scientific considerations that would impact any final site selection. To support any follow-on locational efforts, a decision tree was constructed based upon a prioritization of the critical environmental parameters. Although some 15% of the Earth's land surface is tropical in general character (Veregin, 2005), very little of this area is considered ideal for tropical testing. Worldwide, 16 areas were identified in the 1998 study (King et al., 1998) as suitable localities for Army tropical testing (Figure 1). The first group of six geographic areas, ordered in terms of their relative proximity to the continental U.S., included: northern Honduras, the Isthmus of Panama, French Guiana/coastal northeastern Brazil, the southwestern New Guinea lowlands, low-moderate altitude areas of the East Indies in east-central Java and southeastern Borneo, and the Isthmus of Kra in Malaysia. The premier localities in this group for tropical testing were the Isthmus of Panama and the Isthmus of Kra because both areas offer a spectrum of tropical conditions and environments within a compact geographic area. A second group of ten locations was identified that exhibited the general physiographic and biotic character, but failed to provide one or more of the other important elements considered requisite of the ideal tropical environment for Army testing. This group consisted of coastal Belize, Puerto Rico, southeastern Costa Rica, northwestern Colombia, portions of the Hawai’ian Islands and the Fiji Islands, the Philippines, New Britain-New Ireland, the coastal region of northern Queensland in Australia, and the Bangkok area of coastal Thailand.

In late 1998, guidance was issued directing that the Army tropic test mission be relocated to a US controlled site. In response to this directive, a second study panel was convened in the early part of 1999 to evaluate sites in Hawai’i and Puerto Rico for their capability to support tropical testing. The report, *A Technical Analysis of Hawai’i and Puerto Rico for Tropical Testing of Army Materiel and Systems* (King et al., 1999), contained a number of findings including the fact that Schofield Barracks on the island of Oahu could "adequately" accommodate up to about 80% of the volume of the current TRTC test mission". As a result, YPG-TRTC has focused on the development of test capabilities in Hawai’i, specifically on the creation of a soldier systems jungle test area at Schofield Barracks. Additionally, the second report recommended that additional test facilities should be developed as a part of a "suite of sites" that would enhance the tropical testing capabilities, particularly since the Schofield Barracks site was not suitable for certain testing missions. In the next phase of the work, YPG requested that an ARO expert panel evaluate specific sites in the northern Queensland area of Australia, an area where the Australian Army operated tropical testing and training facilities.

In 2006, the Army is again engaged in tropical testing, now employing a suite of sites that have evolved from the results and recommendations of previous panel study work. Sites include

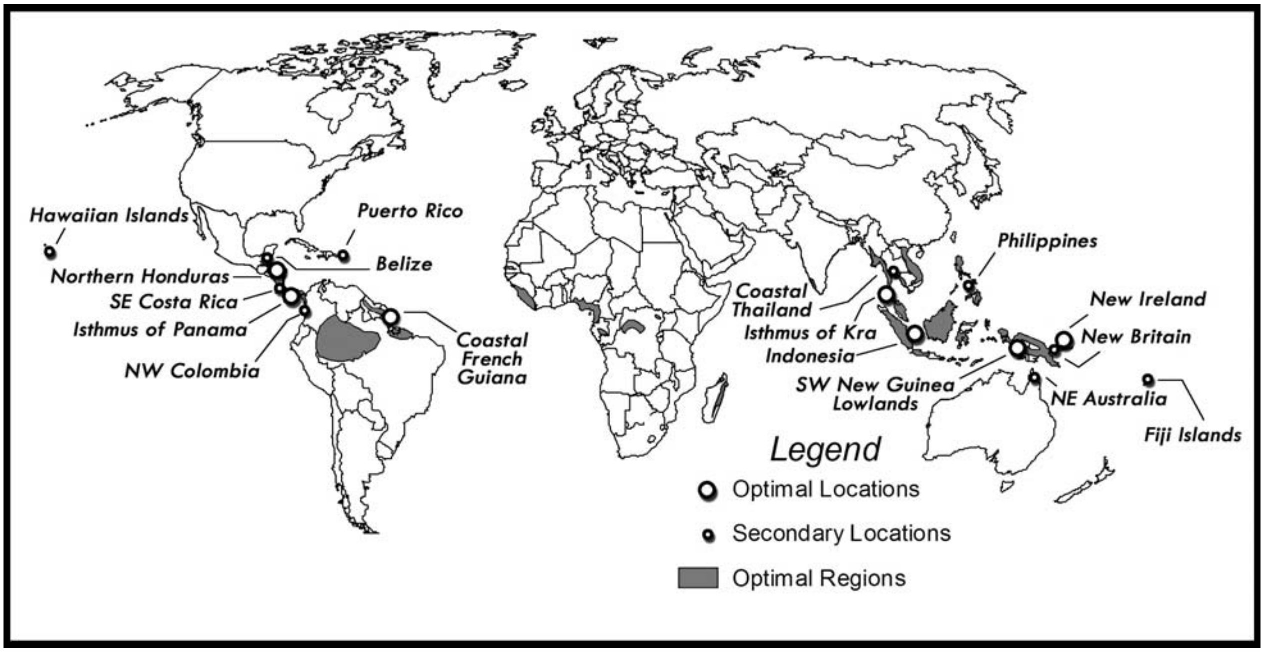

Figure 1. Optimal locations for developmental and operational tropical testing of military equipment, vehicles, and weapon systems (from King et al., 1998; 2004)

locations in Hawaii and limited capability to use sites within Panama. However, certain testing missions still require environmental conditions that are not available within available sites.

A critical shortcoming in overall testing capacity is a place to conduct vehicle testing. Tropical testing of vehicles requires extensive lengths of roads of all surface types, including natural soils, all situated within the hot tropical climate domain. Suriname became a candidate site for these types of tests because the mining of aluminum ores in northern Suriname has a significant road network within a geographic area identified as having ideal biologic and climate conditions in the 1998 study. For this reason the study panel reconvened to analyze sites in Suriname. The membership of the study panel assembled by ARO, together with a brief statement of qualification for each member, is listed in Appendix 1. The goal was to find locations with existing road networks because these types of tests would be damaging to previously undisturbed areas. It was initially hypothesized that vehicle testing could be very successfully accomplished in this area under ideal tropical conditions, and without any further significant disturbance to the environment.

I.3. The Ideal Tropical Test Site.

The study panel began its tasking by implementing the analysis model developed during the previous studies of Puerto Rico, the Hawai'ian Islands, and Australia (King et al., 1999; King et al., 2001).

The requisite characteristics of the ideal environment for a tropical test facility are derived from complex interrelationships among the key factors of climate, terrain, and vegetation.

Climate is the defining characteristic of a tropical region, whereas physiography and geologic factors are closely associated, and the biologic manifestations (land cover/vegetation type) are a direct function of the combination of climate, physiography, and geology within a given region. The criteria identified as defining the ideal tropical test environment from a scientific basis (King et al., 1998) are summarized in Table 1.

I.3.A. Climate Requirements.

Climatic criteria for the humid tropics are defined in Army Regulation, AR 70-38 (U.S. Army, 1979a), which broadly classifies world climates into four "basic climatic design types". Each of these design types is characterized by one or more daily weather cycles. Two daily cycles in the “basic climatic type” represent the humid tropics (Table 2).

The ideal setting for a tropical test facility would lie in a hot and humid tropical climate regime to provide extremes of high relative humidity (RH) in a very high rainfall and constant high temperature environment. As such, the area encompassing the site should have annual precipitation in excess of 2,000mm, monthly-averaged minimum temperature and RH in excess of 18-20°C and 60%, respectively, and mean monthly temperatures and RH of at least 25°C and 75%, respectively. Average rainfall would not fall below 100 mm in any single month, nor exceed 6,000 mm per year. These precipitation requirements address a desire for minimal seasonal variability (i.e., a preference for no absolute dry season). Regions experiencing tropical cyclone (hurricane or typhoon) activity should be avoided, unless all other physical factors indicate the site to be an optimal location. Ideally, a relatively compact area would exhibit variable conditions of climate (e.g., frequency/distribution of precipitation and temperature) across the spatial domain encompassing coastal lowlands to steep relief.

I.3.B. Physical Considerations.

The requirements defined in the ideal test environment are best met in terms of: an area of sufficient size to contain the test mission, variations in slope and relief across the site, surface streams that can support a variety of tests, surrounding land use that is compatible with the testing mission, and the absence of cultural/historical resources or conservation pressures that could infringe on testing. The area should not be a high-risk zone in terms of frequency of natural hazards (e.g. tropical storms, volcanic activity, earthquakes, landslides, flooding, etc.). Also, it should not be affected by significant adverse anthropogenic activities (e.g. high adjacent population density, upstream pollution from urban, industrial, and/or farming activities). Soils need not be a specific type, but must be of sufficient thickness and health to support a diverse suite of lush tropical vegetation and offer significant challenges to the mobility of troops and vehicles.

I.3.C. Biological Considerations.

Given the specific climatic, topographic and geographic constraints listed above, the major biological considerations for a tropical testing site are the vegetation characteristics and the presence of a diverse community of above- and below-ground organisms. In the past, military interest in tropical vegetation was primarily based on the latter’s structure and distribution in both horizontal and vertical dimensions as challenges to vision, mobility, and performance of personnel and equipment. For other organisms, especially microbes, the concerns focus primarily on sufficient density to produce high rates of the metabolic processes and by-products that foul materiel and interfere with equipment and systems. Military testing at present and in the future requires much greater detail and understanding of the structure, function, and interrelationships of species in complex tropical ecosystems.

Table 1. Criteria for an Ideal Tropical Test Area (King et al., 1998)

I. Climate	
Precipitation:	2 to 6 meters (m) per year, > 0.1 m in driest month
Temperature (°C):	18 minimum average, 25 to 40 average daily
Relative Humidity (%):	Mean = 75, range = 60 to 90
II. Physical Setting	
Relief:	Elevation = Sea level to 1500 m, Site relief = 150 m minimum, Slope = 0 to 60 %, coastal location with lowlands.
Surface water:	Perennial small (1 to 2 m) to medium (up to 20m) width streams, with nominal velocities (<20m/s).
Soils:	Oxisols, ultisols, inceptisols, minimum depth in the range of 10m
III. Biological Considerations	
Vegetation Structure: Secondary tropical rainforest with undisturbed growth for greater than 25 years. Closed canopy forest cover. Minimum, 70 to 95% of stems <10cm dbh with remaining stems >20cm dbh, basal area 20 to 70m^2/hectare, established understory growth.	
Microbiology: Diverse fauna and decomposer populations	

I.4. Study Methodology.

Because of complex feedback mechanisms, land cover also influences local/regional climate. Therefore, in a tropic test suitability analysis, the hierarchical ranking of factors in Table 1 (climatic, physiographic/geologic, and biologic factors) provides a simple and direct means for comparative site evaluation. The decision tree developed by the study panel (Table 3) took into consideration the three primary parameters of climate, physical setting, and biological characteristics, weighed from highest to lowest priority according to the criteria listed in Table 1. To implement this ideal test center model in the panel's optimization studies, a set of 14 environmental parameters were developed to summarize the environmental conditions of a specific location. These 14 criteria are: temperature, rainfall, humidity, soils, area size, slopes, relief, surface streams, understory, forest canopy, forest floor fauna, land use/ownership, adjacent land use, and cultural/historical features. Any candidate site can be characterized by its ability to fulfill these environmental parameters. Because the panel recognized that it would be difficult for a site to achieve a perfect match, rather than employing a simple "YES" or "NO"

Table 2. Description of AR 70-38 humid tropical climate types (U.S. Army, 1979a)

Operational Conditions for Storage and Transit

Climate Parameter	B1 Constant High Humidity	B2 Variable High Humidity
Ambient air temperature (^oC)	Nearly constant at 24	26 to 35
Solar radiation (BTU/ft^2/hr)	Negligible	0 to 307
Ambient relative humidity (%)	95 to 100	74 to 100
Induced air temperature (^oC)	Nearly constant at 27	30 to 36
Induced relative humidity (%)	95 to 100	19 to 75

The "Constant High Humidity Cycle" corresponds to conditions under the jungle canopy, and the "Variable High Humidity Cycle" corresponds to conditions in open areas. These conditions occur throughout the year with little or no seasonal variation. Other important characteristics are rainfall, a double canopy of vegetation, a dense understory, and varying degrees of topographic relief. The limits indicated in Table 2 represent the minimum recommended environmental conditions necessary to evaluate the effects of a jungle environment on personnel and equipment.

analysis, a 4-tiered rating scale was developed to assess the relative compliance with each specific environmental criterion (A “0” rating denotes a situation that fails to provide the required setting; a “1” rating denotes a marginal condition that places severe limits on testing; a “2” rating denotes a good setting that meets all critical and most desired criteria; and a “3” rating denotes an excellent setting that is fully capable of supporting the requirement.)**.**

The concluding step in the analysis requires the grading of each site for its overall ability to support each component of the testing mission. To accomplish this task, one additional grading scale was developed to evaluate the ability to conduct a specific type of test in a given location, a scale that analyzes only the essential or important environmental conditions required for a specific test, as listed in Table 4. An overall grade (see Table 5) is derived that reflects the capability of that site to support a specific testing mission based on only the environmental factors that are important to that test.

I.5. Summary.

The overall procedure that was utilized in this study of northeastern Suriname implemented the model developed and proven in the course of the previous work by this panel. The methodology is founded on two primary products from the initial study, (i) a characterization of the ideal test environment (Table 1), and (ii) a decision tree to evaluate areas on a regional basis (Table 3). Candidate sites can then be characterized and compared by their ability to comply with the environmental requirements for the specific test activities listed in Table 4.

Table 3 - Decision tree structure utilized in this study (after King et al., 1999).

Essential tropical parameters include:
Diurnal and annual temperature (mean and ranges)
Annual and monthly precipitation level (mean and ranges)
Relative humidity
Physiography (relief, slope, elevation range)
Biotic communities (vegetation structure)
Characteristics deemed highly desirable, but not critical, include:
Minimal effects of tropical cyclone (hurricane or typhoon) activity
Seasonality (minimal dry season preferred)
Range of vegetation types (rainforest, wetlands, savannah)
Range of landscape types (sea coast, coastal wetland, coastal plain, upland)
Well-developed and variable soil profiles (oxisols, ultisols, inceptisols, entisols)
Range of stream sizes and flow regimes
Screening criteria resulting in elimination of otherwise acceptable locations include:
Intensive geologic hazards (active volcanism, seismic activity, landslides)
High tsunami/storm surge susceptibility
Presence of extensive karst topography (limestone)
Frequent or large-scale disturbance of vegetation (natural and/or anthropogenic)
Presence of high levels of disease vectors
Excessive monthly or annual precipitation
Impacts of farming, industry or urbanization
Land use restrictions

Table 4. Environmental factors required for specific tropical testing missions (King et al., 1999).

