The airport has parking for 710 vehicles. While it is partially submerged and somewhat protected from the wind, it is susceptible to flooding. Parking lots, in general, are locations of major vehicle damage, as vehicles in strong winds bounce around and can be flipped.

7.3.3. Andersen Air Force Base (AAFB)

Andersen Air Force Base (AAFB) (Figure 7.3) is a dual runway operation with a small state-of-the-art air terminal, state-of-the-art navigation aids, and a steel-reinforced concrete 90-foot control tower. Air field navigation aids are vulnerable to damage by strong winds (medium-strong Typhoon Category 3 or higher) and flying debris. The Air Traffic and Approach Control system (CERAP), air field navigation aids, and air field lighting are all served with emergency power from back-up generators.

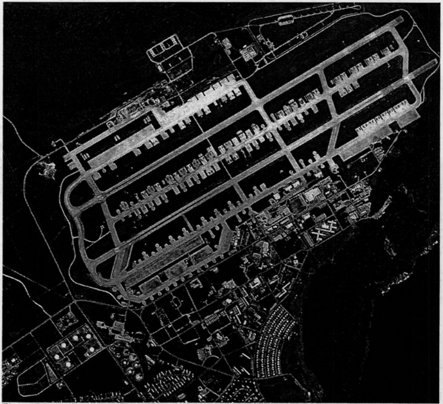


Figure 7.3. Andersen Air Force Base and its runway complex. (Courtesy: Bureau of Planning)

There are several hangers at AAFB, which can house the helicopters of the Navy's HC-5 Squadron and aircraft that aren't able to fly. Since most aircraft on Andersen are transient, they are generally evacuated when sustained winds are predicted to be 50 kt (57 mph) (Tropical Storm Category B) or greater. Those unable to fly are placed in hangers. The doors and the windows of the hangers are vulnerable to damage when winds reach weak Typhoon Category 4 intensity.

AAFB has some on-base generators that can be activated if island power is lost. It also has some water wells with emergency power back-up. Most power poles on the base are solid steel-reinforced concrete, and most will stand up to weak to medium Typhoon Category 5 winds. Most primary lines will stand up to medium Typhoon Category 4 winds, while many secondary lines are vulnerable to weak to medium Typhoon Category 3 winds (see Tables 8.1 and 8.2). The base also has several fuel storage tanks containing several million gallons of jet fuel. These could be vulnerable to medium-strong Typhoon Category 5 winds (see Table 8.3).

AAFB is probably the most survivable location on the Island of Guam.

7.4. SEAPORT FACILITIES

Seaport facilities include the Commercial Port and the US Naval Activities, both located at Apra Harbor. The two facilities share a common outer harbor. The Commercial Port is at the eastern extent of Outer Apra Harbor (Figure 7.4), and is poorly protected. The US Naval port is located in Inner Apra Harbor (Figure 7.5). The inner and outer harbors

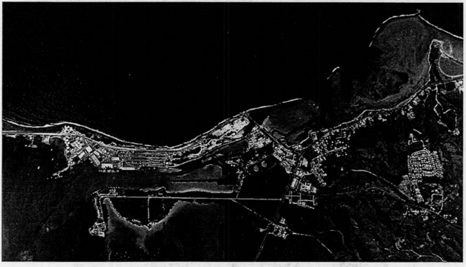


Figure 7.4. Apra Harbor and the Commercial Port at Cabras Island. (Source: Bureau of Planning)

are connected by a channel that passes between the Ship Repair Facility (west) and Polaris Point (east). Apra Harbor has a single, relatively narrow deep-water channel linking the open ocean to port facilities located at the eastern end of the harbor. This channel is critical to the movement of large ships in and out of the harbor. **Were a large ship to sink in the channel, it could take up to 6 months to salvage it and fully reopen the channel.** This could greatly limit the use of the port, and could produce a devastating impact to the Island. For this reason, all large ships should leave the harbor before the onset of 35 mph winds when a typhoon is expected. **A second deep-water channel may be needed inside the harbor.** If winds reach strong Typhoon Category 2 intensity, they could cause a large ship to break or drag anchor, possibly endangering the channel.

The harbor complex also has a ship repair facility complete with floating dry docks. Wharves at the Commercial Port are located at Cabras Island and wharves at the Naval Activities are located in the Inner Apra Harbor (Fig. 7.5).

Figure 7.5. US Naval port complex at Inner Apra Harbor. (Courtesy: Bureau of Planning)

7.4.1. Commercial Port

Guam's Commercial Port is located at Cabras Island (Figure 7.4). It is the busiest US port in the western Pacific, comparable in container traffic to Portland, Oregon. Nearly 100,000 containers are handled annually. It is the major transshipment center for the Mariana Islands and for much of Micronesia. The port can handle ships with a draft of over 32 feet.

The Port facility contains three rail-mounted gantry cranes for off-loading containers from ships. It also has two large rubber-tired strike cranes and one mobile strike crane for handling containers within the large container yard capable of storing several thousand containers. The cranes are vulnerable to strong winds. While they have complex braking systems and can be tied to the wharf area, winds of strong Typhoon Category 4 intensity can begin to twist/torque the upper arm structure of the cranes. Considerable damage is likely to occur to the cranes when winds reach Typhoon Category 5 intensity.

