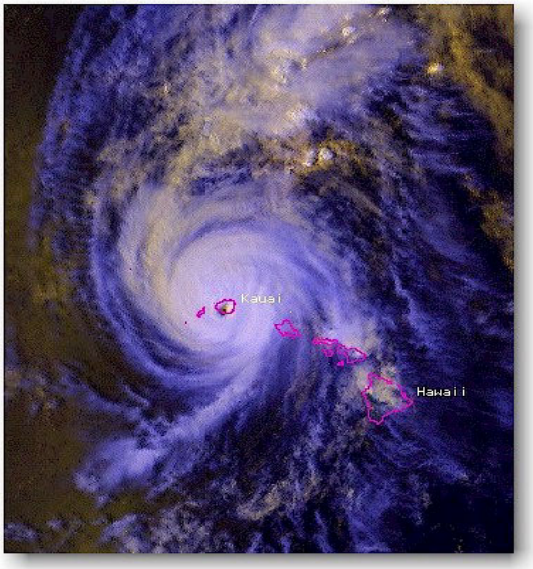
# EVALUATION STUDY of HAZUS MH LOSS ESTIMATES for HURRICANE INIKI




*High resolution infrared image of Hurricane Iniki making landfall on Kauai at 3:15 PM HST on 11 September 1992*

**Prepared for the Office of Planning**
**CZM Program**

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# EVALUATION STUDY of HAZUS MH LOSS ESTIMATES for HURRICANE INIKI

## I. Project Overview

HAZUS MH , Hazards U.S. – Multi-Hazard is a software program developed by the Federal Emergency Management Agency (FEMA) and National Institute of Building Sciences (NIBS) that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Loss estimation is essential to governmental decision-making, providing the basis for developing mitigation plans, emergency preparedness, and response and recovery planning.

FEMA's HAZUS MH loss estimation software now includes a hurricane loss estimation module that may have useful applicability in Hawaii. However, there is no published validation of the model for Hawaii hurricane losses. Like many nationally standardized models, HAZUS-MH Hurricane Model was developed for users in the continental U.S., in this case, primarily for users in the Atlantic coast and Gulf coast regions. This report describes a Hurricane Iniki scenario case study co-sponsored by the Hawaii Coastal Zone Management Program (State of Hawaii Office of Planning) and the NOAA Pacific Services Center that was conducted to compare the output of HAZUS MH versus an existing comprehensive parcel-geocoded post-Iniki reconstruction damage and loss cost database covering each community on Kauai.

The initial priority for consideration of the potential use of the HAZUS MH Hurricane Module by State Civil Defense [in the form of the HAZUS MH Summary of Issues and Comments Relating to Applications in the Pacific Region for Earthquake, Flood and Hurricane Loss Estimation and Related Information Products] and federal agencies in Hawaii [in the form of the Pacific Risk Management *Ohana* Data Analysis and Decision Support Tools *Hui* ] was performing a case study to provide a validation assessment based on a well-documented event. Joint interest in HAZUS MH by the NOAA Pacific Services Center and Office of Planning, State of Hawaii Department of Business, Economic Development, and Tourism began in deliberations that were held during the second Roundtable of Federal Hazard Mitigation Partners in the Pacific Islands (Pacific Risk Management Ohana) [1], and analysis of HAZUS MH applicability in the Pacific is a central tasking within its Decision Support and Analysis Tools Hui. This meeting brought together organizations involved in risk management-related programs and activities in the Pacific. An important objective of this group is insuring that decision support tools are evaluated and tested for applicability in the Pacific.

The goals of multi-hazard mitigation planning include increasing public awareness, preparedness, and mitigation of natural hazards and reducing the risk of loss of life, injuries, economic damage, and loss of community resources. HAZUS MH is a hazard mitigation tool that federal, state, and county civil defense agencies could potentially use to anticipate the scope of hurricane-related damage prior to hurricane events, to plan properly, to estimate potential losses, to prioritize mitigation projects, and to determine where to focus first response resources after an actual hurricane event occurs (NIBS, [2]). This project is one of the first steps in determining the applicability of HAZUS-MH to Hawaii's circumstances and assessing whether or how it should be pursued for hurricane loss prediction purposes.

HAZUS-MH Version MR-1 and ARCGIS Version 9.0 was used for this study.

