

CHAPTER 3.

GEOLOGICAL AND SOIL RESOURCES

3.1 AFFECTED ENVIRONMENT

3.1.1 Definition of Resource

This chapter discusses existing conditions and assesses how the proposed Guam Relocation action alternatives would potentially affect geological and soil resources within the region of influence (ROI) for Marine Corps training on Tinian. Geology describes the surface and subsurface materials of which a land area is composed, including soils and rocks. The characteristics of soils and underlying rocks include stability, slope, compatibility, shear strength, and productivity. Discussions of this resource area typically identify existing geological conditions and determine how action alternatives would likely affect geological and soil resources. Because geology and soils relate to the physical foundation of Tinian, the proposed land uses associated with the action alternatives would affect characteristics of erosion and surface changes (such as land clearing, slope cuts) but not the overall geological and soil conditions. Instead, geology and soils considerations are more pertinent with respect to the placement or location of a particular land use; for example, a sinkhole could provide an obstacle to establishing a housing land use. Consequently, the geological and soil characteristics of an area would have impact on the proposed action as well as the proposed action impacting the geology.

The geology of individual islands in the Marianas is largely dependent on the degree of recent volcanism. The older islands, including Tinian, generally consist of a volcanic core covered by coralline limestone in layers up to several hundred meters thick. As the original volcanoes subsided beneath the ocean surface, coral formations grew, ultimately forming the limestone caps on these southern islands. Uplifting of the Philippine Plate resulted in the limestone caps being pushed several hundred meters above sea level. The volcanic core is exposed in some areas through either volcanic activities or erosion.

3.1.2 Tinian

3.1.2.1 Topography

Topography comprises the natural and man-made features of a place or region that shows relative positions and elevations. Topography generally dictates the suitability of land for building purposes, and can be a major factor in defining an appropriate use of an area.

Tinian is a series of limestone plateaus separated by steep-slopes and cliffs (Young 1989). The five major plateaus are generally level and undulating. In the northern part of Tinian, the ground surface slopes gently, increasing in elevation slightly from west to east. In the northern part of the central plateau is a highland containing one of the highest elevations on Tinian, Mount Lasso, at 531 feet (ft) (162 meters [m]) above sea level. The north-central highland rises within the northern part of the central plateau, halfway between the east and west coasts. The highest point of the north-central highland is 545 ft (166 m). The only point higher on Tinian is on the southeastern ridge. The northern lowland generally is flat with an elevation of 100 ft (30 m) (United States Army Corps of Engineers [USACE] 2007).

The central plateau extends northward and comprises all of central, and some of the northern part of Tinian. The central portion of Tinian is a plateau isolated by steep slopes due to the north-south oriented faults. A broad depression separates the central plateau from the ridge covering the southeastern edge of

Tinian. The ridge includes the highest elevation on Tinian, Kastiyu, at 614 ft (187 m) above sea level (Stafford et al. 2004).

The southeastern ridge is the highest part of Tinian. The ridge consists of a north and south ridge that is separated by a gap near the midpoint. Steep slopes and cliffs rise up to 500 ft (15 m) from the southeast boundary of the ridge. Figure 3.1-1 shows the topography of Tinian. There are no permanent streams for surface drainage on Tinian because all water evaporates or percolates through the highly permeable limestone.

3.1.2.2 Geologic Units

A geologic unit is a volume of rock or ice of identifiable origin and age range that is defined by the distinctive, dominant, easily mapped and recognizable physical characteristics and features that characterize it. Figure 3.1-2 shows the geology of Tinian.

Volcanic

Tinian is located on the Mariana Ridge, a volcanic arc approximately 100 miles (mi) (160 kilometers [km]) west of the Mariana Trench. This ridge was formed as a result of subduction of the Pacific Plate under the Philippine Plate. The foundation of the island of Tinian is volcanic rock that is covered in limestone over most of its surface, with exposed volcanic rock found only in two small, isolated places due to extensive weathering (Young 1989). The volcanic rock has low permeability due to its texture and density.