The rubber-tired cranes are susceptible to rolling in Typhoon Category 4 winds and probably tipping in Typhoon Category 5 winds.

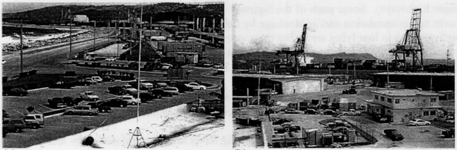
Empty containers can be blown over with medium Typhoon Category 3 winds, while full containers can blow over with weak Typhoon Category 4 winds. Empty containers can become airborne in strong Typhoon Category 4 winds and full containers can become airborne when winds reach weak to medium Typhoon Category 5 winds. The operations buildings are constructed of steel-reinforced concrete, but they are susceptible to flooding from waves and rain. Concrete warehouses will lose many of their doors in Typhoon Category 4 winds to week Typhoon Category 5 winds. The container yard and the check point area are vulnerable to flooding and debris, including large boulders, from the open ocean. Waves can break over the sea wall to the north from the open ocean and over the wharf area from the harbor. The west end of the container yard has an 8-foot block wall, which houses power hookups for cold storage containers. This wall and the emergency generator are also susceptible to damage from the seas generated by Typhoon Category 5 winds.

The Port contains five berths, the largest capable of handling ships over 900 feet in length. The four berths are government run and one is commercially run, primarily for the off-loading of fish and to service fishing boats. Hotel Wharf is west of the port area, and is very susceptible to erosion from wave action. Between Hotel Wharf and the main port area, are two fuel piers for off-loading fuel. These would be susceptible to considerable wind and wave damage in a Typhoon Category 5 situation. There are fairly extensive fuel storage facilities at the port. These are susceptible to damage as discussed in Section 8.3.6. and Table 8.3.

There is also a large foreign tuna fishing fleet at the Port. These trawlers/long-liners are very susceptible to damage when winds become Typhoon Category 2 intensity. They are instructed to leave the harbor at Typhoon COR 2, but for one reason or another, many don't leave, and their ships are frequently damaged or destroyed.

During Typhoon Paka, water levels were 15-16 feet above normal, and the waves threw large boulders across the Access Road (Route 11), knocking down the perimeter fence and coming to rest in the container yard. The container yard also received considerable flooding. A 1991 Army Corps of Engineers Study (USACE 1991) presented a plan for improving the sea wall at Cabras Island. The design wave height was based on the depth limited breaking wave height criteria on a wide flat reef, and from this, engineering specifications for single layer revetment armor stone size were determined. The study determined a design water depth of 8.2 feet and a design wave height of 4.1 feet. These parameters appear too low and should be reevaluated using the experiences of Paka. The Port Authority of Guam has identified a seawall project to protect Route 11 as its top priority for Supertyphoon Paka Supplemental Funding. Other projects included hardening the main container/break bulk piers and gantry cranes, acquisition of a Panamax gantry crane, hardening of the container yard, hardening of the fuel piers and fuel lines, upgrading the pier fendering system, and hardening substations and generators. The total hardening needs are over a $52 million (PAG 1998).

Gantry crane No. 3 is not owned by the port and damages are not reimbursable by FEMA. Typhoon Paka caused several hundred thousand dollars damage to the crane, but the damages were below the deductible limits of the insurance carried by the owners. The Government of Guam must pick up the repair costs (PDN 1999).



(a) (b)

Figure 7.6. (a) Commercial Port container yard showing proximity of the yard to high wave area of the coastline and (b) Commercial Port showing gantry cranes and operations center.

7.4.2. US Naval Activities

The US Naval Activities Guam is located on Orote Peninsula, which forms the south border of Outer Apra Harbor and the west side of Inner Apra Harbor (Figure 7.5). The wharves and primary port facilities are located on the west and southeast sides of the harbor.

The US Naval Activities has been greatly downsized under the 95 Base Realignment and Closure (BRAC) Commission decisions in 1995. The Ship Repair Facility (SRF) and the Fleet Industrial Supply Center (FISC) have closed down, and the Public Works Center (PWC) is in the process of closing as the projects are out-sourced. The Naval Activities also houses the Commander Naval Forces Marianas (COMNAVMAR), which moved from facilities at Nimitz Hill. COMNAVMAR is the Commander-in-Chief Pacific

(USCINCPAC) representative (CINCPACREP), for the Micronesian region, and is a key player in the coordination of military transport for FEMA-directed relief.

The infrastructure on Naval Activities is not as well developed as that at Andersen Air Force Base. The power infrastructure contains a substantial number of wooden poles, which are susceptible to being blown down or broken by weak to medium Typhoon Category 3 or higher winds. It also contains a large number of solid concrete steel-reinforced power poles, which can probably endure sustained winds of at least medium Typhoon Category 5. Most primary lines are on the hollow-spun concrete poles and will stand up to medium Typhoon Category 4 winds. Many secondary lines are on wooden poles and are vulnerable to weak to medium Typhoon Category 3 winds. The Navy also has several fuel storage tanks containing several million gallons of fuel. These could be vulnerable to winds of Typhoon Category 4 and 5, as discussed in Section 8.3.6 and Table 8.3.

