A Technical Analysis of Cerro Tigre and Altos de Pacora, Panama, for Tropical Testing of Army Materiel and Systems

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April 2006

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed , and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE April 2006	3. REPORT TYPE AND DATES COVERED		
4. TITLE AND SUBTITLE A Scientific Analysis of Cerro Tigre and Altos de Pacora, Panama for Tropical Testing of Army Materiel, Equipment and Systems				5. FUNDING NUMBERS
6. AUTHORS COL W.C. King; Dr. R. Harmon; Dr. J. Juvik; COL E.J. Palka; Dr. Jan Hendrickx, and LTC S.D. Fleming				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211				8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander U.S. Army Yuma Proving Ground Yuma, AZ 85365				10. SPONSORING / MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release Distribution Unlimited				12b. DISTRIBUTION CODE A
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 Two sites in the Republic of Panama for tropical testing for the Army. The evaluation panel addressed this tasking through the utilization of an ideal tropic test site model and hierarchical decision tree process to prioritize critical environmental parameters developed in previous studies in Puerto Rico, Hawai'i, and Queensland, Australia.				
14. SUBJECT TERMS Tropic Regions Test Center (TRTC)				15. NUMBER OF PAGES XX 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified		20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-1
298-102

Scientific Characterization of Cerro Tigre and Altos de Pacora Sites in Panama for Tropical Testing and Training

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 wet tropical climates. First, conflicts will continue to occur in these geographic areas; since 1960 more than 75 percent of regional conflicts have had 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 wet 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, at that time 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), Northeast Queensland, Australia (King et al., 2001), and Suriname (King et al., 2006). The specific charter for these follow-on studies was to identify areas of the Hawai'ian Islands, Puerto Rico, the NE Queensland region of Australia, and Suriname 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. 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 5 regions. Based on the findings, from the four 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, 2006). 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. One of the key

recommendations of the original study was that the Army pursue options for reestablishing test sites within the Republic of the Panama. All of the work done to date has confirmed the value of Panama as a tropical test site location and discussions with the government of Panama have shown some willingness for cooperative efforts in this regard. The two sites being characterized in this report have actually been employed for testing missions by the Army. This effort establishes the scientific baseline for their continued use and evaluates their capacity to support an expanded testing mission.

The Pacora Site is located at the headwaters of Rio Pacora. It is a 64-hectare site that is mostly forested and located on private land approximately 50 kilometers NNE of the Pacific entrance to the canal. The site is completely surrounded by private farm land, mostly in rainforest cover, and in a well isolated area. There are broken sections of tall grasses, mostly associated with the lower lying drainage areas, but some are remnants from previous farming activities. The Pacora Site should become a primary site for testing sensors and communications systems. The vegetation, slopes, and rocky surface create a perfect location to challenge both surface and airborne sensor systems.

The Cerro Tigre Site is located at the Panama National Police Training Center, which is approximately 23 kilometers NNW of the Pacific entrance to the Panama Canal. The site is bordered on the east and north by HW 852, on the west by the Soberania National Park, and on the south by the railroad line. Primary use of the overall facility is to train military and police forces for the Republic of Panama. The Cerro Tigre Site is an excellent site for human factors and small arms weapons testing missions. The established man-pack course is extremely challenging because of the density of the undergrowth on the site. The small arms weapons testing capacity will be better than previous facilities operated in Panama. Overall, this site's combination of environmental factors and controlled access make it a strong candidate for many types of tests.

Cerro Tigre and Altus Pacora have been successfully characterized as to their capacity to support environmental testing of military equipment and systems. Both sites have proven to be good to excellent choices for a variety of test missions. The strengths of the Altus Pacora Site are its dense canopy, its isolation from cultural activities that could interfere with some types of tests, and its challenging terrain which is a combination of steep slopes and surface cover. This is an excellent site for a variety of sensor and remote sensing technology tests, although the absence of level forest terrain may be delimiting for some tests. It would also be an excellent candidate for a second human factors (man-pack) course in Panama because it offers a different set of challenges than those seen at the Cerro Tigre Site.

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 wet 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 wet tropics. Since 1960, some 75% of all international and internal conflicts have been in countries whose borders are totally or partially within the wet tropical environment. 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 regard 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 WWI. 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 1990s. 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; 2004) 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 to relocate the Army tropic test mission to a U.S. 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.

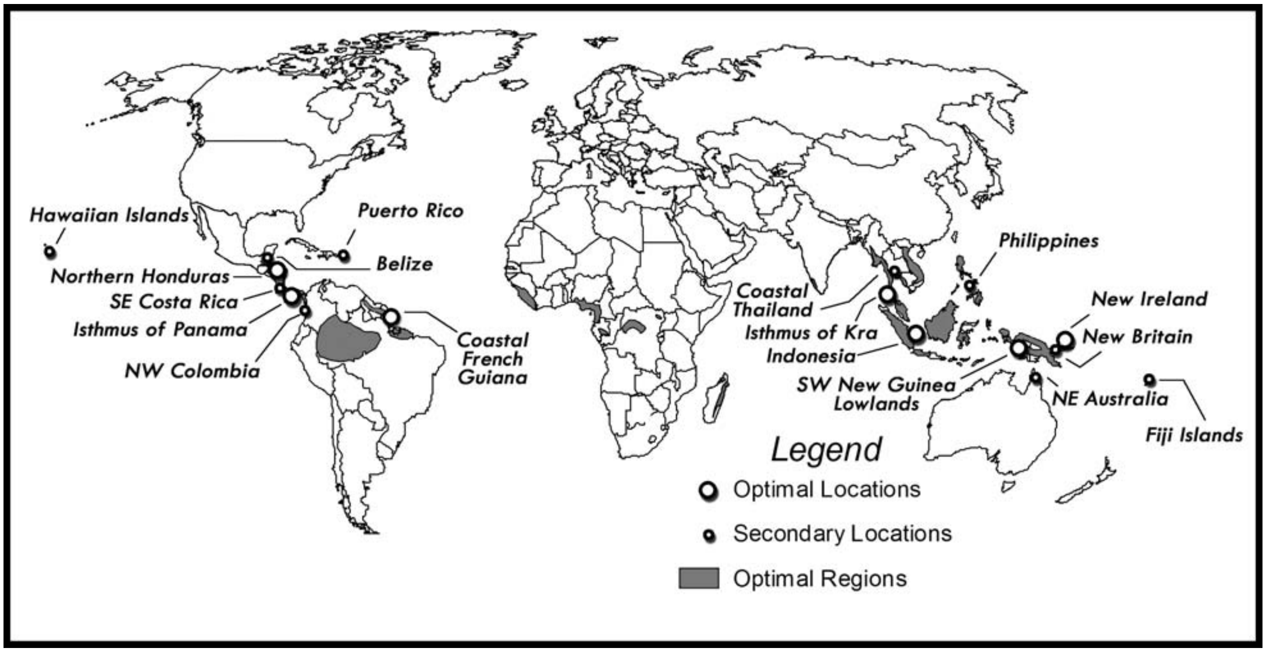

Figure 1. Optimal locations for developmental and operational tropical testing of military equipment, vehicles, and weapon systems (from King et al., 1998; 2004)

In 2006, the Army is again engaged in tropical testing, now employing a suite of sites that has evolved from the results and recommendations of previous panel study work. Sites include locations in Hawaii and limited capability to use sites within Panama.

The purpose for this research study is to conduct an environmental characterization of two sites within the Republic of Panama to determine if those locations can host various types of military systems tests. This characterization compares the basic physical, biotic, and climate parameters with the ideal conditions for tropical testing and training, which had been defined in previous research (King et al, 1999). The first site will be referred to as the Altus de Pacora Site, which is located in the upper Pacora River watershed 50 kilometers NNE of the Pacific entrance to the Panama Canal. The second site is located 23 kilometers NNW of the canal entrance and will be labeled the Cerro Tigre Site. The membership of the study panel assembled by ARO, together with a brief statement of qualification for each member, is listed in Appendix 1.

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 2,000 mm, 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 (^{o}C):	18 minimum average, 25 to 40 average daily
Relative Humidity (%):	Mean = 75, range = 75 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 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" 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)**.**

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.

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 two sites in Panama 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 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
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 (with 0 for non-essential elements)
F	0’s for critical elements	Completely unacceptable

CHAPTER II

THE TESTING 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 protocols 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 testing 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 wet 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 senses 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 (≤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 a relatively flat area in areas of restricted access.

II.2.D. Vehicle Mobility

This testing is directed toward evaluating mobility performance 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 who 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 Objective 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 to the question of whether or not an object is present, with a statistically high degree of confidence. 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.

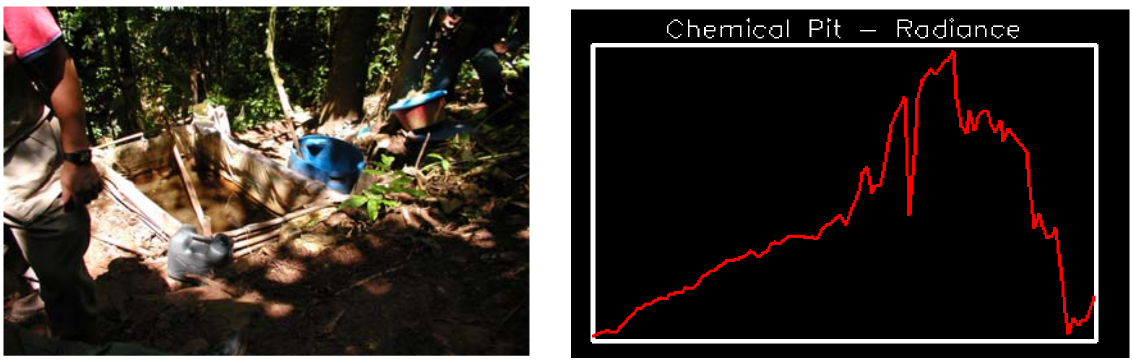

Figure 2. Chemical Pits return a unique spectra to a Hyperspectral Sensor

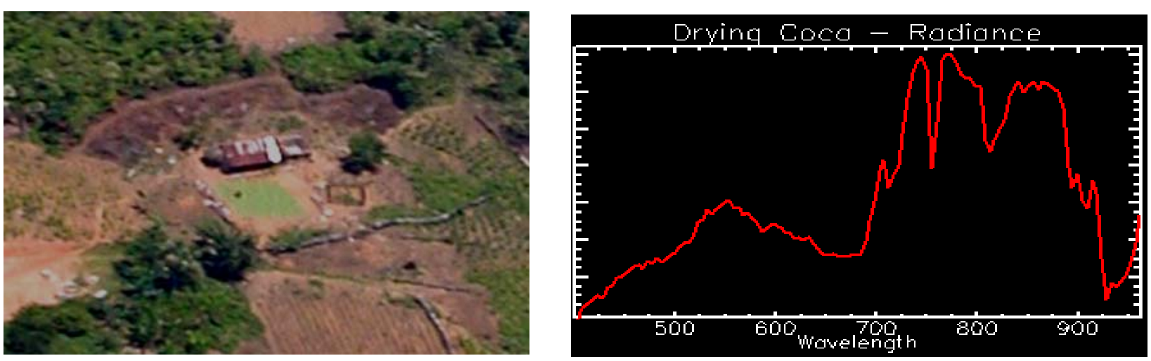

Figure 3. Drying Coca Leaf Spectra Gathered from Airborne Data and Applied to Airborne Data Comparison Profiles

CHAPTER III

CHARACTERIZATION OF TEST SITES

III.1 Physical Geography of Panama

As an integral part of the land bridge between the continents of North and South America, and as the major connecting link between the world’s two largest oceans, the Republic of Panama has proven to be the crossroads of the western hemisphere (Palka, 2004). The country occupies a territorial extent of about 77,400 km², or an area slightly smaller than the US state of South Carolina (US DOD, 1999). Despite its relatively small size, Panama displays a remarkable degree of physical and cultural diversity. Part of the country’s physical and biological complexity stems from its position within the tropics, a function of its absolute location. Panama’s relative location, however, contributes even further to both the physical and cultural diversity of the country.