Mission	Environmental Factors
Equipment Development Testing:	
1) Communication & Electronics	***Understory, canopy, temperature***, humidity, relief, fauna
2) Ground & air sensors	***Canopy, understory***, temperature, humidity, rainfall, soils
3) Chemical & biological defense	***Fauna, understory,*** temperature, relief
4) Environmental exposure	***Humidity, rainfall, fauna, temperature,*** canopy
Operational and Human Performance Testing:	
1) Individual soldier systems	***Temperature, humidity, canopy, understory, rainfall, relief,*** slope, soils
2) Communication and electronics systems	***Canopy, understory, fauna, temperature, humidity***, ***relief,*** rainfall
3) Ground and air sensors	**Canopy, *understory***, temperature, humidity, relief, soils
4) Chemical and biological defense	***Understory, fauna, temperature, humidity,*** relief, canopy
Small Caliber Munitions:	
1) Exposure testing	***Land use, temperature, humidity, fauna,*** rainfall**,** canopy
2) Operational testing and firing	***Land use, adjacent land use***, temperature, humidity
3) Smoke and obscurants	***Understory, temperature, humidity,*** relief, canopy
Large Caliber Munitions:	
1) Exposure testing	***Land use, temperature, humidity, fauna, rainfall***, canopy
2) Operational testing and firing	***Land use, adjacent land use,*** temperature, humidity,
3) Smoke & obscurants	***Understory***, temperature, humidity, relief, canopy
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understory, humidity

Note: The environmental criteria are listed in general order of importance. Criteria presented in bold and italics are considered essential elements for that testing mission.

Table 5. Environmental factor ratings (after King et al., 1999).

Grade	Environmental Ranking	Site Evaluation Description
A	All 3'and 2’s, mostly 3’s	Acceptable testing capability
B	Mostly 2's	Adequate with some limitations
C	2's and 1's	Marginally useful for testing
D	Mostly 1's	Undesirable, limited utility for testing
F	0’s for critical elements	Completely unacceptable

CHAPTER II

THE TEST MISSION

II.1. Overview of the Testing Process.

The testing and evaluation of equipment and systems in the natural environment is conducted using accepted scientific protocol and established engineering practices. This assures repeatability, experimental control, and validation of test results. Many aspects of the testing process are conducted over long periods of time and, therefore, a fundamental requirement for a test location is the constant presence of tropical conditions that meet the needs of the item undergoing testing. Testing also requires a well-characterized and understood suite of tropical field sites that provide environments that are fully representative of those in which soldiers, systems, and materiel may be fielded during combat.

The test and evaluation of equipment and systems is a complex continuum that begins with basic proof of concept, then develops an understanding of how environmental effects impact equipment throughout its life cycle, and finally tests systems with soldier operators. The test continuum is a participative, iterative process among developers, test personnel, and soldiers, in many test phases. Each test phase focuses on maturing the item and furthering it along for inclusion in the Army inventory. Any number of very specific test facilities and capabilities are required to meet various needs during the course of the overall test process. Natural environment developmental testing (DT) addresses technical issues and criteria that require realistic, calibrated test sites and courses where repeatability and control can be ensured over time and events. Operational Testing (OT) addresses force-on-force system effectiveness issues. Both require representative, natural environments. These facilities and capabilities are summarized in the following section.

The tropical environment is the most diverse and complex natural environment in the world and, consequently, is one of the most challenging for soldiers, equipment, and systems. Modern sophisticated technology, with complex integrated electronic circuitry, is more critically affected by tropical factors than the simpler electromechanical systems of the past. The effects of heat, humidity, direct insolation, and biological degradation by organisms such as bacteria and fungus, coupled with a dense cover of a multi-canopy jungle, not only attack and deteriorate equipment, but also create a most hostile natural environment in which the soldier must successfully wield the technology to accomplish the military mission.

II.2. Types of Testing.

Current environmental testing by the Army can be divided into five broad categories: (i) equipment, and system development testing [30% workload]; (ii) equipment and system operational and human performance testing [50%]; (iii) munitions testing including long term storage [15%]; (iv) specialized testing [3%], and (v) vehicle mobility testing [2%]. This testing is encompassed and described by a matrix of six test categories or groups that have common environmental test requirements as described below.

II.2.A. Developmental Testing

Developmental testing typically encompasses the prototype testing of new equipment. It focuses on all types of equipment, systems and materials with current emphasis on communications systems and electronics, ground and air sensor systems, and chemical-biological detection systems. Exposure and wear testing of equipment under both open and jungle conditions is an integral component of this activity. Sites for tropic developmental testing should have "robust" environmental characteristics that provide climatic conditions close to those described in AR 70-38, so as to provide the maximum tropical environmental challenge to the performance envelope of these items. These include (i) a dense jungle canopy for obscuring ground-placed targets to airborne sensors, (ii) a well-developed soil profile (iii) a dense vegetative understory, (iv) topography for challenging line-of-sight communication, and (v) a hot humid jungle environment with abundant biologic decomposition to produce the volatile compounds that challenge chemical-biological detection equipment. An intense tropical environment includes a diverse suite of biological degraders consisting of bacteria, fungus, and insects to challenge long-term material integrity.

II.2.B. Human Factors (HF) Performance Testing

This testing is directed toward the operation of equipment and systems in the manner employed during use by the Army. This allows for testing of both the functionality of the equipment, as well as for the performance of the individual soldier. High temperature and humidity stress the soldiers, thus lessening the ability to move quickly, work long hours, and successfully manipulate complex equipment and systems. The tropical environmental characteristics required are high humidity, high temperature, a well-developed understory and canopy, and appropriate geomorphic features such as relief, streams, and soils. In actual combat conditions, all of these factors combine to create a dark and foreboding atmosphere that can affect soldiers’ attitudes and sense of well-being, and thus their ability to accomplish their mission.

II.2.C. Long-Term Exposure and Testing of Munitions

This activity is focused on the long-term exposure of munitions and testing of small ($\leq$40 mm) and large (>40 mm) weapon systems in tropical environments, in both open and jungle settings. Munitions of all types, particularly larger caliber, are stored for protracted periods to evaluate their stability when subjected to tropical environs. The testing of munitions generates military unique test requirements and, as such, the military infrastructure requirements of established ranges and approved storage areas for munitions must overlay, or be in close proximity to, the environmental test areas. Small caliber munitions involved in operational testing require a similar military-unique infrastructure, as well as the usual environmental characteristics of high heat and humidity identified in AR 70-38. Large caliber weapon systems must be subjected to both exposure and operational testing within the tropical environment. Ultimately, all munitions firing must be conducted on ranges approved for all safety standards. Testing of smokes and obscurants requires relatively flat area in areas of restricted access.

II.2.D. Vehicle Mobility

This testing is directed toward evaluation mobility performance in the tropical environment of wheeled, tracked, and towed vehicles. It includes the testing of trucks, tanks, towed weapons, trailers, and any other types of vehicular system that must move on wheels or tracks. The environmental requirements include a variety of tropical soils capable of yielding mud, slopes up to 60%, varied vegetation in stem size and density, and surface water features that are representative of conditions found in tropical settings worldwide. Continued long-term access to the same mobility courses is a requirement, so that comparative analysis over the same set of slopes, soils, terrain, and environmental conditions can be utilized as new test requirements emerge.

II.3. Other Considerations.

II.3.A. Operational Testing

Operational Testing is the final end testing of an item or system before it enters into the Army inventory. Typically, the system is provided to the soldiers that are conducting normal field exercises, force on force activities or field support activities depending on the item and its projected use. Realistic scenarios are required including the battlefield environment and associated maneuver facilities. Movement is relatively unconstrained at this point and the geographic constraints associated with Developmental Testing sites are no longer applied. It is not uncommon that elements of Developmental Testing will be embedded within or combined into Operational Testing, a trend likely to continue in the future.

II.3.B. New Technologies

In addition to the ongoing testing requirements described above, a vision for future requirements includes the need to test new technologies being developed for the future force and the future combat system. This testing would include: sensors (airborne/space-born and man-portable systems); information, data networking, and communication technologies based on electromagnetic transfer; cloaking, and reduced signature technologies; and product improvements of existing systems (as a cost-saving measure to replacement systems). For example, use of hyperspectral image data has been successfully employed worldwide in recent counter drug operations. With all objects reflecting, absorbing, or emitting electromagnetic radiation based on their composition, hyperspectral sensors using reflected solar radiation (0.4 micrometers - 2.5 micrometers wavelength range), capture unique spectra, or the 'spectral signature' of an object. Using a procedure called BandMax™, spectral characteristics of targets are compared to background signatures. This enables significant spectral features indicative of spectral target material to be exploited, whereby atmospheric effects are avoided and ultimately “false alarms” from similar objects are reduced. This approach provides a ‘yes/no’ answer with a statistically high degree of confidence indicating whether an object is present or absent. Plastics and some other unique materials required in running drug labs do not naturally occur in the tropics and are, therefore, frequently selected as target material (see Figure 2). Demonstrating this differentiation technique, the spectral radiance of a chemical pit is compared with that of drying coca plants in Figure 3. In addition to these sensor techniques, new information and communication systems, such as Land Warrior, spearheaded by PM Soldier, will provide the individual soldiers with advanced technologies and weapons for the battlefield of the 21st century. There will be an increased focus on dual-use or multi-use technologies that have high payback, such as environmental technologies for unexploded ordnance (UXO) detection/location and similar applications. All of these technologies are highly sophisticated and complex. As such, test and evaluation of such new technology and related methods will require a thorough understanding of the environmental factors affecting their technical performance, as well as the synergistic environmental effects that challenge equipment operability and reliability.

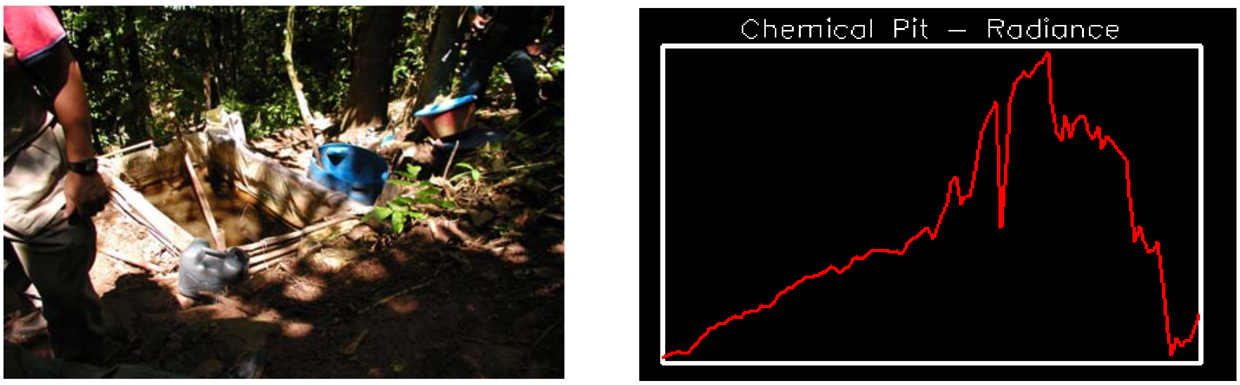

Figure 2. Chemical Pits return a unique spectra to a Hyperspectral Sensor

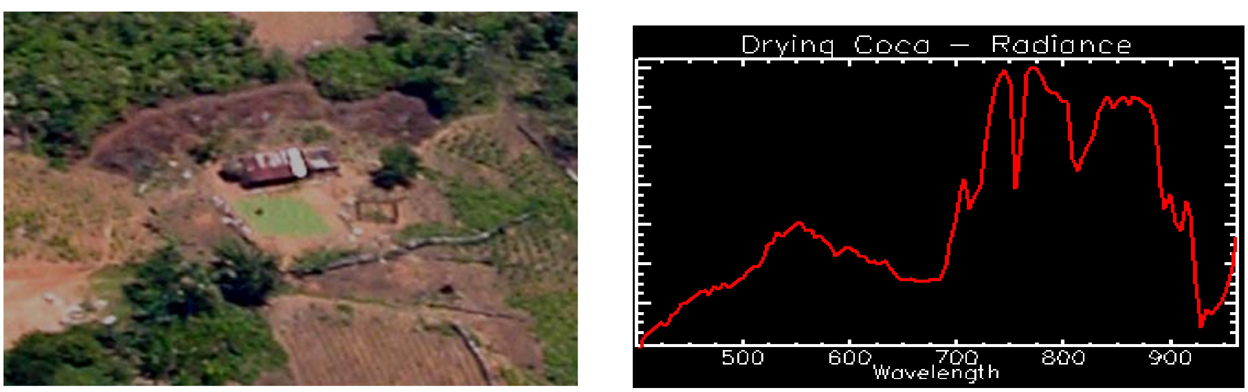

Figure 3. Drying Coca Leaf Spectra Gathered from Airborne Data and Applied to Airborne Data Comparison Profiles

CHAPTER III

GENERAL OVERVIEW OF THE STUDY AREA IN SURINAME

III.1. Geography

The Republic of Suriname, also called Surinam, is located along the northern coast of South America, and shares borders with French Guiana in the east, Guyana in the west, and Brazil in the south (Figure 4). Officially claimed by the Spanish in 1593, the land was settled by the Dutch beginning in 1616 and became a Dutch colony known as Dutch Guiana in 1667 (USDS, 2005). The country gained its independence from The Netherlands in 1975.

Suriname covers an area of 163,265 km^2, an areal extent about the size of the state of Georgia, with a population of 436,935 (Goodwin, 2004). The capital city of Paramaribo, with a population of 216,000, is a classic example of a primate city in a country that maintains a 50/50 ratio between urban and rural residents. The most significant aspect of the population is the tremendous diversity, which includes Hindustani, Creole, Javanese, Bush Negro, Amerindian,

Figure 4: Suriname country map
Source: Adapted from Tomaselli-Moschovitis, 1995.

and Chinese (Tomaselli-Moschovitis, 1995; Goodwin, 2004). The associated languages, religions, and other culture traits combine to make Suriname's population one of the most diverse in the world.

The country can be divided into three broad geographical divisions: a coastal plain, a central plateau and savanna region, and a densely forested mountainous region. The coastal plain (which can actually be subdivided into a narrow coastal zone of mangroves, sandbanks, and mudbanks, and a more southerly east-west band of peat, clay, and sand ridges) is located in the north and is up to 80 kilometers wide in some places (Microsoft Encarta, World Atlas, 2001), with mangrove swamp and brackish waters extending up to 50 kilometers inland (ecocam.com, Suriname, 2005). The central plateau and savanna is a region of rolling hills and sandy soils, stretching across the mid section of the country and including tracts of dunes, broad savannas, and scattered forests. The forested mountainous region contains tropical rainforest with elevations extending up to 1,230 meters in the Wilhelmina Mountains and covers nearly 80% of the country (Encyclopedia Britannica, 2005). Based on the country's topographical relief, with highland areas concentrated in the mid and southern sections of the country, rivers tend to flow north into the Atlantic Ocean, creating a pronounced drainage pattern (Figure 5).