7.5. ISLAND HIGHWAY SYSTEM

For the island's size, Guam has an extensive highway system (see inside front cover for major highways). Some parts of the highway system are susceptible to destruction from storm surge/inundation and/or blockage by debris deposited by the ocean waves. These highways are in low lying areas, but their vulnerability depends on their location on the island relative to the location, motion, intensity, size and speed of motion of the typhoon. These relationships are illustrated in Chapter 3. The most vulnerable areas are:

(1) Route 4 from Inarajan Bay, southwestward to Agfayan Point, and to a lesser degree, westward from Ajayan Bay to Balang Point and around Achung Bay;

(2) Route 4 near the Ylig Bay and Ylig River and near Talofofo Bay and Talofofo River;

(3) Route 1 from East Hagåtña near Trinchera Beach, westward through East Hagåtña to Paseo de Susana, then from the Hagåtña Marina through Anigua to Adelup;

(4) Route 1 from Adelup Point, west-southwestward through Asan and Piti to Tepungan Beach;

(5) Route 1 near Sasa Bay and the Laguas River (northeast of Polaris Point turnoff);

(6) Route 2 near Talifak Bay and Nimitz Beach; and,

(7) Route 11 (Cabras Island) from USO Beach, westward to Hotel Wharf.

Locations (1) and (2) are vulnerable to waves and inundation produced by typhoons passing over southern Guam (medium Typhoon Category 3 intensity or stronger) or

within 100 miles of southern Guam (weak Typhoon Category 4 intensity or stronger).

Locations (3), (4), and (5) are vulnerable to waves and inundation produced by typhoons passing over northern or central Guam (strong Typhoon Category 3 intensity or stronger) or within 50 miles of northern Guam (medium Typhoon Category 4 intensity or stronger).

Location (6) is vulnerable to large slow-moving typhoons that pass to the southwest of Guam. Location (7) is vulnerable to typhoons (of medium Typhoon Category 3 or stronger) that pass over central or northern Guam and produce swells and large waves moving from north to south.

Locations (1) and (7) are vulnerable to extensive pavement damage, while areas (2) through (6) are mostly vulnerable to deposition of sand, rocks, boulders, and coral debris. While the new sea wall being constructed near Inarajan will protect Route 1 from the waves generated by most typhoons, it will not likely hold up to waves from intense Typhoon Category 4 and Typhoon Category 5 winds. (Typhoon Yuri (Nov 1991) passed 80 miles south of Inarajan and still produced 30-foot waves at the Saluglula Pools.)

Most highways are also susceptible to blockage from fallen trees, broken or fallen power poles and lines, and debris deposited by the wind. **The amount of highway blockage can generally be expected to increase with increasing wind speed.**

The vulnerability to wind of various types of power poles is given in Chapter 8, Section 8.3.2.2. There are some areas that have specific problems and show a higher than expected loss of power poles. These areas are:

(1) Cross Island Road (Route 17) and Talofofo area -- This area is susceptible to accelerating winds from both the east and the south. Easterly winds are funneled through the Ylig Bay and up the river valley toward the Cross Island Road. Southerly winds accelerate down the slopes of the southern mountains south of Talofofo.

(2) Tiyan -- Tiyan is on a relatively open plateau with the runway splitting the governmental location in half. This area experiences about the same wind as the windward coastal areas. There is a high number of wooden telephone poles in this area.

(3) Marine Drive (Route 1) from East Hagåtña to Dededo -- This area is very congested and there is very little room for adequate guy wires for the power poles. Many of the concrete poles are set in concrete. This is good for the solid steel-reinforced poles but not good for the hollow-spun concrete poles. The oscillations set up by the wind blowing the power lines and the gusts against the pole put stresses on the pole. The hollow-spun poles are brittle, and the concrete chips at the base where it meets the concrete pad. Eventually, only the rebar is left, and the pole bends or collapses.

(4) Route 4 between Inarajan and Merizo -- Many of the power poles are close to the ocean and subjected to undermining during storm surge/inundation. The guy wires are also undermined by water from the ocean.

8. VULNERABILITY ASSESSMENT FOR INFRASTRUCTURE AND FACILITIES

8.1. SCOPE

Since Guam is extremely isolated, it is totally dependent on on-island resources for initial recovery. Outside assistance may take up to a few days, and its arrival is dependent on the operation of the civilian and military airports and seaports. Thus, Guam is highly dependent on the restoration of water, power, communications, and medical services, especially to the levels necessary to provide emergency services. The most important basic service aside from emergency medical care is the restoration of the water and waste-water systems. This is necessary to provide drinking water and for sanitary waste disposal. In the past, Guam has been faced with a serious "catch-22." Power was necessary to restore water, and water was necessary for power generation. One of the most important typhoon mitigation programs funded by FEMA and the Government of Guam has been to retrofit critical wells and pumping stations with emergency generators. As for local and long distance telephone systems, most of Guam's primary telephone lines are underground, and thus, they have held up well. For long distance service, Guam has both satellite and sub-oceanic links. Another critical need during and after a typhoon is the ability of the government to house those who need shelter. On Guam, the primary shelters are the schools, and thus, it is important to know the survivability of the schools/emergency shelters. Post-typhoon shelters range from a "tent city" after Omar to Andersen South after Typhoon Paka.