One of the keys to understanding the historical development, complexity, and importance of Panama, is derived from an examination of its location. The geographic center of the country lies at approximately 9 °N latitude and 80 °W longitude (Figure 4). The N-S extent of Panama’s borders run approximately from 7-10 °N latitude, and the country extends east to west from 77-83 °W longitude. This E-W extent of about 840 km is equivalent to the approximate distance from Washington, D.C. to Boston in the United States. The country’s N-S distance varies between 60-180 km.

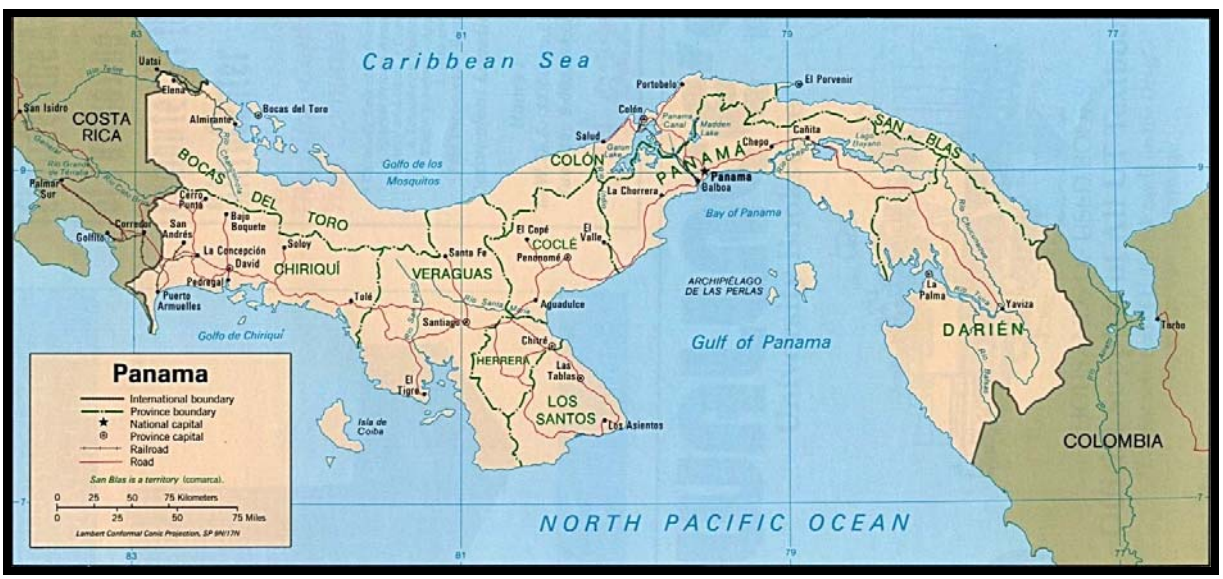

Figure 4: The Republic of Panama

Source: The CIA

Located on the narrowest part of the Isthmus of Panama, the territory of the present-day Republic of Panama long has experienced the flow and interaction of flora, fauna, and people between the continents. Since the completion of the Panama Canal in 1913, the country also has served as the conduit between the Atlantic and Pacific Oceans, contributing further to its biodiversity and re-establishing a connection that previously existed up to about 3 million years ago when the current land bridge formed (Coates and Obando, 1996).

The territory of present-day Panama has been created over the past 140 million years by the interaction of five major tectonic plates: the South American, Caribbean, North American, Cocos, and Nazca plates (Harmon, 2004). The Pacific margin of the country is active tectonically, as compared with the Caribbean (i.e., Atlantic) side, which is passive and characterized by a wide continental shelf. This disparity in tectonic activity establishes the conditions for two distinct coastal zones.

One estimate approximates the total length of coastline in Panama to be about 3,000 km (US DOS, 2000). The Caribbean coastline extends for about 815 km and includes several good natural harbors, whereas the Pacific coast stretches for about 1450 km (Weil *et al.*, 1972). The Caribbean coast features extensive coral reefs and includes the 350 or so San Blas Islands that are arrayed along the coastline for more than 170 km (Meditz and Hanratty, 1987). Strung out along the Pacific coast are more than 1,000 islands (Meditz and Hanratty, 1987), including the Las Perlas Archipelago, the Coiba Island in the Gulf of Chiriquí, and the tourist island of Taboga. The country experiences two distinct tidal regimes, with a microtidal range of less than 2 m along the Caribbean coast, and a macrotidal variation between 4-6 m along the Pacific coast (US DOD, 1999).

The dominant inland terrain feature is a discontinuous spine of mountains running through the middle of southern Central America (Figure 5) that has several regional names - the Cordillera de Talamanca in Costa Rica, the Serranía de Tabasará as it crosses the border into Panama, and then the Sierra de Veraguns as it straddles the former Canal Zone (Weil et al., 1972; Miditz and Hanratty, 1987). Most sources generally use the term 'Cordillera Central' to refer to the range that extends from the border with Costa Rica to the Panama Canal. Other mountainous areas include the San Blas Mountains, which attain elevations >900 m, the Sapo Mountains which attains heights of >1,100 m, and the Darien Mountains which reach 1,876 m. Thus, the combination of volcanism and tectonic uplift, weathering and erosion, and the pervasive influence of climate have established pronounced physiographic features on the landscape: volcanoes, drainage basins, rivers, and a complex coastline.

Given the rugged nature of its relief and its tropical location, one would expect Panama to be well endowed with fresh water resources. The country has about 500 rivers by most accounts, about 350 of which discharge into the Pacific and the remaining 40% of which drain into the Atlantic (Figure 6). Those rivers that flow into the Pacific are generally longer, of shallower gradient, and have longer, more developed basins. The steep, conical character of many of Panama's mountains results in radial drainage patterns, within which streams extend outward in all directions from the mountain summit. The more prominent patterns, however, are the parallel streams that are associated with elongated, parallel mountain ranges of steep relief in close proximity to the coast. For example, the Río Chagres exhibits a parallel pattern (Kinner et al., 2004).

Figure 5: Panama's Physiography

Source: Palka, 2004.

Panama's incredible biodiversity is attributable to its tropical location and its position on the Central American land bridge. Webb (1997) provides a comprehensive statement of the 'Great American Biotic Interchange' noting that more than half of the present land mammals of South America came from North and Central America by way of the land bridge (Webb, 1997). Using Holdridge's (1967; 1974) classification scheme, Panama has twelve life zones, defined by climatic and soil conditions and associated forests. The biological diversity is highlighted by an estimated 10,000 species of plants (Labrut, 1993). More conservative surveys include up to 9,000 vascular plants, along with 218 species of mammals, 929 of birds, 226 of reptiles, and 164 of amphibians (Microsoft, 2001).

Natural vegetation zones include forested mountains, hills, lowlands, savannas, coastal mangrove swamps, and tidal flats. Dense tropical forests include multistory canopies that extend some 20-50 m above the ground in uncleared parts of the eastern and northwestern regions of the country (US DOD, 1999). Mangrove swamps are common along the Caribbean coast, with savannas and rolling foothills in other coastal locations. Land cover estimates vary, but Tomaselli-Moschovitis (1995) concludes that some 54% of the country's

77,400 km² is classified as forest and woodland, 15% as meadows and pastures, 6% as arable mixed, 2% as permanent crops, and 23% as supporting other vegetative covers.

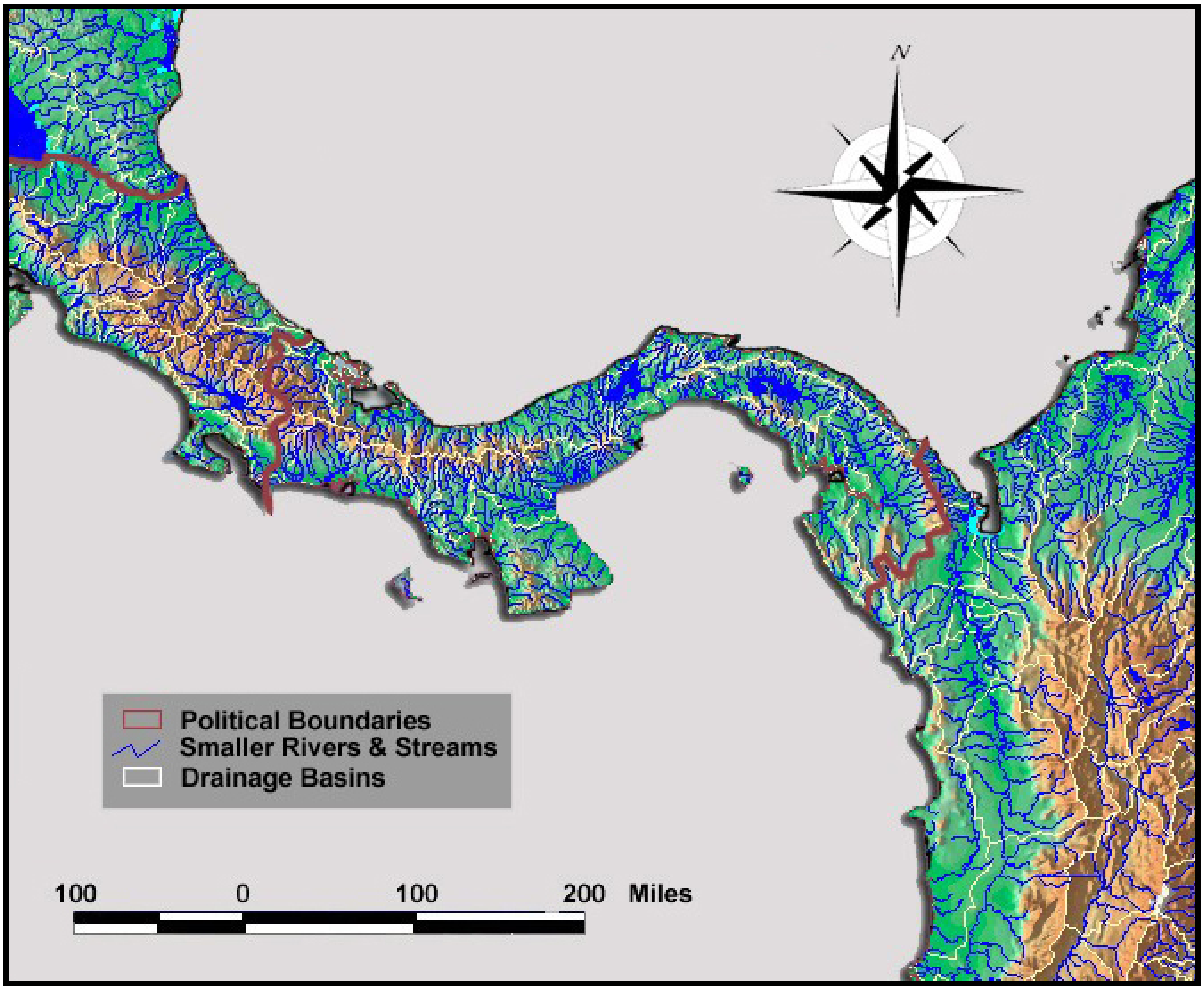

Figure 6: Panama's Drainage Patterns
Source: Palka, 2004

Panama's tropical rainforests deserve special mention because of their incredible biodiversity. Most forests are broadleaf evergreen that include more than 1,000 varieties of trees, including brazilwood, tropical cedars, ceiba, espave, jacaranda, laurel, lignumvitae, and rosewood (Weil *et al*., 1972). Deforestation, however, continues to be a major concern. One estimate identifies an average annual loss of 51,000 hectares of forest, with only three million hectares of forest remaining (Brokema, 1999). Other assessments indicate that tree cover has been reduced by 50% since the 1940s (Meditz and Hanratty, 1987).