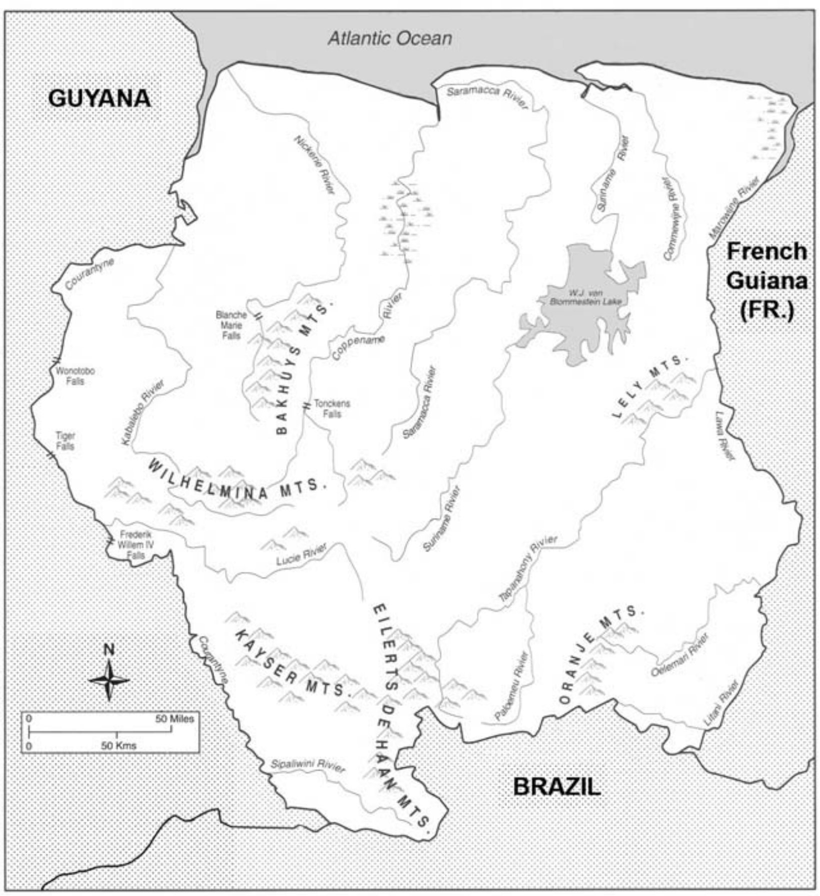

Figure 5: Suriname's relief and drainage pattern.
Source: Adapted from Tomaselli-Moschovitis, 1995.

III.2. Climate.

The climate of Suriname is humid tropical, reflecting its coastal equatorial location (2-6 ^{o}N) and the influence of on-shore, moisture-laden, trade winds that prevail throughout the year. The climate of the low-lying coastal plain of Suriname, which extends from 30-70 km inland, is uniform. To the south, the coastal plain transitions across a 10-15 km zone to the dissected uplands in the interior of the country. Both the North and South Atlantic Equatorial Currents converge along the coast of Suriname and exhibit only slight seasonal variation in sea surface temperature from 26.5-28.0 ^{o}C (Sadler et .al., 1987). Latitudinal shifts in the inter-tropical convergence (ITC), associated with seasonal strengthening and weakening of the Northern and Southern Hemisphere Hadley Cells, modify the delivery of onshore trade winds over Suriname. From December through May, the ITC remains centered slightly south of Suriname and Northern Hemisphere trade winds (from the north-east) dominate over the country. Thermal strengthening of the northern hemisphere Hadley Cell during the June-October period forces the ITC to a position around 10^{o}N, well north of Suriname, and easterly trades winds from the Southern Hemisphere dominate during this time. Relatively moderate changes in diurnal wind strength and atmospheric stability associated with seasonal ITC migration over Suriname impact monthly rainfall patterns.

Rainfall in coastal Suriname is derived largely from periodic small, low-pressure disturbances embedded in the trade wind flow (easterly waves), and local, thermally driven convectional development over the land. Figure 6 illustrates seasonal and annual rainfall patterns for three stations located across the entire 350-km length of the coastal plain, from Nickerie (west) to Moengo (east). Both annual and seasonal rainfall distributions are relatively uniform throughout coastal areas of Suriname. Mean annual rainfall ranges from about 1900 mm in the west to 2370 mm in the Moengo area of eastern Suriname. The seasonal migration of the ITC produces a distinctive ‘dry season’ during the September-October period when monthly rainfall may drop below 100 mm. This dry period results in part from increased atmospheric stability resulting from the stronger nocturnal trade winds from the Southern Hemisphere at this time of year. Figure 6 also shows a secondary ITC transitional period of slightly reduced rainfall during February-March, followed by the 5-month long summer rainy season.

This report focuses specifically on the Moengo area in eastern Suriname, for which only limited rainfall data are available. Consequently, the extensive meteorological dataset from Zanderij (location of the Suriname International Airport located 100km to the west of Moengo) has been considered to facilitate a more comprehensive climatological characterization of the study area. Extrapolation of the Zanderij climate data to the Moengo area is justified in view of the generally uniform landscape character across the coastal plain and the conclusion of Poels (1987) that the Zanderij meteorological dataset is the most reliable in the country. This approach is confirmed in a comparison of the long-term monthly and annual rainfall records for Moengo **(**Figure 6) and Zanderij (Figure 7), where it is observed that both monthly and annual totals are nearly identical for the two sites. Long-term mean annual rainfall at Moengo (2372 mm/yr) meets the Ideal Tropic Test Site standards of 2000 mm/year (King et al., 1998), although year to year variability is comparatively high. For the most recent eleven-year record (1995-2005) at Moengo, annual rainfall ranged from 1335-2921 mm/yr (mean = 2124 mm/yr, standard deviation

= 582 mm). This annual variability indicates that for any given year there is a ~30 % chance that the 2000 mm annual total will not be achieved.

On large-scale global climate maps, coastal Suriname is typically depicted as exhibiting a Monsoon tropical climate (*Am* in the Koppen climate classification (Veregin, 2005) as apposed to *Af* for continuously wet tropical climates) because at least one dry season month receives less that the arbitrary 60 mm/month used to discriminate between seasonal and continuously wet tropical climates. However, this is an artifact of the classification since there is no seasonal reversal of winds in Suriname and many locations across the country have a dry month total in excess of 60 mm. Thus, the driest months in Moengo (see Figure 6) are September (90 mm/month) and October (82 mm/month), which would place this location in the ‘continuously wet’ tropical climate category. The dry season limitation for the ‘ideal tropic test site specifies no months with <100 mm/month. Although the ‘dry’ season at Moengo is comparatively short (~2 months), the site does not quite meet ‘ideal’ conditions’ under this criterion.

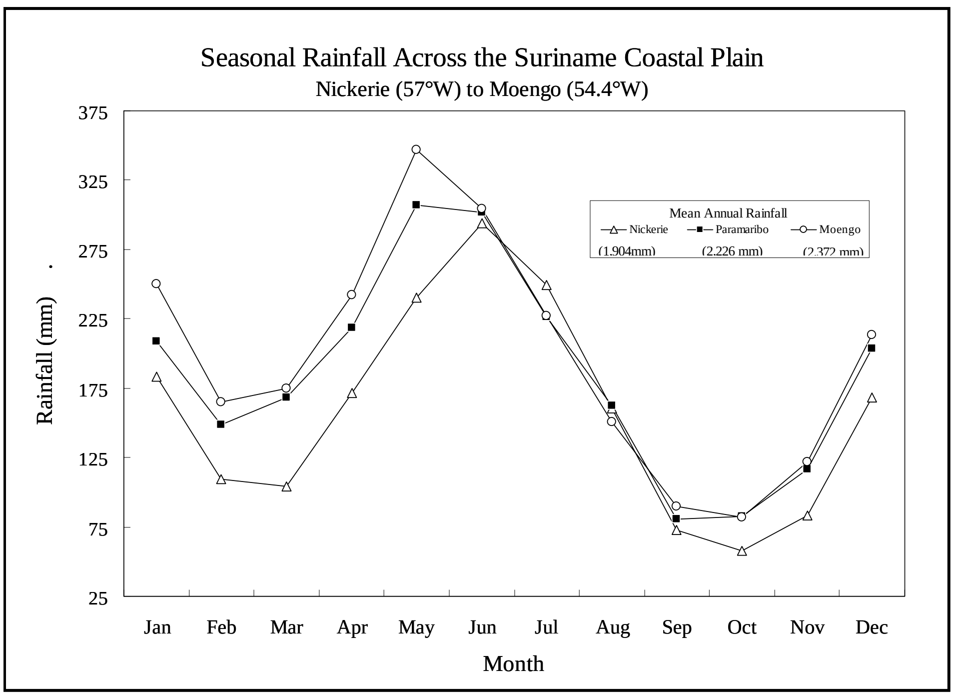

Figure 6. Seasonal rainfall across the Suriname coastal plain from Nickerie at 57°W to Moengo at 54.4°W (www.worldclimate.com)

Long-term atmospheric humidity data from the town of Zanderij, located some 40 km west of Moengo at the same latitude, is presented in Figure 8 and shows expected patterns, largely congruent with seasonal rainfall distribution (annual average relative humidity of nearly 81 %). This, supplemented with some field measurement of humidity within the study area during January 2006, confirm that Moengo fully meets the ideal tropic test site criteria for continuous high relative humidity (range 75-90 %).

Air temperature data from Zanderij presented in Figure 9 indicate average and minimum temperatures that meet the ideal criteria for tropic testing (average temperature >27 ^{o}C, with mean minimum temperatures >18^{o}C). The mean annual temperature at Zanderij is ~27 ^{o}C and monthly mean daily minimum temperatures remain consistently above 21 ^{o}C throughout the year.

Measured pan evaporation data and estimated monthly potential evapotranspiration available for Zanderij, as well as for the town of Kabo 60 km southwest of Zanderij, indicate approximate annual evaporation rates of about 1500-1600 mm (Poels, 1987; Goense, 1987). Seasonal variation in evaporation ranges from 100 mm/month during the rainy season to 150 mm/month during the dry season. Combining available rainfall and evaporation data with an approximation of soil moisture storage capacity (200 mm), enables the construction of a seasonal water balance model for Zanderij, that can reasonably be extrapolated to the Moengo area (Figure 10). The projected small deficit period observed in November is likely to be trivial with respect to prevailing humid tropical conditions for the 612-km^2 study area.

Based on field visits, and both local and extrapolated historical meteorological data, the Moengo area of Suriname appears to possess near ideal long-term climate conditions favorable for tropic testing that are significantly better than climate conditions found at other areas evaluated in Hawai`i and Puerto Rico (King et al., 1999), Australia (King et al., 2001), and Panama (King et al., 2005).

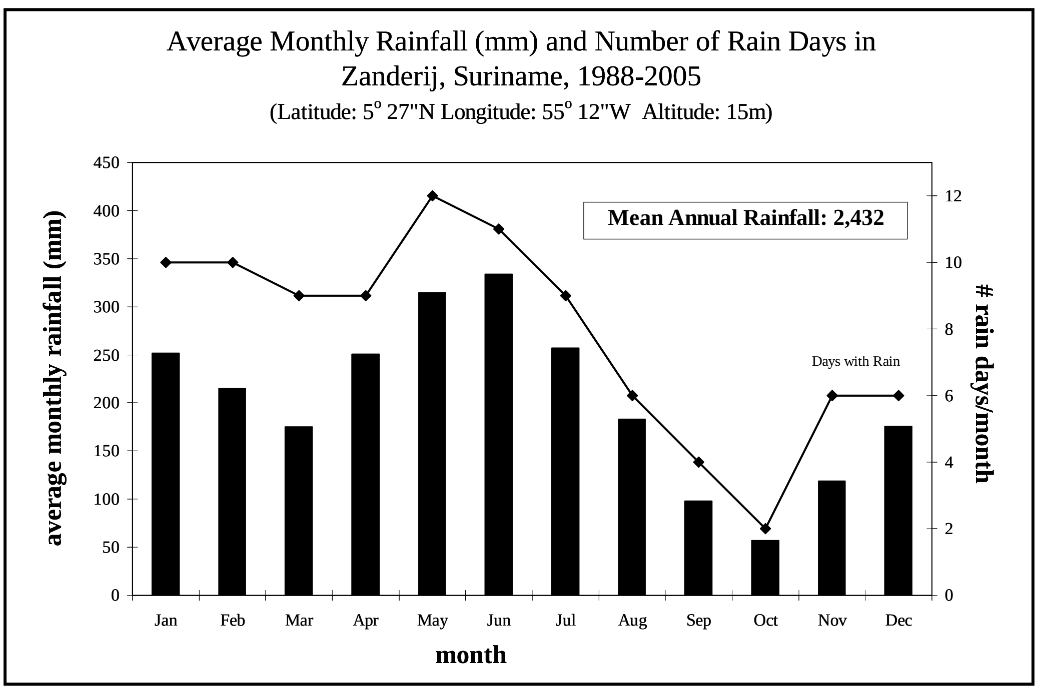

Figure 7. Average monthly rainfall (mm) and number of rain days in Zanderij, Suriname from 1988-2005 (U.S. NCDC, 1996).

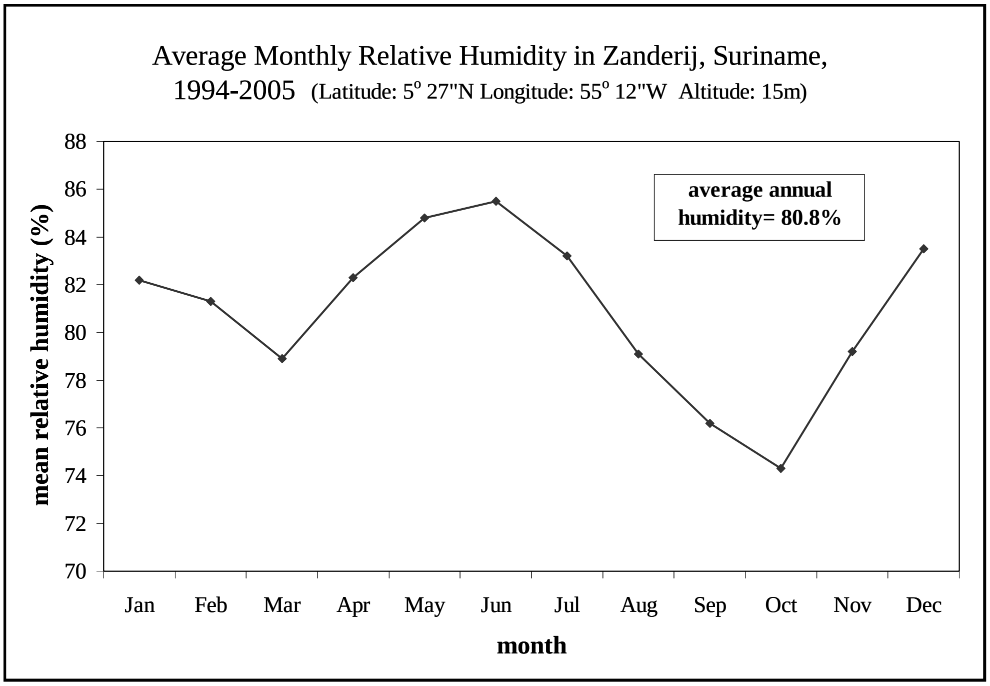

Figure 8. Average monthly relative humidity at Zanderij, Suriname from 1994-2005 (U.S. NCDC, 1996).