## II. Background

The County of Kauai has, over the years, been subjected with some regularity to the ravages and destruction of damaging winds, surf, storm surge and flooding associated with tropical cyclone activity. Within a ten-year period, two hurricanes, Iwa and Iniki, have impaired the County's social fabric and economic structure for extended periods. Hurricanes Dot (1959) and Iwa (1992) were exceptionally damaging. On September 11, 1992, Hurricane Iniki, the strongest and most destructive hurricane to hit the Hawaiian Islands, made landfall just west of Port Allen on Kauai's south shore.

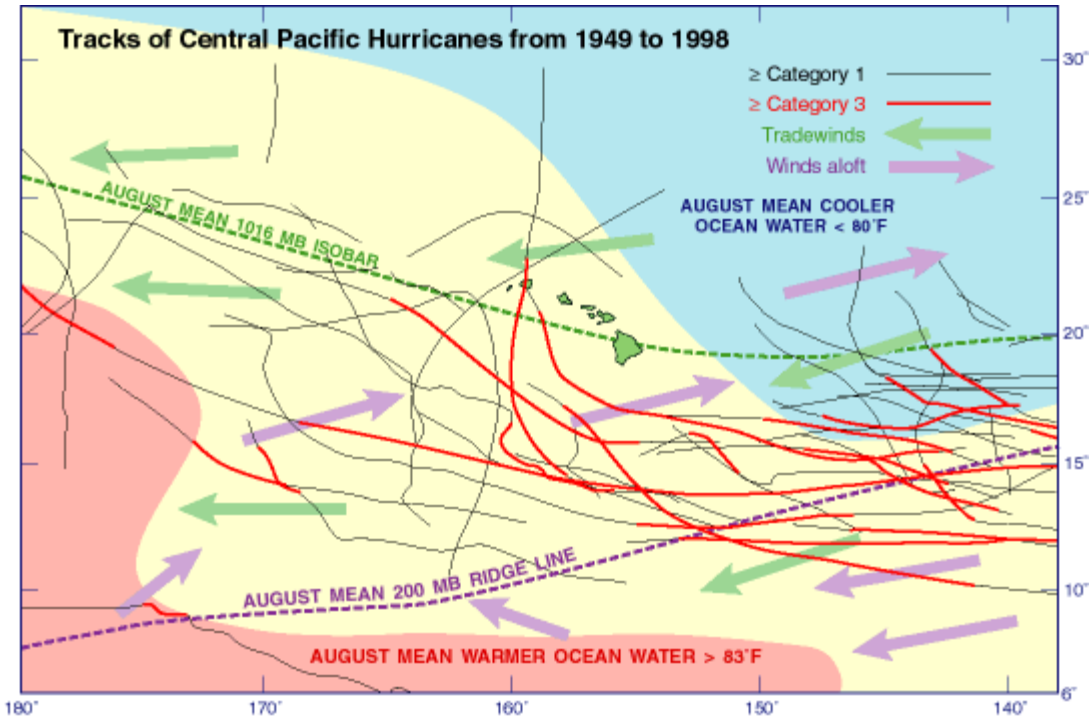


**Figure 1. Central Pacific Hurricanes in Recent History (1949 to 1998)**

Derived from original damage and reconstruction data collected by the FEMA-sponsored Office of Emergency Permitting, the processed loss cost database (Chock [3]) is a very detailed property-geocoded database of Iniki losses for building structures on private property across the entire island of Kauai. It includes damage states, damage type, reconstruction cost, and reconstruction duration. This information on Hurricane Iniki (1992) damage to Hawaii buildings of residential, commercial, and resort occupancies was gathered and geo-referenced on an ArcGIS Geographic Information System model. The comprehensive reconstruction cost documentation was also statistically validated by georeferenced overlays of post-hurricane aerial photography (Air Survey Hawaii [4]).

The geospatial database of building damage was then linked to a robust 1992-era property tax database of construction material and specific building type attributes, year built or altered, and property valuation, building size, height, configuration, and other building attributes. The property tax records included indigenous Hawaii residential construction features. The property

tax database was used in conjunction with the geocoded parcels in GIS to create 1992 equivalent census tract occupancy mapping schemes for the general building stock in HAZUS MH. By this means, HAZUS MH results for Hurricane Iniki could be compared to the actual damage data for *equivalent* building inventory representations.

The comparative analysis in this study focused on residential General Building Stock, for two principal reasons: 1) the HAZUS MH Hurricane Module data for essential facilities uses a composite reflecting a mirroring of the distribution of structural types in the general building stock throughout the census tract, rather than the actual specific building types of the facilities, thus making loss estimates and comparisons for individual buildings difficult to interpret, and 2) the Chock database of Hurricane Iniki damage on Kauai does not include public sector buildings.