Volcanism and tectonic activity have forged the territorial extent and physical relief of the Panama over the past 140 million years, with the most visible development occurring during the past 10 million years (Coates, 1997; Harmon 2004). The effects of the 'Great American Biotic Interchange', which began in Central America less than 3 million years ago, still linger and have contributed significantly to Panama's remarkable biological diversity (Webb, 1997). The country's biodiversity is also enhanced by its tropical location, where warmer and wetter natural environments generally result in increased biological variety.

III.1.A. Climate

The climate of Panama is humid tropical, reflecting it's coastal, near equatorial location (7-10^{o} N) and the influence of on-shore, moisture-laden, winds that alternate seasonally off the adjacent Atlantic and Pacific Oceans. Panama's complex topography of mountains (up to 3,478m) and lowlands interacts with these wind systems to produce a wide range rainfall and temperature regimes within the country. Rainfall in Panama is derived largely from periodic small, low-pressure disturbances embedded in the trade wind flow (easterly waves), and local, thermally driven convectional development associated with atmospheric instability during periods when the inter-tropical convergence ITC lies near Panama (May-November).

Panama's equitable tropical climate is further influenced by surrounding warm ocean waters off the Atlantic and Pacific coasts, which exhibit only slight seasonal variation in sea surface temperature from 26.5-28.5 ^{o}C (Sadler et.al, 1987). Latitudinal shifts in the ITC associated with seasonal strengthening and weakening of the Northern and Southern Hemisphere Hadley Cells, modify the delivery of onshore north-east trade winds from the North Atlantic (dominant in the winter months December through April) and a weaker south-westerly flow off the Pacific during the summer months May-November. Figure 7 illustrates both seasonal wind speed and direction typical of the general area. These seasonal wind patterns strongly control rainfall over Panama (Figure 8). During the December-April period the ITC migrates (with the sun) to the south of Panama bringing stronger trade winds (i.e. 5m/sec) from the north-east (see Figure 7). Persistent atmospheric stability associated with these NE trade winds results in a distinctive dry season across Panama during the January-April period. This dry season is more exaggerated on the Pacific coast, as demonstrated by the three seasonal rainfall patterns for locations around Panama. Appendix 2 presents modeling data developed by the Air Force Weather Agency (AFCC/DOMM, 2004) that shows the general distribution of rainfall and temperatures in Panama. These data are based on 10 years of measurements at all reporting sites throughout the country, adjusted for the impacts of altitude. Local climate controls are known to impact actual site conditions, but the patterns over the country are representative.

III.2. Cerro Tigre Site

III.2.A. Geographic Setting.

The Cerro Tigre Site is located at the Panama National Police Training Center (centered at 9^{0} 4'N and 79^{0} 38'W) approximately 23 kilometers NNW of the Pacific entrance to the Panama Canal (Figure 9). The site is bordered on the east and north by HW 852, on the west by the Soberania National Park, and on the south by the canal railroad line. Primary use of the overall facility is to train military and police forces for the Republic of Panama. The site has a small-arms firing range, a small live-fire MOUT (military operations on urbanized terrain) site, ammunition bunkers, and numerous other military training facilities. It is fenced and well guarded as part of the regular Police Academy operating procedures.

The land is a mix of secondary growth tropical rainforest/jungle and grassland areas which are the result of previous forest clearing operations. Most of the forest area is a dense single canopy with areas of double canopy. A hard surface road circles the small peak that is Cerro Tigre (264 m) and provides primary access to the area. Training sites are accessed through dirt surface roads that are passable in all but the wettest conditions. The understory is very thick and presents major challenges to dismounted maneuvers. Photos of the site depicting these features are provided in Appendix 3.

Small perennial streams exist on the site with the Rio Pedro Miguel being the only named water course. This stream is easily crossed on foot within the area of the training facility. The peak altitude on Cerro Tigre is 264 m with the base elevation for the site being approximately 100m. Slopes up to 24 % exist on the site for short distances, but most slopes are much less severe. Lowlands and grassland exist in isolated locations within the facility. Thick red clayed soils underlay thin A horizons of very dark humus soil. The Cerro Tigre site is located near commercial and residential private properties and is less than 2 kilometers from the Panama Canal. This proximity to such activities, one of Panama's few golf courses for example, could limit the kind of activities that can be conducted on the site.

III.2.B. Climate of Cerro Tigre

Although the Tocuman rainfall data is collected at some distance from Cero Tigre, the seasonal patterns are similar over this area of Panama. Available rainfall data from Summit (on the Canal only 1km from Cerro Tigre) shows a long-term mean annual rainfall of 2,156 mm (13% higher than Tocuman), although the critical dry season rainfall totals in the January/March period are similar (Tocuman = 55 mm; Summit = 42 mm). From the perspective of "Ideal Tropic Test " criteria, Cerro Tigre has a mean annual rainfall that meets the specified requirement of >2000 mm/yr. There is however, a significant 3-4 month dry season with monthly rainfall <100 mm/mo (see Figure 8), which does not meet ideal tropic test conditions for "continually wet" conditions.

Again, no long-term wind data are available specifically for Cerro Tigre, but seasonal wind direction and speed data can be extrapolated to the site from nearby Tocumen National Airport (see Figure 7) located only 25 km to the east.

Long-term atmospheric humidity measurement from Tocuman, presented in Figure 10, show expected patterns, largely congruent with seasonal rainfall distribution (annual average relative humidity of 81 %.) This, supplemented with some field measurement of humidity within the study area during January 2006 (under-forest relative humidity near midday, January 16, 2006 ranged from 77-91%, compared to 60-64% in adjacent clearings; air temperatures ranged from 30-33^{o}C) confirm that Cerro Tigre exceeds the ideal tropic test site criteria for continuous high relative humidity (range 75-90 %).