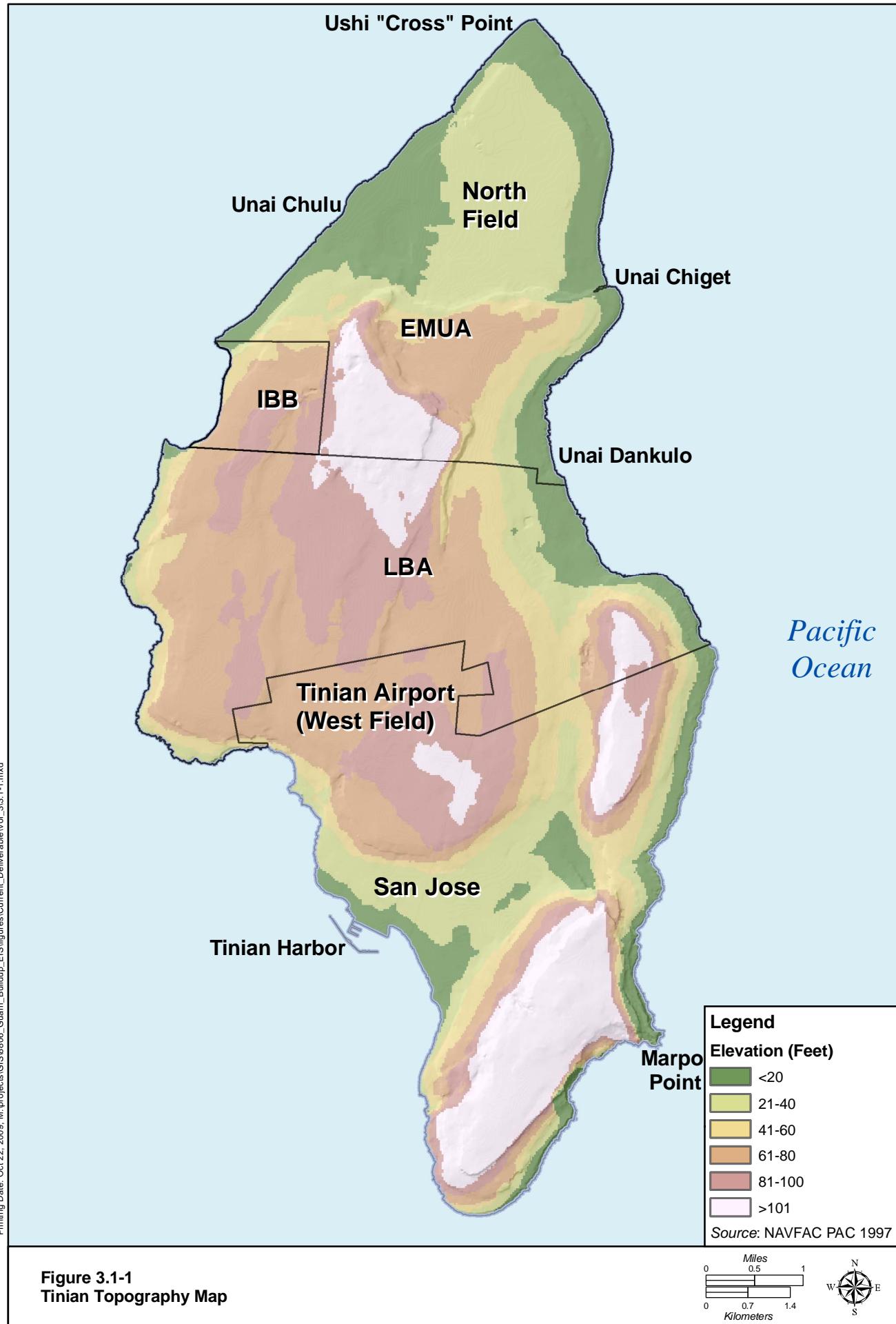
Limestone

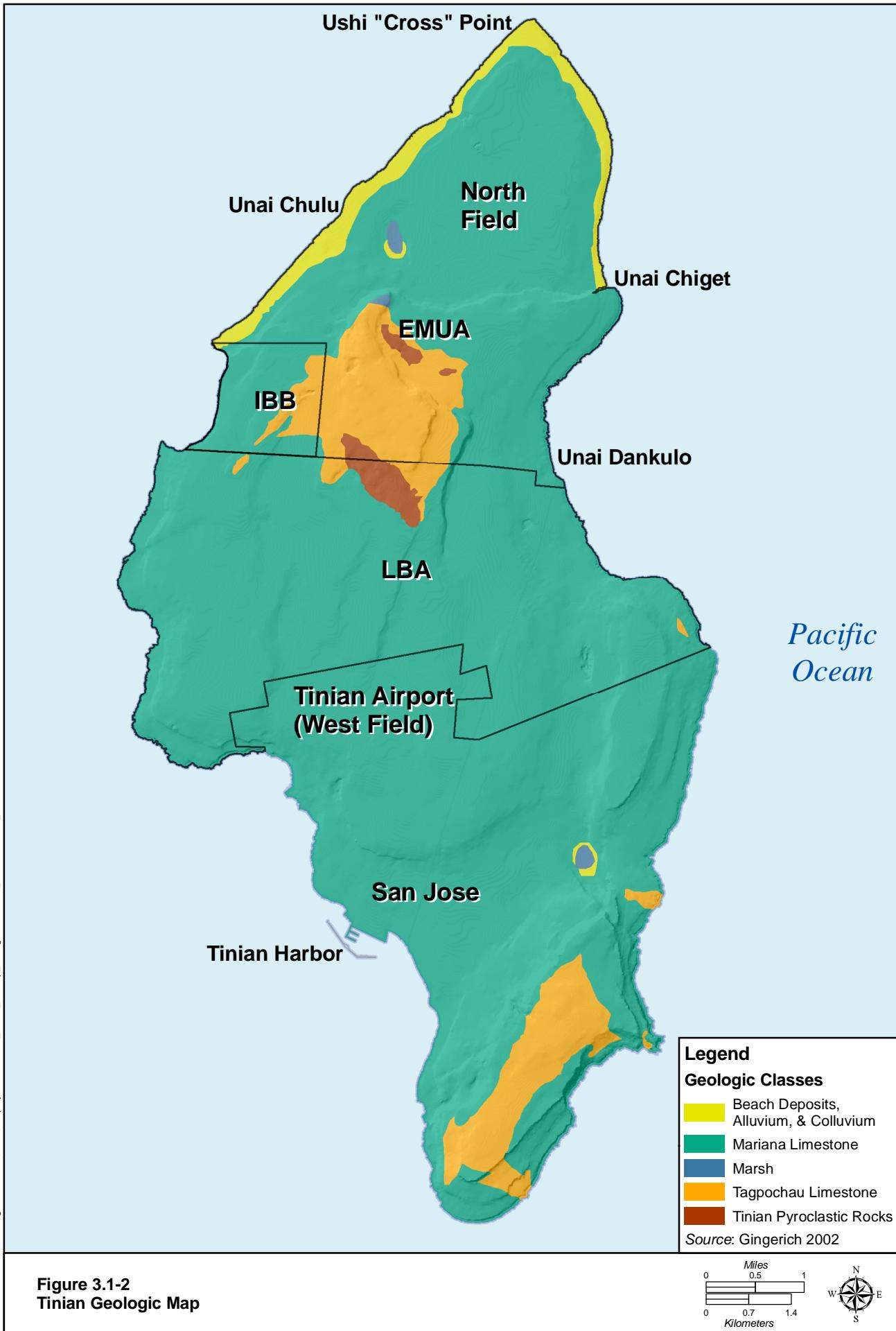
Tinian is composed mainly of coralline and algal limestone overlying volcanic tuff and breccias. The limestone tends to be highly permeable due to its high porosity (Gingerich 2003). Uplifting has occurred as demonstrated by the presence of high-angle normal faults (Stafford et al. 2004).

There are two main limestone formations on Tinian: Tagpochau and Mariana. Tagpochau Limestone covers approximately 16% of Tinian's surface and is composed of three rock types: detrital (majority of the formation), argillaceous, and sandy. It is composed mainly of biogenic calcium carbonate fragments and calcite cement. The Mariana Limestone covers approximately 83% of the Tinian's surface and is composed of seven rock types: constructional coralliferous, constructional algal, detrital coralliferous, detrital shelly, detrital Halimeda, detrital argillaceous and detrital undifferentiated. In the coastal regions, these deposits are overlain by Holocene limestone, developing sands and gravels, and reefs (Stafford et al. 2004).

Most of the shoreline consists of limestone cliffs with sea-level caverns, cuts, notches and slumped border, commonly bordered by intertidal benches. Beach deposits consist mainly of medium- to coarse grain calcareous sands, gravel and rubble interspersed in exposed limestone rock. The north, east and south coasts have very limited fringing or apron reef development. Submarine topography is characterized by limestone pavement with interspersed coral colonies and occasional zones of submerged boulders.

Unai Dankulo (Long Beach) is the largest beach on Tinian, extending approximately 492 ft (150 m) between limestone cliffs that extend to the water line. The Dankulo beaches are composed of white calcareous sands that gently slope into a shallow reef flat separated from the open ocean by a reef crest that is emergent at low tide. The reef crest is continuous across the entire run of the beach.





Karst Geology

Karst is a distinctive topography formed by dissolution of underlying soluble rocks by surface water or groundwater. Karst geology occurs when rainwater dissolves carbonate rocks, such as limestone, causing voids including epikarst, sinkholes, and caves in the surface and subsurface. Limestone is a soluble rock, primarily composed of calcium carbonate. Mylroie et al. (1999) discusses karst geology on Guam, including epikarst, sinkholes, and caves. Epikarst is defined as the upper layer of eroded rock, characterized by rough surfaces, little soil, and small cavities. Epikarst acts as a medium for flow of surface water to the aquifer below, either by diffusion or through pits connected directly to the groundwater. Unsaturated epikarst may provide a large amount of water storage in voids. The fast flow of water through the joints and planes of the epikarst does not allow for adsorption, uptake, or microbial processes to remove pollution from groundwater (Islam 2005).

Surface karst features on Tinian include epikarst, closed depressions, caves and freshwater discharge features (Stafford et. al. 2005). Epikarst is present in all carbonate rocks, such as limestone, on Tinian and its characteristics vary based on nearness to the coast. Coastal epikarst is jagged as a result of the effects of sea spray; surface features become less extreme moving inland (Stafford et al. 2005).