The speed of restoration depends on the level of survival of the infrastructure and maintenance equipment, the number of critical stored spare materials, and the access to the damaged areas. Thus, this section will assess the vulnerability of the following critical infrastructure and facilities:

(1) water and waste-water systems;

(2) power generation and distribution systems;

(3) telecommunication systems;

(4) hospitals and public health facilities;

(5) schools and shelters;

(6) fuel storage facilities; and

(7) dump sites for debris removal.

8.2. METHODOLOGY

Most of Guam's infrastructure is located at higher elevation or at relatively well-protected coastal areas. Thus, the infrastructure (aside from highways, which are discussed in the Transportation Assessment -- Chapter 7) is primarily vulnerable to wind, wind-blown debris, and flood hazards. In a secondary manner, they are vulnerable to sea salt deposition. The latter is more a long term problem rather than an immediate one, unless salt water gets directly into electrical wiring and equipment. In this case, merely drying the equipment will probably not restore it, and repairs can be very expensive, if they are at all possible. For power lines and power equipment that is normally outside, flushing with rain water is usually sufficient.

Some power poles in southeastern Guam are vulnerable to undermining if sea water inundates the area. The same is true of some telephone junction boxes. By and large, however, the majority of damage to the infrastructure is caused by the wind and wind-blown debris, and by flooding that occurs once the structural skin (walls, roof, windows, doors) is penetrated. This vulnerability assessment uses engineering design and historical performance information to determine the vulnerability of the infrastructure and its facilities. The Saffir-Simpson Tropical Cyclone Scale is then used to classify the levels of damage according to tropical cyclone intensity category and wind speed.

8.3. INFRASTRUCTURE VULNERABILITY

8.3.1. Water and Waste-Water Systems

Potable water is essential to preventing disease and possible epidemics. While most of Guam's wells, water pumps, and sewage lift stations now have emergency generators, these are not designed to run for long periods of time, and they require considerable manpower to keep them fueled and maintained. Therefore, **restoration of the water and waste-water systems requires early restoration of critical parts of the power production and power distribution systems.**

Most of the water distribution system is underground and is protected from the effects of strong winds. Two vulnerable parts of the water systems are: (1) the well pump houses and emergency generators and (2) the water storage tanks. While some of the water storage facilities are underground, most are 0.5 to 2.5 million gallon tanks that are above ground. These tanks are vulnerable to damage from Typhoon Category 5 winds, especially if the tanks are not full or they are elevated on towers.

There are six large and two small wastewater treatment plants on Guam. The large facilities are located at Hagåtña (Figure 8-1), Tanguisson, Naval Activities, Baza Gardens Talofofo, Agat, and Umatac. The smaller units are at Inarajan and the Commercial Port GOVGUAM 1998d). These did not incur significant damage during Typhoon Omar or Typhoon Paka, but it is likely that they would be damaged to some extent in typhoons with winds of Typhoon Category 5 intensity.

There are two critical aspects to waste water treatment. One is the transport of the sewage to the treatment plant. The second is the actual treatment of the sewage and disposal of the effluent. The lack of power has affected lift stations and pumps that allow smooth flow of the sewage to the treatment plants. Most of the critical lift stations and pumps have emergency generators, but as with the water system, the emergency generators are not designed to operate for long periods of time. The most vulnerable of the treatment plants is the one at Hagåtña, which is susceptible to storm surge and wave damage. There was some damage to the access road during Typhoon Paka.

When the waste water treatment plants are inoperable or partially inoperable, the effluent is highly contaminated and may contain solid waste. During a typhoon, it is possible that the effluent at the out fall is forced back toward the shore with the strong currents and heavy surf. More study is needed to understand the behavior of the near-shore currents during typhoons and the movement of the sewage at the outfall.

During Typhoon Paka, the Guam Waterworks Authority incurred damages estimated at $10 million.

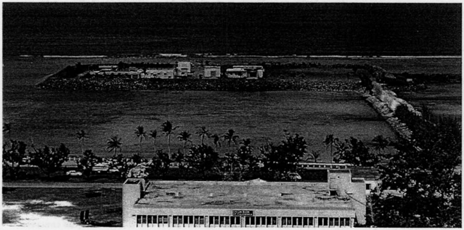


Figure 8.1. Hagåtña waste water treatment plant. The access road (right side of picture) was damaged during Typhoon Paka. The Agana Boat Basin is to the right of the access road.

8.3.2. Power Generation and Distribution Systems

The power production systems are generally powered down when winds reach weak to strong Typhoon Category 1 intensity, depending on the expected maximum intensity of the typhoon. This is done to prevent damage to the power generation system and to prevent electrical shock as components of the power distribution system fail. Power generation is not resumed until the damage is assessed and sufficient repairs are made to critical links of the power distribution system. The Guam Power Authority does have some limited flexibility in the way it routes and energizes portions of the power grid.