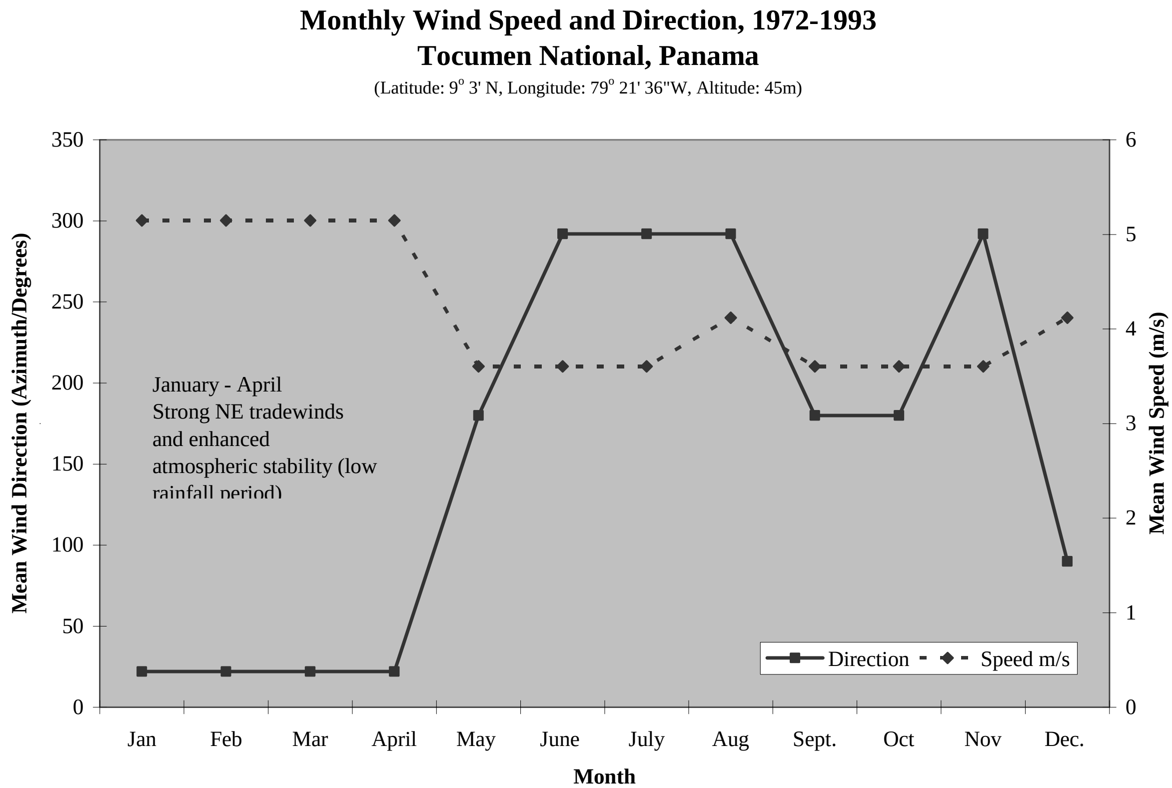

Figure 7: Monthly wind speed and direction

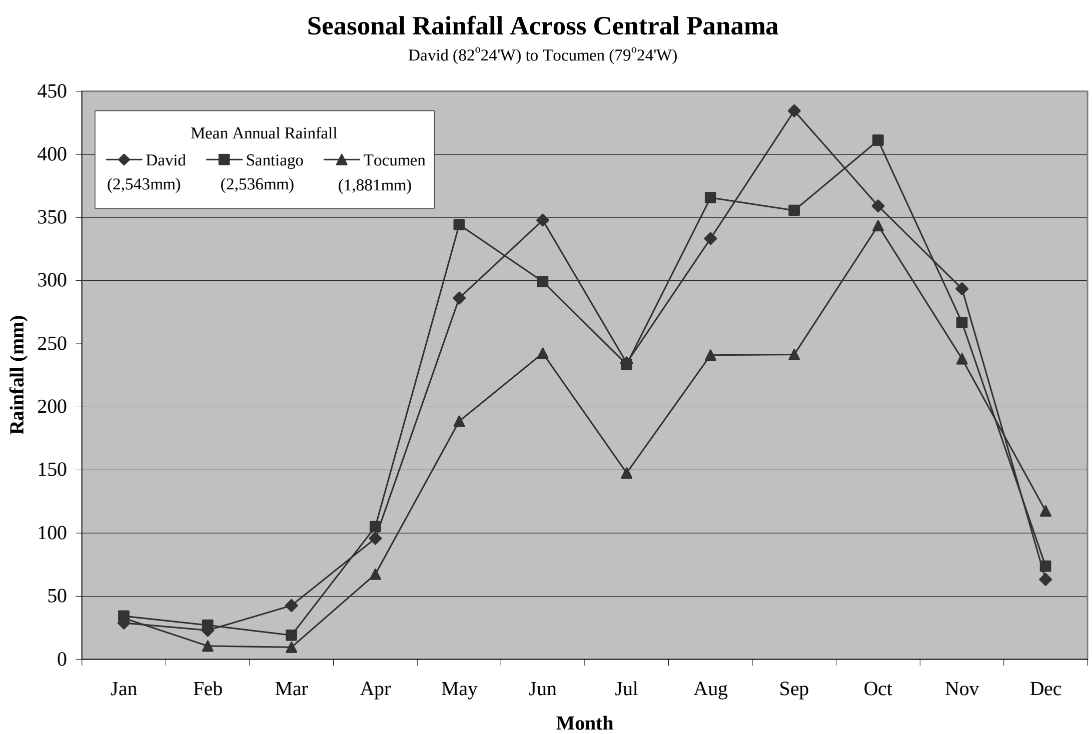

Figure 8: Rainfall Data for Central Panama

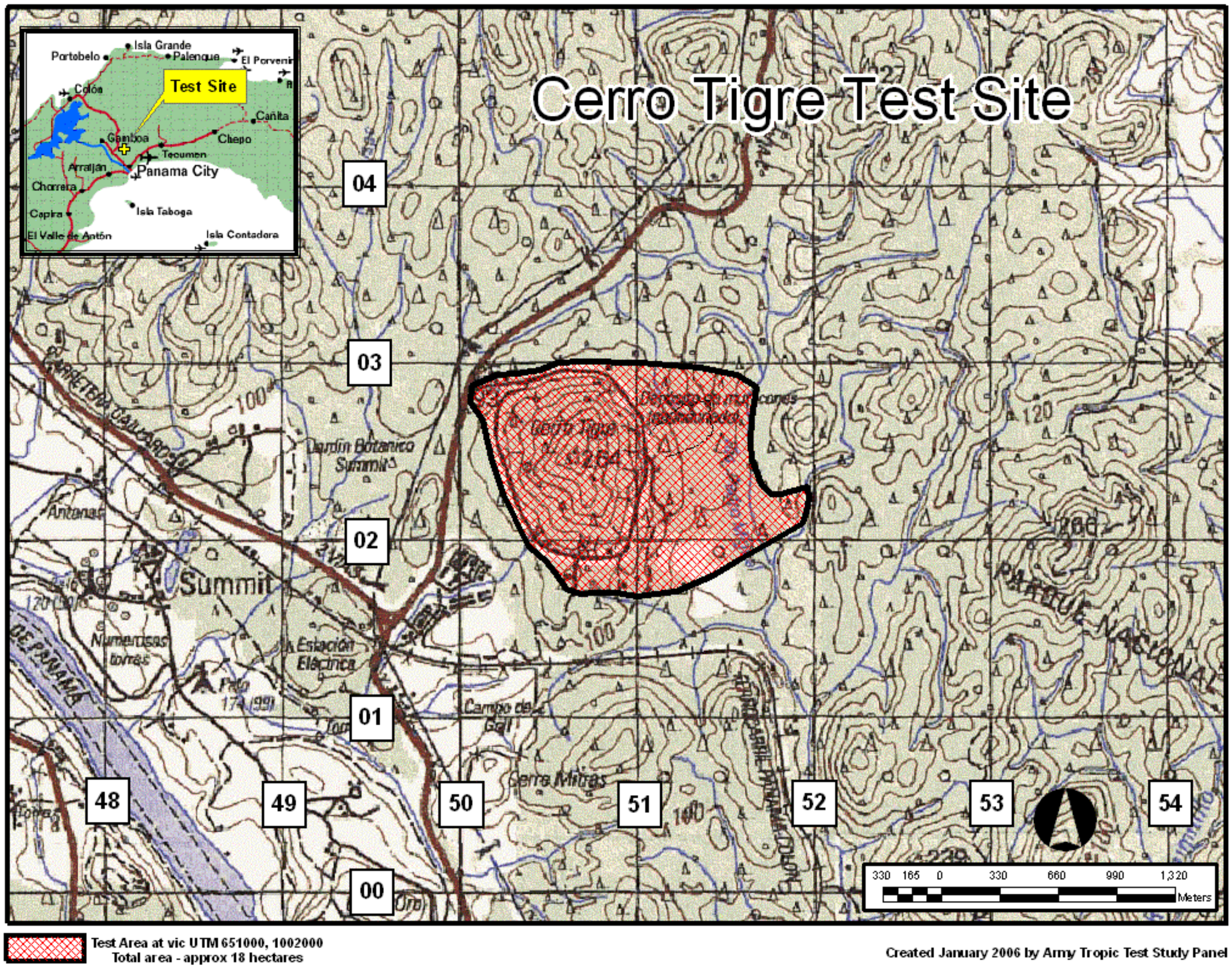

Figure 9: Cerro Tigre Test Site, 9^0 4'N and 79^0 38'W

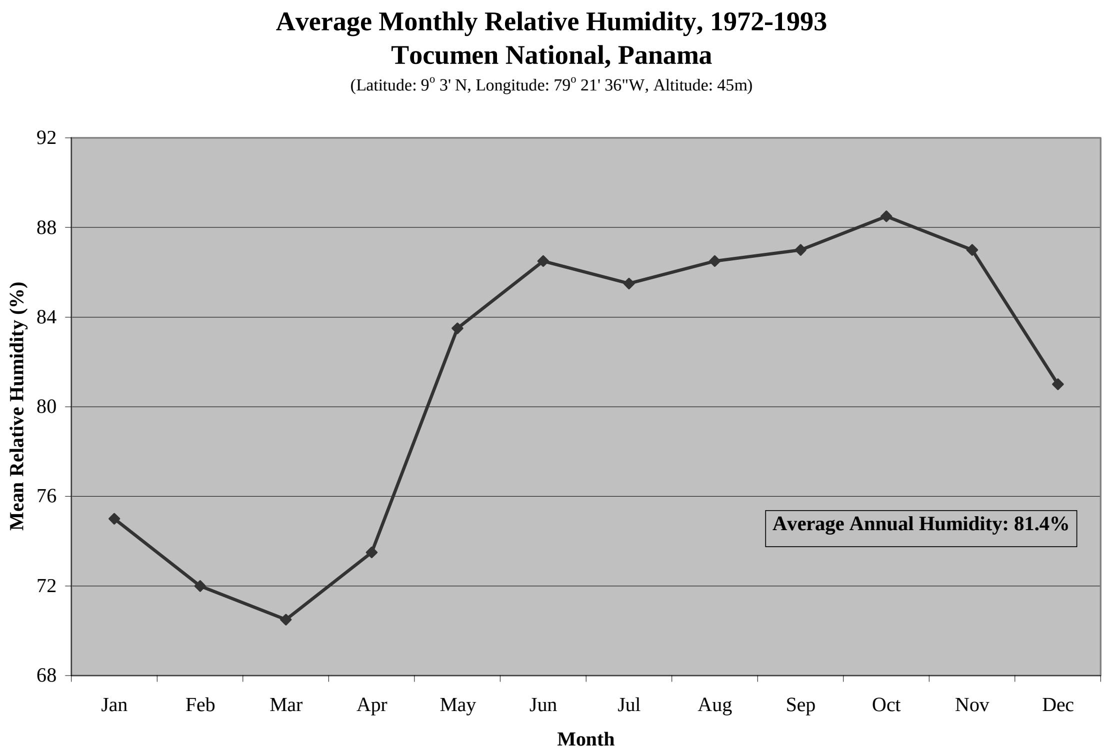

Figure 10: Humidity Data for Panama

Air temperature data from Tocuman (Figure 11) can be reasonably extrapolated to nearby Cerro Tigre because elevation differences, which largely control air temperature variation in the area, are not substantial (Tocuman = 45 m; Cerro Tigre 100-250 m). In tropical maritime localities air temperature typically deceases at a rate of about 0.5^{o}C/100 m, thus we might expect the actual air temperatures for Cerro Tigre (no site specific temperature data available) to be from 0.5-1.0^{o}C cooler than Tocuman. As can be seen from Figure 11, average and minimum temperatures closely approach or meet the ideal criteria for tropic testing (average temperature >27 ^{o}C, with mean minimum temperatures >18^{o}C). At Tocuman, the mean annual temperature is ~27 ^{o}C and monthly mean daily minimum temperatures remain consistently above 23 ^{o}C throughout the year. Even if a slight downward adjustment is made for Cerro Tigre (for elevation), the site essentially meets the tropic test temperature requirements.

Measured pan evaporation data and estimated monthly potential evapotranspiration are also available for Tocuman that indicate approximate annual evaporation rates of about 1,500-1,600 mm. Combining available rainfall and evaporation data with an approximation of soil moisture storage capacity (200 mm), allows the construction of a seasonal water balance model for Tocuman that can reasonably be extrapolated to the Cerro Tigre area (Figure 12).

The projected significant water deficit period in February-April is likely to influence biological activity at the site, including tropical forest development. Based on field visits, and both local and extrapolated historical meteorological data, Cerro Tigre appears to possess seasonally marginal (dry season rainfall) to near ideal (air temperature and humidity) long-term climate conditions favorable for tropic testing.

III.2.C. Vegetation Cerro Tigre.

