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

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13. ABSTRACT *(Maximum 200 words)*

This report presents the findings of a scientific panel assembled by the U.S. Army Research Office (ARO) at the request of the Technical Director, U.S. Army Yuma Proving Ground (YPG), for the purpose of evaluating the suitability of locations in Australia for tropical testing for the Army. The panel addressed this tasking through the utilization of the ideal test site model and hierarchical decision tree process to prioritize critical environmental parameters developed in two previous studies.

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

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

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TABLE OF CONTENTS:

SECTION	PAGE

SECTION	PAGE

FIGURES:

SECTION 1:

SECTION 3:

SECTION 4:

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EXECUTIVE SUMMARY

The lessons to be learned from the history of war and specifically from the history of our Army are irrefutable in understanding the significance of military operations in tropical climates. First, conflicts will continue to occur in these geographic areas; since 1960 more than 75 percent of regional conflicts have their roots in countries located within the tropics. Secondly, successful operations require troops and equipment capable of sustained operation in the heat, humidity, and tropical landscape. To achieve the latter, our equipment must be tested in harsh tropical conditions and our soldiers must train 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. With the loss of both our testing facilities and Jungle Operations Training Center (JOTC), previously located at Fort Sherman in Panama, the Army must act expeditiously to restore these essential capabilities. To this end, the U.S. Army Developmental Test Command (TECOM), through its sub-element at U.S. Army Yuma Proving Ground (YPG), is developing a suite of alternative sites to support the tropical testing mission.

In 1998, YPG requested the assistance of the U.S. Army Research Office (ARO) to convene an expert panel to undertake two related studies. The first study, "A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems" (King et al., 1998), examined the Army tropical test mission to define the conditions that best provide the environmental challenges needed for tropical testing, today and into the next 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 provided the requisite conditions of an ideal environment for tropical testing and training.

As a consequence of the initial study findings a follow-on study examined locations in Hawai'i and Puerto Rico. The specific charter of the second scientific panel was to identify areas of the Hawai'ian Islands and Puerto Rico that best provide a combination of environmental conditions as defined in the initial study panel report requisite to the testing and evaluation of Army materiel, equipment, vehicles, and weapon systems (King et al., 1999). The results developed included a regional analysis of the environmental setting for both Hawai'i and Puerto Rico, an environmental characterization of twelve sites, 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 locales. Based on these findings, YPG has developed and is operating a testing facility at Schofield Barracks in Hawai'i.

Previously, this 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). 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 the requisite environmental conditions.

Australia is being considered because it was identified in the initial study (King et al., 1998) as containing areas possessing the requisite environmental conditions and because the Australian Army has jungle facilities that might be used by US Forces. There are political requirements to be considered, but initial discussions with Australian Defense Forces offered sufficient promise that this study was justified.

The overarching conclusion of this study is --- **access to the sites examined in North Queensland, Australia would significantly enhance the capability of the United States Army to test military equipment and systems in a tropical environment**. Detailed analysis completed in this study fully confirms previous work (King et. al., 1998), which found that the northern Queensland area of Australia possesses the requisite conditions of physical setting, climate and biologic diversity for effective tropical testing. Two of the studied sites, Tully/Jarra and Cowley Beach, have unique environmental settings offering capabilities not available in Hawaii or at any of the other candidate sites examined to date. Even Pin Gin Hill, which is small and lacks a mature tropical forest environment, could have utility because of the availability of existing testing facilities operated by the Australian Department of Defence on that site.

Tully/Jarra Creek is a large area (7,500 hectares) of continuous canopy rainforest that rated as good to ideal for all 14 environmental factors evaluated as part of this study. ***This is best site the panel has seen outside of Panama.*** Tully/Jarra Creek is an ideal site for all types of human factors testing and excellent for many types of developmental and operational testing. Sensor testing could be conducted in Tully in a very acceptable to excellent manner; this would fill a major shortfall in existing testing capacity in Hawaii. Tully/Jarra Creek offers limited ability to fire small arms up to 7.62 mm and detonate explosives in the size of single claymore mines. This area contains permanent facilities of the Australian Army, which could provide limited logistical support for testing. The Jarra Creek system is an ideal location for testing that requires putting troops into fresh water. The health risks from immersion or contact with this water are very low compared to most tropical settings. Overall, access to Tully/Jarra Creek would greatly enhance the existing U.S. Army testing capability.

Pin Gin Hill is a small area (34 hectares) possessing excellent conditions in rainfall, humidity and understorey, and it has the requisite tropical temperatures for a large part of the year. This site was judged as acceptable for certain types of exposure and electronic systems testing. Sensor testing could be possible over short distances, horizontally, and under a limited canopy. Pin Gin Hill could well support static exposure testing of equipment and material in both open and under canopy settings. A strength of this secured site is the existing laboratory and testing personnel in the DSTO activity at Innisfail.

Cowley Beach possesses the temperature, humidity and rainfall desired for tropical testing, while lacking most of the biologic and physical characteristics needed. Foremost, there is little rainforest on this property, only one very small area on the very northern end. The remainder of training area is covered with a swampy marsh offering only low, broken cover. Despite having two ocean beaches, there is little of the salt spray needed for ocean exposure testing because there are almost never waves. Cowley Beach does offer use of a small arms firing range and a currently uncertified ammunition storage bunker. Limited use of the beach for certain types of training currently exists. Should the U.S. Army testing community ever need either freshwater or estuarine swamp conditions, Cowley Beach would provide a challenging location.

Two areas of concern that must be addressed when considering Australia as a test location are cost and land use restrictions. First, transportation of people and equipment is going to be expensive. Military air access is available three to four hours south in the Townsville area, which could help defray some costs on missions involving significant numbers of troops or bulky equipment. Second, there are significant land use restrictions at each site that limit the types of testing allowed. Nearly all of the forests in the three areas are part of the Wet Tropics World Heritage Area lands, which impose significant limits to activities in the areas. Further, any use of Australia Defence lands will require developing some type of government-to-government memorandum of agreement.

Concluding findings from this study are as follows:

- Each of the three sites investigated in Australia should be added to the suite of sites that can support tropical testing. Each site could have utility for future testing.
- Tully/Jarra Creek is an outstanding location for developmental and operational testing of material and systems. The site is particularly useful as a site for human factors testing of all types of equipment; the area is expansive and the environmental conditions are challenging. Use of this area would greatly enhance existing capability for sensor and electronics systems testing of all types
- Pursue discussions with the government of Australia to determine the availability of the sites considered in this study for use as sites for U.S. tropical testing. The panel finds that many types of tests can be more rigorously conducted at sites in Australia than at sites available in Hawaii.
- The panel sees value in developing a cooperative relationship with the Australian Defence Science and Technology Organisation. A cooperative relationship could enhance testing for both countries in that each has interests and experience in tropical testing. Specifically, existing Australian testing assets that are underutilized could support U.S. testing mission to the benefit of both countries.
- Economics will be an overarching concern in successfully implementing testing in Australia. The panel recommends that U.S. Army Development Test Command conduct an economic analysis of the cost of testing in Australia in comparison to Hawaii.

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I. BACKGROUND HISTORICAL REVIEW

I.1. Introduction.

The major military powers of the world recognize the need for field testing of materiel in the tropics. The U.S. experience in the Pacific in World War II and in Southeast Asia during Vietnam clearly demonstrated the need to test the performance of new equipment in the harsh environmental conditions of the tropics. Since 1960, some 75% of all international and internal conflicts have been in countries whose borders are totally or partially within the tropics. Researchers examining past conflicts to better understand the security threats of the future have reached the conclusion that the countries lying within the tropics are the most likely locations for future conflicts (Smith, 1997; Lee, 1999). Further, studies examining the sources of insecurity posed by global environmental degradation see the tropical regions of Africa and Asia 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 materiel, 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). For the U.S., the mission of testing materiel in extreme natural environments for the Army (U.S. Army, 1979b) resides with the Developmental Test Command (DTC) 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 1990's. Under the terms of the Carter-Torrijos Treaty of 1977, the military mission in Panama was required to relocate from the country by December 31, 1999. In 1998, at the request of Yuma Proving Ground (YPG), the Army Research Laboratory’s Army Research Office (ARO) convened an expert panel to undertake a study to evaluate a number of general areas across the globe that could satisfy the test environment that was being lost as a result of departure from Panama.

This 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 siting 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 (Eppenshade, 1987), very little of this area is considered ideal for tropical testing. Worldwide, 16 areas were identified in the 1998 study (King et al., 1998) as suitable localities for Army tropical testing (Fig. 1). The first group of six geographic areas, ordered in terms of their relative proximity to the continental U.S., included: northern Honduras, the Isthmus of Panama, French Guiana/coastal northeastern Brazil, the southwestern New Guinea Lowlands, low-moderate altitude areas of the East Indies in east-central Java and southeastern Borneo, and the Isthmus of Kra in Malaysia. The premier localities in this group for tropical testing were the Isthmus of Panama and the Isthmus of Kra because both areas offer a spectrum of tropical conditions and environments within a compact geographic area. A second group of ten locations was identified that exhibited the general physiographic and biotic character, but failed to provide one or more of the other important elements considered requisite of the ideal tropical environment for Army testing. This group consisted of coastal Belize, Puerto Rico, southeastern Costa Rica, northwestern Colombia, portions of the Hawai'ian Islands and the Fiji Islands, the Philippines, New Britain-New Ireland, the coastal region of northern Queensland in Australia, and the Bangkok area of coastal Thailand.

In late 1998, guidance was issued directing that the Army tropic test mission be relocated to a US controlled site. In response to this directive, a second study panel was convened in the early part of 1999 to evaluate sites in Hawai'i and Puerto Rico for their capability to support tropical testing. The report, *"A Technical Analysis of Hawai'i and Puerto Rico for Tropical Testing of Army Materiel and Systems* (King et al., 1999), contained a number findings including the fact that Schofield Barracks on the island of Oahu could "adequately" accommodate up to about 80% of the 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, a task now well underway. In addition, 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. Accordingly, YPG requested that an ARO expert panel evaluate specific sites in the northern Queensland area of Australia (Fig. 2), an area identified in the original 1998 report as meeting most of the requisite environmental requirements for tropic testing.

The charter of the scientific panel for the Australia study was to evaluate the suitability of sites in northern Queensland that are currently in use by the Australian Army for tropical training and testing. Three sites identified for detailed assessment were: the Aeronautical and Maritime Research Laboratory (Queensland) located 8 km west of the town of Innisfail at Pin Gin Hill, the Land Command Battle School located 16 km west of the town of Tully, and the Land Command

Cowley Beach Training Area located 15 south and 7 km east of the town of Innisfail (Fig. 2). Descriptions of the three sites and their evaluations are given in Section IV.

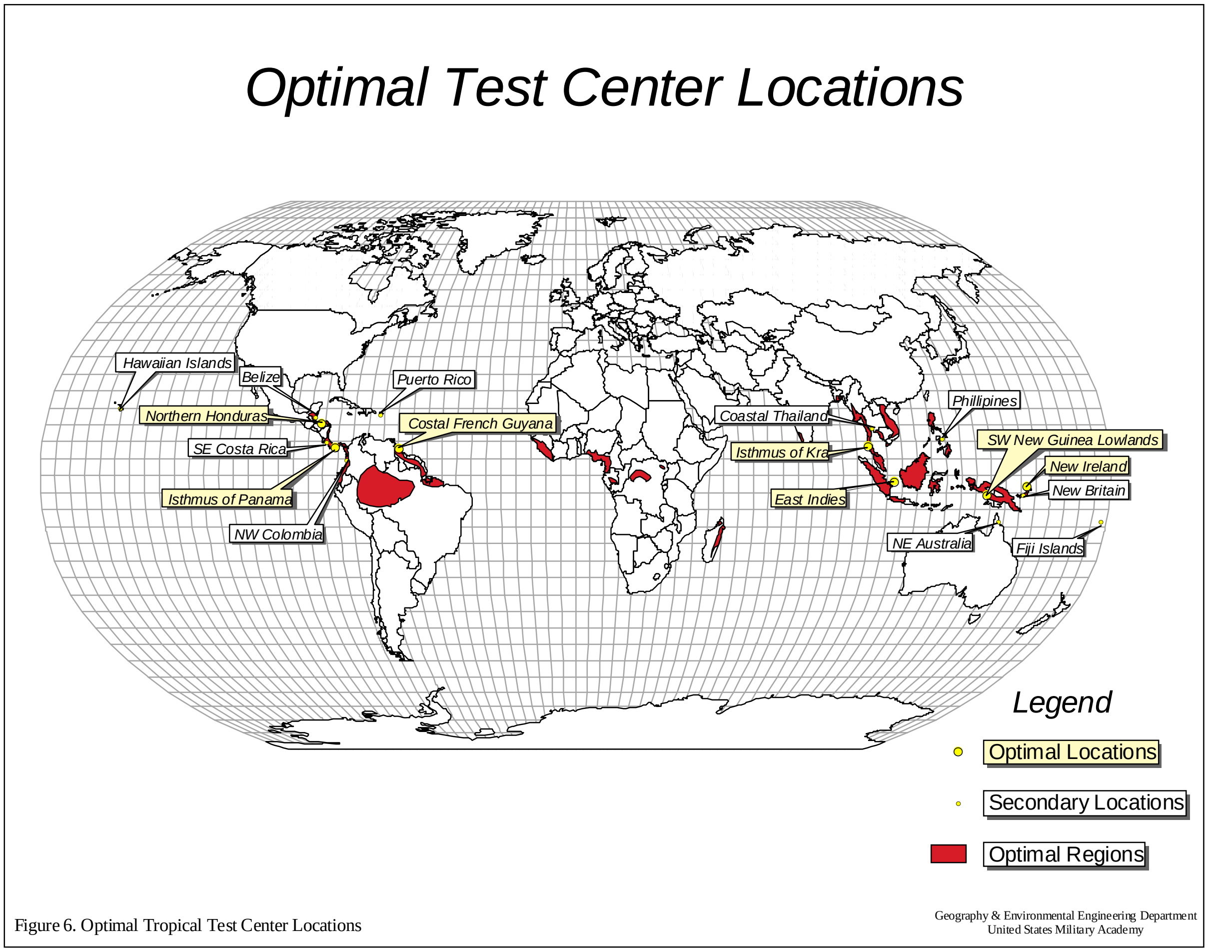


FIGURE 1 - Optimal locations for developmental and operational tropical testing of military equipment, vehicles, and weapon systems (from King et al., 1998)

An important consideration for the successful completion of the follow-on study was for the study panel to fully understand the testing mission and process. Therefore, military personnel and individuals with a military background, who were familiar with the Army requirement for both military equipment testing and training and who could articulate this knowledge, were specifically included in the panel. The membership of the study panel assembled by ARO,together with a brief statement of qualification for each member, is listed in Appendix 1. The specific tasking for the panel is enclosed in Appendix 2.

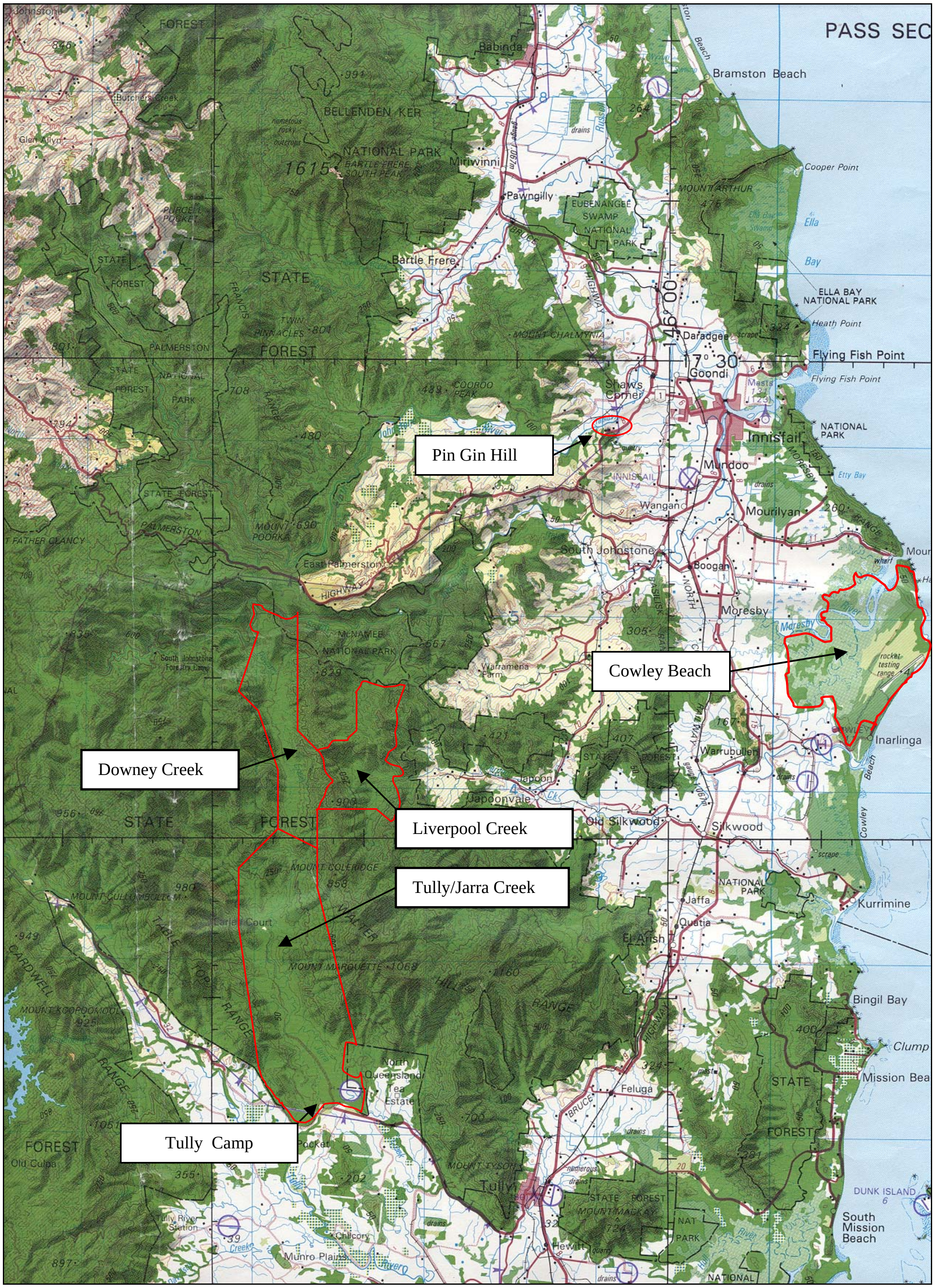


FIGURE 2

Tully-Innisfail Area -- Queensland, Australia

1:250,000 scale, elevation in meters compiled 1984, Royal Australian Survey Corps

I.3. The Ideal Tropical Test Site.