8.3.2.1. Power generation systems

The Guam Power Authority (GPA) operates baseline generators at Cabras, Piti, and Tanguisson. It also operates several turbine "fast track" generators, which are used to back-up and augment the baseline system. Total power output capacity is about 450 megawatts. System peak load is about 275-300 megawatts. In the past, power generation systems on Guam have been susceptible to damage from typhoons. This has primarily been due to the failure of the containment buildings. Now the containment buildings are primarily steel-reinforced concrete, and this should prevent damage to the power generators. The power generation systems are still hampered by not having sufficient water storage capacity to endure a prolonged loss of water distribution. The portions of the water distribution system that supply water to the power generation units must be made robust enough to guarantee a continuous source of water. This may require redundancy in the backup generators.

External pipes, condensers, transformers, and power distribution arrays are exposed and are susceptible to wind damage, especially from winds of Typhoon Category 5 intensity.

(a) **(b)**

Figure 8.2. Typical strong wind damage to (a) wooden power poles and (b) hollow-spun concrete power poles.

8.3.2.2. Power distribution systems

The GPA's distribution system contains approximately 28,500 poles. About 55 percent (16,000) are wood, 44 percent (12,500) are concrete, and less than 1 percent are steel poles and steel lattice towers (FEMA 1998g). The 115 kilovolt (kV) transmission lines are overhead and are usually carried on solid concrete or steel poles/towers. The 34.5 kV primary subtransmission lines are carried on solid concrete, hollow-spun concrete, and wooden poles. The 13.8 kV secondary lines are carried on hollow-spun concrete and wooden poles.

The most vulnerable part of the power system is the power distribution system. Only limited amounts of the power distribution system are underground and are thus protected from strong winds and wind-blown debris. Various parts of the system are vulnerable to different wind speeds; these are listed in Table 8-1 and Table 8-2.

Wooden poles deteriorate with time as they become susceptible to wood rot and termite infestation. Therefore, new poles are stronger than aged poles. The hollow-spun concrete poles are replacing the wooden poles as part of a pole-hardening mitigation program. This project started in 1990, and during subsequent typhoons, losses of hollow-spun concrete poles have been about 12% of the total losses, with wooden poles making up the remaining 88%. Hollow-spun concrete poles are six times more survivable than new wooden poles and 10 times more survivable than old wooden poles. The solid concrete poles are very robust but expensive. Figure 8.2(a) shows the typical damage to wooden poles and Figure 8.2(b) shows the damage to hollow-spun concrete poles. FEMA (1998g) has several recommendations for improvements to the power distribution system.

Table 8.1. Vulnerability of various types of power distribution components on Guam in terms of Tropical Cyclone Wind Speed Categories. Under the specific Categories, "w" indicates the weaker part of the category, "m" indicates the middle part, and "s" indicates the stronger part.

POWER DISTRIBUTION COMPONENTS	TROPICAL CYCLONE WIND CATEGORIES					
	TS B	TY 1	TY 2	TY 3	TY 4	TY 5
PLATFORMS						
Steel Lattice Towers (e.g., Hilly areas Piti)						m-s
Large Steel Poles (e.g., Sinajana)						m-s
Large Solid Steel-Reinforced Concrete Poles						m-s
Small Solid Steel-Reinforced Concrete Poles						w-m
Hollow-Spun Concrete Poles (Guyed)					w	
Hollow-Spun Concrete Poles (Un-Guyed)				m		
New Wooden Poles (Guyed)			s			
Old Wooden Poles (Guyed)		w				
New Wooden Poles (Un-Guyed)		s				
Old Wooden Poles (Un-Guyed)	s					
TRANSMISSION LINES						
Underground						m
Primary High Voltage (>100 kW)						m
Primary Medium Voltage (<100 kW >1 kW)					m	
Secondary Connections (Business)				w		
Secondary Connections (Residential)			s			
SUBSTATIONS						
Enclosed With Concrete Walls						m-s
Enclosed With Chain-link Fence					w-m	
TRANSFORMERS						
Ground-Supported						w
Pole-Supported (See Pole Vulnerability)						

Table 8-2. Vulnerability of various types of power distribution components on Guam in terms of Tropical Cyclone Sustained Wind Speed (mph).

POWER DISTRIBUTION COMPONENTS	TROPICAL CYCLONE WIND CATEGORIES					
	TS B	TY 1	TY 2	TY 3	TY 4	TY 5
PLATFORMS						
Steel Lattice Towers (e.g., Hilly Areas Piti)						165-185
Large Steel Poles (e.g., Sinajana)						165-185
Large Solid Steel-Reinforced Concrete Poles						165-185
Small Solid Steel-Reinforced Concrete Poles						156-175
Hollow-Spun Concrete Poles (Guyed)					136	
Hollow-Spun Concrete Poles (Un-Guyed)				115		
New Wooden Poles (Guyed)			105			
Old Wooden Poles (Guyed)		74				
New Wooden Poles (Un-Guyed)		85				
Old Wooden Poles (Un-Guyed)	63					
TRANSMISSION LINES						
Underground						170
Primary High Voltage (>100 kW)						170
Primary Medium Voltage (<100 kW >1 kW)					140	
Secondary Connections (Business)				111		
Secondary Connections (Residential)			105			
SUBSTATIONS						
Enclosed With Concrete Walls						170-185
Enclosed With Chain-link Fence					131-145	
TRANSFORMERS						
Ground-Supported						156
Pole Supported (See Pole Vulnerability)						

Total damages incurred by the Guam Power Authority from Typhoon Paka were estimated to be $32 million.