In Panama, lowland tropical rainforests show significantly less species diversity than typical South American equatorial rainforests such as those found in lowland Suriname (Perez, et al., 2005). On Barro Colorado Island (in Lake Gatun, Atlantic side of the isthmus) rainforest tree diversity is about 90 species per hectare (Leigh *et al.*, 1999). There is also considerable local variation in both species diversity and canopy structure, largely as a function to geographic position relative to different rainfall regimes in the Atlantic and Pacific lowlands. Annual rainfall across the isthmus ranges from about 1,990 mm at Panama City to more than 3,125 mm 50 km to the north at Gatun, near the Atlantic coast. Although annual rainfall at both sites is sufficient to support high canopy tropical rainforest, it is the magnitude of the dry season on the respective coasts that significantly impacts rainforest

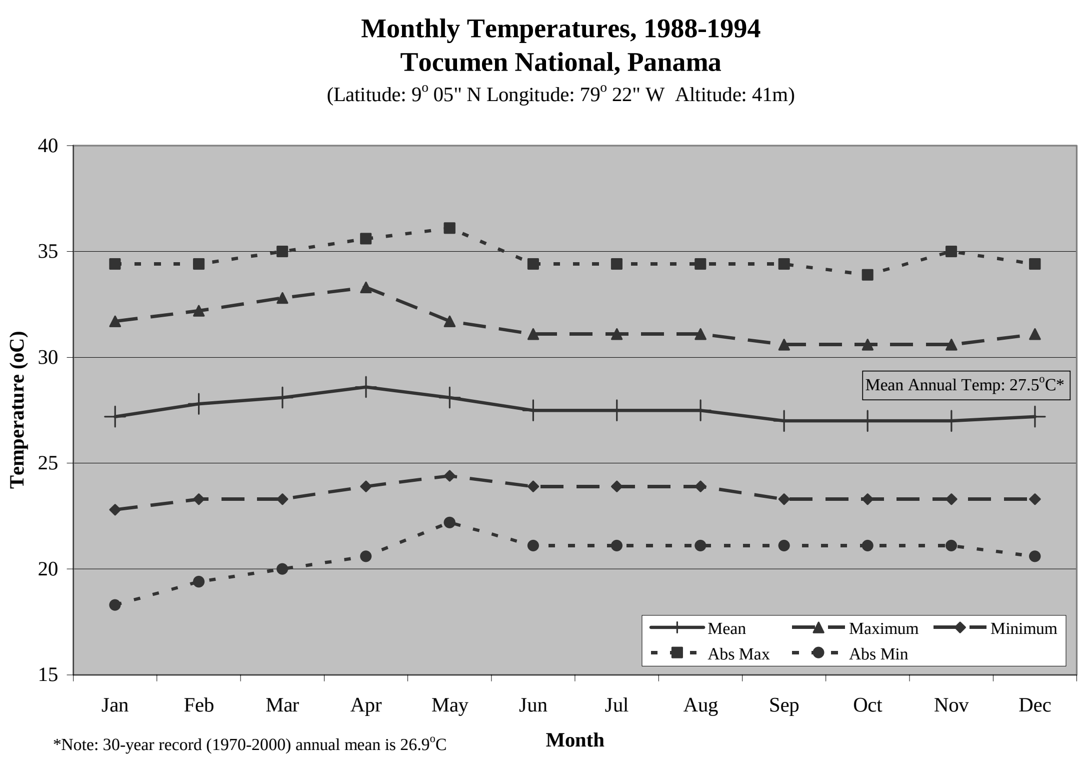

Figure 11: Temperature Data for Central Panama

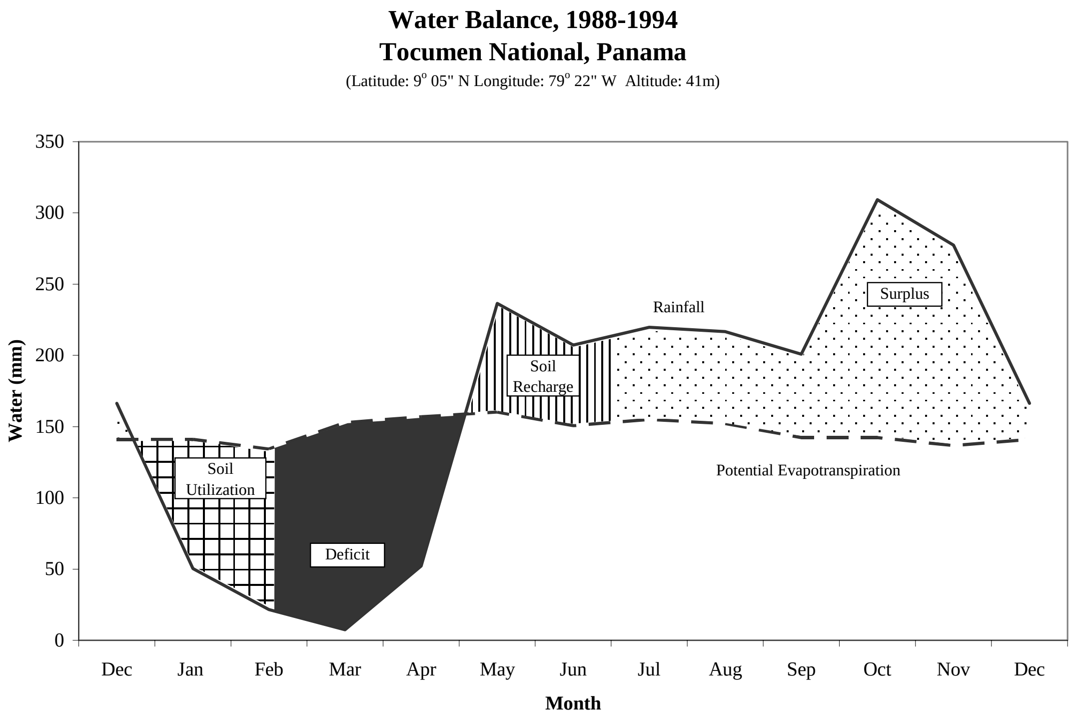

Figure 12: Water Balance for Central Panama

character. The January-March dry season on the Pacific coast (represented by the Tocuman data; see Figure 13) is severe, with only about 55 mm rain during these months. By contrast, at Gatun the "dry season" receives about 175 mm). Expressed in water balance terms, the dry season extends only about 100 days at Gatun, compared to 150 days on the Pacific (Condit et al., 2000). The impact of this seasonality on forest composition includes an increase in deciduous species in the Pacific lowlands. This produces a seasonally more open canopy and resultant compositional differences in sub-canopy composition and forest stature.

The Cerro Tigre study site is located only about 15 km from the Pacific coast, and is thus somewhat intermediate in position between the more extreme conditions on either coast. There is a pronounced dry season at Cerro Tigre (see climate discussion), which, when combined with the history of human disturbance at the site, renders the current setting at best a secondary forest cover, rather than primary tropical rainforest (continuously wet). At Cerro Tigre, this secondary forest occupies generally steep hill slopes ($10\text{-}24^{o}$) at elevations between 100-264 m. It is likely that most of this area was cleared or selectively logged in conjunction with nearby canal construction approximately 95 years ago.

The Cerro Tigre tropical forest (covering approximately 100 ha.) is characterized as a moderately to severely disturbed forest canopy. The forest was sampled by measuring all large trees (DBH>50 cm) along a 685 m forest trail, forming a section of the established MANPAC course in the area. Tree diameters ranged from 0.52 – 1.46 m (mean DBH= 0.9 m), with mean tree height (top of canopy) at 20.6 m (range 18.1 –22.8 m). The multi-layered canopy presented a somewhat open appearance perhaps because of the steep terrain and past disturbance history. The under story was highly variable, with horizontal visibility ranging from only a few meters (3-5 m) is thick bamboo understory to more than 20 m in open palm understory. This forest is characterized by a mean large tree diameter and mean canopy height that is substantially less than that found at the Moengo, Suriname or the Altos de Pacora sites.

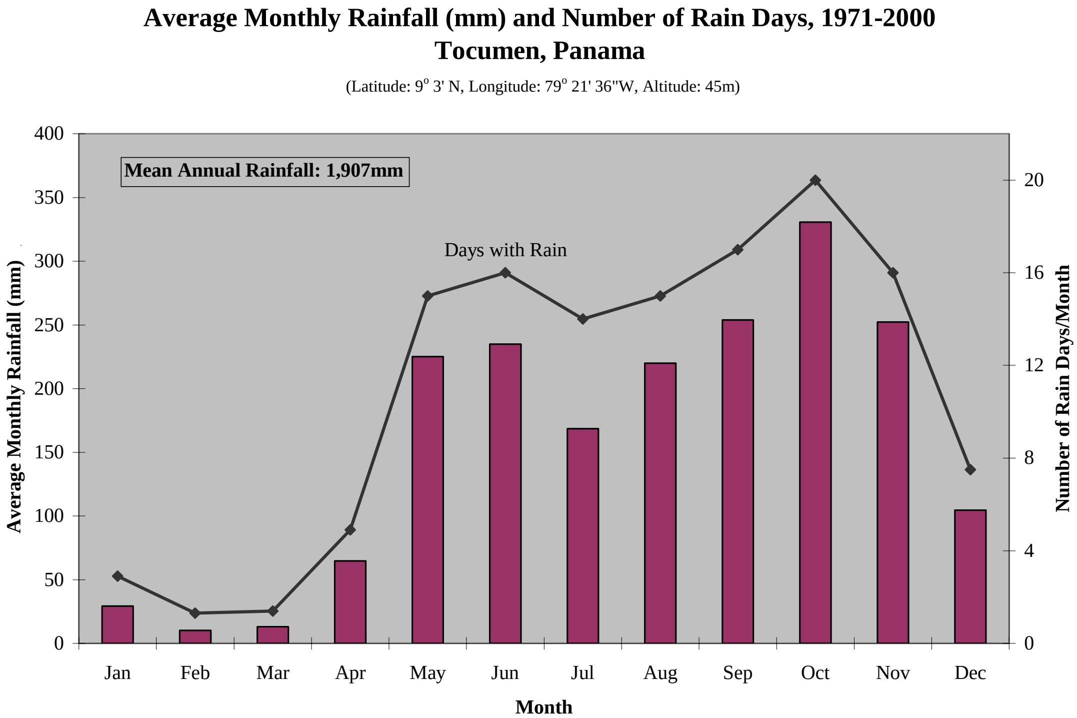

Figure 13: Average Monthly Rainfall and Number of Rainy Days

III.2.D. Soils Cerro Tigre

The soils in the Cerro Tigre originate mainly from andesite bedrocks. They consist principally of Ultisols that are strongly leached, acid forest soils with relatively low native fertility. They are typically found on older, stable landscapes. Intense weathering of primary minerals has occurred, and much Ca, Mg, and K has been leached from these soils. The strong weathering environment results in a soil with high clay contents. Ultisols have a subsurface horizon in which clays have accumulated, often with strong yellowish or reddish colors resulting from the presence of Fe oxides. This subsurface horizon often has a lower permeability than the overlying horizon which leads to lateral flow on the hill slopes (Harrison et al., 2005; Hendrickx et al., 2005).

Two rocks had a magnetic susceptibility of 2815×10^{-5} and 2953×10^{-5} (SI units). The soils showed magnetic susceptibilities from 270×10^{-5} to 1293×10^{-5} with an average value of 725 $\times 10^{-5}$. At the firing range the soils were greatly disturbed with magnetic susceptibility values from 167×10^{-5} to 683×10^{-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. 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.

III.2.E. Surface hydrology Cerro Tigre

Due to the clay rich nature of the soils, the infiltration rates are limited and much of the precipitation is discharged along the hill slopes towards the small streams. Many of the smaller streams fall dry during the dry season. During the field visit, five drainage beds with widths of about 2 m and one with a width of 5m were encountered in 700 meters linear distance. Water was flowing only in the 5m stream bed and then at a very slow speed, noting that this visit occurred at the start of the dry season.

III.3. Altos de Pacora Site.

III.3.A. Climate of Altos Pacora

The Altos Pacora site is located on the Pacific slope in the headwaters of the Rio Pacora drainage at an elevation of 500-700 m. As no long-term meteorological/climate data available at the site (some limited rainfall records are available for nearby Indio Rio), the Tocuman data set has been used to extrapolate climate conditions for this site, with corrections made to compensate for the significant elevation differences (Tocuman is 17 km south-west of Altos Pacora.) Available rainfall data from Indio Rio (5km from Altos Pacora) shows a long-term mean annual rainfall of 2,700 mm (a highly significant 42% higher than Tocuman), although the critical dry season rainfall totals in the January/March period are identical (Tocuman = 55 mm; Indio Rio= 55 mm) . Thus, in spite of substantially different total annual rainfall, dry season biological impact can be considered similar. From the perspective of "Ideal Tropic Test" criteria, Altos Pacaro has a mean annual rainfall that well exceeds the specified requirement of >2000 mm/yr. There is however, a significant dry season with monthly rainfall <100 mm/mo (see Figure 13), which does not meet ideal tropic test conditions for "continually wet" conditions.