The study panel began its tasking by implementing the analysis model developed during the previous study of Puerto Rico and the Hawai'ian Islands (King et al., 1999). Each of the Australian localities was examined for tropic test mission suitability based on the combined factors of climate, physical, and biological setting, utilizing the hierarchical approach developed by the first panel study (King et al., 1998) in the context of the decision tree model described below. The needs of specific testing missions as defined by YPG were incorporated into the analysis.

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), in which world climates are broadly classified 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 high constant temperature environment. As such, the area encompassing the site should have annual precipitation in excess of 2000 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. Rainfall in any single month would not fall below 100 mm, 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.

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 (^oC):	18 minimum, 27 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 understorey growth. Microbiology: Diverse fauna and decomposer populations	

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 understorey, 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.

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 and fungi, the concerns focus primarily on 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.

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. As in the previous study of Puerto Rico and Hawai'i, it was determined that neither infrastructure elements, geopolitical considerations, nor economics would not be used to place restrictions on location identification because such issues touch upon considerations of policy. The decision tree structure 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, understorey, 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

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 (forest, swamp, grassland)
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

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 zero rating denotes a situation that fails to provide the required setting; a 1 rating denotes a marginal condition that places severe limits on testing; a 2 rating denotes a good setting that meets all critical and most desired criteria; and a 3 rating denotes an excellent setting that is fully capable of supporting the requirement.).

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

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

Mission	Environmental Factors
Equipment Development Testing:	
1) Communication & Electronics	***Understorey, canopy, temperature***, humidity, relief, fauna
2) Ground & air sensors	***Canopy, understorey***, temperature, humidity, rainfall
3) Chemical & biological defense	***Fauna, understorey,*** temperature, relief
4) Environmental exposure	***Humidity, rainfall, fauna, temperature,*** canopy
Operational and Human Performance Testing:	
1) Individual soldier systems	***Temperature, humidity, canopy, understorey, rainfall, relief,*** slope, soils
2) Communication and electronics systems	***Canopy, understorey, fauna, temperature, humidity***, ***relief,*** rainfall
3) Ground and air sensors	**Canopy,** ***understorey***, temperature, humidity, relief, soils
4) Chemical and biological defense	***Understorey, 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	***Understorey, 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	***Understorey***, temperature, humidity, relief, canopy
Coastal Exposure Testing	***Salt sea atmosphere,*** temperature, land use
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understorey, 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 rating for all critical elements (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

I.5. Summary.

The overall procedure that was utilized in this study of three Australian sites implemented the model developed and proven in the course of the first two studies 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.

II. THE TEST MISSION

II.1. Overview of the Testing Process.

All materials will be affected by physical and biological processes to varying extents as a natural consequence of environmental exposure. Microbial deterioration is a function of temperature and humidity, and is an inseparable condition of hot-humid tropics and the mid-latitudes. The rate of material deterioration or performance degradation will depend on such factors as material properties, surface treatment, intensity of the process, and length of exposure. Important factors include solar radiation, temperature, moisture, electrolysis, and chemical or biological attack. Climate has both direct and indirect impacts on material degradation.

The tropical environment is the most diverse and complex natural environment in the world and, consequently, is one of the most challenging for soldiers, equipment, and systems. Modern sophisticated technology, with complex integrated electronic circuitry, is more critically affected by tropical factors than the simpler electromechanical systems of the past. The effects of heat, humidity, direct insolation, corrosive sea spray and salt fog, 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.

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

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

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 [17%]; (iv) coastal exposure testing [1%], 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 understorey, (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. Based on the Panama experience, desired specifications for sites to support this component of the testing mission are as follows:

Inland Jungle Exposure Site. An undisturbed full-canopied jungle site of 40 hectares is required that is characterized by both high temperature and humidity ($T \geq 24°$ C, Relative Humidity [RH] = 95 to 100%) during wet seasons, so as to provide constant high humidity conditions in a surrounding of thick vegetation. Rainfall should be in excess of 2,000 mm per year (optimally, near 2,500 mm). This site should have a well-developed soil and established litter groundcover that supports a robust microbial community. Traditionally, the inland jungle site has been the most heavily used of the TRTC static exposure sites. Facilities for a new site would include open steel mesh cages, plus whatever is necessary to provide for security of test items.

POL Tank Farm Site(s). Storage tank exposure site(s) should be conducted in tank farm areas with facilities for storing and pumping fuels. Approximately 20 hectares were used in Panama for this activity.

Sensor and Communications Test Site. An area of triple canopy jungle is required to provide adequate challenge to both passive and active electromagnetic (EM) based sensors, and communications equipment. The canopy should be pervasive and allow little or no sunlight to pass through. Light penetration is important based on an assumption that if light cannot penetrate the canopy, microwave losses due to absorption/scattering will be very high, thus providing the necessary challenge to the system under test. Ideally, the site is located on a relatively flat remote area. Additionally, the site should be relatively free of RF clutter at the frequencies of interest. The site will be carefully characterized to include the topography, soils and vegetation (species and biomass). This site challenges the ability of sensors and communications equipment to acquire targets located beneath the canopy on the jungle floor.

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 understorey and canopy, and appropriate geomorphic features such as relief, streams, and soils. In actual combat conditions, all of these factors combine to create a dark and foreboding atmosphere that can affect soldiers' attitudes and sense of well-being.

This testing mission requires the most complete suite of the parameters considered requisite to the ideal test environment. Specifications for sites are:

<u>Human Factors Evaluation Area</u>. A dense jungle of 100 hectares is required for conducting squad through platoon level exercises on sloping terrain and through running streams. Slopes should range from 0 degrees to 60 percent. Streams should be available for soldiers to cross by foot (up to 1.5 m deep, 1 to 2 m wide) or for rope bridge construction (waist depth or greater, 5 to 20 m in width). The area must fall at least within the variable High Humidity Climate Type of AR 70-38, with Constant High Humidity Type conditions preferred (Table 2).

<u>Equipment Testing Area</u>. An open field 300 x 300 m is needed for testing individual equipment through a series of tasks, and the negotiation of various obstacles (man-made and natural). Additionally, the area will be used for static testing as well as erecting, striking and using equipment. The area must be sufficiently isolated from cultural clutter (noise, light, etc.) so as to not affect soldier concentration or performance.

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

This activity is focused on the long-term exposure of munitions and testing of small ($\leq$40 mm) and large (>40 mm) weapon systems in tropical environments, in both open and jungle settings. Munitions of all types, particularly larger caliber, are stored for protracted periods to evaluate their stability when subjected to tropical environs. The testing of munitions generates military unique test requirements and, as such, the military infrastructure requirements of established ranges and approved storage areas for munitions must overlay, or be in close proximity to, the environmental test areas. Testing of smokes and obscurants requires relatively flat area in areas of restricted access. 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. Details of the sites needed to accomplish this mission are:

Munitions Storage Site. This site must meet appropriate security requirements, as well as AR 70-38 requirements. Space is needed to construct 10 x 15 m double steel mesh security cages, plus meet explosives safety quantity-distance (separation) requirements. Constant high humidity conditions are needed, with minimums meeting variable high humidity requirements of RH = 74 to 100 %. Daily high temperatures of 25.5 to 35°C are required. Missiles and other specialty type munitions may be stored in their original packing containers, or fully exposed to the environment.

Live Fire Ranges. Ranges must have the capability of firing individual weapons, crew-served weapons, mortars, and artillery. Existing range requirements/regulations will dictate location and land area needed. Ranges will be characterized as either static ranges or maneuver ranges. Maneuver ranges will be required for the squad to react to contact, platoon ambush, raid, and attack. Live fire exercises will require various types of targets and, in some cases, fixed structures, depending upon the established test conditions.

II.2.D. Coastal Exposure Testing.

This activity tests the rate of degradation of all types of materials when exposed to a sea salt fog and the ocean environment. High salt levels coupled with solar radiation, warm tropical temperatures and abundant moisture result in a highly corrosive environment. Typically, several exposure sites are aligned with the prevailing winds in a direct line inland from the coast over a distance of no more than one kilometer. The airborne salt content decreases at each of the sites progressing inland, which allows for comparative analysis of materials at varying, but reasonably predictable levels of airborne salt. This type of exposure testing of materials is usually long-term with some tests conducted for periods of up to 20 years. Environmental requirements are coastal sites that have high levels of airborne salt, prevailing onshore winds to carry airborne salt inland, and reasonably level topography upon which to establish the exposure sites. Five sites necessary to meet these requirements are:

Breakwater Site for Salt Spray. A fenced area 50 x 100 m at the wave breakwater/shore interface.

Coastal Site for Salt Fall. A fenced area of ½ to 1 hectare within 200 to 300 m of the breakwater site.

Open Inland Site. A fenced area of ½ to 1 hectare within a clearing, preferably 800 to 1,000 m from the breakwater site.

Marine Underwater Site. A small site (10 x 10 meters) for exposure of material samples and equipment (such as SEAL gear) for various periods of immersion in salt water.

Coastal and River Site. There is an infrequent requirement to evaluate equipment used by Army Special Forces while conducting waterborne operations. Site(s) must be accessible both to "blue" (open coastal) and "brown" (estuarine/river) water.

II.2.E. Vehicle Mobility.

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

Vehicle Mobility Areas. Areas are needed to evaluate mobility, performance, and cooling abilities of vehicles. Requirements include improved and unimproved roads, grasslands for cross country mobility tests, beach areas for amphibious vehicles, water fording sites, and tropical swamp areas including mud, vegetation, root entanglement conditions, etc. Slopes must range from 0 to over 60%. Steep sloped roads need to support testing for large vehicles; current requirements are for vehicles of 25 m in length. Total road and off-road course lengths typically cover several miles to allow safe concurrent operation by several users.

II.3. Other Considerations.

II.3.A. Operational Testing.

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

II.3.B. New Technologies.

In addition to the ongoing testing requirements described above, a vision for future requirements includes the need to test new technologies being developed for the 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). New 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. Additionally, 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 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.

II.3.C. Modeling and Simulation.

Future test technologies to assess performance will require increased sophistication, one aspect of which will be an enhanced reliance on modeling and simulation in the virtual environment to support development and evaluation. Additionally, the test community will have greater flexibility in meeting customer requirements for test data and evaluation through new approaches to modeling and simulation. Therefore, a program has been initiated by YPG to produce digital environmental reference models for virtual modeling and simulation. To accomplish this objective, a set of "Master Environmental Reference Sites" (MERS) has been established at extreme climate test sites under the command of YPG for long-term, in-depth environmental characterization. These carefully characterized MERS will be reference sites for the Virtual Proving Ground (VPG).

III. GENERAL OVERVIEW OF THE STUDY AREA IN AUSTRALIA

III.1. Physical Geography.

Australia (Figure 3) encompasses a land area of approximately 7,686,850 km^2, about 80% the size of Canada and only slightly smaller than the United States (Moschovitis, 1996). The Commonwealth of Australia is made up of six states (Queensland, New South Wales, South Australia, Tasmania, Victoria, and Western Australia) and two territories (the Australian Capital Territory and the Northern Territory).

Situated in Oceania between the Indian and South Pacific Oceans, Australia sits astride the Tropic of Capricorn in the southern hemisphere and extends from about latitude 11 to 44°S, and longitude 113 to 153°E. It is an island continent, bounded on the north by the Timor Sea, the Arafura Sea, and the Torres Strait; on the east by the Coral Sea and the Tasman Sea; on the south by the Bass Strait and the Indian Ocean; and on the west by the Indian Ocean. As the world's smallest continent (but sixth largest country in area), Australia is a broad landmass that extends about 4,000 km from Cape Byrne (near Brisbane) on the east coast to Exmouth (north of Perth) in the West, and about 3,700 km from Cape York (in northern Queensland) in the north to Cygnet (just south of Hobart) in Tasmania in the south.

Australia is unique in that it is both an island and a continent that has evolved in isolation over the past 60 million years after separating from Gondwana and drifting to the north. The continent's flora and fauna are also unique, in large part due to the physical isolation. Based on climate and relief, Australia can be divided into four natural regions: the humid eastern highlands, the tropical savannas of the north, the Mediterranean coastal areas of the southwest and south, and the dry interior. The humid eastern highlands are dominated by the Great Dividing Range, which varies in width from about 150-400 km, running parallel to the east coast, extending from Cape York in the north to Victoria in the southeast. The range provides the drainage divide for rivers flowing eastward into the Coral Sea and South Pacific and those draining into the interior.

Topographically, the continent is a land of low relief, dominated by low tablelands and plateaus, with coastal lowlands on much of the fringe. The ancient surface of the continent has long been exposed to weathering, leaching most of the soil's important nutrients and rendering vast areas of the continent unproductive in terms of vegetation. With the exception of the Great Dividing Range just inland from Australia's eastern coast, where elevations just exceed 2,200 m, the country lacks substantial local relief. Maximum elevations occur within the Great Dividing Range, with Mount Kosciusko being the country's highest peak at 2,228 m, although most of the relief varies from 300-600 m in elevation.

One geographic feature of particular significance is the Great Barrier Reef, which extends more than 2,000 km along the east coast from Cape York in the north to Bundaberg in the south. This unique ecosystem is the world's largest coral reef system.

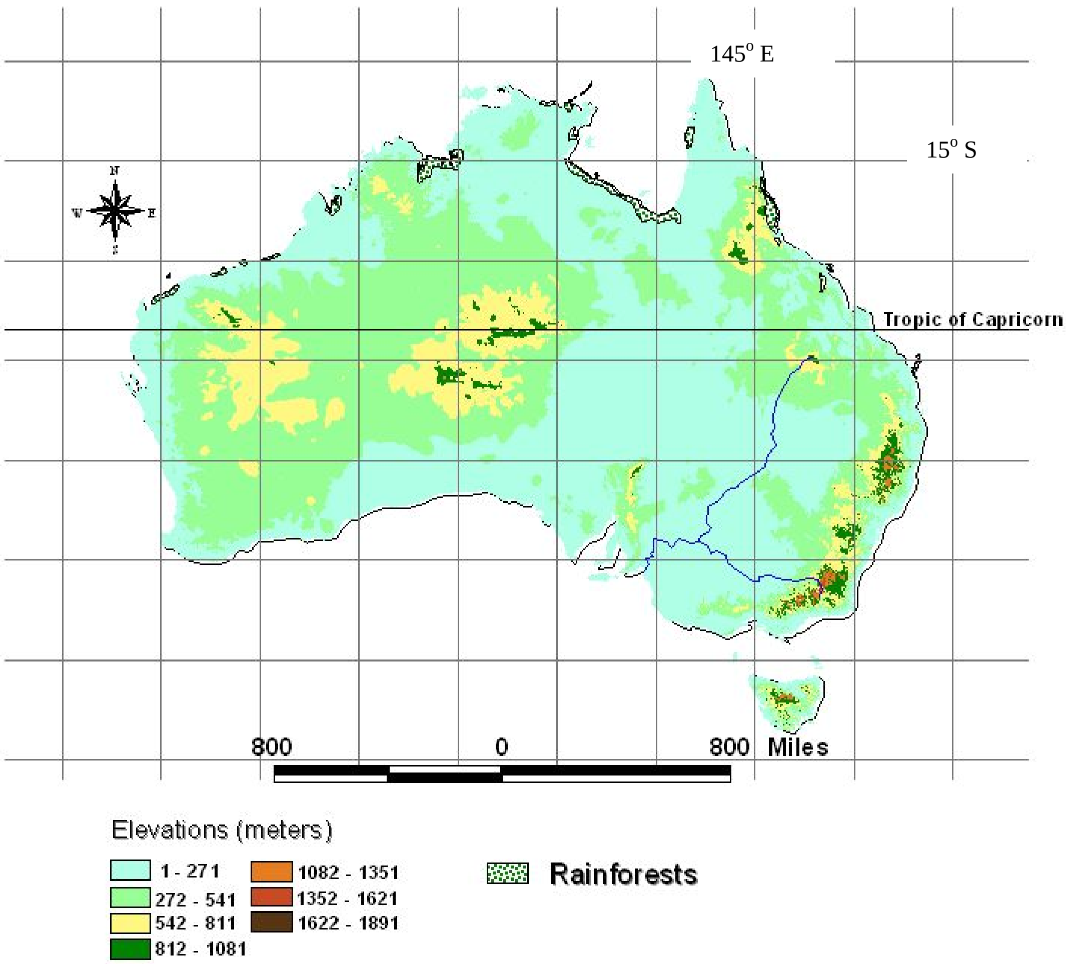


FIGURE 3 - Australia including Rainforests

SOURCE: ESRI data base, 2000.