8.3.3. Telecommunication Systems

8.3.3.1. Local telephone facilities

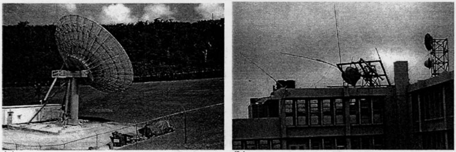
The primary trunk lines of the Guam Telephone Authority (GTA) are underground. Many of the secondary lines are also underground, but all secondary lines to critical facilities need to be placed underground. During Typhoon Omar (Aug 1992) (medium Typhoon Category 3 intensity) and Typhoon Paka (Dec 1997) (ranging from medium Typhoon Category 3 intensity on the east central coast of Guam to strong Typhoon Category 4 on the northwest and west central side of Guam), the primary telephone system survived, but many above-ground junction boxes and secondary lines were damaged or destroyed. The line damage amounted to only 7 percent of the total lines.

Switching facilities, although in concrete structures, have been susceptible to some water damage and power failures. Much of the local communications is conducted via microwave, and these towers are easily blown out of alignment in strong Typhoon Category 2 or stronger winds. They are also susceptible to damage and destruction in weak Typhoon Category 4 or stronger winds (Figure 8.3 (b)).

Despite the hardened nature of the Guam telephone system, the Guam Telephone Authority incurred damages of $5 million from Typhoon Paka.

8.3.3.2. Long distance carrier facilities

Guam is a hub for trans-Pacific communications. It has several long distance carriers, and it has extensive long distance connectivity via trans-Pacific telephone cables and satellite transmission. Thus, even when high winds necessitate that satellite down-link antennas (Figure 8.3 (a)) be parked in an unusable position, Guam still has the benefit of sub-oceanic long distance service. While many of the satellite up-link/down-link antennas are very strong and durable, it is not likely that they would escape damage during moderate to strong Typhoon Category 5 intensity winds.



(a) (b)

Figure 8.3. (a) AT&T satellite communications antenna and (b) microwave tower damage at Nimitz Hill from Typhoon Paka.

8.3.3.3. SMARTNET and cellular telephone systems

While the local telephone system is still the most important communications system during and after typhoons, the SMARTNET (Government of Guam cellular system) and the commercial cellular phone systems were extremely important during and after Typhoon Paka. Their importance will continue to expand in the future. The SMARTNET system is robust, with its towers engineered for sustained winds up to 180 mph (personal communication, Mr. Robert Kelly). This is done by constructing the 100-foot tower with 20-foot tower sections that are designed for towers of 180-240 feet. This is done at a cost increase of only 15-20 percent. The current analog system needs to be upgraded to digital, and a facility is needed to house the *centricom* console that will allow full capability to reconfigure talk channels and talk groups on the network. Even though the towers held up well in Typhoon Paka, some of the antennas and cables were torn away from the towers. Better methods of connecting the antennas to the towers are needed. In addition, **emergency power failed in some instances, and there were reports of electronic damage due to "lightning" or static electricity discharges. The source of this electrical damage needs further investigation.** The SMARTNET towers will likely hold up to medium Typhoon Category 5 winds, if flying debris does not damage the towers or their guy wire systems. However, the antennas are susceptible to damage and destruction from medium-strong Typhoon Category 4 winds.

Commercial systems are not as robust as the SMARTNET system, especially those using microwave to transfer communications signals. These towers are susceptible to misalignment in winds of strong Typhoon Category 2 or stronger. They are susceptible to damage or destruction when winds reach weak Typhoon Category 4 (see Figure 8.3. (b)).

8.3.3.4. Local radio and television transmissions

On Guam, radio is the most important mode of transmitting emergency information to the general public. In the aftermath of typhoons, power is out and even operating television stations have a small audience. Several radio transmission towers and television satellite dishes were damaged or destroyed during Typhoon Omar and Typhoon Paka. Towers would incur severe damage during moderate and strong Typhoon Category 5 winds.

8.3.4. Hospitals and Public Health

8.3.4.1. Hospitals

The Guam Memorial Hospital (GMH) (Figure 8.4) and the US Naval Hospital are the two primary medical facilities on the island. Both of these facilities are susceptible to damage from wind, blowing debris, and especially rain. Some damages occurred during both Typhoon Omar and Typhoon Paka, but most damage was due to water leakage. Both facilities would suffer considerable damage during a typhoon with winds of Typhoon Category 5. The sliding class doors of the GMH are especially vulnerable to being blown in. During Typhoon Paka, GMH had damages amounting to $1 million.

While the hospitals have emergency power generators and some capacity for water storage, it is still imperative that these facilities be reconnected to uninterrupted commercial power and water as soon as possible.

Figure 8.4. Guam Memorial Hospital.

8.3.4.2. Clinics

There are several clinics on the island. These range from the clinic at Andersen Air Force Base, to the five clinics of Public Health (Mangilao, Dededo, Santa Rita, Tamuning, and Inarajan), and the clinics of private health maintenance organizations (e.g., FHP, Seventh-Day Adventist, GMHP). Figure 8.5 shows the Department of Mental Health and Substance Abuse Clinic in Tamuning. Damages to Public Health facilities during Typhoon Paka amounted to about $930,000.