Long-term atmospheric humidity measurement from Tocuman, presented in Figure 10, show 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 Altos de Pacora study area (January 17, 2006; under-forest relative humidity 86-89%, with air temperatures ranging from 23-24 ^{o}C) confirm that Altos Pacora exceeds the ideal tropic test site criteria for continuous high relative humidity (range 75-90 %). The higher elevation at Altos Pacora could be expected to elevate relative humidity values significantly above those found at Tocuman

Air temperature data from Tocuman (see Figure 11) can be reasonably extrapolated to nearby Altos Pacoro, if appropriate correction is made for the difference in altitude (average temperature decrease of 0.5 ^oC per 100 m increase in elevation in the tropics) Using this elevation correction to the 600 m elevation tropical forest site at Altos Pacora, we would expect the actual air temperatures for Altos Pacora (no site specific temperature data available) to be from about 3 ^oC cooler than comparable values for Tocuman. It should be noted that a limited sample (January 16-17, 2006) of under-forest soil temperature measurements (-10 cm) at Altos Pacora (mean 22.3 ^oC) and Cerro Tigre (mean 25.8 ^oC) under comparable daytime conditions would seem to independently confirm the application of the temperatures correction applied above. As can be seen from Figure 11, average monthly temperatures would drop below 24 ^oC and fail to meet the ideal criteria for tropic testing (average temperature >27 ^oC,). However, monthly minimum temperatures for Altos Pacora would remain near 20 ^oC (above the tropic test requirement of >18^oC). Because of elevation induced temperature depression, this site must be considered marginal with respect to a year round hot tropical temperature requirement

The water balance diagram (see Figure 12) prepared for Tocuman can be extrapolated with some modification to characterize the Altos Pacora site. Due to higher cloud cover, and reduced vapor deficit, monthly and annual potential evapotranspiration at Altos Pacora can be expected to be at least 30% less than at Tocuman, estimated at approx 1000 mm/yr. However, since both locations have about the same amount of dry season rainfall in the January-March period, a significant water deficit (if perhaps shortened by a few weeks) will still occur at Altos Pacora. Local residents of the area confirm the presence of a well defined dry season as depicted in the Tocuman data (see Figure 12).

Based on field visits, and both local and extrapolated historical meteorological data, Altos Pacoro appears to possess seasonally marginal (dry season rainfall, and mean air temperature) to near ideal (annual rainfall and average humidity) long-term climate conditions favorable for tropic testing.

III.3.B. Vegetation of Altos Pacora.

In Panama and Costa Rica, classic lowland tropical rainforest transitions altitudinally into lower montane, moist forest at elevations between 600-750 m. Although typically somewhat lower in stature and biomass than lowland tropical forest in Central America, lower montane moist forest is very high in biodiversity with more than 10,000 vascular plants recorded, about 30% of which are endemic (restricted) to the Panama-Costa Rican Montane Ecoregion. The Alto Pacora project area occupies this transitional altitudinal zone (site altitudinal range 460 to 660 m) on the steep upper slopes of the Rio Pacora drainage.

Vegetation in the project area includes a mosaic of comparatively disturbed and intact forest elements:

Grassland (elephant grass *Pennistun purporeum*) cover about 7 ha on the upper west portion of the site and additional grass areas were evident from the air, down slope nearer the river. This vegetation represents areas clear-cut for farming about 30 years ago and subsequently abandoned. Elephant grass forms a dense ground cover to a height of 2-3 m. Horizontal visibility is only 1-3 m within these grasses.

Secondary forest Significant areas on the upper portion of the subject property, adjacent to the access road were apparently selectively cleared in the past (underbrush and small trees removed, and possibly some of the larger more valuable timber species as well) to facilitate commercial coffee planting under a residual shade canopy of native forest. This area was apparently abandoned about 15 years ago, facilitating the natural regeneration of native forest (pers. com. Eric Nicoliasen, local resident, January 2006). This forest type was characterized by an average canopy height of 15 m, a few large trees (DBH > 50 cm) and a preponderance of smaller trees with DBH in the 4-20 cm range. Several palm species were distinctive components in the understory. Horizontal visibility in the relatively dense understory averaged 8 m (range 5-11 m).

Tropical Forest (transitional between lowland and montane**)** Moderately disturbed to largely intact native rainforest covers more than half of the 65 ha subject parcel, primarily on the steep slopes (15-25^{o} slope) descending toward the headwater tributaries of the Rio Pacora. The forest was characterized by measuring all large trees (DBH>50 cm) along a 400 meter transect along a contour forest trail at an altitude of 610-620 m across the property. Tree diameters ranged from 0.51-2.86 m (mean DBH= 1.1 m), with mean tree height (top of canopy) at 28m (range 20-35 m). The canopy presented a somewhat open appearance perhaps because of the steep terrain. The understory was comparatively open with dispersed saplings averaging about 20 cm DBH (range of 3-45 cm). The open understory was confirmed by the horizontal visibility measurements, averaging 25 m (range 19-30m). This forest produced a mean large tree diameters comparable to the Suriname rainforest sites (in the 0.94-1.2 m DBH range), and somewhat larger than found at the Cerro Tigre site (mean DBH =0.9 m). The average canopy height at Altos Pacora was, however substantially less than found at the Suriname rainforest sites (mean canopy height 40 m).

III.3.C. Soils Altos Pacora

The soils in the Alto de Pacora originate from diorite bedrock. They consist principally of Ultisols that are strongly leached, acid forest soils with relatively low native fertility. They are typically found on older, stable landscapes. Intense weathering of primary minerals has occurred, and much Ca, Mg, and K has been leached from these soils. The strong weathering environment results in a soil with high clay contents. Ultisols have a subsurface horizon in which clays have accumulated, often with strong yellowish or reddish colors resulting from the presence of Fe oxides. This subsurface horizon often has a lower permeability than the overlying horizon which leads to lateral flow on the hill slopes (Harrison et al., 2005; Hendrickx et al., 2005).

The magnetic susceptibility of rocks varied from $2112x10^{-5}$ and $8532x10^{-5}$ with an average value of 5199 (SI units). The soils showed magnetic susceptibilities from $462x10^{-5}$ to $3112x10^{-5}$ with an average value of 1602 $x10^{-5}$.

III.3.D. Surface hydrology of Alto de Pacora

Due to the clay rich nature of the soils, the infiltration rates are limited and much of the precipitation is discharged along the hill slopes towards the small streams. Many of the smaller streams dry up during in the December to March dry season. During the field survey of the site covering 400 m linearly, the team encountered five drainages with widths between 1.5 and 3 m and one with a width of 7 m. Water was flowing only in the 7 m width stream. Local residents report that this stream flows year round. The site is bounded at it lowest point by the upper reaches of the Pacora River, a year round water course.

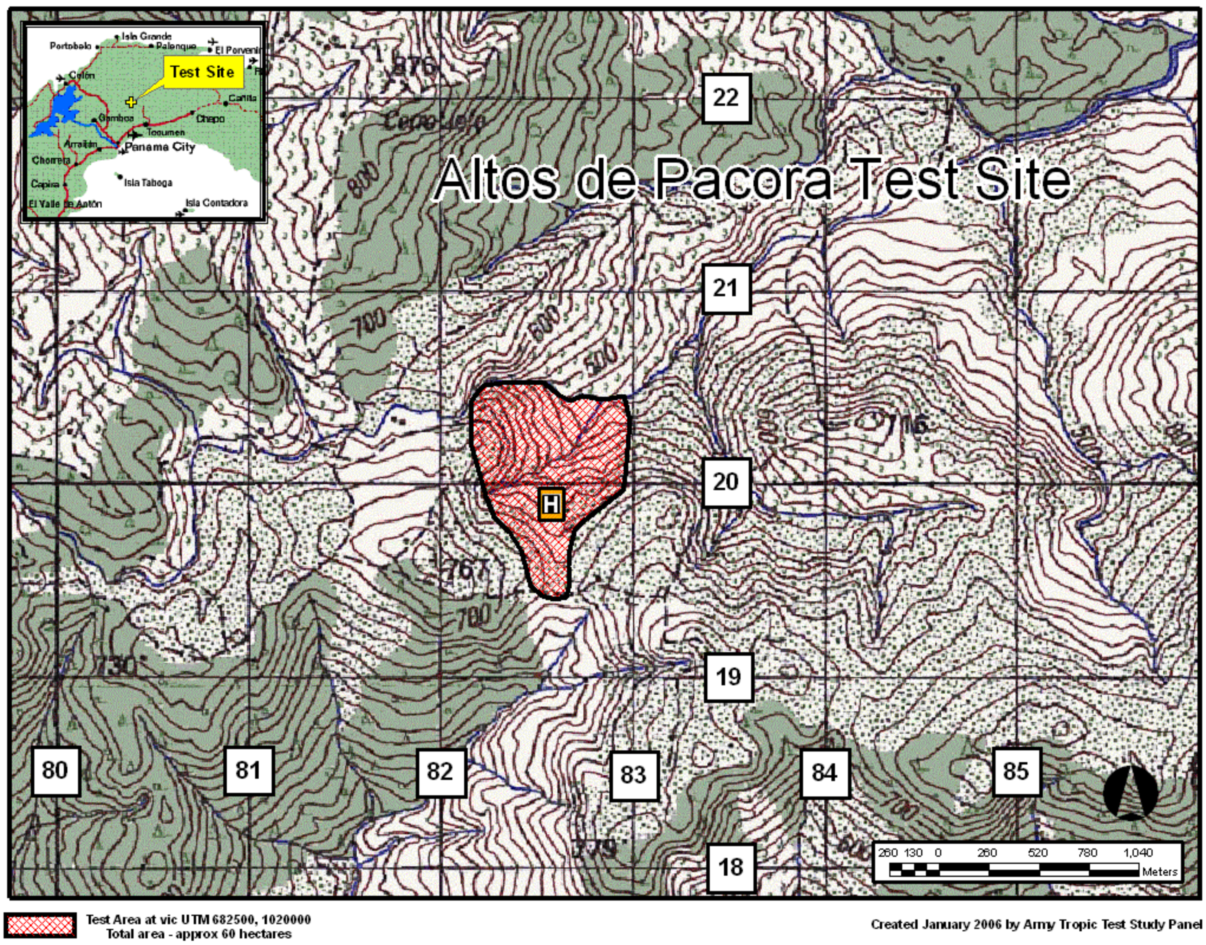

Figure 14: Pacora Test Site in the Upper Charges River Basin--9^0 14’N and 79^0 20’W

CHAPTER IV

EVALUATION OF TESTING CAPACITY

IV.1 Site Ratings

The analysis process begins by grading each of the two sites under study for their ability to support each of the 14 testing missions listed in Table 4 and described in Chapter II. The first step in this process is to assign utility rating values to each of the 14 environmental criteria that characterize the two 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 produces 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 the 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 the other sites in Puerto Rico, Hawai'i, northeast Queensland, Australia, and Suriname that were investigated in previous studies (King et al., 1999; 2001; 2006).