The Insurance Division of the Hawaii State Department of Commerce and Consumer Affairs has indicated that it does not want the master Kauai property loss database released to outside parties because of its detailed nature and potential use by the insurance industry and catastrophic loss modelers. This database is under consideration for use an independent means of checking catastrophic loss models used in insurance rate submittals for residences.

Tasks within this project included:

1. Creating a 1992-equivalent building inventory mapping scheme for Kauai within HAZUS MH by processing of the property tax database.
2. Assembling the actual loss data for Kauai according to census tract mapping and HAZUS-compatible specific building types to produce damage data summaries in categories comparable to HAZUS MH output.
3. Performing a HAZUS MH Hurricane Module run using windfield parameters for Hurricane Iniki and compare damage and direct losses by census tract and by specific building type.

## III. Hurricane Iniki (1992)

Hurricane Iniki was the most destructive storm to hit Hawaii in recorded history. The system initially formed from tropical depression 18E on September 5, 1992 near 12° N, 135° W. On September 7 at 5pm, it was upgraded to Tropical Storm Iniki near 12° N, 144.5° W. Iniki followed a westward track embedded in an easterly flow along the southern edge of the seasonal subtropical high pressure ridge that historically had carried most hurricanes south of the Hawaiian Islands. Iniki became a hurricane with estimated central pressure of 992 mb on September 8 at 11pm Hawaii Standard Time when its position was at 13° N 152° W, and soon began translating west-northwest (See Figure 1).

On September 10, as Iniki approached the weakening western edge of the subtropical high pressure ridge, a large low pressure area at 30° N and cold trough located east of the International Dateline created southwesterly upper level flow and southerly low level flow. As a result, when located near 15° N 159° W Iniki started to "recurve" northward while continuing to intensify (951 mb). At 2:00 pm Thursday afternoon, September 10, 1992, the National Weather Service had issued a bulletin indicating that Iniki would bypass the Hawaiian Islands. However, by 5:30 pm, a Hurricane Watch was issued for Kaua'i with the center of the storm near 16° N 160° W. At 8:30 pm, a Hurricane Warning was issued for Kaua'i. Located 210 km south-southwest of Lihue, Kaua'i on September 11, at 11am, Iniki's central barometric pressure of 938 mb was the lowest ever recorded in a central Pacific hurricane, and Iniki was classified as a Category 4 hurricane with flight-level sustained winds of 65 m/s (145 mph) and gusts of 78 m/s (175 mph).

The hurricane made landfall at 3:30 pm Hawaii Standard Time at Category 3 to 4 intensity (945 to 950 mb) and quickly passed over the island by 4:10 pm (See Figure 2). Iniki was a relatively small and compact storm with a radius to maximum winds of about 15 km, with sustained winds in open terrain of approximately 55 m/s (125 mph) and peak gusts of 72 m/s (160 mph) or more, subject to further increases caused by topographic speed-up. The peak gusts of 64 m/s (143 mph) recorded at Makahuena Point, located at the southeast corner of the island about 20 km distant from the center of the storm, and 58 m/s (130 mph) recorded at Lihue, about 25 km from the center, are considered representative surface windspeeds at landfall to the east of the eyewall in the right forward quadrant of the hurricane, in areas that were relatively free of the topographic effects of the island's principal mountain ranges.

A guide to Saffir-Simpson hurricane categories and windspeeds is given in Table 1. The Iniki storm track and intensity data at six hour intervals are given in Table 2.