Most relevant to this study is Australia's tropical rainforest, which exists in fragmented parcels mostly along the northern coast (see Figures 3 and 4C). Here the variables of temperature, precipitation, length of day, and soil, combine to yield one of the most biologically diverse areas in the world. Figure 4A indicates that the precipitation is a controlling factor isolating rainforests in particular areas at this latitude; and clearly, precipitation in excess of 1.5 meters per year is located only in a few coastal areas of Queensland.

III.2. Climate.

The climate of Australia varies from monsoonal to tropical in the north to temperate in the southeast and Tasmania, with the interior country hot and dry. More than two-thirds of continental Australia, in the west and center of the country, receives less than 500 mm of precipitation a year, and one-third is desert with less than 250 mm of rain annually. Only 10% of Australia in the north, along the eastern and southwestern coasts, and in Tasmania receives more than 1,000 mm of rain a year. Maritime conditions exert little moderating influence beyond the coast, and the highland area of the Great Dividing Range is too small and low to have more than a local climatic effect. Two-thirds of Australia is desert with a semi-arid to arid climate. With one exception, permanent rivers are limited to the wetter eastern and southern margins of the continent, and to Tasmania. The Great Dividing Range is the watershed for the eastern half of Australia. On its eastern flanks, permanent rivers flow to the Coral Sea and South Pacific Oceans. In the area of northern Queensland (of interest to this study), the Johnstone River, the Moresby River, and the Tully River are the major rivers flowing from the Great Dividing Range to the coast.

The tropical regions of Australia are warm and humid, with wet tropical environments found within all four physiographic regions of Queensland (the Eastern Highlands, the Western Plains, the Northwestern Uplands, and the Coastal Plain). The climate across these regions is controlled primarily by the annual fluctuation of the Asian High Pressure Cell Track, which determines the geographic position of the Southeast Trades Winds in the winter and the Asian and Australian Monsoons in the summer. The tropical northern coastal region of Australia has two main seasons: a hot, wet season when the north-western monsoons prevail and a warm dry winter season characterized by the prevalence of south-easterly trade winds. The monsoon reaches inland for varying distances, extending furthest in the Cape York Peninsula. Rainfall in the study area is strongly seasonal and can be highly variable on an annual basis. During the Austral winter (June-November), comparatively high pressure develops over central Australia leading to offshore Southeastern Monsoon airflow and atmospheric conditions that generally are unfavorable for precipitation. Warm sea surface temperature in the Coral Sea off northern Australia, combined with intense heating of the arid interior, produce a persistent low pressure center over the continent during Austral summer (December-May), with the resulting inflow of moist, unstable tropical air masses.

As a result of this climatic setting, heavy convectional rainfall characterizes the summer months in northern Queensland. Many points on the northern and northeastern coast have an average annual rainfall exceeding 1,500 mm and averages 2,540 mm around the Innisfail area. Throughout the Coastal Plain and Eastern Highland regions of northern Queensland, where daily sunshine averages about 3000 hours per year (i.e., 9 hours a day), maximum summer temperature

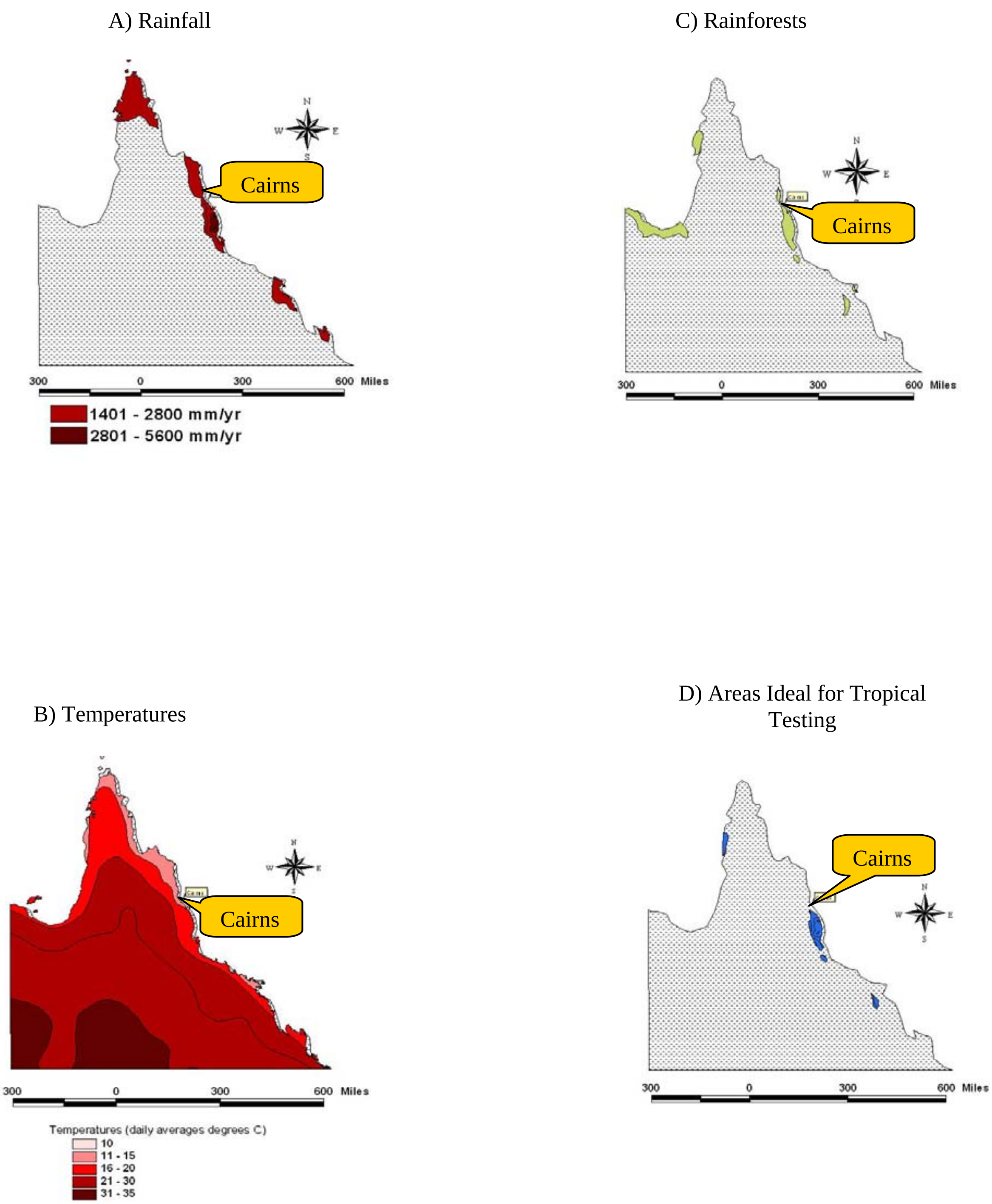


FIGURE 4

Tropical Environmental Locations in Queensland

is around 30°C, and minimum winter temperature only infrequently falls below 20°C. Mean evaporation on Coastal Plain region of northern Queensland varies between 2,500-3,000 mm/year.

The prevailing southern high-pressure system results in southeastern airflow across northern Queensland throughout the summer. In the summer, monsoonal northwesterly winds affect most of the tropical northern portion of Queensland. Along the coast, east to southeasterly winds prevail during the morning, changing to northeasterly later in the day. Gale force winds are a regular occurrence along the coast during the summer months. Downdrafts from large thunderstorms can produce destructive wind gusts. Tropical cyclones are a major natural hazard for northeastern Australia during the summer months.

The focus of the present study (Figure 4) is an area of northern Queensland east of the Atherton Tablelands to the coast, between the towns of Innisfail (17^{o}32'S, 146^{o}02'E) and Tully (17^{o}57'S, 145^{o}46'E). This area, which lies within the region of highest rainfall in Australia, comprises two distinct physiographic elements, the Great Dividing Range and the Eastern Coastal Plain, both of which extend parallel to the east coast of the country from the Cape York Peninsula to southern Australia. The Great Dividing Range generally is characterized by low hills and plateaus that form a topographic barrier to moisture transport by the Southeast Trade Winds. Therefore, large amounts of precipitation fall on its steeper eastern slopes and the natural vegetation is tropical rainforest. The Eastern Coastal Plain, which also is a high rainfall area because of its position adjacent to the eastern slopes of the Great Dividing Range, is highly variable in width but averages between 10-20 km wide in the study area. The rainforest region of northern Queensland is characterized by a variety of local climates that derive from mountain massifs of different sizes, a variety of bedrock protoliths and associated derived soil types, altitudes from sea level to 1,600 m, and annual rainfall gradients away from the coast of 1,300-4,000 mm (Isbell, 1968; Tracey, 1982). In terms of natural hazards, drought affects some part of Australia in most years, and localized floods and tropical cyclones are common. The Innisfail-Tully area receives an annual average of 3,000-4,000 mm of rainfall, whereas nearby mountainous areas such a Bellebden, Ker, and Bartle Frere typically receive an annual average of 7,000-8,000 mm of precipitation. The seasonal nature of precipitation in the study area is illustrated for Innisfail in Figure 5. Rainfall for the three driest months (August-October) averages less than 95mm/month, compared to the three wettest months (January-March) that have an average of 600 mm/month. Figure 5 also illustrates the seasonal temperature pattern. The mean annual temperature at Innisfail is 23 ^{o}C.

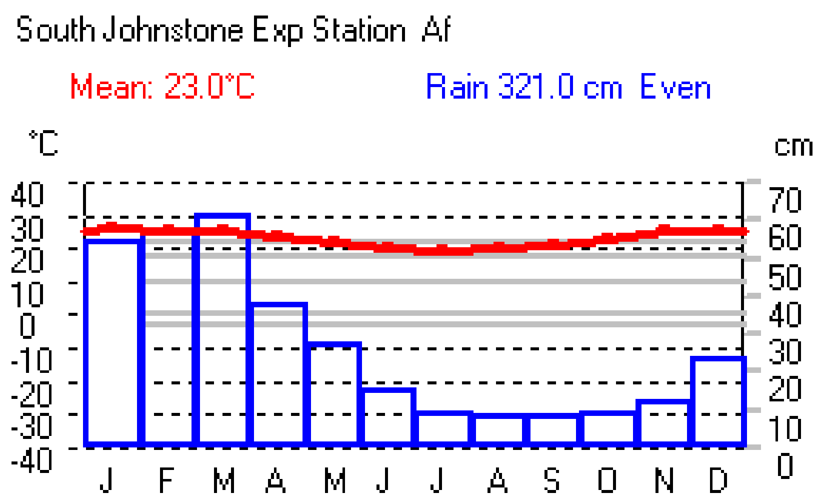


FIGURE 5 - Innisfail Climate Graph

SOURCE: Commonwealth of Australia, 1999.

III.3. Geology and Geomorphology.

Much of Australia is geologically ancient, with most of the continent underlain by a Precambrian metamorphic and igneous basement that ranges in age from 4,300 to 570 million years old. Originally a part of the ancient supercontinent of Pangaea, Australia subsequently was part of the Paleozoic megacontinent of Gondwanaland. During Jurassic time, less than 200 million years ago, Australia and Antarctica rifted from Gondwanaland and began to move eastwards and northwards. Australia emerged as a separate continent about 100 million years ago, when Antarctica broke away and drifted southward. Australia is still moving northwards, away from Antarctica and is in the process of merging with Asia. The Great Dividing Range, which forms the N-S trending orogenic belt along the eastern margin of the continent, is comprised of thick sedimentary rocks that were deposited in the Tasman Geosyncline during Palaeozoic time between about 600 to 250 million years ago. Compressive subduction activity during this time folded and buckled these rocks at least twice, forming thick metasedimentary sequences, intrusive granitic mountain ranges, and chains of basaltic-andesitic island-arc volcanoes. As the Australian continent enlarged during the Paleozoic, depressions developed that were infilled predominantly by non-marine sediments eroded from adjacent upland areas. Cenozoic volcanism and sedimentation associated with extension occurred over much of Queensland, with lava flows forming the widespread plateau features that characterize this region.

Four main geomorphic provinces are present in northeastern Australia: (i) the Eastern Highlands, (ii) the Western Plains, (iii) the Northwestern Uplands, and (iv) the Coastal Plain (including islands and coral reefs). The sites examined in this study lie within the Eastern Highlands (Tully/Jarra Creek and Pin Gin Hill) and the Coastal Plain (Cowley Beach). Landforms within the Eastern Highlands consist of the mountain ranges, plateaus, and isolated peaks of the Great Dividing Range and their associated river drainages. The Coastal Plain is a narrow region of low-relief along the Pacific margin of the region that consists predominantly of fluvial and minor deltaic sedimentary deposits, and associated stabilized sandy soils, derived by fluvial erosion from the Eastern Highlands. Much of the local relief of the coastal region is determined by the shape and configuration of sand dunes that were deposited during the Quaternary.

Two lithologies form the predominant bedrock in the two study sites located on the eastern side the Eastern Highlands, the thick metamorphic flysch sequence of the Silurian-Devonian age (the Barron River Metamorphic Group) and the Late Paleozoic granitoid intrusives and basaltic volcanics of the Coastal Range Igneous Province (Arnold and Fawkner; 1980, Richards, 1980). Typically, streams in this area tend to be incised in steep-sided channels that have developed along predominant vertical joints or traverse broad rock slabs of massive granite in wide, shallow channels. During the Cenzozoic, sequences of basaltic volcanics, occasionally interbedded with continental sediments, were erupted across the region. In the study area, their spatial location and thickness (0-200 m) is consistent with valley infilling. An extended episode of weathering occurred during the Late Miocene that was characterized by the development of deep lateritic weathering profiles throughout the region. Holocene alluvial and lacustrine deposits occur ubiquitously in valley floor settings within the Great Dividing Range at elevations up to about 100 m. Piedmont fan deposits of sand, silt, and minor gravel related to changes in base-level erosion during the Holocene, are common on the landward margin of the coastal plain and here large terrace remnants are preserved as interfluve surfaces.

The study site on the Coastal Plain consists of Quaternary marine deposits and landforms formed over the past 2 million years (Murtha, 1986). A tidal flat and beach dune ridge and swale topography defines the eastern half of the Cowley Beach Training Area, whereas the western portion of the area consists of fluvial flood plain deposits and peat deposits that have formed in freshwater swamps that occur along the margins of the estuarine and beach ridge deposits. Isolated upland inliers of consisting of gneisses and schists of the Barron River Metamorphic Group are present on the coastal plain.

III.4. Surface Hydrology.

The total annual evapotranspiration across the region is estimated to be less than 2,000 mm, but can be as low as 1,270 mm in southeastern Queensland (State Public Relations Bureau, 1980). Since precipitation is two to three times as great as evapotranspiration, a considerable precipitation surplus exists, which causes considerable surface runoff.

Stream flows are quite variable. The peak river runoff occurs in the winter months from January through March, whereas stream discharges are lowest during the June through November timeframe. Stream discharge on a monthly basis is highly variable. For example, during February the Herbert River at Ingham has a maximum monthly discharge that is 3.5 times greater than the average, whereas the minimum discharge during the month can be as low as 10% of the average discharge (State Public Relations Bureau,1980). The maximum daily peak discharges are likely to occur during tropical low-pressure storms and cyclones that develop on the monsoonal trough and commonly produce daily total rainfalls of more than 250 mm (Australian Heritage Commission, 1986). In 1977, one area of the lower foothills of the coastal range near Babinda, south of Cairns, received nearly one quarter of the annual total rainfall of 5,200 mm in five consecutive days in February (Bonsell et al., 1983). An unofficial report mentioned a storm in January 1951 that produced 1,000 mm of rain in five hours.