The next step in the analysis is to develop an overall grade for each site for each test mission. Step 1 produced values of 0 to 3 for each of the 14 environmental criteria for each land unit evaluated (Tables 7 and 9). In Step 2, each test mission is evaluated for its suitability at each site according to the important environmental factors for that particular test (Tables 8 and 10). A summary explanation of the analysis process and the location of the results is presented in Table 6.

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 11, a scale most students will be very familiar with.

Table 6. 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 4 and 9
Select environmental parameters	The mission is analyzed to identify environmental parameters that apply to the needs of the mission.	14 parameters in Table 4
Select sites	Scientific and practical considerations are applied to select candidate sites from selected regions	
Rate sites for compliance with environmental criteria	Used to characterize the environment at each site visited	Analysis in Tables 7 to 10
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.	Table 11

IV.2. Cerro Tigre.

This site is a hot humid setting with adequate rainfall to support dense tropical vegetation. Its one limiting climate factor is that it does have a distinct dry season that lasts about three months (see Figures 12 and 13), which can impact the forest and understory. It is also clear from a study of the site that significant human disturbance is still seen in the succession of the vegetation. The physical characteristics of the site are also excellent except for the absence of a stream network. Land use and ownership is important in planning what types of tests can be conducted at the site. The land is owned by the Republic of Panama, while control is vested with the National Police Academy. The area size limits the types of tests that can be run and the close proximity to civilians also impacts on testing opportunities. A strength of this locale is the existence of a set of small arms ranges within the site. A demanding human factors test course has been established on the site through some of the densest understory on the Cerro Tigre and over some of the steepest terrain.

Temperature, humidity soils, and slopes are rated as excellent for testing at Cerro Tigre, as shown in Table 7. All other factors are rated as good, except for the lack of surface streams, which are important for only limited types of tests. Table 8 is where the environmental factor ratings for Cerro Tigre are compiled for the different types of tests. These data reflect that Cerro Tigre can well support many types of tests. Because of its size and safety considerations, the site has very limited use for large caliber weapons activities. It is also not a good location for vehicle testing. The overall grades for all types of tests as presented in Table 11 by the panel evaluating the data from Table 8 and making judgments when the data fits between the criteria shown in Table 5. For Cerro Tigre, nearly all the testing missions had to be analyzed in this way because each test was mostly equal in numbers of 2s and 3s. This really says that most tests can be conducted adequately at Cerro Tigre and for many tests, if run at the right time of year, the site would be ideal. As already pointed out, the exceptions are large caliber ammunition tests and most vehicle tests.

Specific findings from Table 8 include:

- Human factors and environmental exposure testing are the types of activities best suited for the Cerro Tigre site.
- Small arms activities can also be very adequately executed at Cerro Tigre.
- All types of developmental and human factors testing can be adequately accomplished at Cerro Tigre. Depending on the specific type of test, the location could be rated as ideal for any test where the density of the canopy and understory is not critical.
- Large caliber munitions and weapons systems cannot be tested at Cerro Tigre, with the possible exception of the use of the bunker system for munitions exposure testing. The site has very limited utility for vehicle testing missions.
- The existing security is also a plus for many types of tests such as exposure testing where material must be left unattended for long periods.

Cooperative use agreements to determine the full suite of testing activities that could be conducted by the U.S. Army on the site are the subject of on-going discussions. A human factors course (man-pack) has been established with trails up to 2.9 km established. Tests have already been conducted on this course. A weapons firing range has been constructed that will be able to support 8 firing points with a range of 600 m (see photos in Appendix 3)

TABLE 7 - Environmental Evaluation of: Cerro Tigre Area

Evaluation Criteria	Rating
Temperature	3
Rainfall	2
Humidity	3
Soils	3
Area size	2
Slopes	3
Relief	2
Surface streams	1
Understory	2
Forest Canopy	2
Forest floor fauna	2
Land use/Ownership	2/1
Adjacent land use	2
Cultural/Historical	3
TOTAL	32

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

The Cerro Tigre Site is located at the Panama National Police Training Center (9^0 4'N and 79^0 38'W). It is bordered on the East by HW 852 and on the West by the Soberania National Park. Primary use of the overall facility is to train all types of military and police forces for the Republic of Panama. Joint use agreements for parts of the facility are being examined at this time. A human factors course (man-pack) has been laid out with various trails up to 2.9 kilometers. A weapons firing range is being constructed that will be able to support 8 firing points up to a range of 600 meters. Existing small arms ranges and a urban terrain site are also available for use.

Positive Physical Attributes

Constant high temperature and humidity
Can support small arms weapons
Highly variable understory
Existing ammo storage
Security and controlled access for testing activities

Limiting Factors

Limited double canopy
Joint use limits access to large areas
Land use rates as zero for large caliber munitions
Land use considerations limit vehicle testing at this site

TABLE 8 - Rating of Compliance with Environmental Criteria for All Testing Missions at Cerro Tigre Site

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

Notes:

* The site lacks the space for large scale vehicle testing. There are no current areas for this type of testing and whether large scale vehicle tests would be allowed is unknown.

** 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.

IV.3. Altos de Pacora

Altos de Pacora rates as good to excellent in meeting the criteria for all of the environmental parameters (see Table 9). Because of the influence of altitude, this site is wetter and slightly cooler than the Cerro Tigre site. The canopy is more mature generally from it being less disturbed by human activity than Cerro Tigre. There are a number of massive trees embedded throughout the forest on this site. The terrain is much steeper, while lacking any significant amount of level ground. Land use issues must be considered for any test proposed for Altos de Pacora because of the small area and that all of the adjacent properties are private lands.

The Pacora site is rated as excellent for a variety of tests (see Table 10), but is particularly attractive for equipment development, human factors and sensor testing. Including all sites in the studies in Hawaii, Puerto Rico and Australia, this site is the best found for all types of ground and air sensor testing. It also has versatility for many human factors testing activities because of a combination of steep terrain, isolated areas of good undergrowth, and canopy. There are approximately 5-7 hectares of tall (2+ meters) grasses which are the primary succession on lands that were used for agriculture. This grass area may have some value in certain tests, while representing areas where experiments could be set up outside the canopy.
The weaknesses of the site are its small size and a lack of security which will impact certain tests.

Specific findings from Table 10 include:

- Human factors and environmental exposure testing are the types of activities best suited for the Cerro Tigre site.
- All types of developmental and human factors testing can be adequately accomplished at Altos de Pacora. Depending on the specific type of test, the location could be rated as ideal for any test where the density of the canopy and understory is not critical.
- The area is too small to support vehicle testing.
- Because these are private lands, the site is not able to support any weapons or ammunition testing. No firing or live ammo tests can be run on this site

TABLE 9- Environmental Evaluation of: Altos de Pacora Area

Evaluation Criteria	Rating
Temperature	2
Rainfall	3
Humidity	3
Soils	3
Area size	2
Slopes	3
Relief	3
Surface streams	3
Understory	2
Forest Canopy	2/3
Forest floor fauna	2
Land use/Ownership	2/1
Adjacent land use	2
Cultural/Historical	3
TOTAL	35

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

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Positive Physical Attributes
High rainfall and humidity
Steep slopes, good relief, and challenging terrain to land navigate
Ideal lower montane environment.

Limiting Factors
Altitude of site reduces temperatures slightly
Not a large area
No significant level terrain
Significant areas of open understory

TABLE 10 - Rating of Compliance with Environmental Criteria for All Testing Missions at Pacora Site

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

Notes:

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

* The site lacks the space for large scale testing. There are no current areas for this type of testing. Whether large scale vehicle tests would be allowed is unknown.

** Solar radiation is a significant factor affecting human performance in tropical environments.

TABLE 11 - Evaluation of Capability to Conduct Military Testing at Sites in Panama

SITE	Equipment Development				Human Factors Testing				MUNITIONS TESTING: Small caliber			MUNITIONS TESTING: Large caliber			Other Tests & Training
	CSE	GASS	CBD	EE	ISSHF	CSE	GASS	CBD	EE	SO	FT	EE	SO	FT	VM
Pacora	B	B	B	**A**	**A/B**	B	B	B	F	F	F	F	F	F	C
C Tigre	B	B	B	**A**	**A**	B	B	B	**A**	B	B	B	F	F	C

* A/D – The A rating is for open exposure. The D rating indicates a lack of canopy for forest exposure.

Legend:

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

Sites:	
Cerro Tigre Pacora/ Upper Rio Pacora	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 V

CONCLUSIONS AND RECOMMENDATIONS.

V.1. Summary.

Cerro Tigre and Altus Pacora have been successfully characterized as to their capacity to support environmental testing of military equipment and systems. Both sites have proven to be good to excellent choices for a variety of test missions. The strengths of the Altus Pacora Site are its diverse canopy, its isolation from cultural activities that could interfere with some types of tests, and its challenging terrain, which is a combination of steep slopes and surface cover. This is an excellent site for a variety of sensor and remote sensing technology tests, although the absence of level forest terrain may be delimiting for some tests. It would also be an excellent candidate for a second human factors (man-pack) course in Panama because it offers a different set of challenges than those seen at the Cerro Tigre Site.

The Cerro Tigre site is an excellent site for a variety of testing missions with the man-pack course and the new firing range being the center pieces for testing activities on this site. Further, the ideal conditions at the site for a number of the climate and physical parameters make it an excellent choice for many other testing opportunities. Certainly, any type long term exposure testing activities could be accomplished at this site. It has all of the optimal climate and biotic conditions for environmental exposure testing and is within a secure area. The large area (1 sq km) of easily accessible secondary forest affords the opportunity for many types of tests.

Overall, these two sites are among the best sites for tropical testing examined to date, based on good environmental conditions and excellent access to be able to conduct all types of tests. The two general categories of testing not supported by these sites are vehicle mobility and large caliber weapons testing. The Altus Pacora site is not large enough to support vehicle testing, while land use restrictions would not allow for weapons or ammunition testing. The Cerro Tigre site might support very limited vehicle testing, but is not large enough for a full-scale test track. Further, the level of damage that is produced in vehicle testing would most likely not be acceptable to our hosts in that it may interfere with their uses of the land. It is possible that a small driver training course for police use could double as a small vehicle test track, but that would be a matter for further discussion.

V.2. Recommendations.

- Both the Altus Pacora and Cerro Tigre should be incorporated into the suite of sites available for tropical testing. Each site offers unique features that would add to the Army's overall ability to test in the tropics.
- The Altus Pacora Site should become a primary site for developmental testing of sensor and communications systems. The vegetation, slopes, and rocky surface create a perfect location to challenge both surface and airborne sensor systems.

- Both sites should be developed for human factors testing, which would require installing man-pack courses within the Altus Pacora site. Each course would offer a different set of challenges and conditions. This would provide a variety of trafficability and land navigation conditions that could be valuable over the range of tests to be supported.