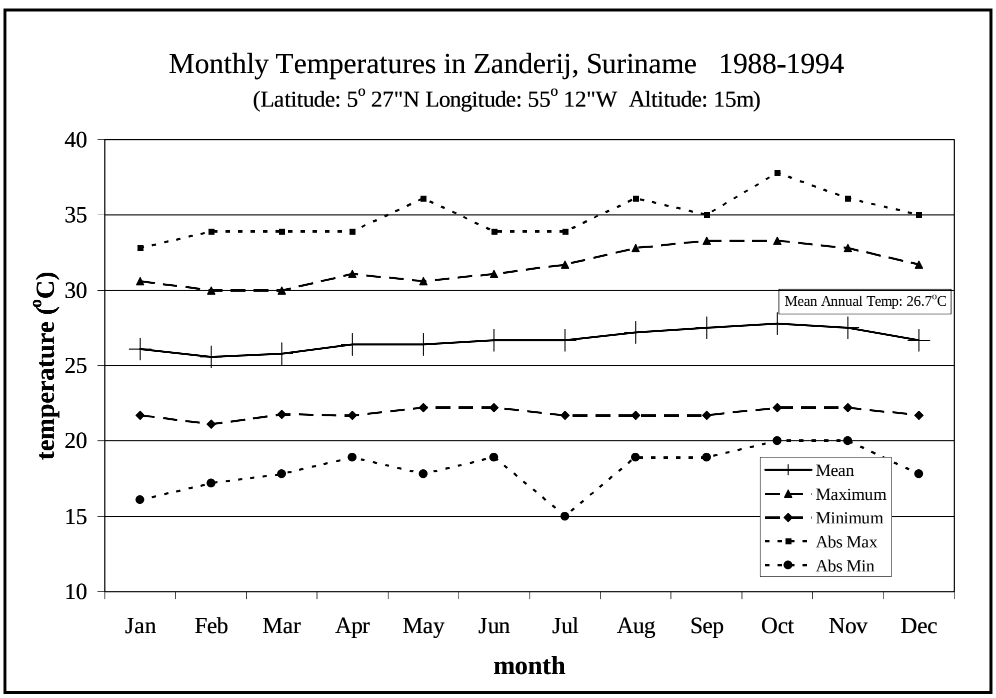

Figure 9. Monthly temperatures at Zanderij, Suriname from 1988-1994 (U.S. NCDC, 1996).

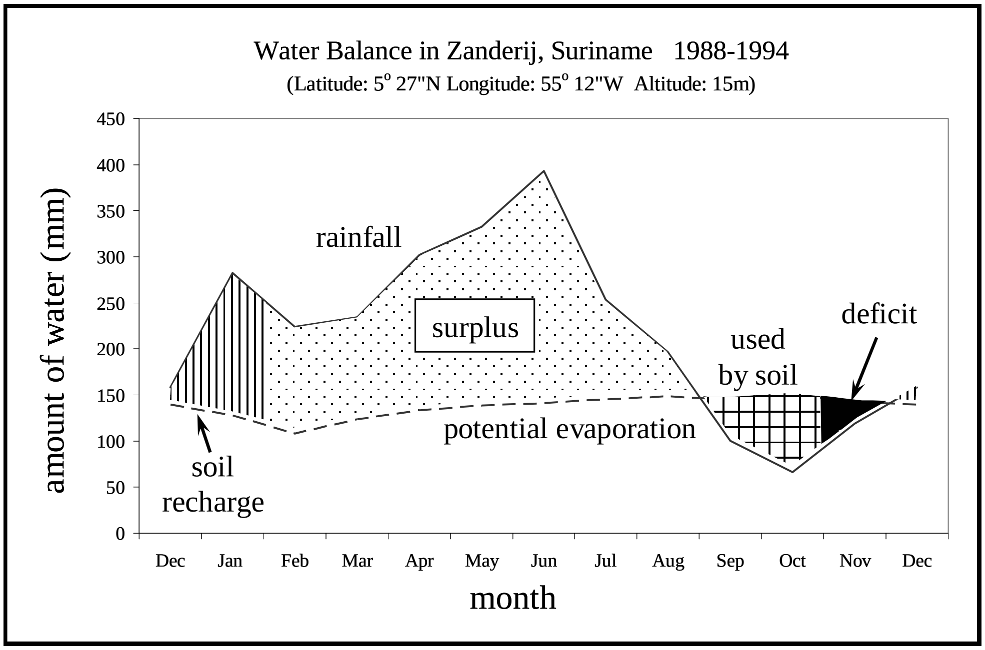

Figure 10. Water balance for Zanderij, Suriname from 1988-1994 (modified from Poels, 1987).

III.3. Geomorphology and Geology

The landscape of Suriname reflects the protracted geological history and diversity of geological process that have affected this region of northern South America to produce a patchwork of local landscapes of varying physical characteristics (topography, geology, hydrology, and forest cover).

As shown in Figure 11, the surface area of Suriname can be divided into three broad geomorphic domains – a broad *Coastal Plain* comprised of younger and older parts (elements I and II in Figure 11) comprising 12% of the country, a narrow *Transition Zone* (element III in Fig 11) which comprises 6% of the country, and a large interior C*entral Plateau Region* (element IV in Fig. 11), locally termed *Residual Hills,* at the southern extent in the study region, encompassing 82% of Suriname.

The coastal plain forms a broad zone of very low-relief, some 30-80 km wide, across the northern part of the country that can be subdivided into younger and older elements. The younger coastal plain, formed during the Holocene, comprises a narrow coastal zone of sandy beach ridges, mud banks and dissected clay flats, natural levees, and mangrove swamps (Brinkman and Pons, 1968). Inland to the south lies the older coastal plain, a marine terrace developed on Tertiary sedimentary rocks during Pleistocene high sea stands containing soil and peat developed during intervening times of low sea stand (Veen, 1970; Bosma et al., 1984) that presently consists of sand ridges, clay zones, and brackish- to fresh-water swamps that can extend up to 80 km inland. The coastal plain is underlain by a sequence of fluvial and estuarine laminated clays and intercalated fine sands overlying a sequence of gravels, coarse sands, and shales that

Figure 11. Relief map of Suriname showing the spatial distribution of the four dominant landscape elements: Coastal Plain I - the Young Coastal Plain, II - the Old Coastal Plain, III - the Transition Zone (termed 'Dek' or 'Zanderij'), and IV - Residual Hills (after Van Vosselen, 2003).

accumulated during Tertiary time as lagoonal deposits in a subsiding sedimentary basin (Brinkman and Pons, 1968).

Extending from the Orinoco River in Venezuela to the Amazon River in Brazil, the central plateau region is the predominant landform domain in Suriname. This is a landscape of rolling hills in the north to locally mountainous areas in the south underlain by rocks of the ancient Guiana shield (Gibbs and Barron, 1993). Five major rock stratigraphic (i.e., lithologic) units are recognized across this region: (i) granitic granulites of Archean age (>2 Ga); (ii) the Trans-Amazonian belt of high-grade metamorphic rocks, schists and gneisses metavolcanics and associated metasediments, and a granitiod-volcanic complex of Proterozoic age (~2.0-1.9 Ga), (iii) dolerite dikes of Permo-Triassic age (~230 Ma) emplaced as a result of crustal extension during breakup of the Gondwanaland supercontinent; (iv) a bauxite/laterite cap of Miocene-Oligocene age (50-30 Ma); and (v) younger local river deposits (Bosma et al., 1984) - where Ga = 10^9 years BP and Ma = 10^6 years BP.

The transition zone between the coastal plain and the interior central plateau is locally known in the study area as the 'Dek'or 'Zanderij' area (Bosma et al., 1984). This is a discontinuous, flat to gently undulating, well-drained topography consisting predominantly of coarse white and brown sands. These deposits, which are the ultimate product of a long series of erosion and deposition cycles that began with weathering of the Precambrian of the interior central plateau, lie directly on the crystalline basement rocks, except where a bauxite cover protected overlying Tertiary age sediments from erosion (Poels, 1987). The extensive bauxite layer overlying these sediments was formed during Eocene to Miocene time some 50-30 million years ago (Van der Hammen and Wijmstra, 1964). Also present are subordinate gravels and kaolinitic clay of Pliocene age that overlay highly-weathered crystalline basement rocks.

Figure 12 is a geological map of the greater Moengo study area between $5^o15'$-$5^o45'$ N and $54^o15'$–$54^o30'$ W. In order of decreasing area these are; (i) biotite-muscovite granite [unit 27], (ii) staurolite-garnet schist [unit 34], (iii) metamorphic greywackes, volcanics, and phyllite [unit 33], (iv) reddish-grey clay [unit 10], (v) coarse brown and white sands [units 11 & 12], (vi) grey clay and peat [unit 7], (vii) dolerite dikes [unit 15], and (viii) bauxite/laterite [unit 13]. The area being considered for Army tropic testing is dominated by compositionally similar staurolite-garnet schists and muscovite-biotite granites, with a band of coarse sand and bauxite/laterite present in the middle of the area and the doleriate dikes and metamorphic greywackes, volcanics, and phyllite restricted to the far southern part of the Moengo area.

III.4. Soils.

In the previous section, four different landscapes are recognized: the Young Coastal Plain, Old Coastal Plain, theTransition Zone (also named 'Zanderij'), and Residual Hills. Each of these landscapes has its own characteristic soils that reflect the local geomorphology and underlying geology. The Younger Coastal Plain along the Atlantic Ocean was formed during the Holocene and is mainly covered by clayey brackish and fresh-water swamps intermingled with sandy beach ridges, natural levees of silty clay, and peat swamps (Brinkman and Pons, 1968). The Old Coastal Plain was formed during the Pleistocene and consists of a northern part consisting predominantly of sand ridges and a southern part dominated by clay flats. The ridges have an elevation from 4-12 m above mean sea level, whereas the flats are found at only 2-7 m above sea level (Bosma et al., 1984).

The Moengo study area is situated near the irregular and diffuse boundary of the Transition Zone with the Residual Hills, but also contains some Coastal Plain soils in its northern part. Figure 13 presents the soil map for the region at an approximate scale of about 1:50,000 that was compiled from the Reconnaissance Soil Map of Northern Suriname (SMODSSD, 1977) at scale 1:100,000. Eight different soil units are recognized. In order of decreasing area these are: (i) gravelly clay over clay on hilltops and slopes [unit 32], (ii) sandy loam and clay on plateaus and slopes, locally with a gravelly topsoil [unit 21], (iii) silt loam and silty clay loam over stiff clay on plateaus [unit 16], (iv) bleached medium and coarse sandy soils on plateaus and slopes [units 19], (v) unbleached medium and coarse sand, sandy loam to sandy clay on plateaus and slopes [unit 20], (vi) unripe pyretic clay soils in swamps [unit 13], (vii) sandy loams and loams on levees and clay soils in basins [unit 17], and (viii) gravelly clay soils, locally with ironstones on the soil, on ridges and slopes [unit 37].

The soil units cover a wide range of textures and soil development stages: from heavy clays in basins [unit 17] and swamps [unit 13] to coarse sands on plateaus and slopes [units 19 and 20]; from unripe clays [unit 13] to completely leached sands [unit 19] and deeply weathered clays [units 21 and 32]. The two major soil units [32] and [21] have developed on ancient Precambrian bedrock of silicic composition and, respectively, have a strong correlation to their parental geological units, the schists [34] and granites [21] of Figure 12 that constitutes the majority of the residual hills landscape. These soils are deeply weathered and consist mainly of clay with some sandy loam or sandy clay loams in soil unit [21]. Using the Keys to Soil Taxonomy (Soil Survey Staff, 2003) as a guide, soil unit [32] mainly consists of oxisols and soil unit [21] of ultisols, both soil types which are characteristic of the humid tropics. The soils in these units can be excessively to imperfectly-drained. Soil unit [16] has a strong correlation with geological rock unit [10] that consists of silt loam and silty clay loams over stiff clays deposited during Pliocene time some 3 million years ago. The small soil unit [37] also has mainly a clay texture. The soil surface had been removed across much of the area affected by mining. At some locations in the mined areas deep erosion gullies have formed. The mined areas are also characterized by many water-filled shallow depressions.

The Transition Zone, which is present at elevations between 6-70 m above sea level, consists of level to undulating sandy and loamy deposits of coarse brown and white sands with small amounts of gravels and kaolinitic clays (Bosma et al., 1984) and is underlain by deeply weathered basement rock (Poels, 1987). The deposits are up to 25 m thick in the north of the Transition Zone and become shallower towards the south. About 40 % of the area consists of bleached soils (white sands) after which the ‘Zanderij’ landscape (i.e. Transition Zone) is named. In the early 1950s, about 7 % of the white sands area was covered with a savannah vegetation of grasses and shrubs, with the remainder under high savannah shrubs or savannah forest (Poels, 1987). The brown sands and loams in this landscape are covered with a mature high (>40 m) tropical forest (Van der Eyk, 1957). The two soil units of the Zanderij landscape are completely different from the soils described above since they have a much coarser texture and consist either of bleached white quartz sand [unit 19] or unbleached brown sand, sandy loam or sandy clays [unit 20]. The iron content of these soils is very low. Their drainage condition varies from well to poorly drained. Forest floor leaf litter decomposes slowly in the well-drained bleached soils and, as a consequence, thick organic layers occur under savannah wood vegetation. No thick litter layers are found in the poorly-drained bleached soils probably because of restricted plant growth (Poels, 1987; Van der Eyk, 1957). The remaining soil units occur through the entire area at the low spots in the landscape as a consequence of sedimentation. They are young soils without much soil development. Along the streams sandy loams and loams are found in levees, clays in basins [unit 13]; in swamp areas unripe clay soils are characteristic [unit 17].