There are three main types of closed depressions found on Tinian: dissolutional, constructional, and human made or modified. Dissolutional depressions are the result of carbonate rock dissolving in surface water. Constructional depressions are formed during carbonate rock formation or as a result of faulting. Human made or modified depressions are the result of excavations such as quarries, borrows pits, and landfills. A karst survey identified 20 closed depressions on Tinian: 7 dissolutional, 8 constructional, and 5 human made or modified (Stafford et al. 2005). Construction activities are major sources of karst collapse that occurs when material overlying the karst geologic formations subsides down along the karst cavity forming sinkholes. Sinkholes can occur as a result of excavation, change of drainage patterns, and lowering of groundwater (Islam 2005). Soil disturbance from construction causes deposits to form in openings near the bedrock surface that get heavier when saturated, causing the underlying structure to collapse. Sinkholes are not only relevant to geological processes, they can potentially be of cultural significance, housing archaeological resources.

Subsurface karst on Tinian includes three types of caves: mixing zone, fissure, and contact. Mixing zone caves, the most common form on Tinian, are globular interconnected chambers that form where different waters meet, such as the interface of the fresh groundwater lens and the underlying salt water. Fissure caves form along faults fractures and joints and may act as a conduit for infiltration of surface water to groundwater. Contact caves develop when surface water is channeled into the subsurface (Stafford et. al. 2005).

Tinian has only a few small surface water bodies. The island has an aquifer of fresh water in the older limestone unit in the south-central portion of the island and may have a smaller aquifer in the north. There are two types of freshwater discharge features on Tinian: seeps and springs. Seeps are releases of freshwater along the surface on beaches. Springs are discharges at rock interfaces and fractures. Three seeps and 14 springs were identified on Tinian (Stafford et al. 2005).

3.1.2.3 Soils

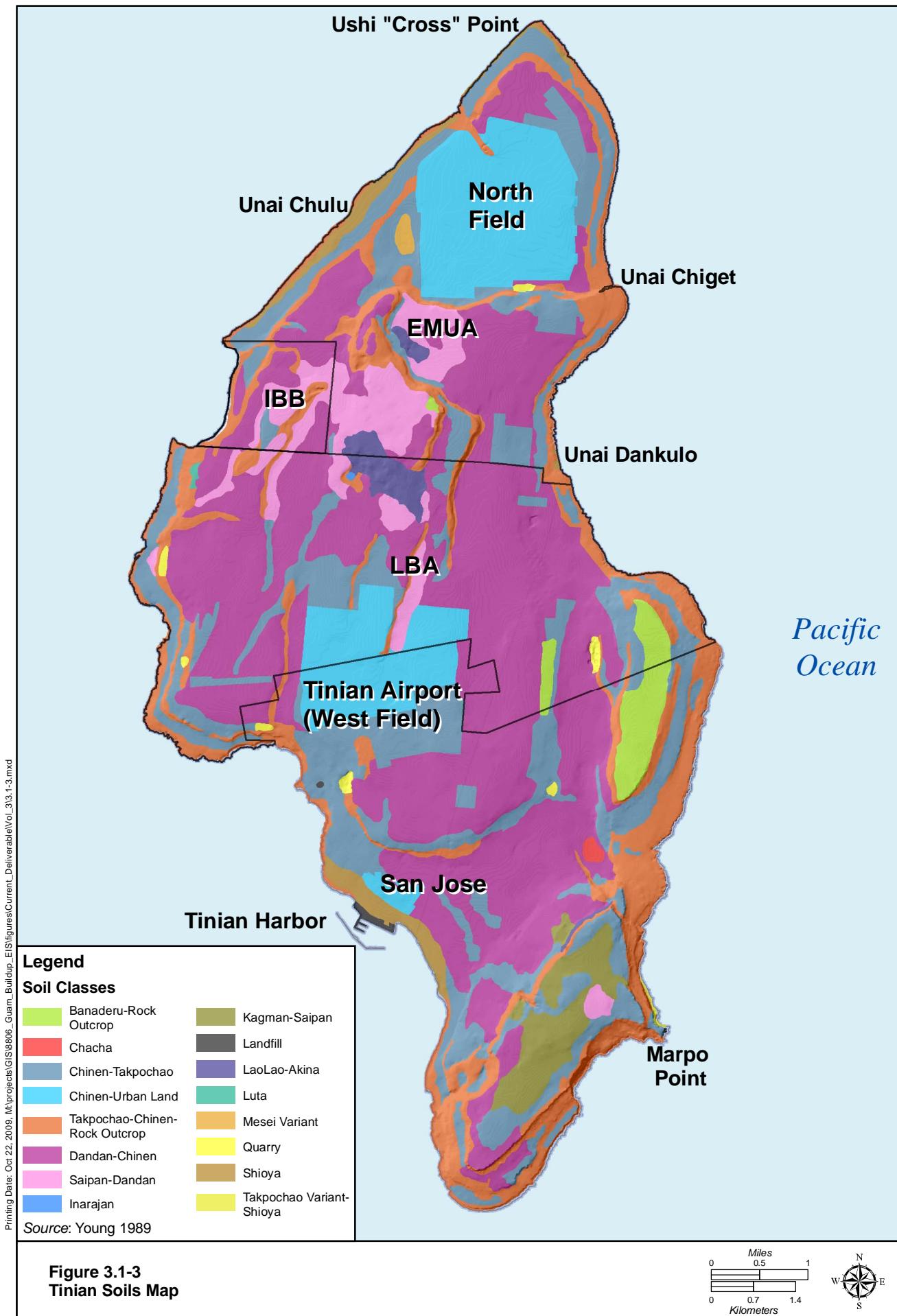
Soils on Tinian are categorized as: lowland, volcanic upland, or limestone upland. Soils developed on volcanic rock tend to be poorly drained clays, while soils developed on limestone are usually shallow and highly porous. Soil classes across Tinian were identified by the United States Department of Agriculture (USDA) Soil Conservation Service in 1985 (Young 1989). Table 3.1-1 describes soil characteristics for

soils found across Tinian. Figure 3.1-3 depicts the soil types found across Tinian. Prime farmland soil classes and potential impacts to agricultural uses are described under land use Volume 3, Chapter 8. Volume 3, Chapter 16 describes the socioeconomic impacts related to agricultural use.

Table 3.1-1. Soils Across Tinian

<i>Soil Class</i>	<i>Soil Description</i>	<i>Runoff Rate</i>	<i>Permeability</i>	<i>Erodibility Factor (K)</i>	<i>Location</i>
Mesei variant	Moderately deep, very poorly drained, level soils in depressions.		1.5 – 5.0	0.05	Lowlands
Shioya	Very deep, excessively drained, level to nearly level soils; on coastal strands.	Slow	15.0-50	0.15	Coastal Limestone Sands
Takpochao variant – Shioya	Very shallow to very deep, excessively drained, levels to gently sloping soils; on coastal strands and plateaus.		1.5 – 5.0	0.15	Lowlands
Banaderu – Rock outcrop	Shallow, well drained, nearly level to moderately steep soils and rock outcrops.		1.5 – 5.0	0.20	Limestone Plateaus
Chinen - Takpochao	Very shallow and shallow, well drained, nearly level to strongly sloping soils; on plateaus and side slopes.		1.5 – 5.0	0.10	Limestone Plateaus
Chinen – Urban Land	Shallow, well drained, nearly level soils and urban areas.		1.5 – 5.0	0.15	Limestone Plateaus
Dandan – Chinen	Shallow and moderately deep, well drained, nearly level to strongly sloping soils.		1.5 – 5.0	0.15	Limestone Plateaus
Kagman – Saipan	Deep and very deep, well drained, nearly level to strongly sloping soils.		0.5 – 1.5	0.15	Limestone Plateaus
Luta	Very shallow, well drained, nearly level to strongly sloping soils.		5.0 - 15	0.10	Limestone Plateaus
Saipan – Dandan	Moderately deep and very deep, well drained, nearly level to gently sloping soils.		1.5 – 5.0	0.15	Limestone Plateaus
Laolao - Akina	Moderately deep, well drained, strongly sloping to steep soils; on volcanic uplands.		1.5 – 5.0	0.15	Uplands
Rock outcrop – Takpochao – Luta	Shallow and very shallow, well drained, strongly sloping to extremely steep soils and rock outcrop; on limestone escarpments.		1.5 – 5.0	0.10	Uplands
Takpochao – Chinen – Rock outcrop	Shallow, well drained, strongly sloping to extremely steep soils and rock outcrop; on limestone escarpments and plateaus.		1.5 – 5.0	0.15	Uplands
Agfayan	Very shallow to very deep, well drained, moderately steep to extremely steep soils; on strongly dissected mountains and plateaus.	Slow	0.5 – 1.5	0.20	Volcanic Uplands
Chacha	Shallow, deep and poorly drained, and found on steep slopes: plateaus and hills.	Medium	0.02 – 0.5	0.15	Limestone Uplands