Figure 8.5. Example of a Clinic: Department of Mental Health and Substance Abuse.

8.3.5. Schools/Shelters

8.3.5.1 Public schools

Guam schools are used as shelters during typhoons. When the island is put into Typhoon Condition of Readiness (COR) 2, schools are closed and are prepared to receive people who need to be sheltered. The schools are run by the Department of Education, but the shelter program is run by the American Red Cross. All of the schools will endure winds of Typhoon Category 2 and most of the schools will endure winds of Typhoon Category 3. However, shelters need to be evaluated closely for their ability to survive winds from Typhoon Category 2 through Typhoon Category 5 intensity cyclones. Figure 8.6 shows one of the new elementary schools. The need for an assessment of shelters was identified in the 1995 Hurricane (Typhoon) Programs Needs Assessment (Guard 1995). **A comprehensive shelter assessment needs to be accomplished.** Such an assessment is beyond the scope of this study.

During Typhoon Paka, Piti Middle School lost its entire roof and many schools had serious roof damage. Total damages to Department of Education facilities amounted to $17 million, including centralized administrative facilities.

Figure 8.6. Public school: Tamuning Elementary.

8.3.5.2. University of Guam and Guam Community College

Historically, the biggest problem for University of Guam (UOG) buildings has been water damage due to leakage. However, the buildings at the UOG have not been subjected to winds stronger than moderate to strong Typhoon Category 3. It is likely that many windows and doors will not hold up to winds of strong Typhoon Category 4, and damage will be heavy with winds of Typhoon Category 5 intensity. The strongest and most survivable building at UOG is the Field House. However, it would receive significant water damage during typhoons of Typhoon Category 4 and Typhoon Category 5. During Typhoon Paka, strong Typhoon Category 3 winds blew out a small upper wall of the Science Building. Figure 8.7 shows some of the newer buildings on campus. The roofs connecting the concrete buildings would likely incur heavy damage in Typhoon Category 4 or stronger winds.
Guam Community College (GCC) is a smaller facility than UOG. GCC is composed mostly of two-story concrete buildings with louvered windows (Type 9R, Chapter 6). There are also sheet metal buildings used for automobile mechanic training, air conditioning training, etc. (Type 5C, Chapter 6). Most of the concrete buildings survived Typhoon Pamela (medium Typhoon Category 4 winds), but most auxiliary buildings have only been exposed to strong Typhoon Category 3 winds.

The pump and salt water line from the ocean to the Marine Laboratory are susceptible to damage from storm surge and wave action. Typhoon Yuri (Nov 91) severely damaged the pump and the line. Both were removed during Typhoon Omar (Aug 92) and Typhoon Paka (Dec 97).

Damage from Typhoon Paka was widespread on the campus. Many air conditioners were blown out and water damage was common. The cost of damages was $7.5 million. Guam Community College also had about $600,000 in damage.

Figure 8.7. The Humanities and Social Sciences Building (left) and the English and Communications Building (right) of the College of Arts and Sciences at the University of Guam.

8.3.6. Fuel Storage Facilities

There are four major fuel storage facilities on the island. These are located at Andersen Air Force Base, the Commercial Port, on Route 1 just south of the Piti Cemetery, and off of Route 5 between the Route 2a junction and Apra Heights. There are also smaller tank farms at the power plants at Cabras, Dededo, Tanguisson, and at Tiyan at the airport. The vulnerability of these tanks depends on several factors: the strength of the wind, whether or not they have tops, the amount of contents, and the age and state of maintenance of the tanks. Damage to these facilities can produce serious environmental damage, especially those located above the northern aquifer. The vulnerabilities of the fuel storage tanks are shown in Table 8.3. Many fuel pipe lines are above ground and are susceptible to damage from debris. Large debris in a typhoon of Category 5 intensity could cause considerable damage to the pipes.

Table 8.3. Vulnerability of fuel storage tanks in terms of Typhoon Wind Speed Category and sustained wind speed. Under categories, "m" refers to middle and "s" refers to strong.

VULNERABILITY OF FUEL STORAGE TANKS						
Fuel Tank Status	Typhoon Category and Wind Speed					
	TY 3	MPH	TY 4	MPH	TY 5	MPH
Under Construction Without Top	m	115				
Marginally Maintained, Empty	s	125				
Well Maintained, Empty			m	140		
Well Maintained, Partially Full					m	170
Marginally Maintained, Partially Full			s	150		
Well Maintained, Full					s	185
Marginally Maintained, Full					m	170

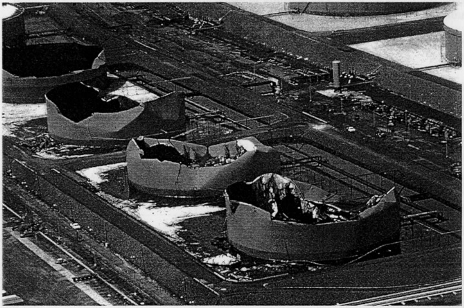


Figure 8.8. Damage to fuel storage tanks in the U. S.Virgin Islands during 160 mph sustained wind from Hurricane Hugo.