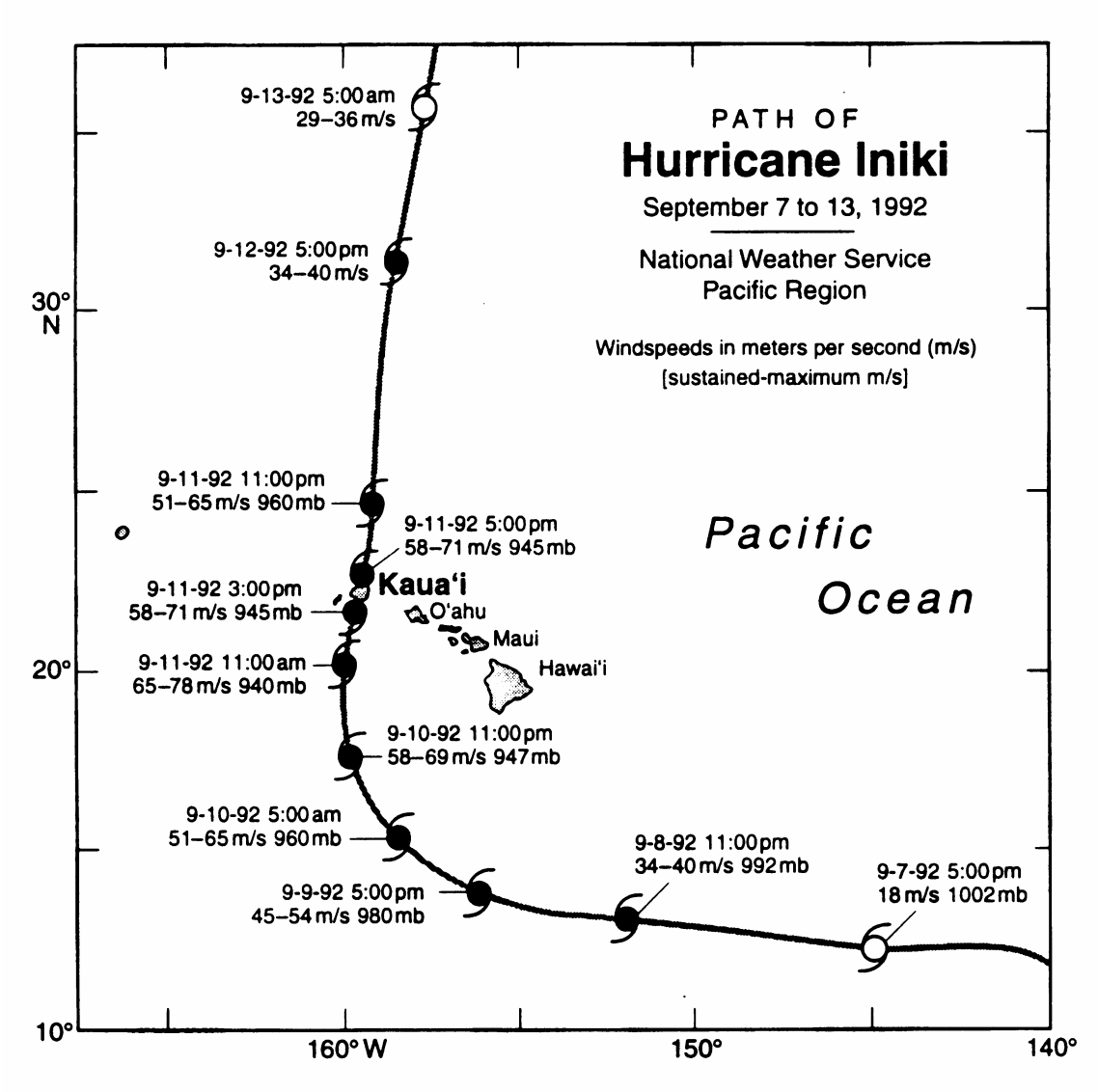


**Figure 2. Track of Hurricane Iniki (1992)**

**Table 1. Saffir-Simpson Categories and Windspeeds**

| Saffir-Simpson Category | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Central Pressure (mb) | >979 | 979-965 | 964-945 | 944-920 |
| 1 minute Sustained (mph) | 74 - 94 | 94 - 110 | 110 - 130 | 130 - 155 |
| Fastest Mile Speed (Legacy UBC) mph | 67 - 88 | 88 - 110 | 110 - 136 | 136 - 169 |
| Peak Gust over land (ASCE & IBC) mph | 82 - 108 | 108 - 130 | 130 - 156 | 156 - 191 |