Source: Young 1989.



Soil types and characteristics often dictate the potential for soils to erode. The USDA defines soil erosion as “the removal of material from the surface soil, which is the part of the soil having an abundance of nutrients and organic matter vital to plant growth.” Natural causes of erosion include wind and water, but humans can worsen erosion particularly by construction projects (Muckel 2004).

Three prime farmland soils classes were identified on Tinian in the Soil Survey of the Islands of Aguijan, Rota, Saipan, and Tinian, Commonwealth of the Northern Mariana Islands (CNMI) (Young 1989), as follows:

- Dandan-Saipan clays, 0-5% slope
- Kagman clay, 0-5% slopes
- Saipan clay, 0-5% slopes

Dandan-Saipan clays 0-5% and Saipan clay, 0-5% were identified within and adjacent to the Leaseback Area as shown on Figure 3.1-4. The Kagman clay 0-5% prime farmland soils are located outside the Military Lease Area (MLA) in the southern area of Tinian.

During construction, grading and filling are often required; this may reduce soil quality that in turn may affect plant growth and runoff. When topsoil is removed, biological activity decreases, as does the presence of organic matter and plant nutrients, thereby affecting plant nutrition, control of pests and disease, water infiltration, and resistance to erosion. Compaction also typically occurs at construction sites and can also increase erosion potential. Compaction occurs when vehicles drive on and off a construction site and compact the soil beneath it. Compaction can lower rates of water infiltration and inhibit plant growth, both increasing runoff. Typically, construction vehicle tires track mud onto streets and roadways, thereby increasing runoff. It has been reported that erosion potential on construction sites are approximately 100 times greater than on agricultural land (Muckel 2004).

Although construction activities are confined to a particular area, the effects of soil erosion can extend offsite beyond the construction zone. The eroded soil becomes a major source of sediment and increased water runoff, thus creating nonpoint source pollution problems. Sediment can clog storm drains, reduce the volume of reservoirs, and add sediment and nutrients to various water bodies (Muckel 2004). Once in a water body, the sediment can smother filter feeding organisms of the reef, and drastically reduce light penetration into the water column. Silt often covers the ocean floor with a soft layer unsuitable for some bottom-dwelling plants and animals.

Erosion potential varies with depth from the surface. The erosion potential is divided into K and T (see discussion below) that are factors in the Universal Soil Loss Equation (USLE). Young (1989) uses the USLE to describe physical and chemical properties of soils. The equation was created to predict the long term average annual rate of erosion on a field slope based on rainfall patterns, soil type, topography, crop system, and management practices. USLE predicts the amount of soil loss that results from sheet or rill erosion on a single slope. Sheet erosion describes uniform removal of soil in thin layers, while rill erosion is the removal of soil by condensed water running through small streams.

Table 3.1-1 shows erosion factors denoting the vulnerability of a soil type to erosion. The value is based on percentage of silt, fine sand, sand, and organic matter, soil structure and permeability. The higher the “K” value in the table, the more susceptible the soil is to erosion (Young 1989). The table shows that Banaderu and Agfayan soils have the highest K values (0.20) and are the most vulnerable to erosion.