III.5. Surface Hydrology

Pan evaporation measurements and monthly estimates of the potential evapotranspiration at the Zanderij weather station yield a total annual evapotranspiration of about 1,500 to 1,600 mm (Poels, 1987). Since the average annual precipitation is about 2,300 mm there is a large precipitation surplus to feed surface streams on an annual basis. This surplus is stored in the soils and shallow aquifers. For smaller watersheds, this surplus may not be sufficient to maintain flow

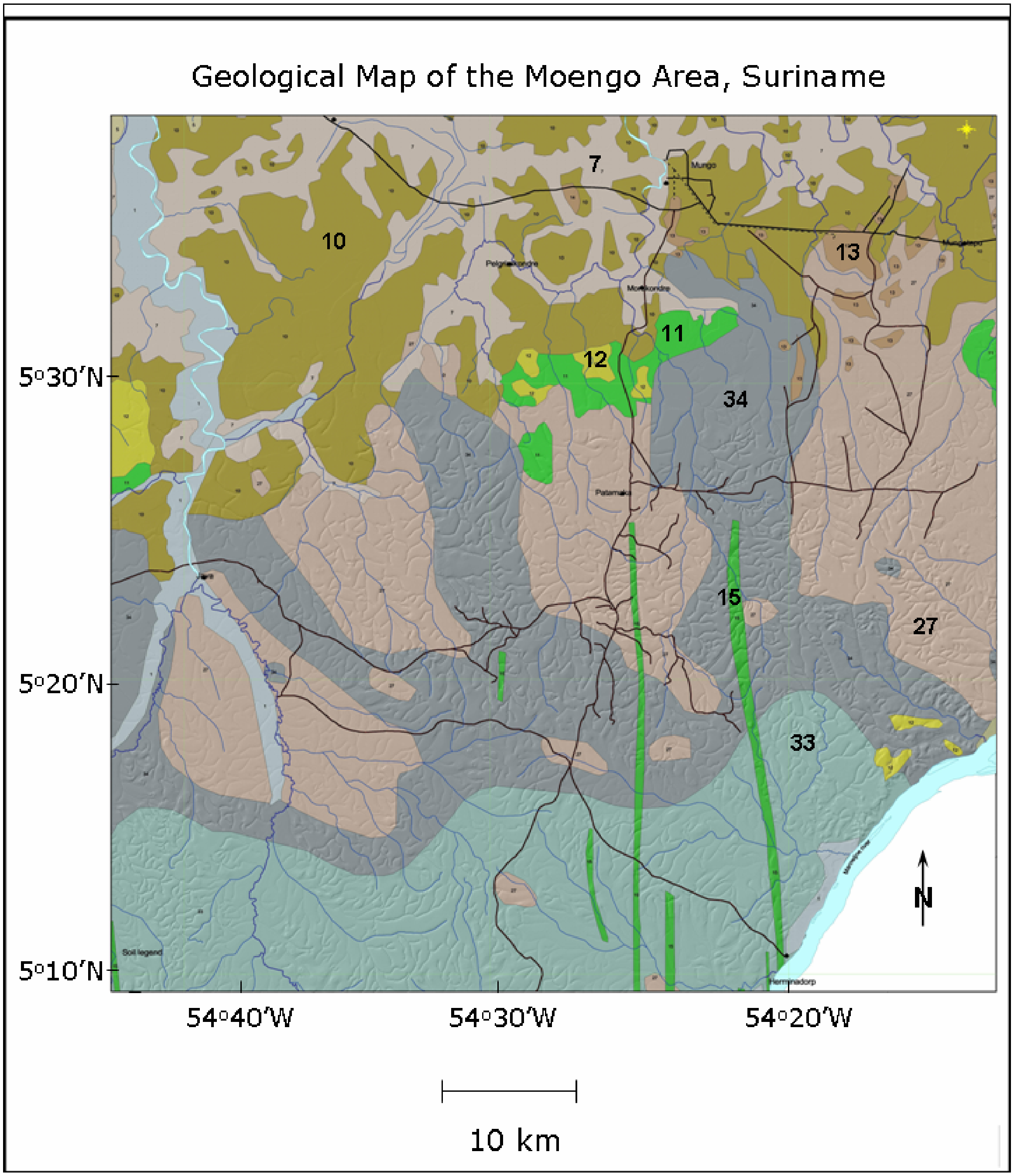

Figure 12. Geological map of the Moengo area of Suriname, with the numbered units referring to those soil types present in the study area.

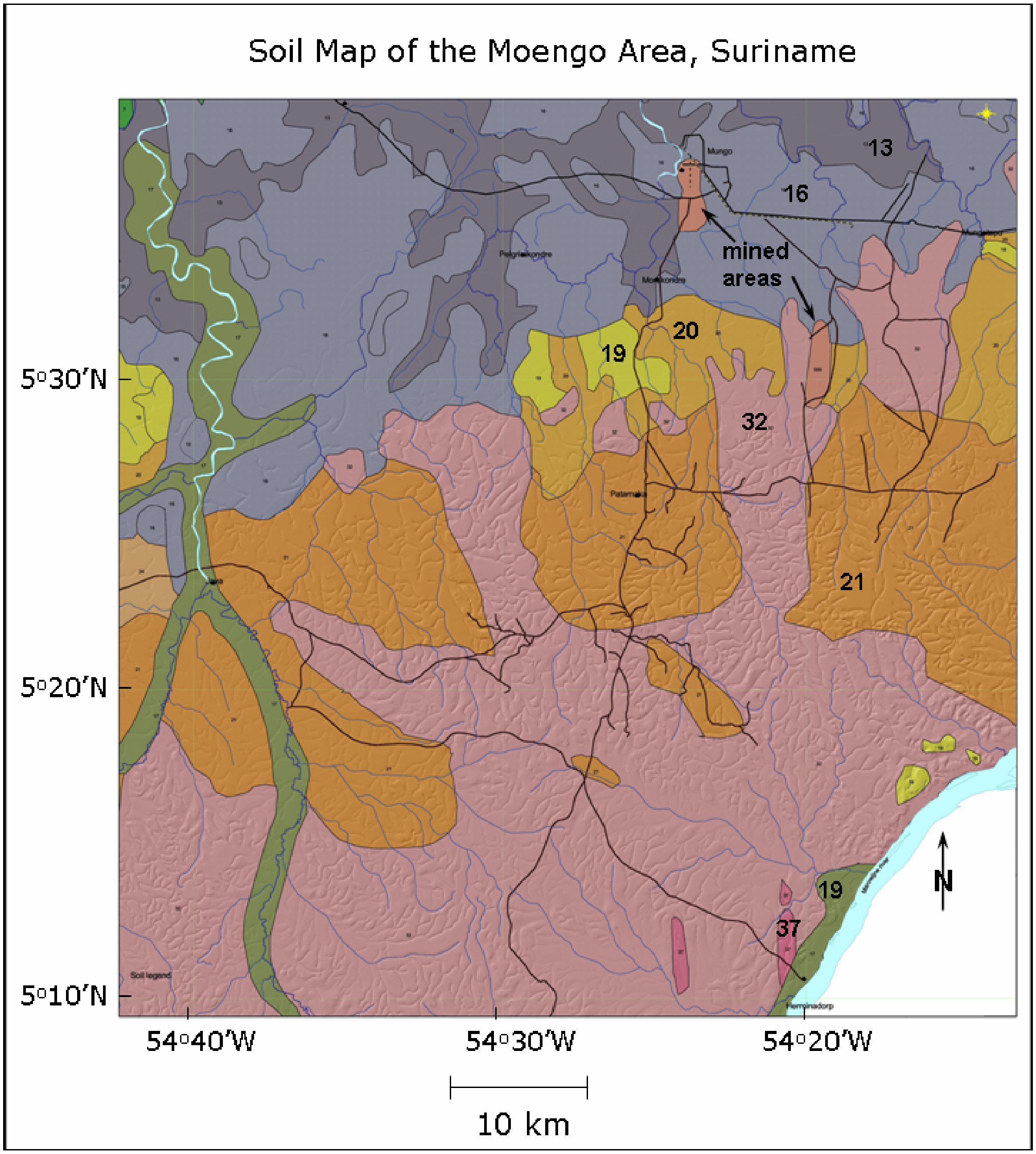

Figure 13. Soil map of the Moengo area of Suriname, with the numbered units referring to those soil types present in the study area.

in the creeks during the dry season. Streams observed during the study panel visit to the area had widths which ranged from 2-32 m with respective estimated depths of 0.2 to 4 m.

Stream flows are quite variable from one month to another as well as among years. The peak runoff occurs in the wet season months from May through September, whereas stream discharges are lowest during the October through December dry season. For example, a small creek draining a 295 ha watershed in Kabo (about 60 km west of the town of Zanderij) in the transition zone did dry out during two out of five years during the period from 1979/80 to 1983/84. Annual rainfall over this time varied from 1,794 to 2,466 mm and the rainfall equivalent discharge from 295 to 862 mm/yr. The lowest discharges occurred during the months September through December. The average discharge was 55 liter/second over the measurement period; the maximum monthly discharge of 220 liters/second (or 195 mm/month rainfall equivalent) occurred during May 1982. The monthly variability within a single year covers about two orders of magnitude; the maximum monthly discharge among years varies by a factor of about 20 for the five year measurement period presented in Table 6 (Poels, 1987).

In another study, the average annual discharge for a 12-year period from a 1800 km^2 watershed in the Transition Zone in western Suriname was estimated to be about 735 mm/year equivalent rainfall (Table 7**;** Sevenhuijsen, 1977). By comparison, groundwater discharge from the same area was estimated as less than 1 mm/year equivalent rainfall (Sevenhuijsen, 1977).

Table 6. Monthly discharges from a 290 ha watershed in the Kabo area of Suriname (Poels, 1987).

Month	Discharge (mm/month – rainfall equivalent)				
	79/80	80/81	81/82	82/83	83/84
November	0	6	12	0	0
December	0	6	24	1	0
January	0	6	24	6	0
February	0	27	27	2	0
March	0	49	46	7	0
April	0	57	165	63	0
May	19	97	195	97	18
June	106	124	147	68	62
July	84	92	117	34	95
August	61	63	67	13	NA
September	20	37	29	4	NA
October	5	37	19	0	NA
Annual total	295	601	862	295	

Table 7. Monthly discharge rates from a 1800 km^2 catchment in the Transition Zone in western Suriname (Sevenhuijsen, 1977).

Month	Discharge (mm/month – rainfall equivalent)	Month	Discharge (mm/month – rainfall equivalent)
January	47	July	103
February	50	August	99
March	44	September	64
April	51	October	36
May	84	November	20
June	118	December	19

Given the relatively coarse texture of the sands and sandy soils of the Transition Zone, it is expected that discharge from the Residual Hills and the Old Coastal Plain is somewhat higher, but still will reflect the variability in rainfall. No data have been found during the two-day mission to Suriname on infiltration rates or peak discharges in the rivers and streams. Likewise, no information on erosion rates has been found. However, deep erosion gullies have been observed in the mined areas. In some locations erosion protection measures should be taken in order to protect the road system for the future.

III.6. Vegetation.

Equatorial Suriname and the adjacent Guianas are bordered on the north by the Orinoco basin and to the south by the Amazon, an area harboring the highest biodiversity on the planet. Tropical plant diversity in this Guianas eco-region (including Suriname) is estimated at more than 8,000 species with perhaps as many as 50% of these forms restricted (endemic) to this area (Boggan et. al., 1997).

Even within this region there are significant local variations in floristic composition. In Suriname, forest species composition changes significantly from east to west. Forest structure and stature also varies with local topographic, soil and moisture characteristics. Linemand and Moolenaar (1955) described six broad classes of forest vegetation in Surname covering 92 % of the land area of the country: I - Coastal mangrove forest on the Young Coastal Plain (115,000 ha or 0.08 %), II -Freshwater swamp forest on the coastal Plain (725,000 ha or 4.9 %), III - Seasonally inundated marsh forest on the Old Coastal Plain (505,000 ha or 3.4 %), IV -Tropical rainforest on well-drained soils in the coastal plain and interior uplands of the Residual Hills province (13,362,000 ha or 90.8 %), V - 'Savannah' forest, primarily on bleached sand soils in the Transition Zone (150,000 ha or 0.01 %). The local term 'Savannah Forest", as used in Suriname, may include relatively closed-canopy forest of diminished stature developed on poor soils. This is at variance with the more widely accepted definition of 'savannah' as a more open landscape of scattered trees with an intervening cover of grasses and shrubs.

In the Moengo study area, historically tropical rainforest covered much of the region before mining related clearing activities began in the 1970s. There are still substantial areas of this forest type present surviving under varying degrees of disturbance (mostly selective logging), largely dependent on proximity roads and forest access trails that facilitate timber extraction. The Suriname tropical rainforest is biologically diverse with typically 100-150 plant species per hectare Sclulcz (1960). If only tree species with DBH (diameter at 4 feet)>25 cm are considered, there are typically 20-30 tree species/ha. A summary of Suriname rainforest composition by plant family representation from Lindeman and Moolenaar (1955) is presented in Table 8.

Typical canopy structure for well-drained Suriname rainforest on the coastal plain is illustrated in the cross-section profile (Figure 14) of Jonkers (1987). This forest type exhibits a complex multi-canopy structure with emergent trees reaching to more than 50 m, and trunk diameters (DBH) up to 3 m (including extensive basal buttresses). Tree biomass in this forest type is estimated at 40 m^3/ha (Jonkers, 1987) which falls well within the range of 20-70 m^3/ha established for ideal tropic testing criterion for tropical rainforest. Forest cover with this structure and biomass is well represented in the Moengo project area. There is some local variation at the site as a function of slope factors and levels of past human disturbance (e.g., selective logging near roads). The most intact stands of tropical rainforest in the Moengo area exhibit significantly better structure/stature characteristics (height, multi-canopy) than other tropical forest sites evaluated to date for tropic testing (Panama, Hawai'i, Puerto Rico, Australia).

The 'Savannah' forest of the transition zone is also present within the general vegetation mosaic of the Moengo area. These forests are developed on bleached white sand (quartz) substrates scattered throughout the area, but which lie generally in a transition zone between the coastal lowlands and the interior hill country. These sandy soils exhibit comparatively low water storage capacities and low nutrient levels. This edaphic limitation leads to reduced forest diversity and stature (i.e., canopy height typically in the range of 20-30 m, and of smaller trunk diameters than in the nearby rainforest.

There are also several areas of freshwater swamp forest in the Moengo area. These tend to occupy topographically low sites where the water table intersects the land surface. An extensive area of freshwater swamp forest some 25-30 km^2 in extent is present in the northern part of the study area south of the town of Muengo. No crocodiles are present in the areas, but Caymans with lengths less than 2 m seem to be common. Piranhas also are present but not the aggressive species. The natives use the streams for swimming.

Table 8. Dominant plant families represented in Surniname rainforest expressed as percent of rainforest species by Family.

Plant Family	%	Plant Family	%
Sapotaceae	17	Rosaceae	4
Papilionaceae	14	Moraceae	3
Lecythidaceae	11	Myristicaceae	3
Burseraceae	8	Lauraceae	2
Mimosaceae	7	Others	24
Vochysiaceae	6		

CHAPTER IV

MOENGO AREA CHARACTERIZATION

IV.1. Area Overview

The greater Moengo area of northeastern Suriname between 5^{o}15'-5^{o}45' N and 54^{o}15'–54^{o}30' W encompasses ~612 km^2 . Figure 14 is a recent remote sensing image of the area with the main residential area of Moengo shown in the upper left area of the figure. Climate characteristics here are uniform with no discernable differences in temperature, humidity or the timing, distribution and amount of rainfall. A variety of local environments are present because the Moengo area includes three of the four landscape elements found in Suriname and is heterogeneous in terms of its geology and soil cover. The area possesses a variety of terrain, from flat lowland areas of both saturated and unsaturated soils that contain streams of variable size and flows, to steeply-sloped hills. Additionally, the region has been variably subjected to a variety of anthopogenic activities related to changing practices and patterns of agriculture since European colonization and bauxite mining since the early 20th century. Cleared areas for mining are shown as the light areas of the image in Figure 14. As a result of recent private corporation (BHP Billiton PLC) mining activity, there exists an extensive road network (linear features of Figures 14) that offers access to the variable environments of the greater Moengo area.