The high rainfall intensity, combined with saturated soil profiles, leads to widespread overland flow occurs on the forested hill slopes throughout northern Queensland, not only on steep slopes but on moderate ones as well. This overland flow occurs instantaneously with the onset of intense storms at any time from December through mid-June (Bonell et al., 1983). The common occurrence of widespread overland flow on the forested slopes of northern Queensland appears to be unique in the world. Studies in other wet tropical rain forests in Central America, Amazonia, Malay Peninsula, Sarawak and West Africa pointed to the unimportance of widespread overland flow as distinct from highly localized saturation overland flow in valley bottoms (Walsh, 1980). In fact, the virtual absence of widespread overland flow is regarded as characteristic of wet tropical rain forests. In this respect, the rain forests of northern Queensland are exceptional (Australian Heritage Commission, 1986). The widespread occurrence of overland flow leads to erosion, even in undisturbed areas. Although plant root systems protect the soil to a major extent, soil losses under natural conditions have been estimated to be on the order of 8 tons per hectare per year. On cleared land, soil losses can be as high as 400 tons per year (Australian Heritage Commission, 1986; Bonell et al., 1983).

III.5. Soils.

All soil types are found on the Australian continent, but poor and mediocre soils with low organic content predominate throughout the country. Rich, high-quality alluvial soils derived from volcanic rock protolith are common only in the northern Queensland area (of the areas of interest to this study). Soil depths in the study area are highly variable, ranging up to about 4 m (Graham and Hopkins, 1983), and it is likely that many granite soils profiles are relatively young (Isbell et al., 1968).

Depending on the specific composition of the parent material, soils derived from protoliths on rugged metamorphic terrain tend to be either podzolic red loams and clay loams of uniform texture that contain variable amounts of silt and sand, or yellow loams to clay loams that frequently contain a high proportion of sand (Graham and Hopkins, 1983). Internally well-drained soils are found in-situ and on colluvial fans sites where parent metamorphic rock weathers to form a permeable soil; whereas, poorly-drained soils occur where weathering results in fine-grained impermeable soils. Granite-derived soils tend to have gradational profiles comprised of sandy loams (A horizon) to sandy clay loams (B horizon) of red color that change to sandy clays, increase in residual quartz content, and merge with the decomposed granite protoliths at a few meters depth. Ridge tops above 200 m elevation tend to be characterized by red podzolithic soils (Graham and Hopkins, 1980). Soils developed on the Cenozoic basalts tend to be nutrient rich red loams and clay loams that lack quartz (Gillman, 1976; Isbell et al., 1976). Typically, such soils are well drained. Brown basaltic soils are also present but less common. Soils on alluvial deposits are highly variable (Graham and Hopkins, 1980, 1983). On the oldest, high-level terraces, where surfaces frequently are covered with a veneer of quartz sand, soils tend to be either brown-yellow sandy loams with red-brown A horizons, or dark earthy loamy sand with dark gray to brown A horizons, and brown sandy loam B horizons that contain lenses of rounded granite gravel and quartz sand. Soils developed on the terrace deposits typically tend to be fine sandy loams to silty clay loams of a pink to yellow color with some subsoil structure typically present in the upper half meter. Mid- to low- elevation terraces tend to be characterized by fine sandy loams to silty clay loams of variable texture that contain a variable content of gravel and boulders at depth. The lowest terraces adjacent to active stream channels have poorly developed silty clay loam soils. Yellow soils occur where drainage is impeded on lower and middle slopes. Such poorly drained soils tend to be characterized by a dense fan palm understorey. Soils near the coast tend to be deep uniform beach, beach ridge, and dune sands that overlie and change to sandy loams toward the coastal plain (Murtha, 1986). Swampy areas contain accumulations of organic material that overlie sequences of strongly gleyed sand, clayey sand, and clay. Acid sulfate soils are present at swampy coastal sites.

III.6. Vegetation.

Australia has a distinctive flora, comprising some 22,000 species of plants. More than 90% are indigenous, and many species are not found elsewhere. Predominantly evergreen, vegetation ranges from the dense bushland and eucalyptus forests of the coast to mulga and mallee scrub and saltbush of the inland plains. Australian plant life is distributed in three main zones: (i) a tropical zone, (ii) a temperate zone that covers the south-eastern coastal area, including Tasmania, and runs up the eastern coast to meet the tropical zone, and (iii) an Eremian Zone that occupies the whole of the arid central and western portions of the continent.

The tropical zone, with its monsoonal climate and high temperatures, is heavily forested, mainly with deciduous trees. Rainforests predominate along the coast of northern Queensland, and on the Cape York Peninsula. Palms, ferns, and vines grow prolifically among the oaks, ash, cedar, brush box, and beeches. Mangroves line the mud flats and inlets of the low-lying northern coastline.

The region of northern Queensland, in which the study area is located, (Fig. 4C) contains the largest continuous area of tropical rainforest in Australia. More than 40% of the original area of rainforest has been cleared for agriculture or the grazing of livestock (Tracey, 1982). The current vegetation classification for Queensland rainforest (Table 6) was developed by Webb (1978) and mapped by Tracey and Webb (1975) and includes a total of 11 distinctive forest types (and associated sub-forest types), distributed according to the local altitude, rainfall, and soil characteristics, that range from tall, multi-canopy lowland evergreen rainforest (Type 1a) at higher elevations to small-leafed deciduous scrublands (Type 11) in dry lowland area with poor soils.

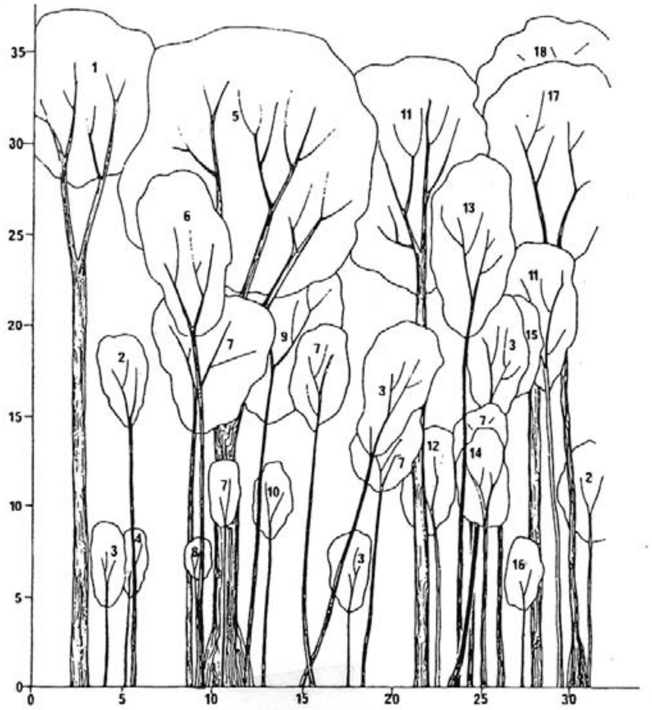
The best developed, tall (35-40 m) closed canopy rainforest (Type 1) is developed on basaltic soils and alluvium, with a typical forest profile and associated floristics as illustrated in Figure 6.

TABLE 6 –

Classification of main rain-forest types in north Queensland in relation to rainfall, altitude, and soil parent materials, as mapped by Tracey and Webb (1975).

Rain-forest type
Complex mesophyll vine forest (CMVF)
1*a*. Very wet and wet lowlands and foothills; basalts, basic volcanics, mixed colluvium on foot-slopes and riverine alluvia
1*b*. Very wet and wet cloudy uplands; basalts
1*c*. Moist and dry lowlands; riverine levées (gallery forests)
Mesophyll vine forest (MVF)
2*a*. Very wet and wet lowlands and foothills; granites and schists
2*b*. Very wet and wet lowlands; beach sands
Mesophyll vine forest with dominant palms (MFPVF)
3*a*. Very wet lowlands, feather-leaf palm *(Archontophoenix)* swamps, basaltic and alluvial soils
Mesophyll vine forest with dominant palms (Contd.)
3*b*. Very wet lowlands and lower foothills; fan-leaf palm *(Licuala)*, seasonally impeded drainage, schists and granites
Semideciduous mesophyll vine forest (SDMVF)
4. Moist and dry lowlands and foothills; granites and basalts
Complex notophyll vine forest (CNVF)
5*a*. Cloudy wet highlands; very limited areas of basalt and basic rocks
5*b*. Moist and dry lowlands; foothills and uplands, basalts
Complex notophyll vine forest (with emergent *Agathis robusta*) (CNVF + emergent *Agathis robusta*)
6. Moist foothills and uplands; granites and schists
Notophyll vine forest (rarely without *Acacia* emergents) (NVF + *Acacia* emergents)
7*a*. Moist lowlands and foothills along coast including islands; granites and schists
7*b*. Moist and dry lowlands; beach sands
Simple notophyll vine forest (often with *Agathis microstachya*) (SNVF + *Agathis microstachya*)
8. Cloudy wet and moist uplands and highlands; granites, schists, and acid volcanics
Simple microphyll vine-fern forest (often with *Agathis atropurpurea*) (MFF + *Agathis atropurpurea*)
9. Cloudy wet highlands; granites
Simple microphyll vine-fern thicket (MFT)
10. Cloudy wet and moist wind-swept top-slopes of uplands and highlands; granites
Deciduous microphyll vine thicket (DVT)
11. Dry lowlands and foothills; granite boulders

SOURCE: Graham and Hopkins, 1980.



1. *Beilschmiedia* sp.aff. *B. oligandra* BRI. 138203
2. *Opisthiolepis heterophylla*
3. *Endiandra tooram*
4. *Cryptocarya mackinnoniana*
5. *Eugenia gustavioides*
6. *Endiandra sankeyana*
7. *Citronella smythii*
8. *Toechima erythrocarpum*
9. *Sloanea macbrydei*
10. *Litsea leefeana*
11. *Prunus turnerana*
12. *Cryptocarya angulata*
13. *Castanospora alphandi*
14. *Endiandra pubens*
15. *Endiandra sankeyana*
16. *Agliaia ferruginea*
17. *Dusoxylum pettigrewianum*
18. *Gmelina fasciculiflora*

Floristics

CANOPY. *Acmena graveolens, Argyrodendron peralatum, Alstonia scholaris, Castanospermum australe, Dysoxylum pettigrewianum, Elaeocarpus grandis, Ficus pleurocarpa.*

SUBCANOPY. *Cryptocarya mackinnoniana, Endiandra pubens, Flindersia acuminata, Myristica muelleri, Sterculia laurifolia.*

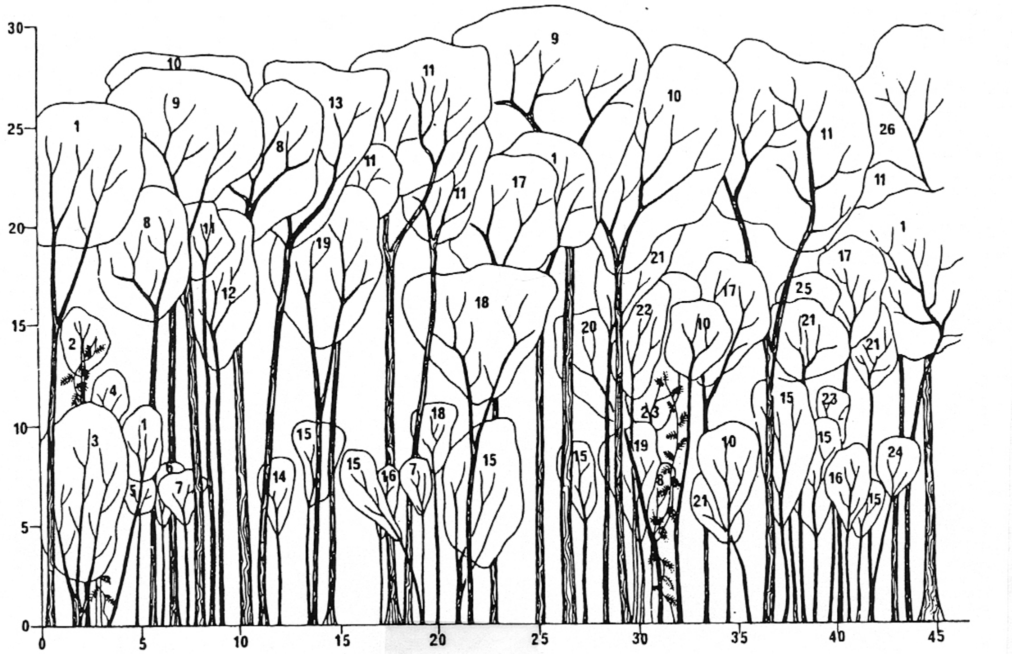
GROUND LAYER. *Calamus* spp. *Pandanus monticola, Bowenia spectabilis.* Ferns include species of *Blechnum, Callipteris, Diplazium, Lindsaea* and *Tectaria,* the tree fern *Cyathea woollsiana.* Also prominent are *Selaginella longipinna, Corymborkis veratrifolia,* and giant fleshy herbs notably zingibers – e.g. *Alpinia arctiflora, A. modesta, A. racimigera, Amomum dallachyi, Hornstedtia scottiana, Tapeinocheilos pungens,* the aroid *Alocasia macrorrhiza,* the banana *Musa banksii.*

. LIANES. *Calamus australis, C. moti, Bambusa moreheadiana, Connarus conchocarpus, Faradaya splendida, Merremia peltata.*

EPIPHYTES AND HEMI-EPIPHYTES. *Arthropteris palisotii, Asplenium nidus. A. simplicifrons, Drynaria rigidula, Ficus scandens, Freycinetia excelsa, Piper banksii, P. mestonii, Platycerium bifurcatum, P. superbum, Pothos longipes, Rhaphidophora australasica, R. pachyphylla, R. pinnata, Schefflera actinophylla.*

FIGURE 6 – Complex Mesophyll Vine Forest in Australia (type 1a)

SOURCE: Graham and Hopkins, 1980.



1. *Gillbeea adenopetala*
2. *Darlingiana darlingiana*
3. *Apodytes brachystylis*
4. *Polyosma hirsuta*
5. *Citronella smythii*
6. *Prunus turnerianum*
7. *Polyalthia nitidissima*
8. *Carnarvonia araliifolia*
9. *Flindersia pimenteliana*
10. *Doryphora aromatica*
11. *Cryptocarya oblata*
12. *Grevillea pinnatifida*
13. *Eugenia kuranda*
14. *Palaquium glactoxylon*
15. *Brombya platynema*
16. *Helicia nortoniana*
17. *Endiandra sankeyana*
18. *Endiandra hyptoephra*
19. *Dysoxylum klanderi*
20. *Randia fitzalani*
21. *Endiandra tooram*
22. *Endiandra montana*
23. *Kissodendron australianum*
24. *Toechima erythrocarpum*
25. *Cryptocarya mackinnoniana*
26. *Sloanea macbrydei*

Floristics

CANOPY. *Alstonia muellerana. Cardwellia sublimis. Cryptocarya mackinnoniana. Darlingia darlingiana, Doryphora aromatica, Dysoxylum klanderi, Endiandra montana, Eugenia* sp.nov. (BRI 126045), *Flindersia pimenteliana, Grevillea pinnatifida, Palaquium galactoxylon, Podocarpus neriifolius. Sloanea macbrydei, Xanthophyllum octandrum.*

SUBCANOPY. *Archontophoenix alexandrae, Arenga appendiculata, Austromyrtus minutiflorus, Brombya platynema, Delarbrea micheana, Guioa acutifolia, Helicia nortoniana, Lepidozamia hopei, Licuala ramsayi, Pilidiostigma tropicum, Polyosma hirsuta, Ptychosperma elegans, Randia fitzalani.*

UNDERSTOREY. *Bowenia spectabilis, Cyathea rebeccae, Eugenia wilsonii, Lasianthus strigosus, Linospadix intermedia, Pandanus monticola.*

GROUND LAYER. *Blechnum cartligineum, Selaginella longipinna.*

LIANES. *Calamus australis, C. moti, Connarus conchocarpus, Derris trifoliata, Hypserpa laurina, Lygodium reticulatum, Melodinus acutiflorus, Melodorum uhrii, Strychnos colubrina, Tetracera nordtiana.*

EPIPHYTES. *Arthropteris palisotii, Freycinetia excelsa, F. scandens, Pothos longipes.*

FIGURE 7 – Mesophyll Vine Forest in Australia (type 2a)

SOURCE: Graham and Hopkins, 1980.

The Type 2 rainforest that develops on poorer granitic and lowland soils (Fig. 7) is of slightly lower stature (30-35 m). As illustrated in the two figures, both rainforest types comprise a complex, multi-layered, closed canopy structure that is representative of typical tropical rainforest.

The hot, humid tropics is one of Australia's most biodiverse environments. Because of its high biodiversity and rapid disappearance through deforestation for logging and agriculture during much of the 20th century, the Australian Federal government created the Wet Tropics World Heritage Area in northern Queensland during the late 1980's. The area designated for protection encompassed virtually all remaining large tracts of rainforest between 15-19^{o}S under both government and private ownership, including the military training areas at Tully-Jarra Creek and Cowley Beach (Fig. 2). World Heritage status places significant environmental controls on the use and modification of lands so designated. Current Australian Army training activities are subject to World Heritage monitoring and compliance.

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IV. SITE CHARACTERIZATION

IV.1. The Pin Gin Hill Site. The area recognized as Pin Gin Hill is located approximately 8 kms west of Innisfail and 87 km south of Cairns in northern Queensland. The area is located (Fig. 2) at latitude 17° 32′ 30″ S, and longitude 145° 57′ 00″ E. Supplemental data and photos of the area are provided in Appendix 3 of this report.