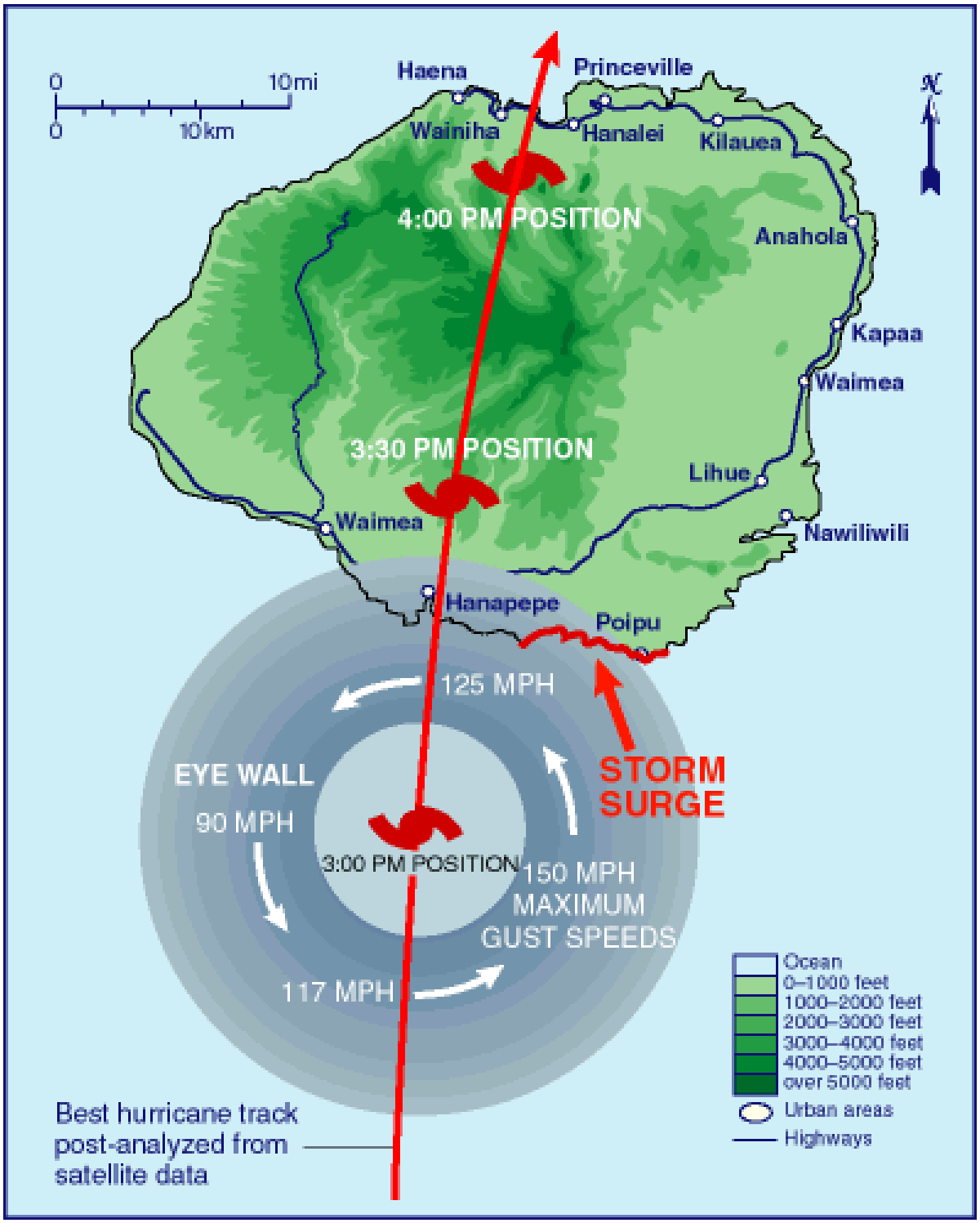


**Figure 3. Best Track of Hurricane Iniki over the Island of Kauai (by Bussinger, Steven) Originally Presented at a Hurricanes and Extreme Weather Phenomena Symposium**