The Moengo area includes a complex mosaic of natural and modified vegetation elements ranging from denuded mined areas to largely intact multi-canopy, primary rainforest (Figure 15). Forest cover across the area is of different types ranging from residual elements of largely intact triple-canopy tropical rainforest in the southern part of the study area only marginally affected by selective logging of the largest trees (not observed), to widespread but dissected secondary forest of varying age, to very young, single-canopy secondary jungle that has grown since the conclusion of mining activity at different times over the past three decades. The remaining rainforest areas have been subject to both legal and illegal selective logging, but this appears largely limited to areas immediately adjacent to access roads and trails. In spite of more than 30 years of mining and associated disturbance, comparatively large tracts of largely intact native tropical forest on well-drained soil (Appendix 2, Fig 1) are easily accessible in the project area. Limited areas of swamp forest (Appendix 2, Fig 2) and 'savannah' forest (Appendix 2, Fig 3) also are present within the Moengo area.

The soils have a wide range of different characteristics. A large part of the area is covered by oxisols and ultisols which are typical for the humid tropics. Oxisols are highly weathered soils that contain few nutrients and are often rich in iron and aluminum oxide minerals such as bauxite. They have very low nutrient reserves. Therefore, in oxisol ecosystems most nutrients are contained in the standing vegetation and decomposing plant material. The oxisols are mainly found in soil unit 32 (See Figure 13) derived from schists. Ultisols are stongly leached, acid forest soils with relatively low native fertility. They are typically found on older, stable landscapes. These soils are deeply weathered and much of the natural Ca, Mg, and K has been leached. They have a subsurface horizon in which clays have accumulated, often with strong yellowish or reddish colors resulting from the presence of Fe oxides. The ultisols are mainly

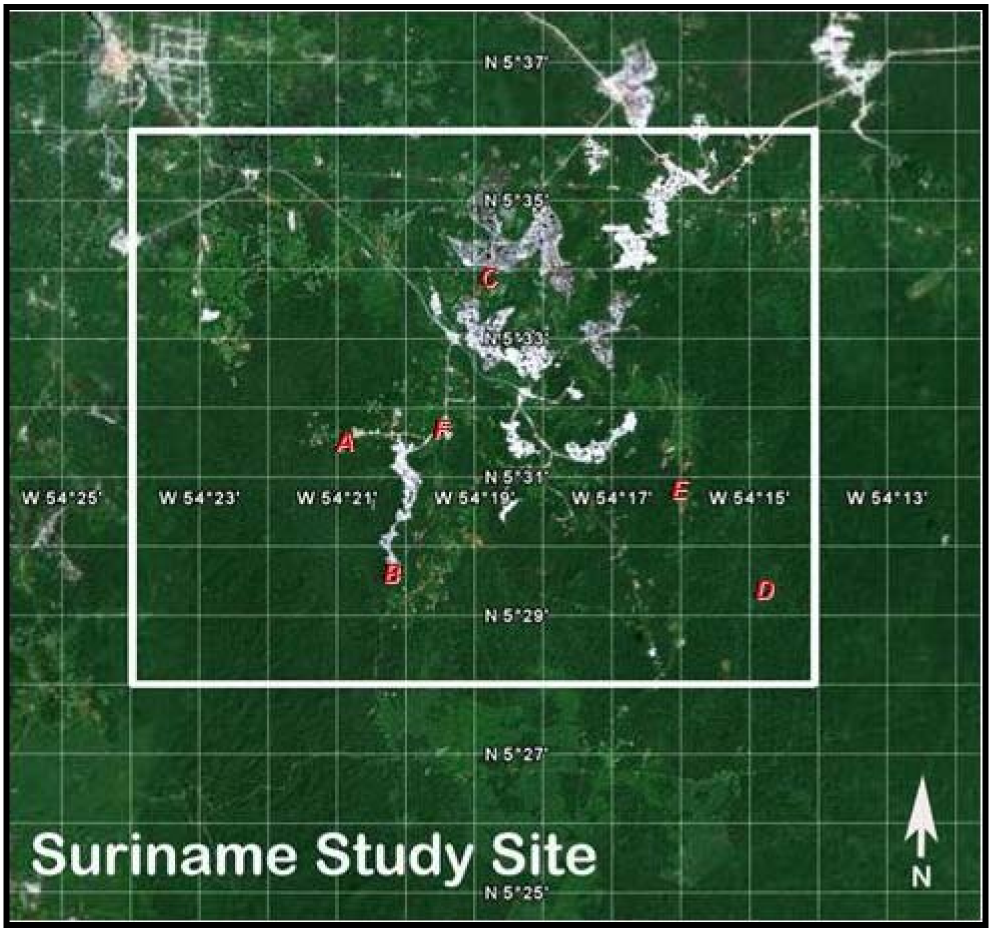

Figure 14 – Moengo Area of Suriname

found in soil unit 21 (Figure 13) derived from granite. Another class of soils is the coarser textured soils in the Transition Zone that consists either of bleached white quartz sands or unbleached sands and sandy loam to sandy clay. These soils have a very low iron content. The coarse white quartz sands have a low water retention capacity and as a consequence the vegetation suffers from moisture deficits. The final soil class consists of swamp soils and the levee and basin soils along the streams. Swamp soils often consist of unripe clays, while the basin soils are heavy clay soils in lower lying areas. Levee soils have a coarser structure than the adjoining basin clays and consist of sandy loams and loams.

The area is covered by a dense network of surface streams that drain the abundant precipitation. The discharge in these streams is quite variable from month to month and reflects precipitation patterns. The lowest discharges are recorded during the months October through December, while peak discharges occur during May through September.

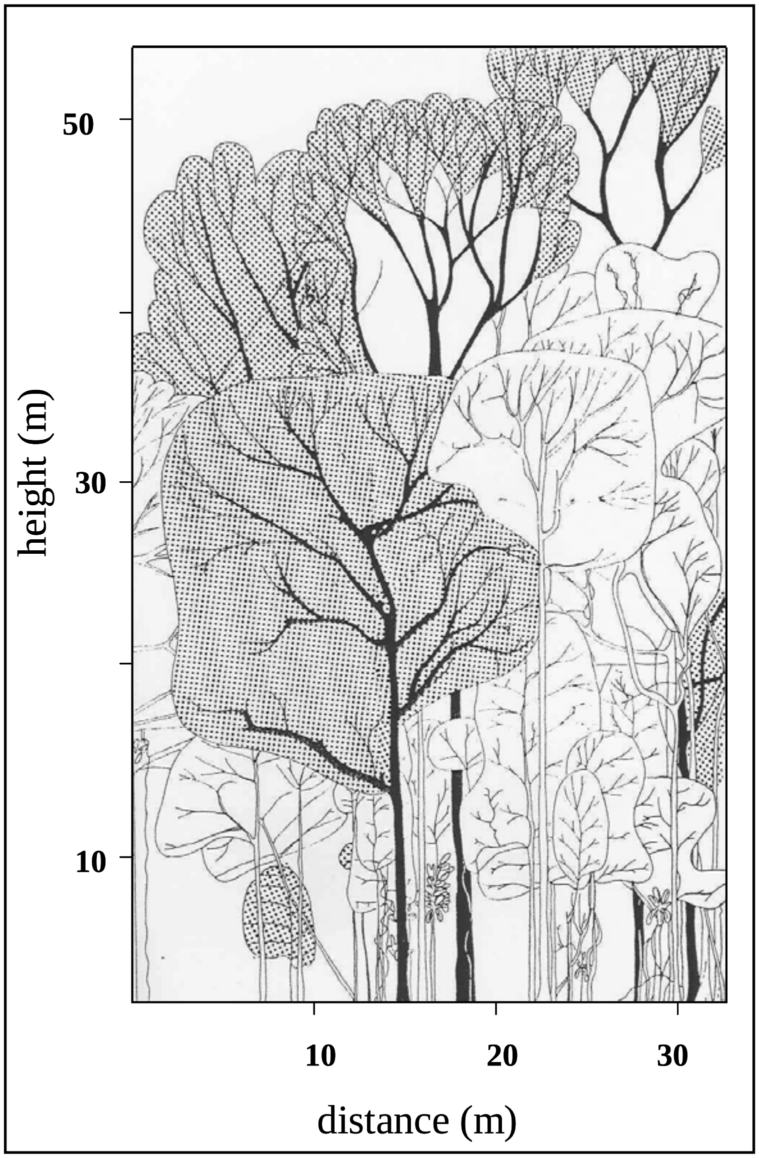

Figure 15. Typical canopy structure diagram showing trees larger than 10 m total height for well-drained Suriname rainforest (after Jonkers, 1987).

IV.2. Forest Characterizations

IV.2.A. Tropical Rainforest on Well-Drained Soils

Three forest characterization transects were examined in largely undisturbed sites within the tropical rainforest on well-drained sites in the transition zone and residual hills of the interior uplands within the Moengo study area. These locations are identified as points A, B, and C in Figure 15 are defined by the following coordinates: A = 5°31’37” N, 54°20’55” W; B = 5°29’36”N, 54°20’15”W; C = 5°33’47”N, 54°18”38”W. Local relief at the three sites varied from

10-50 m, with slope conditions ranging from essentially flat to short (100-200 m) but steep slopes of 20-30 ^{o} in local drainages.

General regional climate conditions for the entire Moengo project area are discussed in section III.2. At the three sites of tropical rainforest on well-drained soils, midday/afternoon temperature (air and soil) and humidity measurements were taken under the forest canopy for comparison with adjacant open areas. Under-canopy air temperatures range from 26.9-28.9 ^{o}C, with relative humidity between 87-92 %. Soil temperature (-10 cm) on the forest floor was consistent at 25 ^{o}C (Note: mean air temperature for the Suriname coastal plain in January is about 26 ^{o}C, compared to 28 ^{o}C in the warmer months of September-October). By comparison with these under-canopy micro-climate conditions, midday/afternoon conditions in adjacent cleared areas were substantially warmer (air temperature 32-34 ^{o}C) and drier (relative humidity 55-75 %).

Characteristics of the tropical rainforest on well-drained soils were surveyed at three specific sites (locations A-C in Figure 14) judged to be representative of largely undisturbed conditions. Tree size (diameter and height of all trees >0.5 m DBH) and understory conditions were evaluated for approximately 0.5 ha sample areas. Mean tree diameters (including trunk buttresses) averaged 0.94-1.2 m (DBH) at these sites for an absolute range of 0.5 –3.1 m (DBH), Height of canopy trees ranged from 35-47 m (mean = 40 m), with individual trees emerging from the canopy and reaching to 50m+ in height. A relatively well-developed understory of saplings, 2-20 cm in stem diameter (DBH) was present, with a variable sub-canopy that included a significant component of native palm species achieving heights of 5-15 m. The forest floor at all sites, was relatively free of herbaceous plants and covered by 2-4 cm of decomposing leaf-litter.

'Horizontal visibility' in the forest sub-canopy at a height of 1-2 m was assessed by measuring the distance (along random sight-lines) from an observer to the point where a standing man in camouflage clothing was no longer detectable in the undergrowth (under midday ambient light conditions, see Appendix 2, Figure 4). The average horizontal visibility for the three forest sites was 15.4 m, ranging from 11.6-19.8 m.)

Soils in this environment consist of oxisols and ultisols which are typical for high, dry tropical forests. Their clay content tends to be quite high: for example, for the soils shown in Figure 13, soil unit [32] consists mainly of clay whereas soil unit [21] is characterized by textures varying from sandy loam to sandy clay loam to clay. The magnetic susceptibility of the soils was measured with the MS2 magnetic susceptibility system (Bartington Instruments LTD, 1999) and observed to vary between 100 to 244×10^{-5} (in SI units) for this environment. These susceptibilities are similar to those measured before in similar geological environments in Panama and Hawaii (Van Dam et al., 2005).

The area is intersected by many streams with adjacent sedimentary soils consisting of sandy loams and loams as well as clays in the lower areas. The vegetation adjacent to the streams is characterized as a seasonally flooded forest due to the shallow water table that fluctuates from flooding to depths 1-4 m. At some locations swamps have formed with clay soils and possibly some peat that are covered by swamp forests. The magnetic susceptibility of the soils next to the streams varied between 0 and 74×10^{-5}.

The clay texture of the soil combined with its magnetic susceptibility will makes this site challenging for electromagnetic sensors. The attenuation of radar signals in clay soils, especially when wet during the rainy season, is high (Miller et al., 2004). The relatively high magnetic susceptibility probably will interfere with UXO detection and may challenge the remote sensing tests. During the rainy season, the wet clay soils on steep slopes make vehicle and personnel mobility difficult.

Considerable disturbance has occurred on the mined portions of the study area and the soils appear to be completely mixed at some locations due to restoration efforts. In these mined areas there are numerous shallow depressions that have accumulated rain water. Large patches of the mined areas have low vegetation density or bare soils.

Due to the clay texture, the infiltration rates of the across most of the study area are rather low. Therefore, a dense drainage network has developed consisting of a large number of streams. During the January field visit, observations were made of streams with measured widths from 2 to 32 m and estimated depths ranging from 0.2 to 4 m. Some of the smaller streams did not have flowing water even though the visit took place in the ‘short’ rainy season (Figure 7).

IV.2.B. Vient Hill

Vient Hill is a site of tropical rainforest on well-drained soil at 5^{o}29’19” N and 54^{o}14’49” W that has a summit elevation 350 m (Point D on Figure 14**)**. It is the only significant topographic feature in the northern half of the study area. Slopes of 10-35 ^{o} are present across the flank of the hill.

Heavy rains occurred during the study panel site visit on 11 January 2006 precluding collection of representative micro-climate measurements, but under-canopy temperature and humidity conditions at Vient Hill are expected to be comparable to values recorded at nearby tropical forest sites as the 350-m elevation range is not sufficient to significantly depress temperatures.

A survey of forest cover on the well drained comparatively steep slopes of Mt. Vient revealed forest characteristics of somewhat reduced stature and diversity, compared to the nearby, forest sites described in the previous section. The largest tree diameters measured averaged 0.73 m (DBH), ranging from 0.5-1.1 m, and tree heights were in the range of 20-35 m, with a mean of 29 m. Both of these values are significantly below those determined for the other tropical forest sites described in Section IV.2.1. The sub-canopy included smaller saplings 4-20 cm in diameter (DBH), with heights in the 6-15 m range. The forest floor was relatively free of herbaceous plants and covered by 1-3 cm of decomposing leaf litter. The soils on Vient Hill are similar to those in the across the remainder of the region except in the coarse sand areas of the transition zone. Their magnetic susceptibility was on the order of $20x10^{-5}$. This rather low number could have been caused by a higher organic matter content. The slope here is characterized by small, ephemeral drainage streams that were dry during the January visit.

IV.2.C. 'Savannah' Forest

Two 'Savannah' forest sites were evaluated within the transition zone of the Moengo study area. Identified as points E and F on Figure 14, these sites are defined by the following coordinates: E = 5°29'32" N, and 54°15'52" W; F = 5°31'38" N and 54°19'25" W. These 'Savannah' sites occur on relatively flat deposits of coarse white sand that have a local relief of >3 m with no significant slopes. Interior forest micro-climate conditions were similar to those in the nearby areas of tropical forest on well-drained soil discussed above (i.e., air temperatures were in the 27-29 °C range and relative humidity was near 90 %).