Area Size. The areal extent of Pin Gin Hill is 35½ hectares, of which 1½ hectares are devoted to the headquarters, laboratories, administrative buildings, and test facilities. The remaining land is comprised of second growth tropical rain forest available for testing activities.

Slope and Relief. The Pin Gin Hill site lies approximately 40-60 m above sea level and is set on a gently undulating land surface formed on a Cenozoic basalt flow (CSIRO, 1985; Stephenson et al., 1980). The forested area of the site is dissected by deep gullies. Slopes in Pin Gin Hill are less than 15 percent, over horizontal distances of less than 100 meters. Relief significant to the testing mission is absent from the area.

Soil. The soils are typical for a basalt area and consists of kraznozems, i.e. red, strongly structured clay soils (CSIRO, 1985).

Land Use/Ownership. The facilities at Pin Gin Hill date to the early 1960's and were designed and equipped to undertake visual, chemical, and physical evaluations of materials, both during and after exposure (Department of Defence, Joint Tropical Trials and Research Establishment) [JTTRE, 1997]. Most activity has been undertaken within the 1 and ½ hectares of hot-wet, cleared land. The hot-wet jungle area comprises 34 hectares of secondary rainforest that is located immediately adjacent to the cleared site. The former permits testing under different climate and vegetative conditions. Activities have focused on the static and mechanical testing of materials and equipment. The Pin Gin Hill lands are State lands that are leased by the military.

Adjacent Land Use. Pin Gin Hill is situated north of, and adjacent to, the Palmerston Highway. Scattered residential dwellings and dispersed farmsteads occur in neighboring, privately owned lands. Principal agricultural activities include cattle-raising and the production of sugar cane and bananas.

Cultural/Historical. Since its establishment in 1962, testing activities at Pin Gin Hill have been largely restricted to the static and mechanical testing of materials and equipment within the 1½ hectare cleared portion of the site. The 34 hectares of secondary tropical rainforest has been used sparingly. There are several static test stands currently located within this area. Encroachment by neighboring activities and/or land uses does not appear to be a concern.

Surface Waters. This site contains no perennial surface waters, with only small, ephemeral drainage systems flowing only immediately after rain events. The area drains into the South Johnston River, which is located within 1 km north of the tract.

Climate. Detailed climate summary statistics (for both open and under forest canopy sites) for Pin Gin Hill are provided in CSIRO (1985). Figure 8 illustrates a standard climate graph for Pin Gin Hill.

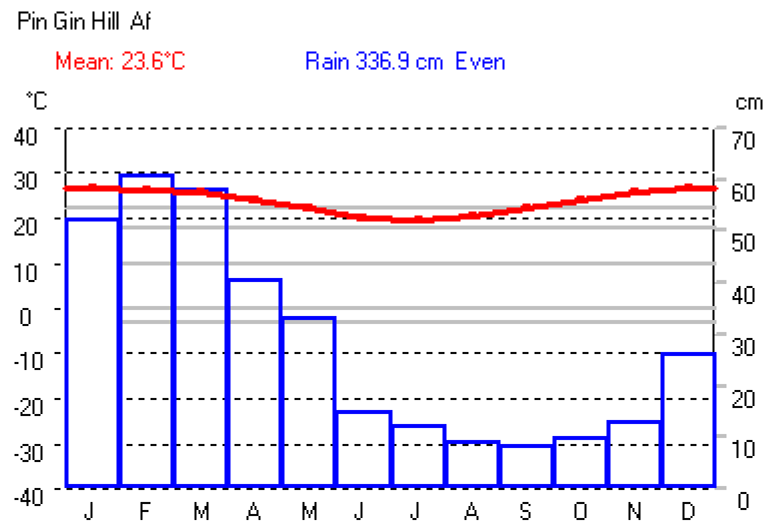

Figure 8 - Climate Graph for Pin Gin Hill

SOURCE: CSIRO, 1985, and AMRL, 2001.

Temperature. The mean annual temperature at Pin Gin Hill is 23.8°C, with mean monthly temperatures ranging from 26.9°C in January to 19.6°C in July. Mean daily maximum temperatures exceed 29°C during the October-March period. The temperature regime generally meets the AR-70-38 (Basic: variable-humid) climate criteria except during the cooler winter months of June and July. Comparative open-site and under-canopy air temperature data are also available for Pin Gin Hill (Table 5 in CSIRO, 1985) and are presented in Appendix 3 of this report. By comparison to the open-site situation, average monthly temperatures are 1°C cooler and mean daily maxima about 2°C cooler under the canopy.

Rainfall. Annual mean rainfall (1964-1978) at Pin Gin Hill is 3,400 mm. Precipitation is strongly seasonal with March receiving the highest monthly rainfall at 737 mm, and the wettest four months (January-April) totaling 2,270 mm or 64% of the total annual rainfall. August is the driest month with 73 mm Monthly rainfall only drops below the Tropical Test Site minimum ideal of 100 mm during the driest months (August-October).

Humidity. Mean annual relative humidity at Pin Gin Hill is 81.3% (open site) and 88.0% (under canopy) with monthly means ranging from 76-86% (open site) and 83-93% (under canopy).

Biological Forest Cover. A detailed account of the forest history of the Pin Gin Hill forest block (33 ha) is provided by CSIRO (1985). The original lowland primary rainforest (Type #1 complex-mesophyll vine forest) was logged or otherwise partially cleared for agriculture. Tropical cyclones have also devastated area forests repeatedly during the 20^{th} Century (e.g., 1918, 1946 and 1956). Currently, the secondary forest (See photos in Appendix 3) at Pin Gin Hill is characterized by a canopy generally less than 25 m in height and few trees with trunk diameters exceeding 50 cm. There is considerable canopy vine cover and a fairly dense lower sub-canopy resulting from light penetration to the forest floor. The forest structure at Pin Gin is substantially more degraded than that found at Tully-Jarra Creek. Although degraded, approximately 33% of the Pin Gin forest block has been mapped as remnant Type #1 Tall, complex-mesophyll rain forest.

IV.2. The Tully - Jarra Creek Site. The Tully site is situated approximately 18 kms northwest of the township of Tully in north Queensland. The camp location (Fig. 2) is in the vicinity of latitude 17° 53′ 20″ S and longitude 145° 48′ 40″ E. Supplemental data and photos of the area are provided in Appendix 4 of this report.

Area Size. The Tully and Jarra Creek training site includes 7,558 hectares that are currently in use (Department of Defence, 1997). This area includes the Tully Camp area, the Jarra Creek training area and the Commonwealth lands identified as the impact area (Earle's Court). The adjacent areas of Liverpool Creek and Downey Creek provide an additional 1,619 hectares and 2,830 hectares respectively, and have been used in the past (Williamson et al., 1987).

Slope and Relief. The Jarra Creek catchment lies approximately 40 to 500 m above sea level east of the Atherton Tableland and adjacent to the alluvial fans of the Tully Valley. It is located in a zone of rugged topography formed by the granite massifs of the Walter Hill Range (Graham and Hopkins, 1980). Significant relief exists on both sides of Jarra Creek and on the hills on north end of the training area. Slopes transition from 10 % rising out of the flat river area to exceed 60 % over hundreds of meters of horizontal distances on the hillsides. This relief offers excellent capability and capacity for testing. The slopes of the fan deposits are much milder. The lateral streams are either entrenched in steep-sided gorges or traverse broad rock slabs of massive granite.

Soil. The soils at this site can be broadly classified on the basis of their geological origin as Granite Soils, Basalt Soils, and Fan Deposit Soils (Graham and Hopkins, 1980). The most typical Granite Soils are the red earths (Gn 2.11-Gn 3.11)[1] which cover about 55% of the Jarra Creek area (Northcote, 1971). They are mostly located on the middle slopes and well-drained lower slopes. Typically the A horizon (0-18 cm) is a reddish-brown loam, sandy loam, or light sandy clay loam varying to a dark red sandy clay loam B horizon with increasing quantities of quartz sand with depth. Some areas of rock slab occur and the soils proximal to these are invariably shallow (<80 cm). At other locations the profile is deeper and grade into a brown sandy loam C horizon with large quantities of quartz sand and gravel. On ridge tops above 200 m elevation, red podzolic soils (Gn 3.14) are found, while yellow xanthozems (Gn 3.74) and yellow earths (Gn

[1] Australian soil symbols are included in brackets for reference.

2.24) occur on midslopes and lower slopes where internal drainage is impeded. A typical yellow earth profile varies from a dark grey brown sandy loam A horizon to a yellow brown B horizon and thence to a yellow sandy clay C horizon at 60 cm.

The most common basalt soil type in the Jarra Creek area is the kraznozem (Gn 3.11), which occurs on the well-drained ridges and moderate slopes under rainforest. The soil can be distinguished from a similar red earth developed on the granites by the complete lack of quartz grains. The morphology and chemical properties of these soils have been described in detail by Isbell et al. (1976) and Gillman (1976). These soils occupy only a small part of the area (± 5%).

The fan deposit soils cover approximately 40% of the area. They vary in composition from coarse to fine. On the upper slopes profiles of earthy sands (Uc 5.21) are typical, with a dark grey loamy sand A horizon (0-35 cm) grading to a dark brown sandy loam and coarse gravel B_1 horizon (35-50 cm), underlain by a deep B_2 horizon of brown sandy loam with rounded granite gravel and quartz sand. On the lower terraces where drainage is impeded, the soil is flooded part of the year and so fine-textured grey to yellow profiles develop. These water logged soils (Um 5.5, Um 6.34) typically grade from a brown fine sandy clay or silty clay loam A horizon (0-10 cm) to a yellow-brown silty clay loam or silty clay B horizon (10-55 cm) dispersed with very fine mica. At depths below 55 cm the profile is yellow sand.

Land Use/Ownership. The Tully site is home to the Australian Army Land Command Battle School. The role of the site is to provide Army training at the squad and platoon level, in close cover, under hot and humid conditions (Department of Defence, 1997). Activities include jungle operation techniques, survival training, land navigation and scouting, and small unit tactical operations up to the company level. Blank ammunition and pyrotechnics are routinely employed. Live detonation of claymore mines and firing of 5.56 mm and 7.62 mm ammunition are permissible within the designated impact area. Training throughput since 1990 has been approximately 1,000 soldiers per year. The impact area is designated as Commonwealth land. The remainder of the site is located on State land and has been leased by the Army. Under terms and conditions of the 1998 Wet Tropics Management Plan, zoning for the lower Jarra Creek area is classified in "zone B" (that is forest lands not remote from disturbance but still in a mostly natural state). The Wet Tropic Management Authority (WTMA) intends for such lands to be restored to their natural state wherever practical (WTMA, 1997).

Adjacent Land Use. Adjacent lands to the north, east, and west are not inhabited. The Tully-Cardston Road serves as the southern boundary and borders privately owned lands. Dispersed farmsteads of sugar cane and tea prevail along the southern and southeastern boundaries of the site. There is no evidence of encroachment.

Cultural/Historical. The entire site is contained within the Wet Tropics of Queensland World Heritage Area. As such, all activities must be conducted within the constraints and restraints of the environmental management plan. A quarry (currently known as Earl's Court) was previously established within the present-day boundaries of the site, and is used as a firing range and for explosive ordnance detonation (Department of Defence, 1997).

Surface Waters. The Tully and Jarra Creek training area is completely contained in the headwaters of the Jarra Creek watershed, which flows in a generally southern direction. The northern boundary of the Tully training area also approximates the northern extent of the Jarra Creek watershed. The total drainage area of the Jarra Creek watershed is roughly 18,000 hectares. Approximately 7,000 hectares of the drainage area are civilian lands lying generally south of the training area and include relatively flat terrain. Additionally, there are some 3,000 hectares of public lands both west and east outside the training areas that also drain into Jarra Creek. Jarra Creek flows over a linear distance of approximately 28 km, 17 km of which lie within the training area.

The surface water drainage system within the training area is a complex set of named and unnamed, perennial and ephemeral streams discharging into Jarra Creek as it flows from north to south through the narrow forest-covered valley. Jarra Creek is a pool and riffle stream in the reaches within the training area, transitioning into a meandering flow south of the training area and before reaching the Tully River. The water quality in Jarra Creek within the training area is remarkably clean for a tropical environment. The water system is considered completely safe by the Australian Army for all types of training requiring contact or immersion.

Climate. Detailed climate summary statistics (open site) for the Tully-Jarra Creek Training Area are provided in Graham and Hopkins (1980) and included in Appendix 3 of this report [pages 11 & 12 in that report]. Figure 9 illustrates a standard climate graph for Tully Camp on lower Jarra Creek (elev. 50 m).

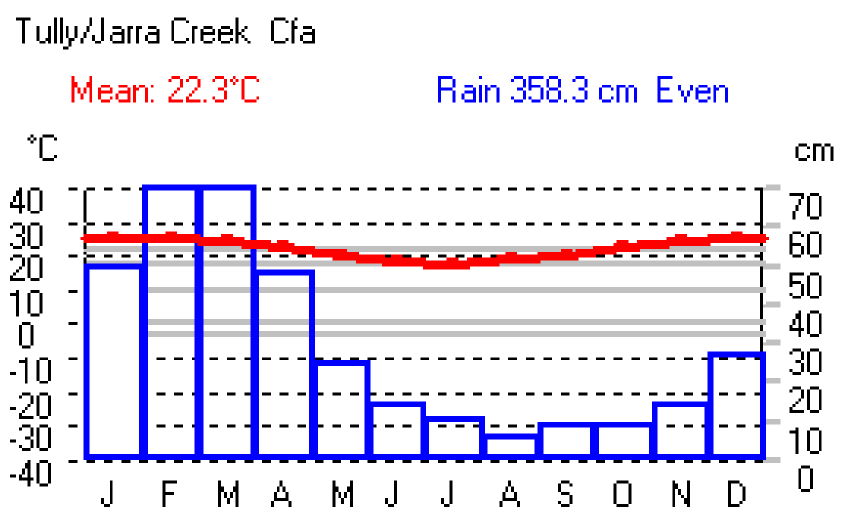

Figure 9 - Climate graph for Tully-Jarra Creek

SOURCE: CSIRO, 1985.

Temperature. The mean annual temperature at Tully Camp is 22.3 ^{o}C with a range in mean monthly temperatures from 25.8 ^{o}C (January) to 18.0 ^{o}C (July). Mean daily maximum temperatures exceed 29 ^{o}C during the October-March period. The temperature regime generally meets AR-70-38 (Basic: variable-humid) climate criteria except during the cooler winter months of June and July.

Rainfall. Annual mean rainfall (1968-1979) at Tully Camp was 3,583 mm. Precipitation is strongly seasonal with March receiving the highest monthly rainfall at 738 m, and the wettest four months (January-April) totaling 2,423 mm or 68% of the total annual rainfall. August is the driest month with 59 mm. Only during the driest months (August-September) does monthly rainfall drop below the Tropical Test Site minimum ideal of 100 mm/mo.

Humidity. Mean annual relative humidity at Tully Camp is 83.8% with monthly means ranging from 79% (October -November) to 88% (April- under canopy). During all months of the year, more than half of each 24hr period exhibits relative humidity values exceeding 90%.

Biological. Forest Cover. The tropical rainforest vegetation of the Tully-Jarra Creek site has been mapped in detail by Graham and Hopkins (1980) and includes significant areas of well-developed complex, multi-canopy mesophyll vine forest with height exceeding 30 m (Types #1 and #2, Table 6.

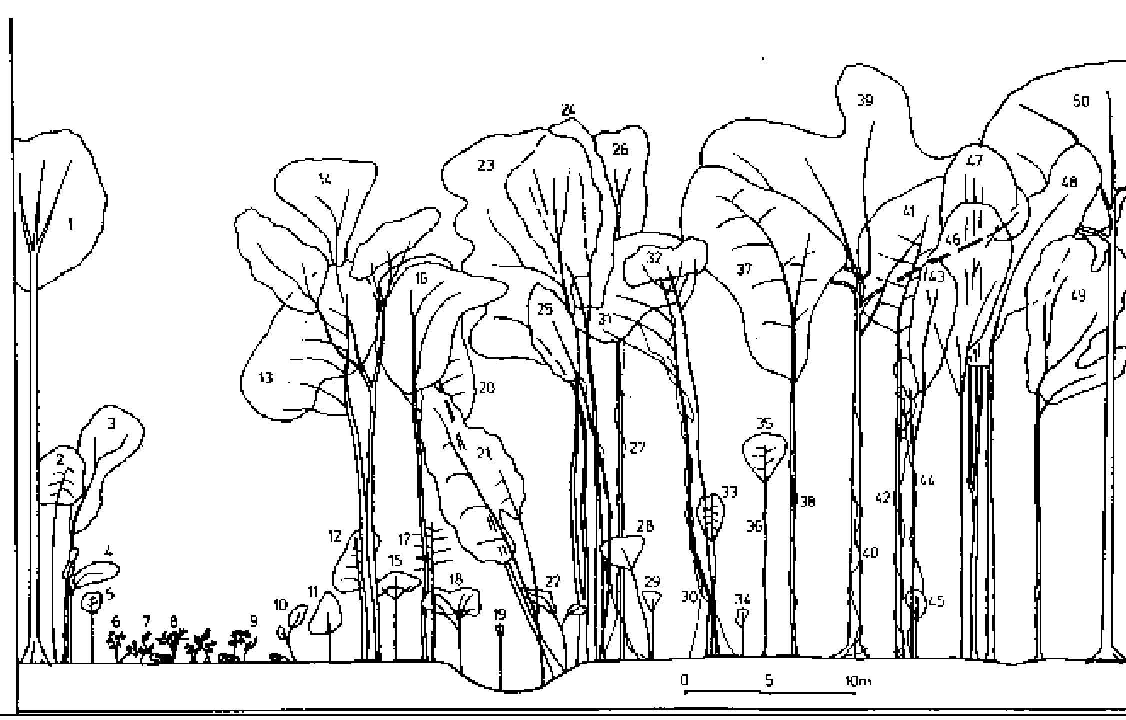

FIGURE 10 - Complex to Mixed Mesophyll Vine Forest on lower series of alluvial terraces

SOURCE: Graham and Hopkins, 1980.