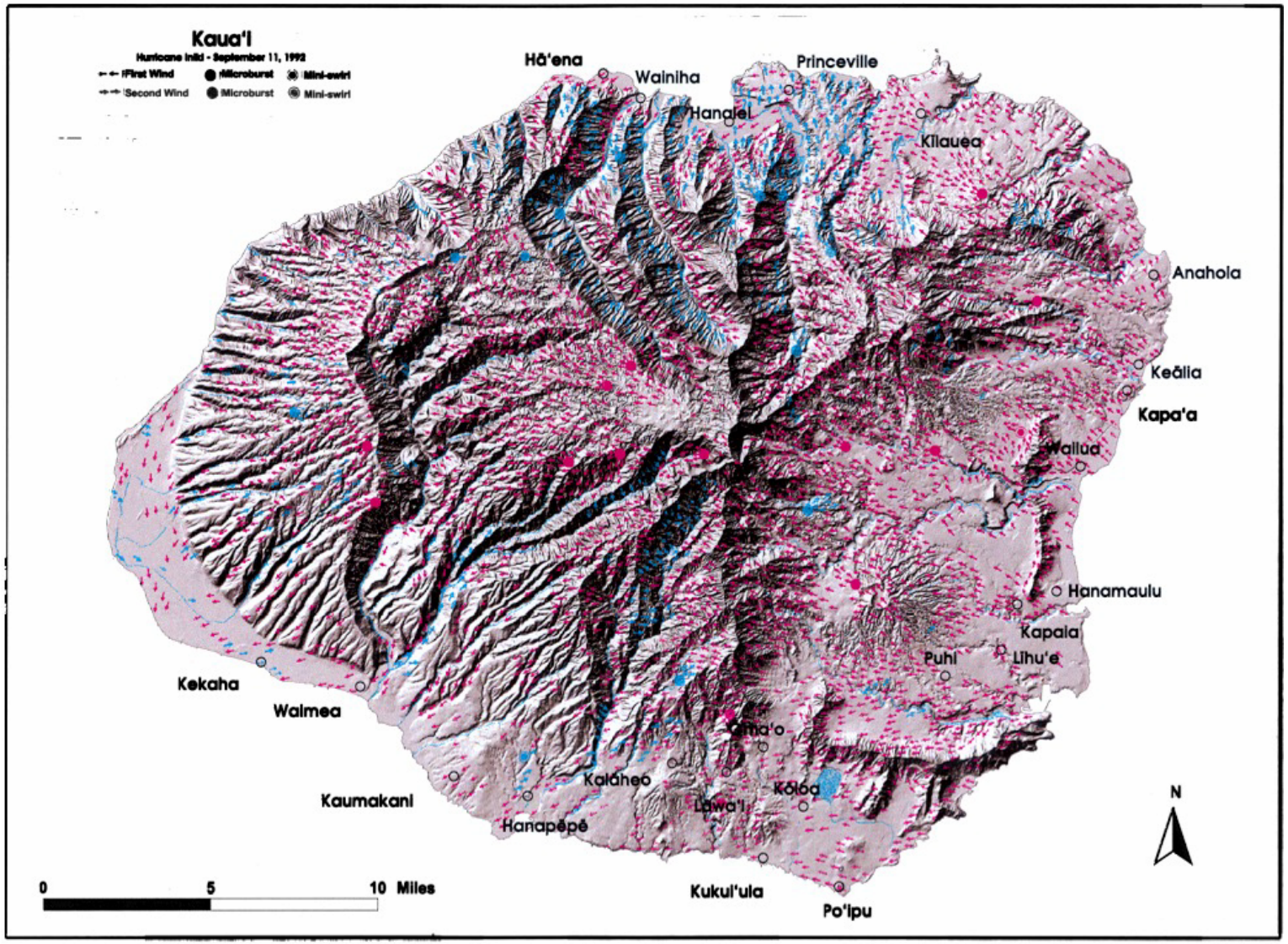


**Figure 4. Wind Field Map (after T. Fujita [5]) indicating wind directions before and after eye passage, based on vegetation blowdown**