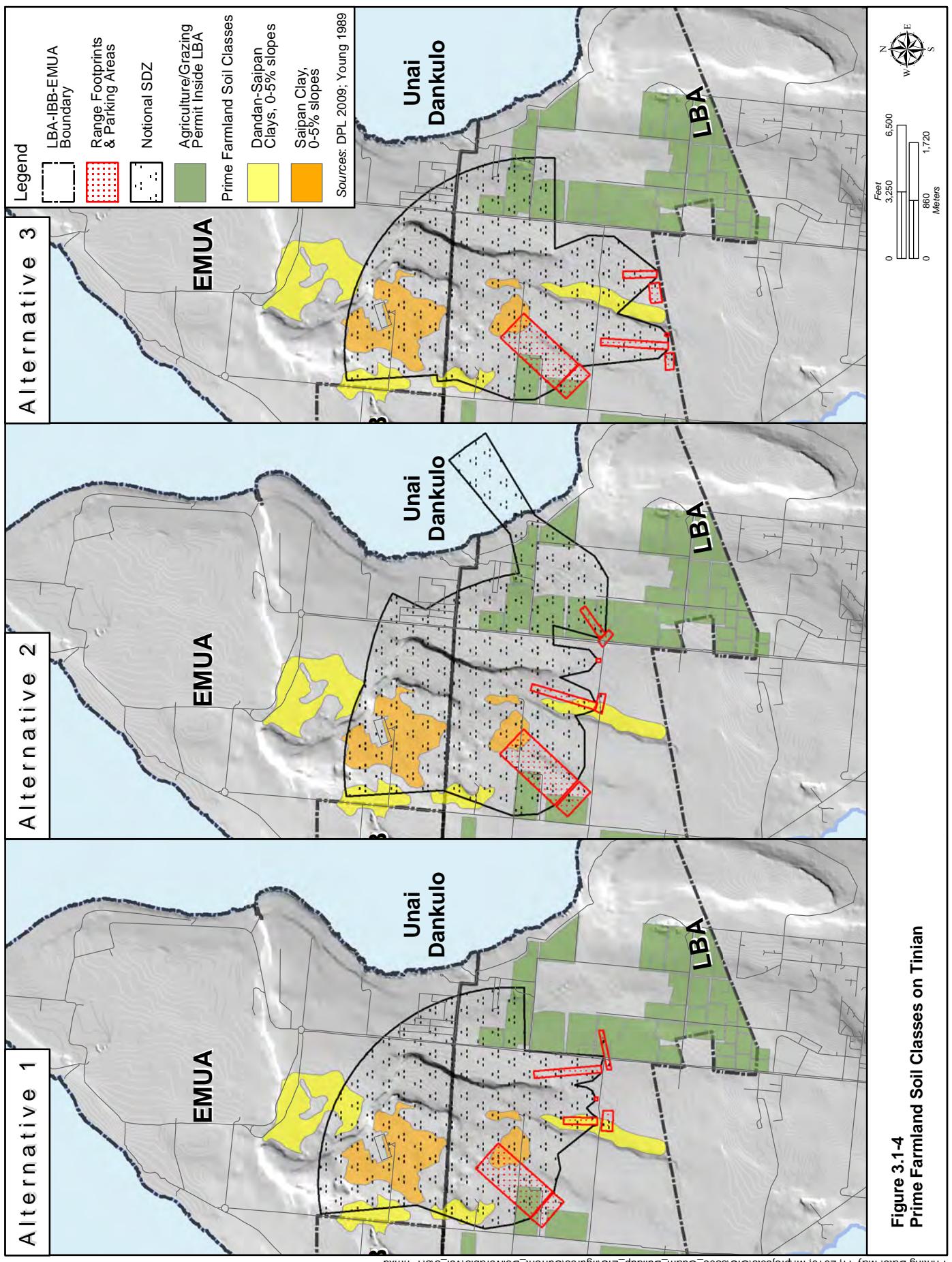


Figure 3.14
Prime Farmland Soil Classes on Tinian

3.1.2.4 Geologic Hazards and Seismicity

Seismic Activity

The Earth is made up of approximately a dozen major tectonic plates and multiple minor plates. Tectonic plates are the large, thin, relatively rigid plates that move next to one another on the outer surface of the Earth. The Earth's tectonic plates are constantly moving; however, not at equal rates. The fastest plate moves 15 centimeters (cm) (6 inches [in]) a year and the slowest at less than 2.5 cm (0.9 in) per year (United States Geological Service [USGS] 2008). Many geological phenomena, such as earthquakes, tsunamis, and volcanic eruptions, originate in areas where plates meet (USGS 2008). Due to movement of these lithospheric plates, Tinian is vulnerable to earthquakes. Between 1849 and 1911, four earthquakes with a magnitude of 7.0 or greater on the Richter Scale occurred in the vicinity of Guam. The most recent large-magnitude earthquake was recorded in 1993 and measured 8.1 on the Richter scale (Pacific Air Force 2006). Earthquake activity is common across the entire Mariana Island chain (Lander et al. 2002). Earthquake is a term used to describe the sudden slip of a fault that results in ground shaking and radiated seismic energy caused by the slip, volcanic or magmatic activity, or other sudden stress changes in the earth (USGS 2008). Faults, the cause of seismic activity, zigzag across Tinian and are the result of collisional stresses and rock failure, where the Philippine Plate and the Pacific Plate converge (Siegrist et al. 1998). A fault is defined as a bedrock fracture along opposite sides that have moved. Fault activity on Tinian can be inconsistent and unpredictable, and ultimately dependent on the angle that the Philippine Plate collides with the Pacific Plate, the rate of subduction, and the dip in the Benioff Zone (Siegrist et al. 1998). The USGS defines the Benioff Zone as a dipping flat zone of earthquakes produced by the interaction of a down going oceanic crustal plate with a continental plate. These earthquakes can be produced by: (1) a slip along the subduction thrust fault, or (2) a slip on faults within the down going plate as a result of bending and extension as the plate is pulled into the mantle.

Fault types differ across Tinian. Normal faults, or Dip-slip faults, are inclined fractures where the blocks have mostly shifted vertically. If the rock mass above an inclined fault descends, the fault is termed normal; however, if the rock above the fault ascends, the fault is termed reverse (USGS 2008). Strike-slip faults are vertical (or nearly vertical) fractures where the blocks have mostly moved horizontally. If the block opposite an observer looking across the fault moves to the right, the slip style is termed right lateral; if the block moves to the left, the motion is termed left lateral. Tinian can be separated into five areas based on the locations of the high-angle faults: Northern Lowland, North-Central Highland, Central Plateau, Median Valley, and Southeastern Ridge (Stafford et al. 2005).

Landslides

The effects of an earthquake are typically local, but can also affect areas beyond its origin. Local effects can include slope failures and landslides, predominantly in limestone terrain. The weather on Tinian, mainly tropical, rapidly weathers and easily erodes the volcanic rock found on the island. Slope destabilization and landslides often occur from a combination of natural events, and seismic activity usually destabilizes a slope. When destabilization is followed by heavy rainfall, the destabilized slope is saturated, and mudflows result (GovGuam 2008).

Potential landslide occurrence depends on local geology, the angle of a slope, groundwater elevations, rainfall, and local geologic structures (e.g., faults and joints). The most appropriate approach to defining landslide hazard risks on Tinian involves determining the vulnerability of an area based on geologic units mapped at the surface. Such vulnerability has been determined by the geology and the slope angle of the various specific areas on the island. Tinian does not have a Hazard Mitigation Plan. However, the Guam

Hazard Mitigation Plan uses these two factors to develop a qualitative rating of the potential of an area for a landslide to occur. The potential ratings in the Guam Hazard Mitigation Plan are expressed as high, moderate to high to moderate and low (Table 3.1-2).

Table 3.1-2. Risk Potential for Landslides to Occur

Slope Angle	Potential Risk of Landslide
Less than 5%	Low potential regardless of geologic deposits
30% or more	Moderate to high

The overall likelihood for landslides to occur on Tinian is generally low. The consolidated nature of the limestone and volcanic units reduce the potential for slope failure. Steep slopes can be found on the sea cliffs and cliff faces at the coastline along the perimeter of the island, and along the northeastern flanks of Mount Lasso. The remainder of northern Tinian is primarily flat.

Liquefaction

Another effect of seismic activity is liquefaction, a process where water-saturated sediment temporarily loses strength and acts as a fluid (USGS 2008).

Certain conditions and geological units are more susceptible to liquefaction than others. Geologic information and historical occurrences are the only data available to determine susceptibility to liquefaction. The limestone and volcanic geologic units are not usually susceptible to liquefaction as they are consolidated. There is no fill on the island of Tinian.

Tsunamis

Earthquakes and landslides can cause big wave events called tsunamis. A tsunami is a sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands (USGS 2008). Tinian is susceptible to tsunamis because of the volcanoes to the north and the Marianas Trench to the east, which has a history of large seismic events. Three tsunamis, in 1849, 1892, and 1993 have caused damage. According to Lander et al. (2002), the impacts of a local tsunami would most likely occur on Guam's east coast, due to the eastern location of the Mariana Trench, the origin of many local earthquakes. Because of the proximity, one can assume the same is true of Tinian. If a tsunami has a southern origin it can impact both the west and east coast of Tinian (Lander et al. 2002). There are no published probability statistics for tsunamis occurrences on Tinian.

The band of coral reef that surrounds Tinian provides protection from tsunamis, and the steep slope of the ocean floor surrounding the island lowers the risk of significant wave run-up.

The Pacific Tsunami Warning Center considers the tsunami evacuation safety zone to be above 30 ft (9 m) elevation and over 100 ft (30 m) inland. Tinian is recognized as Tsunami Ready and Storm Ready by the National Weather Service. To qualify as a Tsunami Ready community, a community must:

- Establish a 24-hour warning point and emergency operations center
- Create a system that monitors local weather and ocean conditions
- Develop multiple ways to receive tsunami and severe weather warnings, and alert the public in a timely manner
- Develop a formal hazard plan and conduct emergency exercises
- Promote public readiness through community education

3.2 ENVIRONMENTAL CONSEQUENCES

3.2.1 Approach to Analysis

3.2.1.1 Methodology

The methodology for identifying, evaluating, and mitigating impacts to geology and soil resources has been established through geologic and soil studies and reports, along with federal statutes and regulations, including state and local building codes and grading ordinances. This assessment of geology was conducted by reviewing available literature including previously published National Environmental Policy Act (NEPA) documents for actions in the Mariana Islands Range Complex (MIRC) and surrounding area. A site-specific geotechnical investigation was not undertaken for this Environmental Impact Statement (EIS). Geologic and soil impacts would include any resulting effects that the proposed action would have on the geology and soils of each geographic area as described in the previous affected environment section. Geology and soils may affect the placement or location of a land use as well; the geological and soil characteristics of an area would have an impact on the proposed action rather than the proposed action impacting the geology.