Typical forest canopy profiles for Types #1 are illustrated in Figures 6, 7, and 10. The range of forest and understorey types found at Tully-Jarra Creek are also shown in photos included in Appendix 4. There are a total of 3.5 km^2 of forest type #1 and 9 km^2 of forest type #2 present in the Tully-Jarra Creek Training area. This combined area of 12.5 km^2 covers 21% of the entire training area as mapped (Graham and Hopkins, 1980).

IV.3. <u>Cowley Beach.</u> The Cowley Beach site (Fig. 2) is located at latitude 17° 39′ 18″ S, and longitude 146° 8′ 26″ E, approximately 30 km south of Innisfail and 238 km north of Townsville in northern Queensland. Appendix 5 contains photos and supplemental data for the site.

Area Size. Cowley Beach includes 4,100 hectares of coastal lowlands, including 8 km of beach. With the inclusion of Lindquist Island, the site totals 5,260 hectares.

Slope and Relief. More than 93% of the Cowley Beach area is classified as level with slopes less than 1%, but this classification is based on a digital elevation model employing 20 m contours (Sinclair Knight Merz, 1997). For example, the average height of sand ridges is 10 m (Australia Topographic Survey, Innisfail, Sheet 8162-4). Two beach ridge plains cover more than 40% of the area. They have a relative relief less than 5 m and slopes mainly below 1%. One beach ridge has a 2 to 4 m dune capping and isolated slopes on this ridge reach 2%. Tidal flats occupy another 37% of the area. They consist mainly of regularly inundated intertidal flats with mangroves and tidal creeks. Another 10% is occupied by freshwater swamps (5%) and estuarine channels and streams. Sloping land (>1%) covers only 7% of the area and is found on the steep metamorphic hills of Brown Range, Double Point and the Esmeralda Hill to Georgi Hill area. Most of this land is rolling to very steep with slopes greater than 10%. While all flat land has an elevation of less than 20 m above sea level, the hills rise up to heights between 93 m (Ethel Hill) and 176 m (Georgie Hill). These hills offer up to 60 % relief over very short horizontal distances.

Soil. Sinclair Knight Merz (1997) have compiled a soil map from the regional 1:50,000 soil map by Murtha (1986), a specific soil map prepared by Murtha as part of a vegetation survey (Hopkins et al., 1979), and the Atlas of Australian Soils at a scale of 1:2 million for the mountains and hills (Isbell et al., 1968). They recognized more than ten different Soil Series. One main group consists of deep uniform sands covering the beach ridge plains and covering about 38% of the area. Those soils are classified as arenic rudosols and aeric podosols (15%), semiaquic podosols (18%), and aeric podosols (5%). Another important group are the intertidal hydrosols and supratidal hydrosols (37%), which consist of undifferentiated mottled saline clayey sands to sandy clays and cover the mangrove areas. The hills are covered by stratic rudosols (7%) consisting of shallow and very gravelly red friable loams with prominent rock outcrops.

All soils within the Cowley Beach area have the following characteristics in common: (1) Uniform to gradational texture profiles, rather than duplex profiles in which the surface layer abruptly changes to a subsoil with much higher clay content; (2) The absence of any significant sodicity, which decreases permeability and increases erodibility; and (3) Acid pH throughout the soil profile. The latter feature is of special consequence for equipment testing since acid sulfate soils may generate sulfuric acid that leaks into drainage and flood waters. The sulfuric acid lowers pH, which can result in dissolution of aluminum and corrosion of concrete and steel (Dent and Pons, 1993). Acid sulfate soils are common in lowland humid tropical deltas and coastal plains. Such soils have been reported in Kalimantang, Vietnam, Thailand, and coastal areas of West Africa. They also can occur under temperate conditions such as The Netherlands.

Acid sulfate soils only generate acid when drained and/or disturbed by humans, which allows the sulfidic material to oxidize. The most likely locations of acid sulfate soils within Cowley Beach are in the intertidal flats, supratidal flats and freshwater lagoons of the mangrove areas, the swamps and the low-lying alluvial plain bordering the mangrove areas. Investigations by Department of Natural Resources officers have identified an acid sulfate hazard at one site along the western border of the Cowley Beach area. Sinclair Knight Merz (1997) identify a significant acid sulfate hazard within Cowley Beach, as well as along its western and southwestern boundaries. Two soil samples were analyzed for acid sulfate hazard. It would take about 435 tons of lime to neutralize the acid released from these layers. They consider about half the area of Cowley Beach to have a potential for the presence of acid sulfate soils. Since reclamation of these soils could cost several million US dollars, the issue of acid sulfate hazard should be addressed before making any commitment to the Cowley Beach area.

Land Use/Ownership. Tropical testing at Cowley Beach dates to 1955 (Department of Defence, 1997). Cowley Beach was formally established as a permanent site for the Tropical Trials Establishment in 1966. Since 1989, the site has become more important as a training area than as a research and testing site. Activities have included static testing and small unit training for up to company-sized elements. The site also includes an administrative area, a live fire range for small arms and claymore mines, and a beach area that permits amphibious landings. Since 1988, most of the site (minus the range area) has been part of the Wet Tropics of Queensland World Heritage Area. Under terms and conditions of the 1998 Wet Tropics Management Plan, most of the Cowley Beach area is classified in “zone B” (that is forest lands not remote from disturbance but still in a mostly natural state). The Wet Tropic Management Authority (WTMA) intends for such lands to be restored to their natural state wherever practical (WTMA, 1997).

Adjacent Land Use. To the northeast and east, the site is adjacent to the Great Barrier Reef Marine Park and World Heritage Area. The principal land uses surrounding the site on the northwestern, western, and southern margins are devoted to growing sugarcane and raising cattle. Additionally, Cowley Beach serves as a retirement community and holiday settlement.

Cultural/Historical. Over the past 45 years, the Cowley site has transitioned from a testing site for static equipment, materials, weapons systems, and ammunition, to a training area that hosts small unit tactical, survival, and amphibious training. With its designation as a part of the Wet Tropics of Queensland World Heritage Area in 1988, all activities must conform to the standards specified in the associated environmental regulations.

Surface Waters. The surface drainage system of Cowley Beach is a network of marine swamps and estuarine streams and rivers with some freshwater swamps widely interspersed. The dominant drainage feature is Mourilyan Creek, which flows into the Moresby River in the center of the training area. The southern end of the training area drains south into Liverpool Creek shortly before the creek discharges into the Coral Sea. On the north, Armit and Walter Creeks flow into Mourilyan Harbor, a sheltered inlet connected to the Coral Sea. Much of the landscape is covered with marine swamps heavily impacted by tidal activity. Only the small areas of relief on the very north and southern ends of the training area lack swamps. The swamps teem with numerous hazards, from Tiapan snakes to a variety of smaller insects.

Climate. Detailed climate summary statistics (open site) for the Cowley Beach Training Area (1974-1998) are included as Appendix 5 to this report. Figure 11 illustrates a standard climate graph for Cowley Beach .

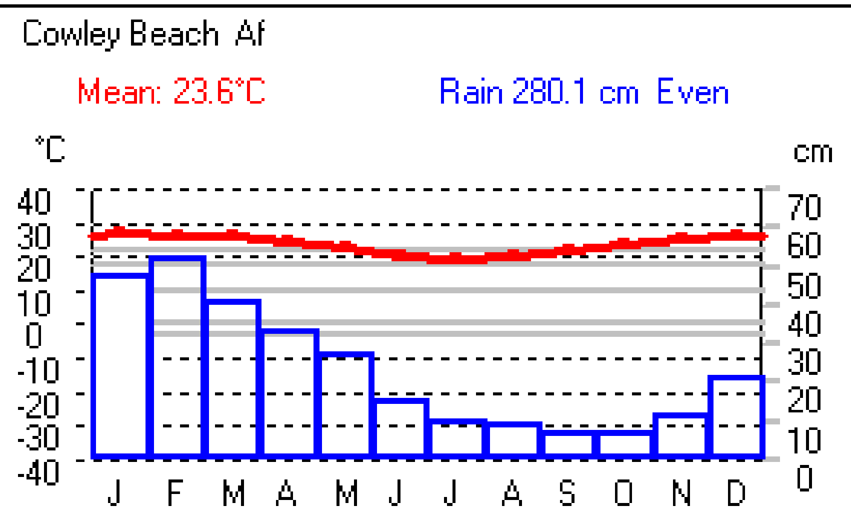

Figure 11- Climate graph for Cowley Beach

SOURCE: CSIRO, 1985, and AMRL, 2001.

Temperature. The mean annual temperature at Cowley Beach is 23.6°C with a range in mean monthly temperatures from 26.7°C (January) to 19.3°C (July). Mean daily maximum temperatures exceed 29°C during the November-March period. The temperature regime generally meets AR-70-38 (Basic: variable-humid) climate criteria except during the cooler winter months of June and July.

Rainfall. Annual mean rainfall (1974-1998) at Cowley Beach is 2796 mm. Precipitation is strongly seasonal with February receiving the highest monthly rainfall at 520 mm, and the wettest four months (January-April) totaling 1731 mm or 62% of the total annual rainfall. October is the driest month with 65 mm. Only during the driest months (August-October) does mean monthly rainfall drop below the Tropical Test Site ideal minimum of 100 mm/mo.

Humidity. Mean annual relative humidity at Cowley Beach is 84%, with monthly means ranging from 87% (May) to 81% (November).

Biological Forest Cover. A detailed mapping and structural analysis of the Cowley Beach vegetation mosaic was undertaken by Hopkins et al. (1979). Because of the complex coastal geomorphic processes, a wide range of vegetation types have been identified at the Cowley Beach site. Degraded primary rainforest, coastal swamp forest and herbaceous coastal (e.g. salt marsh) plant communities occur in close proximity. No significant intact areas of high quality tall stature rainforest remain at the Cowley Beach site. A full description of the range of vegetation types present at the site is characterized in the Hopkins et al. (1979).

V. ANALYSIS OF TESTING CAPACITY FOR AUSTRALIAN SITES

V.1. Overview

Analysis requires the grading of each site for its ability to support each of the 14 testing missions listed in Table 4 and described in Chapter 2. The first step in this process is to assign utility rating values to each of the 14 environmental criteria that characterize each of the three candidate testing sites. These ratings depict how well site environmental conditions match the ideal criteria tabulated in Table 1. These rating are produced through deliberations by the panel study team based on the collected data and their site visit assessments. The panel includes both scientists expert in different aspects of environmental sciences and testers expert in the requirements of natural environmental testing. Applying this experience produces results that are not just scientifically accurate, but also practical with regard to the true environmental needs for testing. This approach does not reduce the value of the science, but better achieves the study goals because it enables the analysis to directly assess the value of a site for testing. Further, the scientific team includes the experience of the first two studies, which supports comparative analyses between the “Ideal Model”, Panama, and the other sites that have been investigated to date. Table 8 is the completed environmental evaluation of the Pin Gin Hill site. With this as an example, it is seen that Pin Gin Hill is excellent in rainfall and humidity, has adequate temperatures, but completely lacks surface streams that could support testing.

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 environmental criterion at each site. In Step 2, each test mission is summarized for each site according to the important environmental factors for that test. Examining Table 9 is the best manner to explain this process. Consider operational and human performance testing of individual soldier systems for one example. For the critical requirements of understorey, humidity, and rainfall, the Pin Gin Hill site is excellent. For the critical factors of temperature and canopy, it is rated as adequate, while the site is only marginal for relief. Likewise, for the important parameters of slope and soils, the site rates as marginal and adequate, respectfully. These values, again as in the first step, are assigned by team analysis and technical judgment.

The final step in the analysis process is assign a grade to each site for each testing mission. Table 14 is a compilation of the grades for the sites examined in this research. Judgments are again applied in the gray areas where the Table 5 values do not perfectly fit.

The ratings of compliance tables have been left unchanged from the previous study to maintain comparability of results. However, there are special conditions within Australia, primarily the restriction imposed on the rainforest that are part of the Wet Tropics World Heritage Area. Because of these special restrictions land use will be a critical rating factor for several testing missions beyond those shown in Tables 9, 11, and 13. Specifically, land use restrictions caused the failing grades for vehicle mobility testing throughout the WTWH area and impacted several other grades to a lesser degree. A summary of the analysis process and the location of the results is present in Table 7.

V.2. Pin Gin Hill

Analysis of the ability of a site to support testing begins with an evaluation of each of the 14 environmental characteristics that define a tropical test location. The results of this analysis are provided in Table 8. From these data it is then possible to rate Pin Gin Hill as to its capability to support each of the 14 different test missions; this analysis is reported in Table 9. Table 14 shows that Pin Gin Hill would be adequate for certain tests. Because of existing static test facilities and personnel at the site, it could provide a good location for static exposure testing of items requiring only a small area and where humidity, rainfall and understorey are the most important elements.

V.3. Tully / Jarra Creek

Table 10 contains the environmental factors analysis and Table 11 presents the results of the analysis of this site for testing capability. In the final analysis of Table 14, this site clearly has robust capacity for testing of material and systems, even though Tully/Jarra Creek is rated as only adequate for temperature. A minor seasonal drop to just below the standard causes this rating for temperature. Nevertheless, excellent temperature conditions for tropical testing exist at least eight months of the year; and during the period January through March, superb conditions of temperature, rainfall, humidity and overall nasty tropical conditions exist.

V.4. Cowley Creek

Table 12 contains the environmental factors analysis, while Table 13 presents the results of the analysis of this site for testing capability. Although the site receives overall poor grades in Table 14, the panel sees that special testing missions might find utility for this area. The ability to test in lowland swamps is offered at Cowley Beach. This is not a testing mission being analyzed for in this study, but one that might be needed in the future.

TABLE 7 - Analytical model for tropical test site evaluation

Process Goal	Study Activity	Location of Results
Define test mission	The testing community defines their mission requirements in quantifiable environmental criteria.	Section II
Define environmental requirements	Select the climate, physical, and biologic conditions necessary to achieve mission	Table 1
Select a hierarchy for analysis	Determine the importance of each environmental parameter to be used in analysis	Table 3
Select geographic region	Apply screening tools to a regional analysis.	Figure 2
Select environmental parameters	The mission is analyzed to identify environmental parameters that apply to the needs of the mission.	14 parameters in Tables 8, 10, &12
Select sites	Scientific and practical considerations are applied to select candidate sites from selected regions	3 sites discussed in Section III
Rate sites for compliance with environmental criteria	Used to characterize the environment at each site visited	Analysis in Tables 8, 10, & 12
Grade sites by testing mission	Critical criteria from Table 4 used to grade (Table 5) each site versus each component of the test mission, a rating of testing capability is made.	Tables 9, 11, &13 with grades compiled in Table 14

TABLE 8 - Environmental Evaluation of: Australia – Pin Gin Hill (A1)

Evaluation Criteria	Rating
Temperature	2
Rainfall	3
Humidity	3
Soils	2
Area size	1
Slopes	1
Relief	1
Surface streams	0
Understorey	3
Forest Canopy	2
Forest floor fauna	1
Land use/Ownership	3
Adjacent land use	2
Cultural/Historical	3
TOTAL	27

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

Pin Gin Hill is a 34 hectare site located adjacent to the Aeronautical and Maritime Research Laboratory – Queensland.