The 'Savannah' forests of the Moengo area (classified as 'tall savannah forest' by Lindeman and Moolenaar, 1987) form a specialized forest type that develops locally on the very well-drained and nutrient-poor quartz sand deposits within the transition zone of northern Suriname. Due to nutrient and moisture storage limitations, these forests are of diminished species diversity and stature. At the two sites surveyed, large tree diameters were typically in the range of 25-50 cm (DBH), and the maximum canopy height ranged from 18-25 m (with some emergent trees reaching upwards of 30 m). The forest floor was relatively free of herbaceous species and covered by 1-3 cm of decomposing leaf litter.

A poorly stratified sub-canopy of smaller saplings, 3-10 cm diameter (DBH)a and reaching heights of 5-8 m, forms the forest understory. Horizontal visibility here was observed to be slightly greater than in the other tropical forest sites. Whereas it might have been anticipated that a lower and more open upper canopy might have resulted in a denser understory (and therefore comparatively reduced horizontal visibility), the overall site limitation for plant growth in general (moisture and nutrients) seem to limit understory development as well.

The soils of the Savannah Forest in the transition zone are completely different from other soils of the Moengo area formed on granite and schist bedrock. Instead of clay, these soils consist either of bleached white quartz sands or unbleached sands and sandy loam to sandy clay. Due to extensive leaching these soils have a low iron content and no magnetic susceptibility could be measured. The nutrient content of these soils is low. The coarse white quartz sands have a low water retention capacity and as a consequence the vegetation suffers from moisture as well as nutrient deficits. The unbleached soils have a somewhat higher water retention capacity and, therefore, can sustain more vegetation. Due to the coarse texture, the infiltration rates of the soils are rather high. Therefore, the drainage network is much less dense than on the oxisols and ultisols observed across the remainder of the Moengo area. The flat areas visited did not have any surface streams.

CHAPTER V

ANALYSIS OF TESTING SUITABILITY IN NORTHEASTERN SURINAME

V.1. Analysis Overview

The analysis process requires the grading of the different environments identified within the Moengo area for their ability to support each of the 14 testing missions listed in Table 4 and described in Section II. The first step in this process is to assign utility rating values to each of the 14 environmental criteria that characterize the three candidate test environments. These ratings depict how well the local conditions within each environment match the ideal criteria presented in Table 1. These rating are produced through deliberations by the study panel based on a review of literature information together with an on-site assessment. The panel includes both scientists expert in different aspects of environmental sciences and test engineers expert in the conduct of natural environmental testing. Applying these combined experiences produce results that are not just scientifically justified, but also practical with regard to identifying the true needs for environmental testing. This approach does not reduce the value of the science, but enhances the study goals because it enables the analysis to directly assess the value of specific sites or areas for different test missions. Further, this scientific team included members with experience in the four previous studies, which supported comparative analyses between the 'Ideal Tropic Test Site Model'of King et al. (1998), current provisional U.S. Army test sites in Hawai'i and Panama, and other sites in Puerto Rico, Hawai'i, and northeast Queensland, Australia that were investigated in previous studies (King et al., 1999; King et al., 2001).

V.2 Site Ratings

The next step in the analysis is to develop an overall grade for each site for each test mission. For the Moengo area, three environments, rather than specific sites, were examined: Environment I – Mature Tropical Rain Forest on Well Drained Soils; Environment II – Vient Hill, an area of Mature Tropical Rain Forest on Well Drained Soils on a residual hill; and Environment III – the 'Savannah Forest of the Transition Zone .

Step 1 produced values of 0 to 3 for each of the 14 environmental criteria for each land unit evaluated. In Step 2, each test mission is evaluated for its suitability at each site according to the important environmental factors for that particular test. A summary explanation of the analysis process and the location of the results is presented in Table 9. Tables 10-15 present compilations of the evaluations for the three tropical environments of the Moengo area examined in this study.

The final step of the evaluation process is to establish grades for each site for each type of testing mission. Grades are assigned as **A** to **F** as described in Table 15, but as all students will be very familiar with.

Table 9. Analytical model for tropical test site evaluation

Process Goal	Study Activity	Location of Results
Define test mission	The testing community defines their mission requirements in quantifiable environmental criteria.	Section II
Define environmental requirements	Select the climate, physical, and biologic conditions necessary to achieve mission	Table 1
Select a hierarchy for analysis	Determine the importance of each environmental parameter to be used in analysis	Table 3
Select geographic region	Apply screening tools to a regional analysis.	Figure 2
Select environmental parameters	The mission is analyzed to identify environmental parameters that apply to the needs of the mission.	14 parameters in Tables T, V, & X
Select sites	Scientific and practical considerations are applied to select candidate sites from selected regions	3 Suriname environments discussed in Sections III and IV.1I
Rate sites for compliance with environmental criteria	Used to characterize the environment at each site visited	Analysis in Tables T, V, & X
Grade sites by testing mission	Critical criteria from Table 4 used to grade (Table 5) each site versus each component of the test mission, a rating of testing capability is made.	Tables U, W, &Y with grades compiled in Table Z

Consider, for example the test activity of '**operational and human performance testing'** of individual soldier systems at Vient Hill Site. This area is excellent (3) for the critical requirements of temperature, humidity, rainfall and relief (Table 12). Likewise, the site rates as excellent for the important parameters of slope and soils. Whereas, the site is only considered good (2) in terms of the character of its understory, and canopy, both of which are critical factors for this particular test. These values, as in the first step of the evaluation process, are assigned via team concurrence on the basis of individual technical judgments (Table 13). The final step in the analysis process is to assign an overall grade for each testing mission (Table 16). Judgments are again applied in the gray areas where the Table 13 values do not fit perfectly. In the Vient Hill example for '**operational and human performance testing',** the site receives an **A** because most of the critical environmental parameters are a 3 and the rest are 2. The ratings of compliance tables and procedures have been left unchanged from the previous studies to maintain comparability of results.

Table 10. Environmental evaluation of the Moengo area of northeast Suriname – Environment I: Mature Rain Forest on Well-Drained Soil.

MATURE RAIN FOREST ON WELL-DRAINED SOIL

Evaluation Criteria	Rating
Temperature	3
Rainfall	3
Humidity	3
Soils	3
Area size	3
Slopes	3
Relief	2
Surface streams	3
Understory	2
Forest Canopy	3
Forest floor fauna	3
Land use/Ownership	3
Adjacent land use	3
Cultural/Historical	3
TOTAL	40

Evaluation rating scale: 0=unacceptable; 1=marginal; 2=good; 3=ideal

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Positive Physical Attributes
- Diverse surface characteristics (relief, slope, and small streams)
- Diverse mosaic of tropical rainforest vegetation with double-triple canopy
- Well-developed understory where areas of very dense understory exists
- Large available land area

Limiting Factors
- Wildlife and vegetation hazards to human factors testing

Table 11. Rating of compliance with environmental criteria for all testing missions in Moengo area - Environment I: Mature Tropical Forest on Well-Drained Soil

TESTING MISSION	*ENVIRONMENTAL FACTORS*	*RATINGS*
Equipment Development Testing:		
1) Communication & Electronics	***Understory, canopy, temperature***, humidity, relief, fauna	**2, 3, 3,** 3, 3, 3
2) Ground & air sensors	***Canopy, understory***, temperature, humidity, rainfall, soils	**3, 2, 3**, 3, 3,3
3) Chemical & biological defense	***Fauna, understory,*** temperature, relief	**3, 2,** 3, 3
4) Environmental exposure *	***Humidity, rainfall, fauna, temperature,*** canopy	**3, 3, 3, 3,** 3
Operational and Human Performance Testing:		
1) Individual soldier systems **	***Temperature, humidity, canopy, understory, rainfall, relief,*** slope, soils	**3, 3, 3, 2, 3, 3,** 3, 3
2) Communication and electronics	***Canopy, understory, fauna, temperature, humidity***, ***relief,*** rainfall	**3, 2, 3, 3, 3, 3,** 3
3) Ground and air sensors	**Canopy**, ***understory***, temperature, humidity, relief, soils	**3, 2,** 3, 3, 3, 3
4) Chemical and biological defense	***Understory, fauna, temperature, humidity,*** relief, canopy	**2, 3, 3, 3,** 3, 3
Small Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna,*** rainfall, canopy	**0, 3, 3, 3,** 3, 3
2) Operational testing and firing	***Land use, adjacent land use***, temperature, humidity	**0, 3, 2,** 3
3) Smoke and obscurants	***Understory, temperature, humidity,*** relief, canopy	**2, 3, 3,** 3, 3
Large Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna, rainfall***, canopy	**0, 3, 3, 3, 3,** 3
2) Operational testing and firing	***Land use, adjacent land use,*** temperature, humidity	**0, 3, 3, 3**
3) Smoke & obscurants	***Understory***, ***temperature, humidity***, relief, canopy	**2, 3, 3**, 3, 3
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understory, humidity	**3, 3, 3, 3, 3,** 2, 3

Notes:
* Solar radiation effects are a primary agent in materials deterioration.
** Solar radiation is a significant factor affecting human performance in tropical environments.
-The environmental criteria are listed in general order of importance.
- Criteria presented in bold and italics are considered essential elements for that testing mission.

Table 12. Environmental evaluation of the Moengo area of northeast Suriname – Environment II - Vient Hill

VIENT HILL

Evaluation Criteria	Rating
Temperature	3
Rainfall	3
Humidity	3
Soils	3
Area size	2
Slopes	3
Relief	3
Surface streams	1
Understory	2
Forest Canopy	2
Forest floor fauna	3
Land use/Ownership	3
Adjacent land use	3
Cultural/Historical	3
TOTAL	37

Evaluation rating scale: 0=unacceptable; 1=marginal; 2=good; 3=ideal

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Positive Physical Attributes
- Only location within study area with relief (250+m)
- Distinctly different forest type within the study area

Limiting Factors
- Limited spatial extent of forest canopy
- Wildlife and vegetation hazards to human factors testing
- Diminished forest stature and canopy development

Table 13. Rating of compliance with environmental criteria for all testing missions in Moengo area - Environment II: Vient Hill

TESTING MISSION	*ENVIRONMENTAL FACTORS*	*RATINGS*
Equipment Development Testing:		
1) Communication & Electronics	***Understory, canopy, temperature***, humidity, relief, fauna	**2, 2, 3,** 3, 3, 3
2) Ground & air sensors	***Canopy, understory***, temperature, humidity, rainfall, soils	**2, 2,** 3, 3, 3, 3
3) Chemical & biological defense	***Fauna, understory,*** temperature, relief	**3, 2,** 3, 3
4) Environmental exposure *	***Humidity, rainfall, fauna, temperature,*** canopy	**3, 3, 3, 3,** 2
Operational and Human Performance Testing:		
1) Individual soldier systems **	***Temperature, humidity, canopy, understory, rainfall, relief,*** slope, soils	**3, 3, 2, 2, 3, 3,** 3, 3
2) Communication and electronics	***Canopy, understory, fauna, temperature, humidity***, ***relief,*** rainfall	**2, 2, 3, 3, 3, 3,** 3
3) Ground and air sensors	**Canopy, *understory***, temperature, humidity, relief, soils	**2, 2,** 3, 3, 3, 3
4) Chemical and biological defense	***Understory, fauna, temperature, humidity,*** relief, canopy	**2, 3, 3, 3,** 3, 2
Small Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna,*** rainfall**,** canopy	**0, 3, 3, 3,** 3, 2
2) Operational testing and firing	***Land use, adjacent land use***, temperature, humidity	**0, 3,** 3, 3
3) Smoke and obscurants	***Understory, temperature, humidity,*** relief, canopy	**2, 3, 3,** 3, 2
Large Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna, rainfall***, canopy	**0, 3, 3, 3, 3,** 2
2) Operational testing and firing	***Land use, adjacent land use,*** temperature, humidity,	**0, 3,** 3, 3
3) Smoke & obscurants	***Understory, temperature, humidity,*** relief, canopy	**3, 3, 3,** 3, 2
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understory, humidity	**3, 0[1], 3, 3, 1,** 2, 3

Notes:
* Solar radiation effects are a primary agent in materials deterioration.
** Solar radiation is a significant factor affecting human performance in tropical environments.
[1] No existing roads in this area would allow vehicle testing without unacceptable disturbance of the forest
- The environmental criteria are listed in general order of importance.
- Criteria presented in bold and italics are considered essential elements for that testing mission.

Table 14. Environmental evaluation of the Moengo area of northeast Suriname – Environment III – Transition Zone 'Savannah' Forest

TRANSITION ZONE 'SAVANNAH' FOREST

Evaluation Criteria	Rating
Temperature	3
Rainfall	3
Humidity	3
Soils	0
Area size	1
Slopes	0
Relief	0
Surface streams	0
Understory	2
Forest Canopy	2
Forest floor fauna	2
Land use/Ownership	3
Adjacent land use	3
Cultural/Historical	3
TOTAL	25

Evaluation rating scale: 0=unacceptable; 1=marginal; 2=good; 3=ideal

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Positive Physical Attributes

- Unique environment within the Moengo study area
- White quartz sand produces special characteristics features for remote sensing testing
-Well drained and nutrient deficient soils produces a regionally distinct stunted forest that is locally referred to as'Savannah'
- Soil with very low magnetic susceptibility

Limiting Factors

- Small size and patchy distribution
- Lack of developed forest canopy (scrub forest)
- Lack of perennial streams
- Wildlife and vegetation hazards to human factors testing and training

Table 15. Rating of compliance with environmental criteria for all testing missions in Moengo area - Environment III: 'Savannah' Forest

TESTING MISSION	*ENVIRONMENTAL FACTORS*	*RATINGS*
Equipment Development Testing:		
1) Communication & Electronics	***Understory, canopy, temperature***, humidity, relief, fauna	**2, 2, 3,** 3, 0, 2
2) Ground & air sensors	***Canopy, understory***, temperature, humidity, rainfall, soils	**2, 2,** 3, 3, 3, 3
3) Chemical & biological defense	***Fauna, understory,*** temperature, relief	**2, 2,** 3, 0
4) Environmental exposure *	***Humidity, rainfall, fauna, temperature,*** canopy	**3, 3, 2, 3,** 2
Operational and Human Performance Testing:		
1) Individual soldier systems **	***Temperature, humidity, canopy, understory, rainfall, relief,*** slope, soils	**3, 3, 2, 2, 3, 0,** 0, 0
2) Communication and electronics	***Canopy, understory, fauna, temperature, humidity, relief,*** rainfall	**2, 2, 2, 3, 3, 0,** 3
3) Ground and air sensors	**Canopy, *understory***, temperature, humidity, relief, soils	**2, 2,** 3, 3, 0, 0
4) Chemical and biological defense	***Understory, fauna, temperature, humidity,*** relief, canopy	**2, 2, 3, 3,** 0, 2
Small Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna,*** rainfall**,** canopy	**0, 3, 3, 2,** 3, 2
2) Operational testing and firing	***Land use, adjacent land use***, temperature, humidity	**0, 3,** 2, 2
3) Smoke and obscurants	***Understory, temperature, humidity,*** relief, canopy	**2, 3, 3,** 0, 2
Large Caliber Munitions:		
1) Exposure testing	***Land use, temperature, humidity, fauna, rainfall***, canopy	**0, 3, 3, 2, 3,** 2
2) Operational testing and firing	***Land use, adjacent land use,*** temperature, humidity,	**0, 3,** 3, 3
3) Smoke & obscurants	***Understory***, ***temperature, humidity***, relief, canopy	**2, 3, 3,** 0, 2
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understory, humidity	**0, 0, 0, 3, 0,** 2, 3

Notes:
* Solar radiation effects are a primary agent in materials deterioration.
** Solar radiation is a significant factor affecting human performance in tropical environments.
- The environmental criteria are listed in general order of importance.
- Criteria presented in bold and italics are considered essential elements for that testing mission.