## Table 2. Hawaii Iniki Storm Parameters for Validation Studies

| Year | Month | Day | Hour (Zulu) | Lat. | Long. | **Vtrans (mph)** | Theta | Vrot(kt)* | Central Pressure | Category | Vrot(mph) | Rmax (km) | **Rmax (miles)** | **B**** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | 9 | 5 | 18 | **11.90** | **-133.00** | **0.00** | 90.00 | 25 | **1010** | TD | 28.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 6 | 0 | **11.90** | **-135.90** | **32.68** | 90.00 | 25 | **1010** | TD | 28.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 6 | 6 | **12.00** | **-137.20** | **14.69** | 94.40 | 25 | **1010** | TD | 28.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 6 | 12 | **12.10** | **-138.50** | **14.69** | 94.40 | 30 | **1009** | TD | 34.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 6 | 18 | **12.20** | **-139.80** | **14.68** | 94.40 | 30 | **1008** | TD | 34.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 7 | 0 | **12.30** | **-141.10** | **14.68** | 94.40 | 25 | **1008** | TD | 28.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 7 | 6 | **12.20** | **-141.70** | **6.75** | 90.00 | 25 | **1007** | TD | 28.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 7 | 12 | **12.20** | **-142.40** | **7.96** | 81.87 | 30 | **1006** | TD | 34.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 7 | 18 | **12.10** | **-143.00** | **6.85** | 80.54 | 30 | **1004** | TS | 34.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 8 | 0 | **12.00** | **-144.50** | **16.93** | 86.19 | 35 | **1002** | TS | 40.25 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 8 | 6 | **12.00** | **-146.00** | **16.90** | 90.00 | 40 | **1000** | TS | 46.0 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 8 | 12 | **12.10** | **-147.50** | **16.93** | 93.81 | 40 | **1000** | TS | 46.0 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 8 | 18 | **12.30** | **-149.00** | **17.04** | 97.60 | 50 | **996** | TS | 57.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 9 | 0 | **12.40** | **-150.20** | **13.55** | 94.76 | 60 | **996** | TS | 69.0 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 9 | 6 | **12.70** | **-151.60** | **16.11** | 102.10 | 65 | **992** | 1 | 74.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 9 | 12 | **13.00** | **-152.90** | **15.00** | 103.00 | 65 | **992** | 1 | 74.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 9 | 18 | **13.40** | **-154.30** | **16.36** | 105.96 | 80 | **984** | 1 | 92.0 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 10 | 0 | **13.80** | **-155.50** | **14.20** | 108.44 | 85 | **980** | 2 | 97.75 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 10 | 6 | **14.30** | **-156.90** | **16.67** | 109.65 | 90 | **960** | 2 | 103.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 10 | 12 | **14.70** | **-157.80** | **11.04** | 113.96 | 100 | **960** | 3 | 115.00 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 10 | 18 | **15.20** | **-158.60** | **10.60** | 122.01 | 100 | **951** | 3 | 115.00 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 11 | 0 | **15.90** | **-159.30** | **11.19** | 135.00 | 110 | **948** | 3 | 126.5 | 40 | **24.9** | **1.90** |
| 1992 | 9 | 11 | 6 | **16.80** | **-159.80** | **11.75** | 150.95 | 115 | **947** | 4 | 132.25 | 30 | **18.6** | **1.90** |
| 1992 | 9 | 11 | 12 | **18.20** | **-160.20** | **16.71** | 164.06 | 120 | **939** | 4 | 138 | 28 | **17.4** | **1.90** |
| 1992 | 9 | 11 | 18 | **19.50** | **-160.00** | **15.13** | 188.75 | 125 | **938** | 4 | 143.75 | 20 | **12.4** | **1.85** |
| 1992 | 9 | 12 | 0 | **21.50** | **-159.674** | **23.13** | 185.71 | 115 | **945** | 3 | 132.25 | 20 | **12.4** | **1.90** |
| 1992 | 9 | 12 | 6 | **23.70** | **-159.215** | **25.69** | 190.31 | 100 | **959** | 3 | 115.00 | 20 | **12.4** | **1.95** |
| 1992 | 9 | 12 | 12 | **25.70** | **-159.00** | **23.41** | 191.31 | 80 | **980** | 1 | 92.00 | 20 | **12.4** | **2.00** |
| 1992 | 9 | 12 | 18 | **28.10** | **-158.90** | **27.66** | 182.39 | 80 | **980** | 1 | 92.00 | 20 | **12.4** | **2.00** |
| 1992 | 9 | 13 | 0 | **30.40** | **-158.80** | **26.51** | 182.49 | 65 | **990** | 1 | 74.75 | 20 | **12.4** | **2.00** |
| 1992 | 9 | 13 | 6 | **33.00** | **-158.70** | **29.96** | 182.20 | 65 | **990** | 1 | 74.75 | 20 | **12.4** | **2.00** |
| 1992 | 9 | 13 | 12 | **35.00** | **-158.50** | **23.11** | 185.71 | 50 | **1000** | TS | 57.5 | 20 | **12.4** | **2.00** |
| 1992 | 9 | 13 | 18 | **36.70** | **-158.10** | **19.93** | 193.24 | 40 | **1002** | TS | 46 | 20 | **12.4** | **2.00** |

Notes: Bold items are those used to define the storm in HAZUS MH. Hawaii Standard Time is Zulu (UTC) time – 10 hours Includes Bussinger correction to track at landfall

* Vrot(kts) may also be estimated by 9.6 [1 014-Po(mb)]^0.585, Atkinson & Holiday (1977) ;** B is calculated from B = 1.5 + [980 - Po(mb)] /120, Hubbert et al. (1991)

## IV. Creating a 1992-Equivalent Building Inventory Mapping Schemes for Kauai Within HAZUS MH

**HAZUS-MH**, is a standardized methodology and software program that contains modules for estimating potential losses from earthquakes, floods, and hurricane winds. HAZUS-MH was developed by under a Federal Emergency Management Agency (FEMA) contract to the National Institute of Building Sciences (NIBS) and is available for free.