Activities associated with construction and operation may include:

Construction

- Cut and fill activities leading to soil erosion
- Removal of vegetation and landscaping leading to soil erosion
- Use of heavy equipment resulting in soil compaction
- Impacts to karst topography
- Increased risk of damage from liquefaction, landslides, seismic activity, and tsunamis

Operation

- Impervious surface increase resulting in increased soil erosion
- Vehicle movements on unpaved surfaces resulting in increased soil erosion and compaction
- Troop movements resulting in increased soil erosion
- Munitions impacts resulting in soil and subsurface contamination
- Explosive detonations resulting in soil and subsurface contamination
- Fires resulting in reduced vegetation and increased soil erosion

The potential effects of these activities and their significance within the areas of occurrence under the alternative actions are described below. The analysis of potential impacts to geology and soils considers both direct and indirect impacts. Such disturbance may cause increased erosion and loss of productive soil. Direct impacts result from physical soil disturbances or topographic alterations, while indirect impacts include risks to individuals from geologic hazards, as well as impacts to water or marine biological resources away from the construction/operation site. Factors considered in determining whether an impact would be significant include the potential for substantial change in soil or slope stability. An impact to geological resources would be considered significant if the action would have the potential to disrupt geologic features, or if actions were to be affected by potential geologic hazards.

Many effects are associated with the training operations activities. Increases in runoff due to the removal of ground cover may increase sedimentation. Siltation and formation of sediment plumes and heavy metals and hazardous materials may be leached from munitions and explosives of concern.

Indirect groundwater impacts associated with the construction and operational activities include direct contamination of groundwater resources through percolation for surface runoff. Stormwater runoff can contribute to groundwater contamination. Water impacts are addressed in Chapter 4.

Construction activities are major sources of karst collapse, which can occur as a result of excavation, change of drainage patterns, or lowering the groundwater table (Islam 2005). Soil disturbance from construction can cause deposits to form in openings near the bedrock surface, which get heavier when saturated causing the underlying structure to collapse.

Potential geology and soil impacts addressed in this chapter are limited to elements of the proposed actions that could affect onshore land forms or that could be affected by geologic hazards. Potential soil contamination issues are addressed in Chapter 17 (Hazardous Materials and Waste). Increased soil erosion also may indirectly impact water quality and aquatic ecosystems. Potential impacts to these resources are described in Chapter 4, Water Resources and Chapter 10, Terrestrial Biological Resources.

Applicable Regulatory Standards

CNMI Earthmoving and Erosion Control Regulations (CR Vol. 15, No. 10, October 15, 1993) (CNMI Environmental Protection Act, Public Law 3-23, 2 CMC §§ 3101 to 3134, and 1 CMC §§ 2601 to 2605) establish a permit process for construction activities, identify investigations and studies that are required prior to construction and design, and standards for grading, filling, and clearing.

Per the CNMI Wastewater Treatment and Disposal Rules and Regulations, a Class I Aquifer Recharge Area is defined as an “area contributing surface infiltration to a geologic formation, or part of a formation, that is water bearing and that currently transmits, or is believed capable of transmitting water to supply pumping wells or springs.” It is inferred from mapping of the freshwater lens, that most of the proposed project area lies within a Class I Aquifer Recharge Area. Groundwater aquifers on Tinian are vulnerable to contamination by substances introduced onto the soil surface because the porous soil and underlying limestone do not significantly impede the passage of contaminants to the shallow aquifers. Seismic, liquefaction, and ground shaking are reduced by following Unified Facility Code (UFC) 3-31-04, that provides the Department of Defense (DoD) requirements for:

- Earthquake-resistant design for new buildings
- Evaluating and rehabilitating existing buildings for earthquake resistance
- Guidance on applying seismic design principles to specialized structural and non-structural elements

The new UFC adopts the seismic design provisions of the 2003 *International Building Code* for use in DoD building design.

3.2.1.2 Determination of Significance

For geology and soils, the significance of potential project impacts is determined by subjective criteria, as well as by regulatory standards. An impact to geologic resources would be considered significant if the action would have the potential to disrupt geologic features, or if actions were to be affected by potential geologic hazards. To be considered a significant impact, the following factors are considered for each project area:

- Increased rate of erosion and soil loss from physical disturbance
- Loss of vegetation
- Alteration of surrounding landscape and affect on important geologic features (including soil or rock removal and filling of sinkholes that would adversely affect site drainage)

- Diminished slope stability
- Increased vulnerability to a geologic hazard (e.g., seismic activity, tsunami, liquefaction), and the probability that such an event could result in injury

3.2.1.3 Issues Identified During Public Scoping Process

As part of the analysis, concerns relating to geology and soils resources that were mentioned by the public, including regulatory stakeholders, during scoping meetings were addressed. These include:

- Implementing erosion control measures for construction and post construction phases
- Ensuring the proper permitting and local government clearances are sought where applicable

3.2.2 Alternative 1 (Preferred Alternative)

3.2.2.1 Tinian

Construction

On Tinian, site development and construction of the ranges would occur within the MLA. The MLA encompasses 15,353 acres (ac) (6,213 hectares [ha]). In order to streamline development of a construction estimate for the training ranges and supporting activities, each individual item was assigned to a “prototype” element, with complete construction estimates developed for a representative sample of each of the prototypes.

Construction of ranges and berms would change the landscape and disturb and compact topsoil in the developed areas. The total area of disturbance for the four proposed ranges is 225 ac (91 ha). Although construction footprints would be minimal, it is assumed the full area would be graded or cleared of vegetation. These disturbances would temporarily increase localized erosion during the construction phase, but would not be likely to have a long-term impact on soil resources. Very limited areas of Prime Farmland Soil would be disturbed (refer to Figure 3.1-4). Vegetation that is lost during the construction phase would return to the ranges upon completion of construction. None of the proposed range locations lie over the Takapochao Limestone that holds the main drinking water supply for Tinian; therefore, compaction of soils would not affect infiltration of surface water into the groundwater. The proposed ranges lie over Mariana Limestone that would be disturbed in areas during the construction process, but are unlikely to have long-term significant impacts to underlying limestone. Topography is flat, thus slope stability would not be diminished. Therefore, Alternative 1 would result in less than significant impacts to unique geologic resources and would not result in significant soil erosion or compaction, or loss of productive soils.

The action area is located in an area with karst geologic features that are of concern for the construction and operation of ranges. Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion. As a result of mitigation, the sinkholes would not be affected by construction activities. A survey by a licensed geologist is required prior to construction to ensure that all sinkholes have been identified. If additional sinkholes are discovered, significant impacts to these sinkholes would be determined and projects would be designed in consideration of these sinkholes as appropriate. Any known sinkholes, along with any others found, that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. With mitigation, less than significant impacts to sinkholes would occur and Alternative 1 would result in less than significant impacts to unique geologic resources.

Although Tinian is located in a potentially active seismic zone, the hazards associated with earthquakes, fault rupture, slope instability and liquefaction would be minimal. The proposed ranges would be located

on a relatively flat area that would not be subject to slope instability. Because there are no proposed buildings or permanent structures associated with the proposed range development, there would be no seismic hazard.