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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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Appendix 2 Climate Modeling Data for Panama (USAF, 2004)

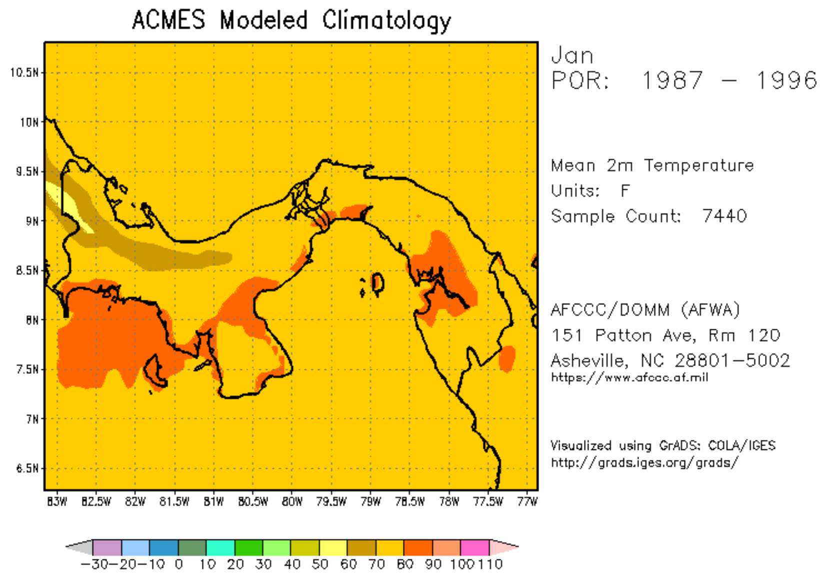


Figure 1, Appendix 2: January Mean Temperatures in Panama

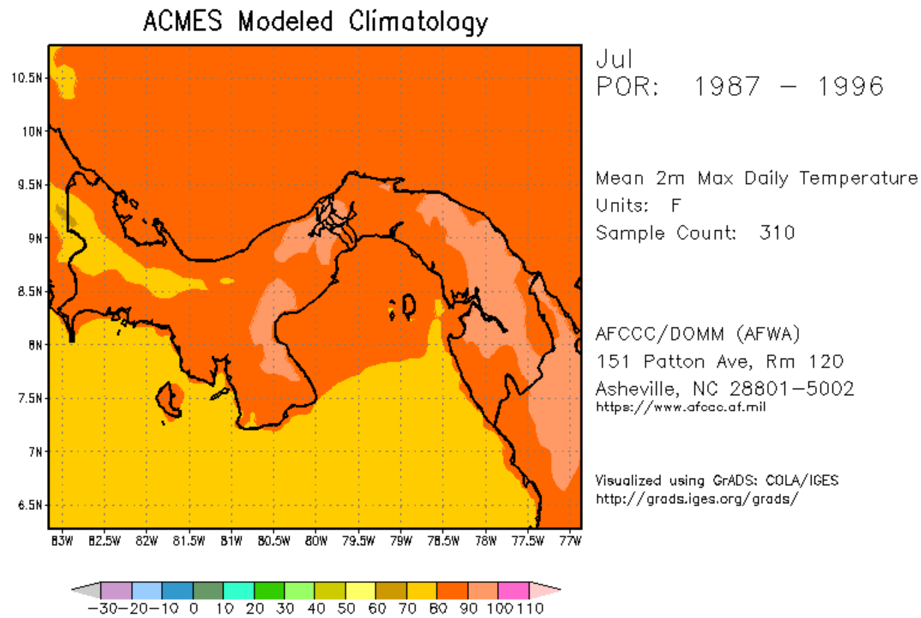


Figure 2, Appendix 2: July Max Daily Temperatures in Panama

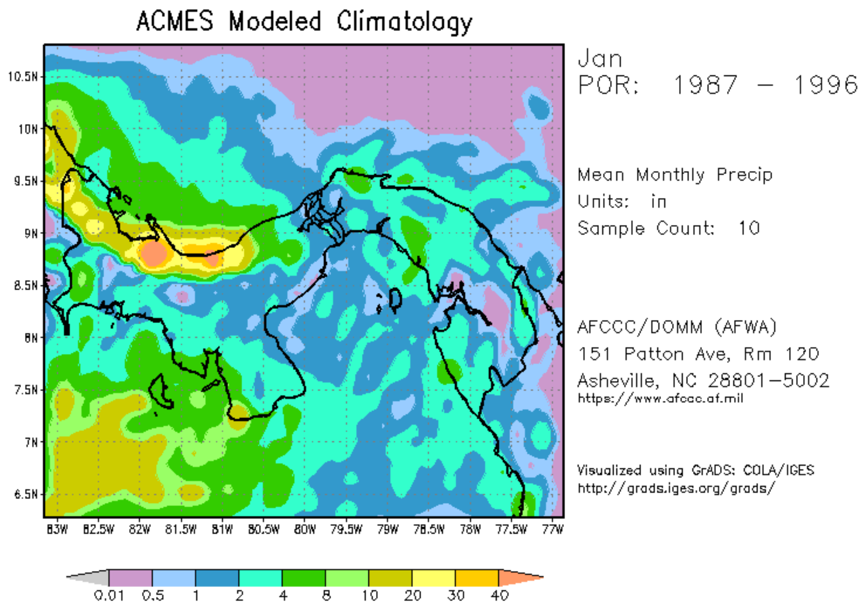


Figure 3, Appendix 2: January Mean Precipitation in Panama

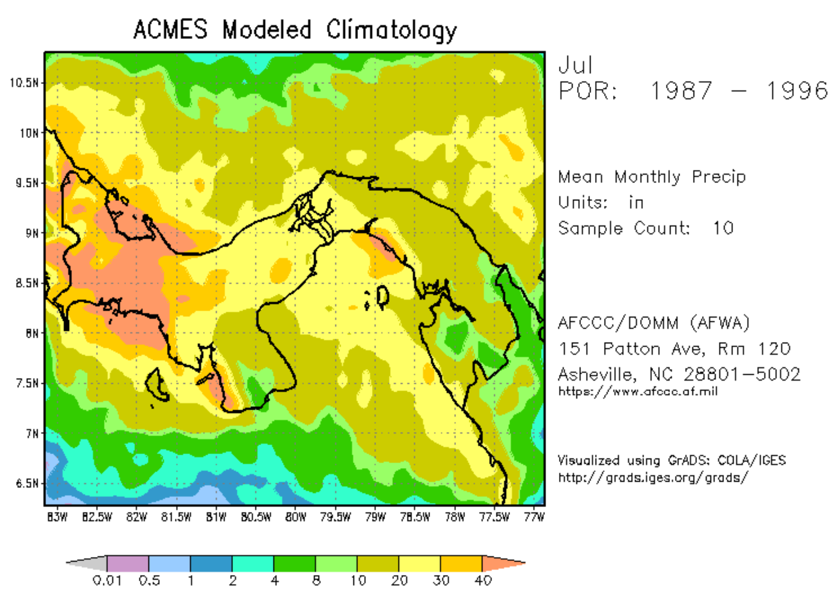


Figure 4, Appendix 2: July Mean Precipitation in Panama

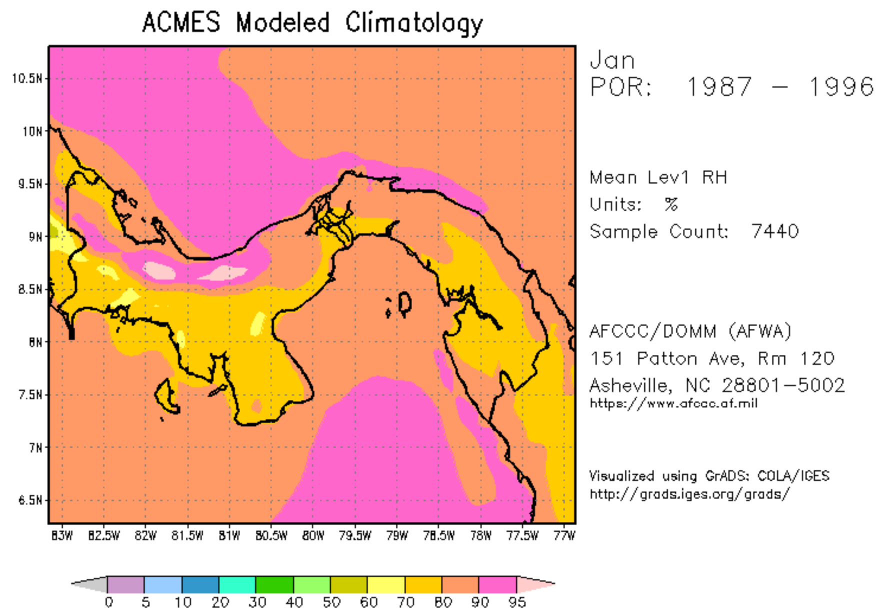
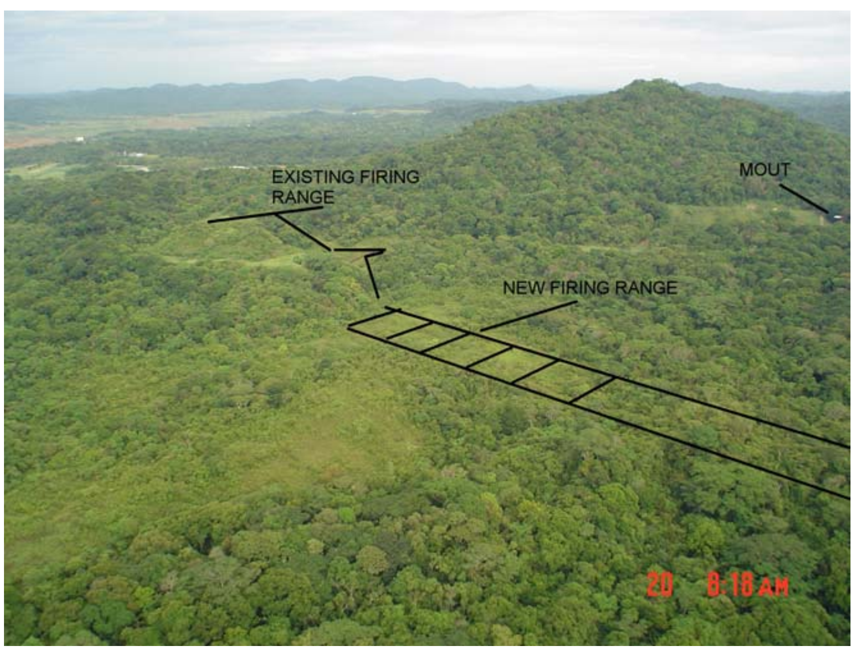


Figure 5, Appendix 2 January Mean Humidity in Panama

APPENDIX 3

Photographic Description of Cerro Tigre

CERRO TIGRE from the Air
Peak Shown in Upper Right Background, July 2004



Layout Of the 600 Meter Firing Range

600 Meter Range from Firing Point

600 Meter Firing Range from Location of 500 M Target

Ammunition Storage Bunker – 130 by 30 feet

Ammunition Storage Bunker Door

Canopy at Man-Pack Course

Undergrowth for Man-Pack Course

Soil and Vegetation at Range Site

Typical Soil Profile

Photographic Description of Pacora Area

Aerial View of Pacora Area

Undergrowth under Canopy

Undergrowth and Canopy

Canopy from Clearing

Trees and Boulders

Nine Foot Diameter Tree

Upper Canopy

Small Steam that Dissect the Site

On-Site landing Pad and Staging Area