Positive Physical Attributes
High rainfall and humidity
Dense understorey
Collocated with existing military testing infrastructure
Open and canopy exposure capability—with laboratory monitoring

Limiting Factors
Small size
Lack of developed forest canopy
Lack of perennial streams
Lack forest floor fauna in density and diversity
Snakes and other hazards to human factors testing

TABLE 9 - Rating of Compliance with Environmental Criteria for All Testing Missions at Pin Gin Hill Test Site

TESTING MISSION	*ENVIRONMENTAL FACTORS*	*RATINGS*
Equipment Development Testing:		
1) Communication & Electronics	***Understorey, canopy, temperature***, humidity, relief, fauna	**3, 2, 2,** 3, 1, 1
2) Ground & air sensors	***Canopy, understorey***, temperature, humidity, rainfall	**2, 3,** 2, 3, 3
3) Chemical & biological defense	***Fauna, understorey,*** temperature, relief	**1, 2,** 2, 1
4) Environmental exposure *	***Humidity, rainfall, fauna, temperature,*** canopy	**3, 3, 1, 2,** 2
Operational and Human Performance Testing:		
1) Individual soldier systems **	***Temperature, humidity, canopy, understorey, rainfall, relief,*** slope, soils	**2, 3, 2, 3, 3, 1,** 1, 2
2) Communication and electronics	***Canopy, understorey, fauna, temperature, humidity, relief,*** rainfall	**2, 3, 1, 2, 3, 1,** 3
3) Ground and air sensors	**Canopy, *understorey***, temperature, humidity, relief, soils	**2, 3,** 2, 3, 1, 2
4) Chemical and biological defense	***Understorey, fauna, temperature, humidity,*** relief, canopy	**3, 1, 2, 3,** 1, 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	***Understorey, temperature, humidity,*** relief, canopy	**0**
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	***Understorey***, temperature, humidity, relief, canopy	**0**
Coastal Exposure Testing *	***Salt sea atmosphere,*** temperature**,** land use	**0**
Vehicle Mobility Testing	***Soils, slope, relief, rainfall, streams***, understorey, humidity	**2, 1, 1, 3, 0,** 3, 3

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

TABLE 10 - Environmental Evaluation of: Australia Tully/Jarra Creek Area (A2)

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

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

Tully/ Jarra Creek area is the location of the Land Warfare School.

Positive Physical Attributes
High rainfall and humidity
Existing training facilities with small arms capability
Relief and slope
Diverse mosaic of tropical rainforest vegetation with double-triple canopy
Well-developed understorey
Large available land area
Surface streams supportive of human factors testing

Limiting Factors
Limited spatial extent of complex forest canopy
Constrained by Wet Tropics World Heritage Area status
July and August rainfall and temperature sub-optimal
Snakes and other hazards to human factors testing

TABLE 11 – Rating of Compliance with Environmental Criteria for All Testing Missions at Tully/Jarra Creek Training Area

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

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

TABLE 12 - Environmental Evaluation of: Australia – Cowley Beach (H3)

Evaluation Criteria	Rating
Temperature	3
Rainfall	3
Humidity	3
Soils	1
Area size	2
Slopes	2
Relief	1
Surface streams	2
Understorey	2
Forest Canopy	0
Forest floor fauna	1
Land use/Ownership	2
Adjacent land use	1
Cultural/Historical	2
TOTAL	24

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

Cowley Beach is a training and test area for the Australian Army.

Positive Physical Attributes
Existing infrastructure and testing facilities
Existing small arms and explosive detonation capability

Limiting Factors
Very limited spatial extent of forest canopy
Constrained by Wet Tropics World Heritage Area status
July and August rainfall and temperature sub-optimal
Snakes and other hazards to human factors testing

TABLE 13 – Rating of Compliance with Environmental Criteria for All Testing Missions at Cowley Beach Training Area

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

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

TABLE 14 - Evaluation of Capability to Conduct Military Testing at Sites in Australia

	Equipment Development				Human Factors Testing				Munitions Testing: small caliber			Munitions Testing: large caliber			Other Testing & Training	
	CSE	GASS	CBD	EE	ISSHF	CSE	GASS	CBD	EE	SO	FT	EE	SO	FT	CE	VM
A1	B	B	C	B	B	C	B	B	F	F	F	F	F	F	F	F
A2	**A**	**A**	B	**A**	**A**	**A**	**A**	**A**	B	**A**	**A**	F	F	F	F	F
A3	F	F	C	**A**/D*	F	F	F	C	C	D	B	F	F	F	B	F

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

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

Legend:

A1 = Pin Gin Hill A2 = Tully / Jarra Creek A3 = Cowley Beach	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

VI. CONCLUSIONS AND RECOMMENDATIONS.

VI.1. Conclusions.

Previously, this 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). This conclusion was based on the absence of an ideal test site, one possessing the requisite environmental conditions and practical to access. The overarching conclusion of this study is --- **access to the sites examined in North Queensland, Australia would significantly enhance the capability of the United States Army to test military equipment and systems in a tropical environment**. Detailed analysis completed in this study fully confirms previous work (King et. al., 1998), which found that the northern Queensland area of Australia possesses the requisite conditions of physical setting, climate and biologic diversity for effective tropical testing. Two of the studied sites, Tully/Jarra and Cowley Beach, have unique environmental settings offering capabilities not available in Hawaii or at any other candidate sites examined to date. Even Pin Gin Hill, which is small and lacks a mature tropical forest environment, could have utility because of the availability of existing testing facilities operated by the Australian Department of Defence on that site.

Two areas of concern that must be addressed when considering Australia as a test location are cost and land use restrictions. First, transportation of people and equipment is going to be expensive. Military air access is available three to four hours south in the Townsville area, which could help defray some costs on missions involving significant numbers of troops or bulky equipment. Second, as will be discussed below in the analysis of individual sites, there are land use restrictions at each site that limit the types of testing allowed. Nearly all of the forests in the three areas are part of the HWTR lands, which impose significant limits to activities in the areas. Further, any use of Australia Defence lands will require developing some type of government-to-government memorandum of agreement. This agreement should be detailed in the types of testing that could be accomplished at each site. Preliminary discussions were conducted with the Director of Trials as a part of this study and the mood of these talks was very positive on both sides. From a scientific standpoint, it is logical to conclude that this type of cooperative relationship would have a positive synergistic effect with both sides able to learn from the other. Further, there appears to be testing capacity available for use by the U.S. without adversely impacting the Australian Defence testing mission. The Defence Science and Technology Organisation at Innisfail is an ideal group to work cooperatively with in conducting testing outside the U.S. Foremost, they are testing experts and speak the same language, both scientifically and culturally.

Since technical analysis of this study considered lands currently under use by the Australian military at Tully/Jarra Creek, Cowley Beach and Innisfail/Pin Gin Hill, the following conclusions are presented on a site-specific basis.

Conclusions for Innisfail/Pin Gin Hill

This site possesses excellent conditions in rainfall, humidity and understorey, and it has the requisite tropical temperatures for a large part of the year. This site was judged as acceptable for certain types of exposure and electronic systems testing. Sensor testing could be possible over short distances, horizontally, and under a limited canopy. Pin Gin Hill could well support static exposure testing of equipment and material in both an open and under canopy setting. A strength of this secured site is the existing laboratory and testing personnel in the DSTO activity at Innisfail.

Conclusions for Tully/Jarra Creek

This is a large area of continuous canopy rainforest that rated as good to ideal for all 14 environmental factors evaluated as part of this study. ***This is best site the panel has seen outside of Panama.*** Tully/Jarra Creek is an ideal site for all types of human factors testing and excellent for many types of developmental and operational testing. Sensor testing could be conducted in Tully in a very acceptable to excellent manner; this would fill a major shortfall in existing testing capacity in Hawaii. Tully/Jarra Creek offers limited ability to fire small arms up to 7.62 mm and detonate explosives in the size of single claymore mines. This area contains permanent facilities of the Australian Army, which could provide limited logistical support for testing.

The Jarra Creek system is an ideal location for testing that requires putting troops into fresh water. The health risks from immersion or contact with this water are very low compared to most tropical environments. The streams offer a variety of flows and depths, which would allow for robust testing protocols. Under current rules, no vehicle mobility testing would be possible in this area. The entire forest is protected under the covenants of the WTWH, thus each test mission considered would require careful scrutiny to assure compliance. It should be noted that the Australian Army is able to conduct company sized jungle warfare training in this area while complying with this same set of rules. Overall, access to Tully/Jarra Creek would greatly enhance the exiting U.S. Army testing capability.

Conclusions for Cowley Beach

This area possesses the temperature, humidity and rainfall desired for tropical testing, while lacking most of the biologic and physical characteristics needed. Foremost, there is little rainforest on this property, only one very small area on the very northern end. The remainder of training area is covered with a swampy marsh offering only low, broken cover. Despite having two ocean beaches, there is little of the salt spray needed for ocean exposure testing because there are almost no waves. Cowley Beach does offer for use a small arms firing range and a currently uncertified ammunition storage bunker. All activities within the area must comply with the regulations of the WTWH. Limited use of the beach for certain types of training currently exists. Should the U.S. Army testing community ever need either freshwater or estuarine swamp conditions, Cowley Beach would provide a challenging location. However, for the test missions being evaluated in this study, this site offers few advantages over the other sites in Australia or sites in Hawai’i.

VI.2. Recommendations.

a. Each of the three sites investigated in Australia should be added to the suite of sites that can support tropical testing. Each site may have utility for future testing.

b. Pursue discussions with the government of Australia to determine the availability of the sites considered in this study for use as sites for U.S. tropical testing. The panel finds that many types of tests can be more rigorously conducted at sites in Australia than at sites available in Hawai'i.

c. The panel sees value in developing a cooperative relationship with the Australian Defence Science and Technology Organisation. A cooperative relationship could enhance testing for both countries in that each has interests and experience in tropical testing. Specifically, existing Australian testing assets that are underutilized could support U.S. testing mission to the benefit of both countries.

c. Tully/Jarra Creek is an outstanding location for developmental and operational testing of material and systems. The site is particularly useful as a site for human factors testing of all types of equipment; the area is expansive and the environmental conditions are challenging. Use of this area would greatly enhance existing capability for sensor and electronics systems testing of all types. Sensor testing is one of the testing areas not well supported by sites in Hawai'i and Puerto Rico (King et. al., 1999). Tully/Jarra Creek is limited to small arms firing and currently excludes vehicle testing.

d. Economics will be an overarching concern in successfully implementing testing in Australia. The panel recommends that U.S. Army Development Test Command conduct an economic analysis of the cost of testing in Australia in comparison to Hawai'i.

e. It is strongly recommended that one testing mission be proposed for Tully/ Jarra Creek to more fully evaluate the practical considerations of use of this area by U.S. forces. Any test that does not require a large group of people, does not involve explosives, is not over a long duration, and is not well supported within existing test sites would be a good candidate test. The panel believes that actually executing a test protocol in Australia is the best way to evaluate future use of the sites. This trial should reveal hidden strengths and weaknesses of U.S. tropical testing in Australia.

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VII. BIBLIOGRAPHY.

Australian Department of Defence, 1997. Praff Environmental Management Plan.

Australian Heritage Commission, 1986, Tropical rainforests of North Queensland: Their conservation significance. Special Australian Heritage Publication Series No. 3 (Australian Government Publishing Service, Canberra.).

Bird, E.C.F. 1970. The steep coast of Macalister Range, North Queensland. Journal of Tropical Geography 31:33-39.

Bird, E.C.F., 1984, *Coasts*, (Blackwell Publishing Ltd., Oxford), 320 p.

Blair, W.B. and Chambers, J.V., 1959, Canal Zone Analogs X: Analogs of Canal Zone Climate in Australia and New Guinea, U.S. Army Quartermaster Research and Engineering Center Technical Report EP-113, 26 p.

Bonell, M., Gilmour, D.A. and Cassells, D.S., 1983, Runoff generation in tropical rainforests of Northeast Queensland, Australia, and the implications for land management. Hydrology of Humid Tropical Regions with Particular Reference to Hydrological Effects of Agriculture and Forestry Practice, Proceedings of the Humid Tropics Symposium, August, IAHS Publication No. 140.

Bridges, E.M., 1990, *World Geomorphology* (Cambridge University Press, Cambridge), 260p.

Brunig, E.F., 1983, Vegetation Structure and Growth. in *Ecosystems of the World 14A, Tropical Rain Forest Ecosystems, Structure and Function* (F.B. Golley, ed.) Elsevier Publishing Co. (Amsterdam): 49-75.

Büdel, J., 1965, Die Relief Typen der Flachenspil-Zone Sud-Indiens am Ostabfall Dekens Gegen Madras: Coll. Geog. Bonn, 8.

Chambers, J.V., 1960, Canal Zone Analogs X: Analogs of Canal Zone Climate in the Pacific Islands, U.S. Army Quartermaster Research and Engineering Center Technical Report EP-142, 30p.

CSIRO. 1985. An ecological assessment of the Pin Gin Hill rainforest joint tropical trials and research establishment. CSIRO, Institute of Biological Resources, Division of Water and Land Resources, Canberra, Australia. 30p.

Dent, D.L. and L. Pons. 1993. Acid and muddy thoughts. In *Proceedings of the National Conference on Acid Sulphate Soils.*

Dvorak, V. F., 1973, A Technique for the Analysis and Forecasting of Tropical Cyclone Intensities from Satellite Pictures, NOAA Technical Memorandum NESS-45, U.S. Department of Commerce, Washington D.C., February, 1973.

Espenshade, E.B. (ed.), 1987, *Goode's World Atlas (*17th Ed.), Rand-McNally (New York), 367p.

Faniran A. and Jeje, L.K., 1983, *Humid Tropical Geomorphology* (Longman, Inc., London), 414p.

Frangi, J.L., and Lugo, A.E., 1985, Ecosystem Dynamics of a Subtropical Floodplain Forest: Ecological Monographs, 55:351-369.

Gillman, G.P. 1976. Red basaltic soils in North Queensland. II. Chemistry. CSIRO Australia, Division of Soils Technical Paper 28:23-49.

Golley, F.B., 1983, Ecosystems of the World 14A, Tropical Rain Forest Ecosystems, Structure and Function, Elsevier Scientific Publishing Co., 381 p.

Golley, F.B., 1989, *Ecosystems of the World 14B, Tropical Rain Forest Ecosystems. Biogeographical and Ecological Studies*, Elsevier Scientific Publishing Co. (Amsterdam), 713p.

Graham, A.W. and Hopkins, M.S., 1980. The forests and soils of the Jarra Creek Area, North Queensland. CSIRO, Institute of Earth Resources, Division of Land Use Research, Canberra, Australia. Technical Memorandum 80/26, pp. 39.

Hey, K.M., 1999, Desktop assessment and use of on-site indicators as preliminary methods for recognition of acid sulphate soils. in (K.M. Hey, C.R. Ahren, V.J. Eldershaw, J.M Anorov, and K.M. Watling, eds) *Acid Sulfate Soils and Their Management in Coastal Queensland: Forum and Technical Papers.* (Department of Natural Resources Queensland),2:1-18.

Hopkins , M.S., Graham, A.W., and Murtha, G.G., 1979, The vegetation of the Cowley Beach area, Joint Tropical Trials Research Establishment, North Queensland, CSIRO Australia, Division of Land Use Research Technical Memorandum 79/13.

Isbell, R.F., Webb, A.A., and Murtha, G.G.. 1968. Atlas of Australian Soils, Sheet 7, with explanatory data, CSIRO Australia/Melbourne University Press.

Isbell, R.F., Stephenson, P.G., and Murtha, G.A.. 1976. Red basaltic soils in North Queensland. II. Environment, morphology, particle size characteristics and clay mineralogy. CSIRO Aust. Div. Soils Tech. Pap. 28:1-22.

Jordan, C.F., 1970, Flow of Soil Water in the Lower Montane Tropical Rain Forest. in *A Tropical Rain Forest* (H.T. Odum, and R.F. Pigeon, eds.), National Technical Information Service (Springfield, VA): H201-H204.

Jordan, C.F., 1983, Productivity of Tropical Rain Forest Ecosystem and the Implications for their Use as Future Wood and Energy Sources. in *Ecosystems of the World 14A, Tropical Rain Forest Ecosystems: Structure and Function* (F.B. Golly, ed.), Elsevier Publishing Co.(Amsterdam):117-136.

Juvik, S. P., and Juvik, J.O., 1998, *Atlas of Hawaii*, (3rd Ed.), University of Hawaii Press (Honolulu), 333 p.

King, W. Christopher, 2000, *Understanding International Environmental Security: A Strategic Military Perspective,* Army Environmental Policy Institute (Atlanta).

King,W.C., Harmon, R.S., Bullard, T., Dement, W., Doe, W., Evans, J., Larsen, M.C., Lawrence, W., McDonald, K., and Morrill, V., 1998, A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems, Army Research Office Report to Yuma Proving Ground, July 1998, 47p.

King, W.C., Harmon, R.S., Bullard, T., Evans, J., Juvik, J.O., Johnson, R., and Larsen, M.C., 1999, A Technical Analysis of Hawai'i and Puerto Rico for Tropical Testing of Army Materiels and Systems. Army Research Office Report to Yuma Proving Ground, April 1999, 74p.

Lee, J.R., *Inventory of Conflict and Environment,* 1999, paper prepared for Army Environmental Policy Institute (Atlanta).

Moscohovitis, 1996, Asia on File. New York: CM&A/Summit Digital, Inc.

Murtha, G.G., 1986. Soil of the Tully-Innisfail Area, North Queensland, CSIRO Division of Soils Divisional Report Number 82.

Musk, L. F., 1988, *Weather Systems*, Cambridge University Press (Cambridge), 160p.

Northcote, K.H, 1971, A factual key for the recognition of Australian soils. Rellim Technical Publications, 3rd Edition, (Glenside, South Australia), 123p.

Powell, B. and Ahern, C.R., 1999. Nature, origin and distribution of acid sulfate soils: issues for Queensland. in (K.M. Hey, C.R. Ahren, V.J. Eldershaw, J.M Anorov, and K.M. Watling, eds.) *Acid Sulfate Soils and Their Managment in Coastal Queensland: Forum and Technical Papers.* (Department of Natural Resources Queensland), 1:1-11.