Standard Operating Procedures (SOPs) and a Storm Water Pollution Prevention Plan (SWPPP) as required by the National Pollutant Discharge Elimination System permit would be implemented to minimize impacts. The construction SOPs would include requirements for stormwater compliance with stormwater Best Management Practices (BMPs), including the SWPPP, to ensure that all aspects of the project construction would be performed in a manner to minimize impacts during construction activity. A description of the standard BMPs and resource protection measures required by regulatory mandates can be found in Volume 7. Implementation of measures noted in the geology and soils column would prevent erosion; therefore impacts from soil erosion would be less than significant. A more detailed explanation of regulatory permitting requirements may also be found in Volume 8.

Indirect impacts to geological resources, water resources, and marine biological resources from soil erosion during construction would be prevented by implementation of BMPs.

Operation

The ranges would not contain additional impervious surfaces such as facilities or concrete pads, so the surface water would still be able to infiltrate into the ground during rain events. None of the proposed range locations lie over the Takapochao Limestone that holds the main drinking water supply for Tinian, so compaction of soils during training activities would not affect infiltration of surface water into the groundwater. Also, training activities would be conducted with established procedures aimed at minimizing topsoil loss, soil compaction and erosion. Very limited areas of Prime Farmland Soil would be disturbed (refer to Figure 3.1-4). Therefore, Alternative 1 would result in less than significant impacts to unique geologic resources and would not result in significant soil erosion. Erosion potentials for soil found in north Tinian are all slight and can be found in Table 3.2-1.

Table 3.2-1. Tinian Soil Erosion Potential at Proposed Sites

<i>Soil Type</i>	<i>Location</i>	<i>Erosion Potential</i>
Saipan Clay, 0-5% slope	Platoon Battle Course	Slight
Dandan-Chinen Complex, 0-5% slope	Platoon Battle Course	Slight
Dandan-Chinen Complex, 5-15% slope	Platoon Battle Course	Slight
Dandan-Chinen-Pits Complex, 0-5% slope	Platoon Battle Course	Slight
Dandan-Chinen-Pits Complex, 5-15% slope	Platoon Battle Course	Slight
Dandan-Chinen Complex, 0-5% slope	Automated Field Fire Range	Slight
Dandan-Chinen-Pits Complex, 5-15% slope	Automated Field Fire Range	Slight
Chinen-Urban Land Complex, 0-5% slope	Automated Combat Pistol Fire	Slight
Chinen-Urban Land Complex, 0-5% slope	Rifle Known Distance	Slight
Chinen-Clay Loam, 0-5% slope	Rifle Known Distance	Slight
Chinen-Clay Loam, 5-15% slope	Rifle Known Distance	Slight
Chinen-Rock Outcrop Complex, 15-30% slope	Rifle Known Distance	Moderate
Dandan-Saipan Clay, 0-5% slope	Rifle Known Distance	Slight
Takpochao-Rock Outcrop Complex, 30-60% slope	Rifle Known Distance	Slight

Source: Young 1989.

Firing Range operations could potentially result in soil contamination from munitions; however, ordnance would be handled and stored in accordance with Marine Corps explosive safety directives (*Marine Corps Order P8020.10A, Marine Corps Ammunition Management and Explosives Safety Policy Manual*), and all munitions handling would be carried out by trained, qualified personnel. Therefore, no impacts related to explosives safety are anticipated.

Fire potential would be increased from firing range operations. Fire can directly affect soil as a result of increased erosion from loss of vegetation. Grass fires are regular occurrences on Tinian, and there is greater danger during the dry season. Data cited in the 1997 Tinian INRMP (NAVFAC Pacific 1997) shows that the worst fire hazard exists during the driest months (May through July) of the dry season and during this short time 200 or more acres may get scorched each year. Information presented for 1991 showed that 33 fires burned, the largest occurring in the month of March, and two-thirds of the fires burned between 1 and 8 ac (0.4 and 3 ha), while approximately one-third burned 9 to 20 ac (4 to 8 ha). The reduction in ground cover caused by fire could increase rates of erosion.

As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts would be less than significant.

Topography or landscape features would not be changed substantively by the proposed action. Topography is flat, thus slope stability would not be diminished. The action area is located in an area with karst geologic features that are of concern for the construction and operation of the ranges. Operations would not occur over unstable karst features. Any sinkholes found in the area that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. There would be no loss of productive soils or vegetation. Therefore, Alternative 1 would result in less than significant impacts to unique geologic resources and would not result in significant soil contamination, erosion or compaction.

Although Tinian is located in a potentially active seismic zone, the hazards associated with earthquakes, fault rupture, slope instability and liquefaction would be minimal because there would be no buildings or permanent structures associated with use of the proposed ranges. The Alternative 1 proposed ranges are to be located on a relatively flat area that would not be subject to slope instability. The predominant limestone bedrock is not vulnerable to liquefaction. Due to the limited duration of operational activities (1 week per month on average), exposure potential to seismic ground shaking and fault rupture would be minimal. Therefore, Alternative 1 would result in less than significant impacts associated with geologic hazards.

Indirect impacts to geological resources, water resources, and marine biological resources from soil erosion during operation would be prevented by implementation of BMPs (refer to analysis in Chapters 4 and 10).

3.2.2.2 Summary of Alternative 1 Impacts

Table 3.2-2 summarizes Alternative 1 impacts.

Table 3.2-2. Summary of Alternative 1 Impacts

<i>Area</i>	<i>Project Activities</i>	<i>Project Specific Impacts</i>
Tinian	Construction	<ul style="list-style-type: none"> • Changes in landscape under Alternative 1 would result in less than significant impacts to topography on Tinian. • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 1. • Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 1. Less than significant impacts would occur with the use of BMPs.
	Operation	<ul style="list-style-type: none"> • As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.

3.2.2.3 Alternative 1 Proposed Mitigation Measures

Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion. As a result of mitigation, the sinkholes would not be affected by construction activities. A survey by a licensed geologist is required prior to construction to ensure that all sinkholes have been identified. If additional sinkholes are discovered, significant impacts to these sinkholes would be determined and projects would be designed in consideration of these sinkholes as appropriate. Any known sinkholes, along with any others found, that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. With mitigation, less than significant impacts to sinkholes would occur.

3.2.3 Alternative 2

3.2.3.1 Tinian

Alternative 2 involves a different configuration of the proposed ranges than Alternative 1. However, geological resources conditions (topography, geologic units, erosion potential, and geological hazards) are similar.

Construction

Impacts to soil and geological resources during construction would not differ from those of Alternative 1.

Operation

Impacts to soil and geological resources during construction would not differ from those of Alternative 1.

3.2.3.2 Summary of Alternative 2 Impacts

Table 3.2-3 summarizes Alternative 2 impacts.

Table 3.2-3. Summary of Alternative 2 Impacts

<i>Area</i>	<i>Project Activities</i>	<i>Project Specific Impacts</i>
Tinian	Construction	<ul style="list-style-type: none"> Changes in landscape under Alternative 2 would result in less than significant impacts to topography by on Tinian. Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 2. Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 2. Less than significant impacts would occur with the use of BMPs.
	Operation	<ul style="list-style-type: none"> As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.