Table 16. Evaluation of capability to conduct military testing in the Moengo area of northeastern Suriname

	Equipment Development				Human Factors Testing				MUNITIONS TESTING: small caliber			MUNITIONS TESTING: large caliber			Other Testing & Training
	CSE	GASS	CBD	EE	ISSHF	CSE	GASS	CBD	EE	SO	FT	EE	SO	FT	VM
HILL	B	B	B	**A**	**A**	**A**	B	**A**	F	F	A	F	A	F	F
DRY	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	F	**A**	**A**	F	F	F	**A**
SAV	B	B	B	**A**	D	D	C	B	F	C	F	F	C	F	F

Grade	Site Evaluation Description
A	Acceptable testing capability
B	Adequate with some limitations
C	Marginally useful for testing
D	Undesirable, limited utility for testing (with 0 for non-essential elements)
F	Completely unacceptable

Legend:

SAV = Savannah Forest DRY= Tropical Forest HILL = Vient Hill Site	CSE = Communications Systems & Electronics GASS = Ground & Air Sensor Systems CBD = Chemical/Biological Defense Equipment ISSHF = Individual Soldier System & Human Factors Performance EE = Environmental Exposure SO = Smokes & Obscurants FT = Firing Tests CE = Coastal Exposure VM = Vehicle Mobility

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS.

VI.1. Conclusions.

This study has characterized the area around the township of Moengo (Figure 15) in the northern coastal plain of the Republic of Suriname for its ability to support the full suite of U.S. Army tropical testing activities. The region was selected for analysis based on the original world-scale search for areas possessing the biologic, climatic, and physical variables that define an ideal tropic test location (King et al., 1998), as depicted in Figure 1. The world distribution of regions capable of supporting hot-humid tropical testing included an area of coastal plain along northern South America. Within this larger region, the Moengo area of Suriname was selected for consideration because it represented an area currently leased to BHP Billiton PLC for the mining of aluminum ore (bauxite). These mining activities have developed a lengthy system of roads throughout the area that were considered candidate sites for vehicle testing, a special emphasis for this study because of an absence of this type of test capability within the current YPG-TRTC tropical test site inventory.

This study has documented that ideal tropical testing conditions for all fourteen environmental parameters are present within the general Moengo area. The climate constrains are uniformly met throughout the study area. There are short temporal excursions in monthly rainfall, but the impact of these excursions do not alter the vegetation or other required conditions considered ideal for testing. The climate conditions will allow for year-round testing under nearly ideal to ideal climate conditions.

The physical parameters for ideal testing are also present within the study area. The area possesses a good variety of terrain, from flat lowland areas of both saturated and unsaturated soils that contain streams of variable size and flows, to steeply-sloped hills covered with lush rainforest. Soil types also vary extensively, from sandy well-drained loamy soils to clay-rich soils. The spatial variability of bedrock geology and soil type within relatively close areas significantly enhances the value of the Moengo area for testing. All types of sensor, vehicle mobility, human factors testing plus any other tests requiring mobility challenges can be accomplished somewhere within the Moengo area. There are substantial areas of environmental disturbance within the area, including the partially reclaimed mined areas, logging sites, and the extensive road network that has been constructed for mining exploration. These represent both opportunities and concerns that must be addressed. It can be expected that the road networks could be used without any further measurable damage because the limited testing miles that might be conducted would represent only a small impact in comparison to the mining and logging traffic. Additionally, any specialized courses needed for certain vehicle tests could be built on the old mining sites without causing additional environmental damage. The negative side of the existing human disturbance involves the liability aspects for the existing environmental disturbance. The Army must clearly delineate its responsibility as only limited to additional damage that might result from its activities, which could be completely mitigated by proper planning and operations.

The biologic setting is predominately a hot humid rainforest with isolated areas of savannah forest present in the coarse sand areas. These forest areas are impacted by some variability of the geology within the study area, but more by human activity. In this case, the variability of terrain and forest cover within the Moengo area should be seen as a positive factor because it offers the potential to support a more varied suite of testing. For example, remote sensing testing needs a variety of forest and land cover type to fully test the accuracy and sensitivity of the systems. Conditions from relatively open canopies to old growth dense multiple-canopy forests are available within the Moengo area to support many different types of sensor tests.

There is one non-scientific factor that makes Moengo a strong candidate for tropical testing and that is the availability of local support facilities through the presence of BHP Billiton mining activity. The company has made known its willingness to rent all types of support facilities to support the testing mission. For example, a large complex of mechanical shops is already in place to provide maintenance for vehicle testing. Rental lodging, food stores, and medical facilities are present in Moengo and rental office and laboratory space is also available. Transportation into the site is readily available for personnel, either by air or road, and barge transport is possible even for very large pieces of equipment.

VI.2. Recommendations.

a. The Moengo Site in Suriname should become the primary location for vehicle mobility tropical testing for the Army.
b. The site should be considered for a variety of sensor tests, both for aerial and ground based electronic sensor systems. The strengths of the area for remote sensing include large areas absent of cultural interferences, a great variety of terrain, a diversity of vegetation type and structure, and the ability to test under different geologic and soil conditions.
c. The area is large, isolated, and without residents. This would make the use of all types of aerial energy transmitting systems with a variety of frequency signatures easier to use without interference in any civilian activities.
d. Human factors testing should be considered for the site. The great variety in surface conditions across the Moengo area presents a great variety of testing and training opportunities for individual soldier systems. The terrain varies from lowland swamps to classical uplands multi-canopy rainforest, with a range of secondary forest of differing ages.
e. The area is entirely suitable and should be considered for a variety of other testing activities, particularly tests that require extensive logistical support.
f. Agreements to obtain use of the sites should be developed jointly with the mining company and the government of Suriname.
g. A scientific exchange should be developed between YPG and the university in Suriname. The work should initially be focused on environmental monitoring and compliance measures for tropical testing activities. It could also support characterization of larger areas of the southern parts of the mine lease holdings that are reported to contain more undisturbed forest areas and could be expected to be more biologically diverse.

CHAPTER VII

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APPENDIX 1 – Study Panel Membership

The Scientific Peer Panel for the Tropic Test Center Relocation Study is made up of those individuals listed below. A statement of qualification is included.

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A TECHNICAL ANALYSIS OF SURINAME FOR TROPICAL TESTING OF ARMY MATERIEL AND SYSTEMS

APPENDIX 2

PHOTOS OF THE STUDY SITE

MARCH 2006

Figure 1. Disturbed land on the BHP mining concession south of the town of Moengo.

Figure 2. Examples of the extensive road network on the BHP mining concession in the Moengo area under dry conditions

Figure 3. Examples of the extensive road network on the BHP mining concession in the Moengo area under wet conditions

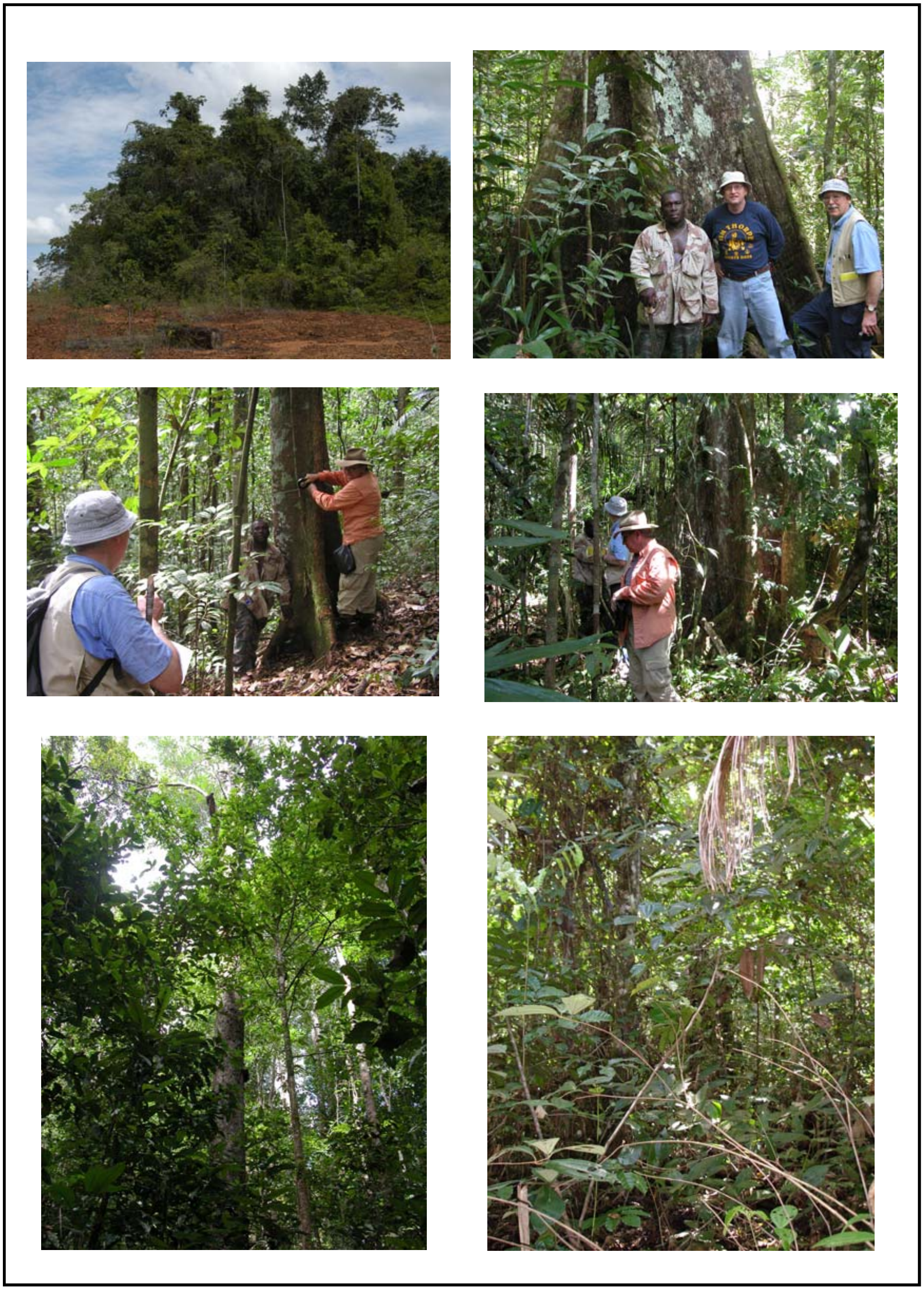

Figure 4. Photographs of typical native tropical forest on well-drained soil in the Moengo area.

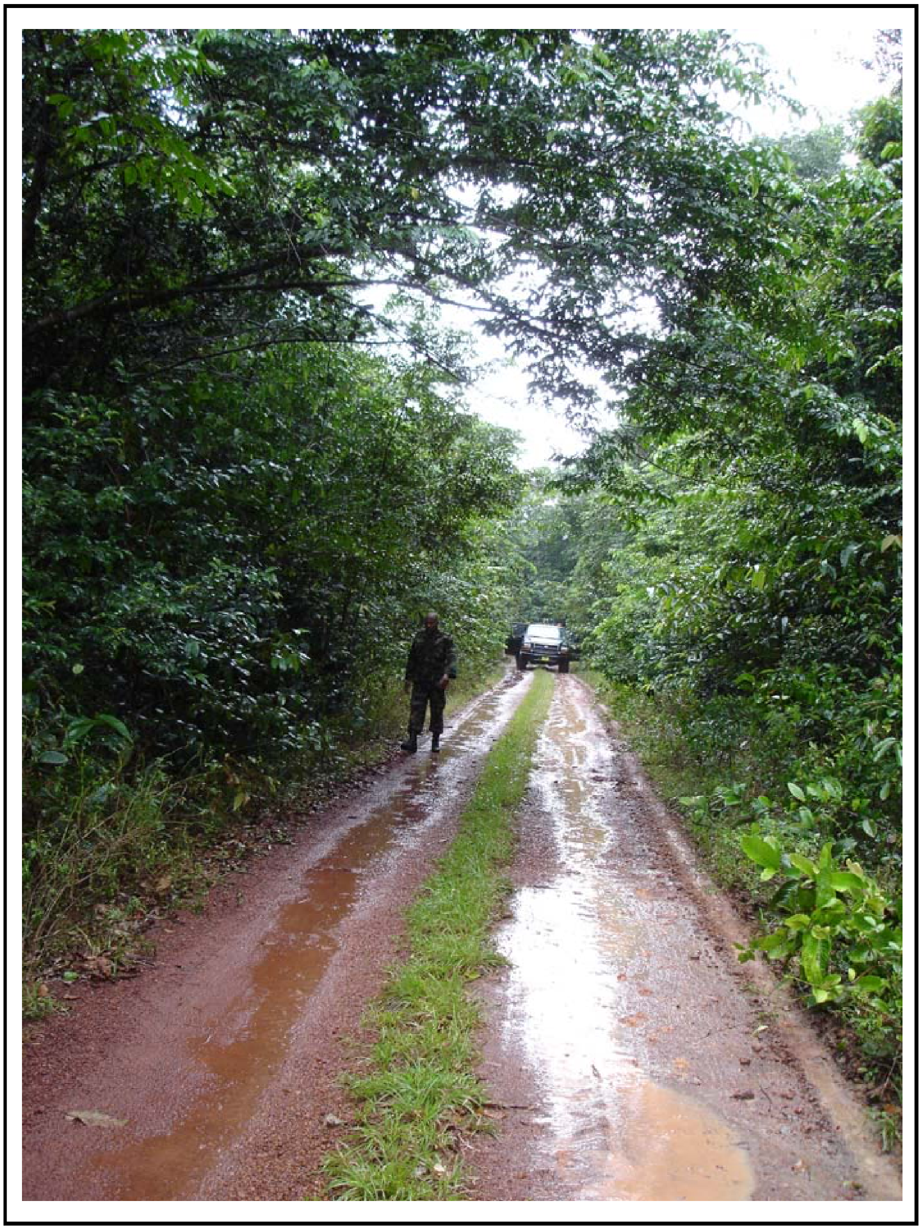

Figure 5. Photograph of typical freshwater swamp forest that forms in topographicallylow parts in the Moengo area.

Figure 6. Photographs of native tropical forest on the well drained soil of the Vient Hill site.

Figure 7. Photograph of typical ‘Savannah’type forest that forms on the coarse sands of the transition zone in the Moengo area.

Figure 8. Corporal of the Suriname Army in typical understory of tropical forest on well-drained soil.