Figure 8.8 shows the damage incurred to partially filled fuel storage tanks in the U. S. Virgin Islands during 160 mph sustained winds (weak Typhoon Category 5 winds) from Hurricane Hugo in 1989.

During Typhoon Paka, an empty tank lost its roof and was crushed. These tanks can cost $2 million to $4 million each. During Typhoon Omar, a fuel tank without a roof was crushed due to winds being funneled between two other fuel tanks.

8.3.7. Dump Sites for Debris Removal

Historically, one of the biggest challenges after a typhoon has been the designation of dump sites for debris removal. Typhoon Paka strained the ability of the Island to manage the debris removal and debris storage problem. Had the entire eye of Paka hit the Island, instead of only the south one-half, the amount of debris would have been 50- 75% greater. A medium Typhoon Category 5 storm passing over the Island would likely more than quadruple the amount of debris generated by Paka, while a strong Category 5 typhoon would produce debris amounting to more than 10 times that produced by Paka. **Item 5 of the Government of Guam-Federal Emergency Management Agency Hazard Mitigation Survey Team Report (GOVGUAM 1998a) addressed the need for a comprehensive debris management plan.** While it is beyond the scope of this study, projections of debris amounts could be estimated for different intensities of typhoons (FEMA 1997). **The inability to efficiently cope with debris removal would unnecessarily delay recovery.**

8.4. SUMMARY OF DAMAGE TO INFRASTRUCTURE DURING TYPHOON PAKA

Estimated costs of damage incurred by major parts of the infrastructure are summarized in Table 8.4. The damages to the port, airport, and highway system have been added from Chapter 7.

Table 8.4. Summary of Typhoon Paka damage costs to critical infrastructure and facilities. (Source: Phillips 1998)

Infrastructure or Facility Government Sector	Estimated Costs ($)
Guam International Airport	4,000,000
Commercial Port of Guam	6,450,000
Water and Waste-Water	10,000,000
Power Generation and Distribution	32,000,000
Telecommunications	5,015,000
Public Schools and Administration	17,000,000
University of Guam	7,500,000
Guam Community College	600,000
Guam Memorial Hospital	1,000,000
Clinics	897,000
Public Works (roads, street lights, signs, etc.)	3,138,000
Mass Transit (Public buses)	875,000
Parks and Recreation (parks, ball fields)	2,350,000
TOTAL	90, 825,000

9. SOCIO-ECONOMIC VULNERABILITY ASSESSMENT

9.1. HISTORICAL INSIGHT INTO SOCIAL IMPACTS

9.1.1. Social Impact of Typhoons on Guam

Guam is subject to more frequent tropical cyclones than most other tropical islands in the world. While population and economic growth have put more people and assets at risk from typhoon damage, mitigation measures implemented by the Government of Guam and the private sector have served to minimize the social and economic impact of typhoons on the Island.

Ideally, this report would compare the social and economic impact of typhoons on Guam over time. Unfortunately, comparable data on typhoon damage and the impact of typhoons on Guam's population and economy are very limited. Increases in Guam's population and changes in the economy, infrastructure, and building stock make it difficult to compare the relative impact of disasters over time. Moreover, the impact of economic crises in Asia, which are clearly affecting Guam's economy, make it very difficult to isolate the broader social and economic impacts of a single typhoon. Therefore, this report focuses primarily on the social and economic impact of Typhoon Paka, which struck Guam on December 16-17, 1997. Some comparisons of disaster assistance provided by the Federal Emergency Management Agency and the American Red Cross following Typhoon Paka and earlier disasters on Guam are provided. However, the primary focus of this report is on segments of Guam's population and sectors of Guam's economy affected by Paka, and those that will likely remain at risk in the future.

9.1.2. Typhoons and Growth on Guam

Since 1970, Guam has been struck by sixteen significant typhoons (see Table 9.1). While several storms striking Guam have had winds characterized by Guard[1] as Typhoon Category 4 winds, Paka had the highest sustained winds on Guam of any storm since Super Typhoon Karen in 1962. Karen reportedly had sustained winds on Guam of 155 miles per hour and gusts to 195 mph.[2] Karen killed nine people and did damage in excess of an estimated $200 million in 1962 dollars.[3] Typhoon Pamela was weaker at 140 mph with gusts to 170 mph, but it crossed the Island more slowly, producing damage estimated at about $500 million in 1976 dollars.

[1] Guard, Charles. Hurricane (Typhoon) Program Needs: Assessment for the Territory of Guam. Water and Energy Research Institute, University of Guam, Appendix 4.

[2] Government of Guam and Federal Emergency Management Agency. Hazard Mitigation Survey Report: Typhoon Paka, March 1998. Appendix 4, C. Guard. Hurricane (Typhoon) Program Needs: Assessment for the Territory of Guam. Water and Energy Research Institute, University of Guam.

[3] Government of Guam and Federal Emergency Management Agency. Hazard Mitigation Survey Report: Typhoon Paka, March 1998, p. 3. Guard, Charles. Hurricane (Typhoon) Program Needs: Assessment for the Territory of Guam. Water and Energy Research Institute, University of Guam, Appendix 4, p. AP-4-10.