3.2.3.3 Alternative 2 Proposed Mitigation Measures

Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion. As a result of mitigation, the sinkholes would not be affected by construction activities. A survey by a licensed geologist is required prior to construction to ensure that all sinkholes have been identified. If additional sinkholes are discovered, significant impacts to these sinkholes would be determined and projects would be designed in consideration of these sinkholes as appropriate. Any known sinkholes, along with any others found, that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. With mitigation, less than significant impacts to sinkholes would occur.

3.2.4 Alternative 3

3.2.4.1 Tinian

Alternative 3 differs from Alternative 2 due to relocation of the Platoon Battle Course.

Construction

Impacts to soil and geological resources during construction would not differ from those of Alternative 1.

Operation

Impacts to soil and geological resources during operations would not differ from those of Alternative 1.

3.2.4.2 Summary of Alternative 3 Impacts

Table 3.2-4 summarizes Alternative 3 impacts.

Table 3.2-4. Summary of Alternative 3 Impacts

<i>Area</i>	<i>Project Activities</i>	<i>Project Specific Impacts</i>
Tinian	Construction	<ul style="list-style-type: none"> Changes in landscape under Alternative 3 would result in less than significant impacts to topography on Tinian. Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 3. Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 3. Less than significant impacts would occur with the use of BMPs.
	Operation	<ul style="list-style-type: none"> As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.

3.2.4.3 Alternative 3 Proposed Mitigation Measures

Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion. As a result of mitigation, the sinkholes would not be affected by construction activities. A survey by a licensed geologist is required prior to construction to ensure that all sinkholes have been identified. If additional sinkholes are discovered, significant impacts to these sinkholes would be determined and projects would be designed in consideration of these sinkholes as appropriate. Any known sinkholes, along with any others found, that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. With mitigation, less than significant impacts to sinkholes would occur.

3.2.5 No-Action Alternative

Under the no-action alternative, no new construction or new training activities associated with the Marine Corps relocation to Guam would occur in Tinian, and the Marine Corps would not meet training needs and requirements in support of the proposed action. The purpose and need for training in Tinian as described in Chapter 1 would not be met. Existing operations on Tinian would continue. Therefore, the no-action alternative would have no impacts to geologic resources.

3.2.6 Summary of Impacts

Table 3.2-5 summarizes the potential impacts of each action alternative and the no-action alternative. A text summary is provided below.

Table 3.2-5. Summary of Impacts

<i>Alternative 1</i>	<i>Alternative 2</i>	<i>Alternative 3</i>	<i>No-Action Alternative</i>
Construction			
Topography			
LSI • Changes in landscape under Alternative 1 would result in less than significant impacts to topography on Tinian.	LSI • Changes in landscape under Alternative 2 would result in less than significant impacts to topography on Tinian.	LSI • Changes in landscape under Alternative 3 would result in less than significant impacts to topography on Tinian.	NI • No impacts to geological and soil resources.
Geology			
SI-M • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 1.	SI-M • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 2.	SI-M • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 3.	NI • No impacts to geological and soil resources.
Soil			
LSI • Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 1. Less than significant impacts would occur with the use of BMPs.	LSI • Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 2. Less than significant impacts would occur with the use of BMPs.	LSI • Soil disturbances and loss of vegetation would cause increased rate of erosion and soil loss from physical disturbance at all proposed construction areas under Alternative 3. Less than significant impacts would occur with the use of BMPs.	NI • No impacts to geological and soil resources.

Table 3.2-5. Summary of Impacts

<i>Alternative 1</i>	<i>Alternative 2</i>	<i>Alternative 3</i>	<i>No-Action Alternative</i>
Operation			
Geology and Soil			
LSI • As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.	LSI • As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.	LSI • As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.	NI • No impacts to geological and soil resources.
Geologic Hazards			
LSI • Due to the limited duration of operational activities and lack of structures associated with operations, exposure potential to seismic ground shaking and fault rupture would be minimal.	LSI • Due to the limited duration of operational activities and lack of structures associated with operations, exposure potential to seismic ground shaking and fault rupture would be minimal.	LSI • Due to the limited duration of operational activities and lack of structures associated with operations, exposure potential to seismic ground shaking and fault rupture would be minimal.	NI • No impacts from geologic hazards.

Legend: LSI = Less than significant impact, SI-M=Significant impact, mitigable, NI = No impact.

The development of proposed training ranges on Tinian would require construction that would potentially disturb soil, increase erosion, and change the landscape of Tinian in four separate areas of northern Tinian.

Construction of ranges and berms would change the landscape and disturb topsoil in the developed areas. These disturbances would temporarily increase localized erosion during the construction phase, but would not be likely to have a long-term impact on soil resources. Very limited areas of Prime Farmland Soil would be disturbed (refer to Figure 3.1-4). Vegetation that is lost during the construction phase would return to the ranges and berms upon completion of construction. None of the proposed range locations lie over the Takapochao Limestone that holds the main drinking water supply for Tinian. The proposed ranges lie over Mariana Limestone that would be disturbed in areas during the construction process, but are unlikely to have long-term significant impacts to underlying limestone. Topography is flat, thus slope stability would not be diminished.

Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion. As a result of mitigation, the sinkholes would not be affected by construction activities. A survey by a licensed geologist is required prior to construction to ensure that all sinkholes have been identified. If additional sinkholes are discovered, significant impacts to these sinkholes would be determined and projects would be designed in consideration of these sinkholes as appropriate. Any known sinkholes, along with any others found, that are deemed hazardous would be fenced off and signs put in place to warn of the potential danger. With mitigation, less than significant impacts to sinkholes would occur. BMPs and a Stormwater Management Plan would be included in SOPs to ensure that all aspects of the project construction would be performed in a manner to minimize impacts during construction activity. As a BMP, a fire management plan would be developed as part of a Range Training Area Management Plan. The plan would include assigned logistic support unit for fire control during training events, fuel management, and a fire danger rating system. With the implementation of this BMP, impacts to soil and geological resources would be less than significant.

Although Tinian is located in a potentially active seismic zone, the hazards associated with earthquakes, fault rupture, slope instability and liquefaction would be minimal because there would be no buildings or permanent structures associated with the proposed range. The proposed ranges would be located on a relatively flat area that would not be subject to slope instability.

The construction SOPs would include requirements for stormwater compliance with stormwater BMPs, including the SWPPP, to ensure that all aspects of the project construction would be performed in a manner to minimize impacts during construction activity. A description of the standard BMPs and resource protection measures required by regulatory mandates can be found in Volume 7. Implementation of measures noted in the geology and soils column would prevent erosion; therefore, impacts from soil erosion would be less than significant. Indirect impacts to geological resources, water resources, and marine biological resources from soil erosion during construction and operation would be prevented by implementation of BMPs.

3.2.7 Summary of Proposed Mitigation Measures

Table 3.2-6 summarizes the proposed mitigation measures.

Table 3.2-6. Summary of Proposed Mitigation Measures

<i>Alternative 1</i>	<i>Alternative 2</i>	<i>Alternative 3</i>
Topography		
• None	• None	• None
Geology		
<ul style="list-style-type: none"> • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 1. 	<ul style="list-style-type: none"> • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 2. 	<ul style="list-style-type: none"> • Known sinkholes would be avoided and a buffer zone of vegetation would be left around them as a mitigation measure to prevent further erosion or expansion at any sinkholes found. Any sinkholes discovered would be evaluated to determine significant impacts and projects would be designed in consideration of these sinkholes as appropriate. With mitigation, there would be less than significant impact to sinkholes under Alternative 3.
Soil		
• None	• None	• None
Geologic Hazards		
• None	• None	• None

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