Queensland State Public Relations Bureau, 1980.

Reading, A.J., R.D. Thompson & A.C. Millington, 1995, *Humid Tropical Environments*. Blackwell Publishers (London), 429 p.

Riehl, H., and Simpson, J., 1979, The Heat Balance of the Equatorial Trough Zone, Revisited. Contributions to Atmospheric Physics, 52:287-305.

Ritter, D.F., Kochel, R.C., and Miller, J.R., 1995, *Process Geomorphology* (3rd Ed.), W.C. Brown Publishers (Boston), 546p.

Ropelewski, C. F., and M. S. Halpert, 1996, Quantifying Southern Oscillation Precipitation Relationships. Journal of Climate, 9:1043-1059.

Rula, A.A., 1979, Investigation, Characterization of Test Environment, Final Report, U.S. Army Tropic Test Center, AD A113162:C1-C9.

Sinclair Knight Merz Inc., 1997, Cowley Beach Training Area. Resource Assessment Study. Department of Defense, 183p.

Smith, Dan, 1997, Investigation of Test Environment, U.S. Army Tropic Test Center, AD A113162:C1-C9.

Stephenson, P.J., T.J. Griffin, F.L. Sutherland. 1980. Cainozoic volcanism in Northeastern Australia. in *The Geology and Geophysics of Northeastern Queensland*, (R.A. Henderson and P.J. Stephenson, eds.). Geological Society of Australia (Brisbane): 349-374.

Strahler, A.N., 1967, *Physical Geography* (John Wiley and Sons, New York), p.181-208.

Thompson, W.F. 1958a, Canal Zone Analogs II: Analogs of Canal Zone Climate in India and Southeast Asia, U.S. Army Quartermaster Research and Engineering Center Technical Report EP-91, 24p.

Tracey, J.G., 1982, Vegetation of the humid tropical region of North Queensland, CSIRO Australia, Division of Plant Industry Long Pocket Laboratories (Indooroopilly), 124p..

Tracey, J.G. and Webb, L.J., 1975, Vegetation of the humid tropical region of North Queensland (15 maps at 1:100,000 scale + key), CSIRO Australia, Division of Plant Industry Long Pocket Laboratories (Indooroopilly).

U.S. Army Regulation 70-38, 1979a, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions.

U.S. Army Tropic Test Center Report 790401, 1979b, Materiel Testing in the Tropics, DTIC AD NO: A072434. 269p.

Webb, L.J., 1978, A general classification of Australian rainforests: Australian Plants, 9:349-363.

Wiley, S.C., Dodd, A.V., and Chambers, J.V. 1955, Environmental Handbook of Fort Sherman and Fort Gulick, Panama Canal Zone, Analogs of Canal Zone Climate in the Pacific Islands, U.S. Army Quartermaster Research and Engineering Center Technical Report EP-17, 50 p.

Williamson, R., Dement, W.A., Downs, G.F. III, and Appel, L.G., 1987b, Relocation of the Tropic Test Center: Surveys of Australian Sites, U.S. Army Material Command, Test and Evaluation Command unpublished report TTCR-03, 27 p.

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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 - Letter of Tasking

DEPARTMENT OF THE ARMY
UNITED STATES ARMY YUMA PROVING GROUND
YUMA, ARIZONA 85365

REPLY TO
ATTENTION OF

CSTE-DTC-YP-TRTC 21 Jun 01

MEMORANDUM FOR Dr C.I. (Jim) Chang, Director, US Army Research Office
P. O. Box 12211, Research Triangle Park, NC 27709-2211

SUBJECT: Tropic Test Center Relocation Requirement

1. US Army Yuma Proving Ground is an activity that is dedicated to the test and evaluation of all types of materiel and systems of military interest. One of the key missions of YPG is testing in the natural environmental extremes. YPG currently has a number of test sites located throughout the world including tropical sites. Tropic Regions Test Center has been in the process of relocating its mission to suitably identified sites located in and around the equator. These sites have been identified and analyzed by expert scientific teams assembled by the Army Research Office at the request of YPG. We are well underway with that effort.

2. We are again asking ARO's assistance to convene a panel to independently evaluate potential sites in particular, the North Queensland, Australia area identified in the 1998 ARO (A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems) utilizing the criteria developed for assessing tropical sites for testing suitability.

3. As always YPG will provide funding for the project based on your cost estimate. POC for this issue is Lance Vander Zyl (520) 328-2124 or email Lance.Vanderzyl@yuma-exch1.army.mil

JAMES L. WYMER
Technical Director
Yuma Proving Ground

APPENDIX 3

SUPPLEMENTAL DATA

PIN GIN HILL AREA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
Aeronautical and Maritime Research Laboratory - Queensland

METEOROLOGICAL SUMMARY
1963 --- 1998

PIN GIN HILL HOT WET CLEARED SITE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE (c)													
Highest daily Maximum	40.8	38.3	38.8	34.9	32.5	31.6	31.0	33.3	35.0	36.4	41.1	41.5	41.5
Average daily Maximum	31.2	30.6	29.8	28.1	26.1	24.4	23.9	25.3	27.3	29.0	30.7	31.4	28.2
Average daily Mean	26.7	26.4	25.7	24.1	22.3	20.1	19.5	20.6	22.1	23.8	25.6	26.5	23.6
Average daily Minimum	22.9	23.0	22.4	20.8	19.2	16.5	15.8	16.5	17.5	19.2	21.0	22.2	19.8
Lowest daily Minimum	17.7	18.2	16.0	14.0	9.5	7.2	6.3	9.6	10.5	11.3	15.5	17.0	6.3
RELATIVE HUMIDITY %													
Highest daily Maximum	100	100	100	100	100	100	100	100	100	100	100	100	100
Average daily Maximum	96	97	97	97	97	96	96	96	96	96	96	95	96
Average daily Mean	83	85	86	87	87	85	83	82	80	79	79	80	83
Average daily Minimum	62	66	66	67	69	64	61	58	53	53	56	58	61
Lowest daily Minimum	17	17	16	26	28	25	11	18	11	9	4	14	4
PRECIPITATION													
Highest Monthly Rainfall (mm)	2548.0	2036.8	1226.0	1011.6	875.3	454.5	447.5	402.0	322.6	341.9	554.5	1050.0	2548.0
Average Rainfall (mm)	519.7	605.2	581.8	402.7	332.2	146.5	121.9	90.8	82.6	97.5	128.1	261.7	3370.6
Average Rain Days	17	19	21	21	20	13	13	13	10	11	11	14	182
RADIATION													
Average Sun Hours	198.1	154.0	162.4	139.8	134.3	149.3	156.4	174.4	206.2	226.9	225.0	218.7	2145.6
Total Global Horizontal (MJ/m^2)	598.6	464.9	477.2	400.4	343.7	341.5	363.9	431.0	525.1	600.8	606.6	605.3	5758.9
Total UV (MJ/m^2)	25.4	19.9	19.1	17.2	14.4	14.1	14.5	17.0	21.6	24.8	24.8	26.0	238.9

Figure A3. a. - Overview of exposure test site at Pin Gin Hill site.

Figure A3.b - MAJ J. Ashbaugh (US Army) in secondary jungle at Pin Gin Hill

Figure A3.c. - COL B Hall (Australian Army) in secondary jungle at Pin Gin Hill

Figure A3. d. - Decaying tank drive shaft in secondary jungle at Pin Gin Hill - Pigeon Hill Ridge site.

APPENDIX 4

SUPPLEMENTAL DATA

TULLY – JARRA CREEK AREAS

TABLE A4 - Long Term Temperature Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean daily max temperature												
Pin Gin Hill	31.2	30.4	29.6	27.9	25.8	24.3	23.8	25.8	27.1	29	30.9	31.2
Liverpool Creek	31.3	30.1	29.	28	25.7	24.3	24.	26	26.5	29.5	31.1	31.0
Jarra Creek	31.9	30.2	29.7	27.3	25.5	24.2	23.9	26.	27.8	29.8	31.6	32.2
Innisfail	31.1	30.7	29.8	29.3	26.4	24.8	24.2	25.1	26.8	28.6	29.9	31.1
Mean Monthly Temperature												
Pin Gin Hill	26.9	26.6	26.	24.3	22.2	20.3	19.6	21.1	22.3	23.9	25.9	26.6
Liverpool Creek	24.8	24.9	24.	22.5	20.0	18.2	17.3	18.6	20.2	22.2	24.3	24.7
Jarra Creek	25.8	25.	24.6	22.5	20.4	18.3	17.8	19.	20.6	22.6	24.8	25.6
Innisfail	26.7	26.5	25.6	24.0	21.9	20.2	19.1	19.6	21.4	23.3	24.8	26.1
Mean daily min temperature												
Pin Gin Hill	22.5	22.7	22.3	20.5	18.7	16.3	15.5	16.4	17.4	18.9	20.7	21.7
Liverpool Creek	20.8	22.	20.6	18.6	16.	13.5	12.4	13.1	15.5	16.8	18.6	20.
Jarra Creek	21.4	22.	21.2	19.2	16.8	13.9	13.2	13.9	15.2	16.9	19.2	20.5
Innisfail	22.3	22.2	21.3	19.7	17.4	15.6	14.2	14.2	15.9	17.9	19.8	21.2

Source: JTTRE records; Graham & Hopkins, 1983; Graham & Hopkins, 1980.
Data covers 15 years for Pin Gin Hill, 12 years for Jarra Creek, 9 years for Liverpool Creek, and 29 years for Innisfail.

Figure A4.a. - COL B. Hall (Australian Army) and LTC C. Miller (US Army) in rainforest understorey at the Earle's Court location at the Tully-Jarra Ridge site.

Figure A4.b. - COL E. Palka (US Army) in rainforest understorey at the Earle's Court location at the Tully-Jarra Ridge site.

Figure A4.c. - MAJ M. Clarke (Australian Army) in rainforest understorey in jungle in live-fire area on north side of Earl'es Court

Figure A4.d. - Army pack and old target nylon filling on jungle floor at Earle's Court after >30yr exposure

Figure A4.e. - View upstream along Jarra River at Tully-Jarra Ridge site.

Figure A4.f. - MAJ J. Ashbaugh in rainforest undergrowth on east side of Jarra River at the Tully-Jarra Ridge site.

Figure A4.g. - COL C. King (US Army) in undergrowth in jungle at Camp Tully river crossing.

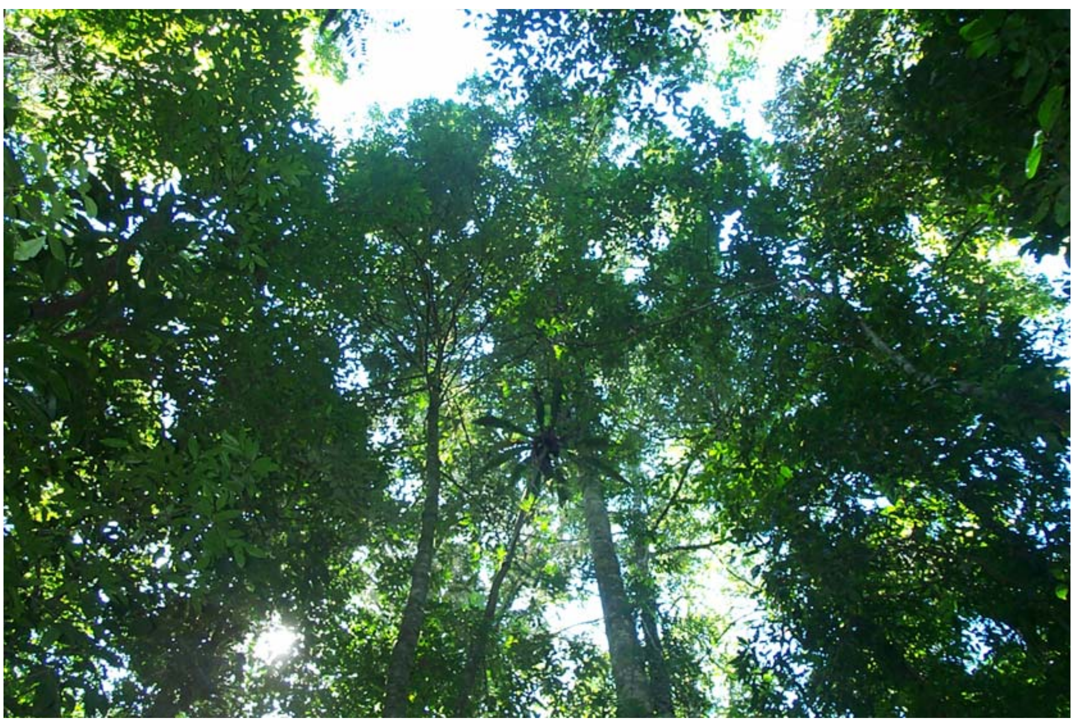

Figure A4.h. - View up into 40-50m double canopy in mature N. Queensland rainforest affected by a major cyclone in late 1980's.

APPENDIX 5

SUPPLEMENTAL DATA

COWLEY BEACH AREA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
Aeronautical and Maritime Research Laboratory - Queensland

METEOROLOGICAL SUMMARY
1974 --- 1998

COWLEY BEACH MARINE ATMOSPHERIC SITE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE (c)													
Highest daily Maximum	38.5	37.0	37.3	31.8	31.5	31.3	31.3	31.3	31.4	33.6	34.1	39.0	39.0
Average daily Maximum	30.2	29.8	29.1	27.4	25.3	23.3	22.8	23.7	25.8	27.9	29.3	30.2	27.1
Average daily Mean	26.7	26.5	26.0	24.6	22.5	19.8	19.3	20.0	21.7	23.8	25.4	26.4	23.6
Average daily Minimum	23.3	23.3	22.8	21.7	19.7	16.0	15.7	16.1	17.5	19.4	21.3	22.6	19.9
Lowest daily Minimum	18.6	16.7	17.0	11.4	9.3	5.9	6.3	6.4	8.9	9.7	14.5	16.5	5.9
RELATIVE HUMIDITY %													
Highest daily Maximum	100	100	100	100	100	100	100	100	100	100	100	100	100
Average daily Maximum	97	97	96	97	97	98	98	98	97	97	97	97	97
Average daily Mean	84	85	84	85	87	85	86	85	82	82	81	83	84
Average daily Minimum	69	70	69	71	74	68	69	68	64	63	63	65	68
Lowest daily Minimum	29	13	21	25	28	25	26	22	14	18	17	29	13
PRECIPITATION													
Highest Monthly Rainfall (mm)	2361.8	1550.0	929.8	783.0	544.3	494.0	285.0	386.3	391.5	187.0	601.8	924.5	2361.8
Average Rainfall (mm)	476.3	520.2	409.3	325.8	271.1	148.7	102.9	89.6	71.9	64.8	110.4	205.3	2796.3
Average Rain Days	16	19	19	21	20	14	13	13	9	8	10	12	174
RADIATION													
Average Sun Hours	200.0	160.5	172.4	146.3	139.2	148.5	160.0	170.4	196.8	230.2	218.5	225.4	2168.1
Total Global Horizontal (MJ/m²)	550.6	426.4	449.4	361.0	336.7	359.2	392.6	460.4	489.0	526.7	617.0	645.1	5614.2
Total UV (MJ/m²)	2.1	1.8	1.4	1.1	1.1	1.1	1.3	1.6	1.4	2.1	2.1	2.6	19.5

Figure A5.a. - Exposure cage at Cowley Beach main post

Figure A5.b. - View north along coast at Cowley Beach main post

Figure A5.c. - Southern end of Cowley Beach Rocket Range

Figure A5.d. - Standing water in coastal swale at north end of Cowley Beach site.

APPENDIX 6 – Abbreviations

AR	-	Army Regulation
ARO	-	U.S. Army Research Office
BTU	-	British thermal unit, measure of heat
CSIRO	-	Australian Scientific Research Institute
Dbh	-	Diameter at breast height
DoD	-	Department of Defense
DT	-	Developmental testing
DSTO	-	Defence Science and Technology Organization
GASS	-	Ground and Aerial Remote Sensing System
GPS	-	Global Positioning System
HF	-	Human Factors
JOTC	-	Jungle Operations Training Center, Ft Sherman, Panama
km	-	Kilometers
MERS	-	Master Environment Reference Sites
MIL STD	-	Military Standard
M/S	-	Meters per second
mm		Milimeters
OPFOR	-	Operational Force
OT	-	Operational testing
PM	-	Program Manager
RDT&E	-	Research, Development, Test, and Evaluation
RH	-	Relative Humidity
TECOM	-	U.S. Army Developmental Test Command
TTC	-	Tropic Test Center
USATTC	-	U.S. Army Tropic Test Center
USFS	-	U.S. Forest Service
USMA	-	United States Military Academy
UTM	-	Universal Transverse Mercator
UXO	-	Unexploded Ordnance
VPG	-	Virtual Proving Ground

APPENDIX 6 – Abbreviations (continued)

WTMA - Wet Tropic Management Authority
WTWH - Wet Tropics World Heritage

YPG - Yuma Proving Ground

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