HAZUS-MH uses state-of-the-art geographic information system (GIS) software to map and display hazard data and the results of damage and economic loss estimates for buildings and infrastructure. The default HAZUS MH general building stock representation for Hawaii in the Hurricane Module is based on *county-wide* aggregations, and the distribution of building types does not vary by census tracts. Hawaii census tracts in HAZUS MH differ only by the quantity of structures, but not by each community's economic cost profile, age, type of construction, or urban or rural land use zoning. To create a accurate building inventory model for Kauai at the time of Hurricane Iniki, a 1992-equivalent, Level 3 building inventory customization was developed for Kauai census tract aggregations by processing of the property tax-derived database (See Table 3).

The residential Kauai property tax database was used in conjunction with geocoded parcels in GIS to create the 1992 equivalent census tract occupancy mapping schemes for general building stock in HAZUS MH. The 1994 tax files kept by the State of Hawaii archives were used to be consistent with the Iniki building inventory; and any post 1992 records were excluded. This tax year database did not yet reflect post-reconstruction values of existing homes. The residential database utilized in this study included single-family, two-family, multi-family, detached "ohana" homes, and horizontal property regime units (i.e., condominiums). In this study we focused on low-rise residential housing and limited the consideration to units under single ownership, and condominiums were excluded. Kauai also has a separate commercial property tax database that includes apartments and hotels and other commercial and institutional buildings. The commercial building database was excluded from the comparative analysis.

Categorization of occupancy types and specific building types were performed based on attribute field associated SQL queries in Access, since HAZUS lacks the flexibility to use customized local specific building types. The property-tax-derived database was parsed by GIS selection per census tract boundaries. Occupancy mapping schemes to Specific Building Types were empirically derived for all structures in each census tract.

**Table 3. Tax Assessor Data Fields Most Pertinent To This Study**

| List of Pertinent Tax Assessor Fields | Description | |
|---|---|---|
| **Taxkey** | The Tax Map Key Parcel ID number | |
| **Card** | Building # : Structure number within the parcel | |
| **Bldg value** | Assessed valuation at that time | |
| **Bldg living area** | Building Area in square feet | |
| **Bldgs** | # of structures on the parcel | |
| **Total bldg value** | Total of valuations for all structures | |
| **Total living area** | Total of the areas for all structures | |
| **Address** | Address field | |
| **Zip** | Address field | |
| **Year built** | Original year built | |
| **Effective year built** | Year based on substantial improvements | |
| **Pitt** | Code for property usage for taxation | |
| | Residential | 100 |
| | (Unimproved Residential) | 800 |
| | Apartment | 200 |
| | Industrial | 400 |
| | Commercial | 300 |
| | Hotel and Resort | 700 |
| | Agriculture | 500 |
| | Conservation | 600 |
| | Mixed | 999 |
| **Bldg type** | Description of general occupancy/type | |
| **Structure code** | A code for structure type in the commercial sector, not necessarily buildings | |
| **Occupancy** | Residential field for single-family, two-family, multi-family, hpr, or ohana | |
| **Class** | Dwelling or other classification | |
| **Prop type** | Residential or commercial or other | |
| **Project** | Name of project for multi-unit buildings | |
| **Roof design** | Configuration(flat, gable, gambrel, hip, shed, or other) | |
| **Roof material** | Roofing system (built-up, composition, tiles, corrugated iron, metal, shake, shingle, and other) | |
| **Roof structure** | Roof structure material: Wood, Steel, Concrete | |
| **Framing** | Exterior wall structural system for residential; “Single wall” wood, “Double wall” wood, Masonry, Steel | |
| **Exterior wall** | Exterior wall sheathing material | |
| **Interior wall structure** | Interior wall structural system | |
| **Floor Construction** | Floor framing material | |
| **Foundation** | The foundation component directly underneath floor framing: Wood piers, Stone, Masonry, Concrete | |
| **Stories** | Number of stories above ground: 1, 2, or more | |

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GIS geocoding of parcel TMK identifications allowed parcels to be grouped by query into mutually exclusive regions according to geographically assigned boundaries. Within each region, the single-family residential structures, multi-family and multi-unit residential structures, and commercial structures were identified and segregated.

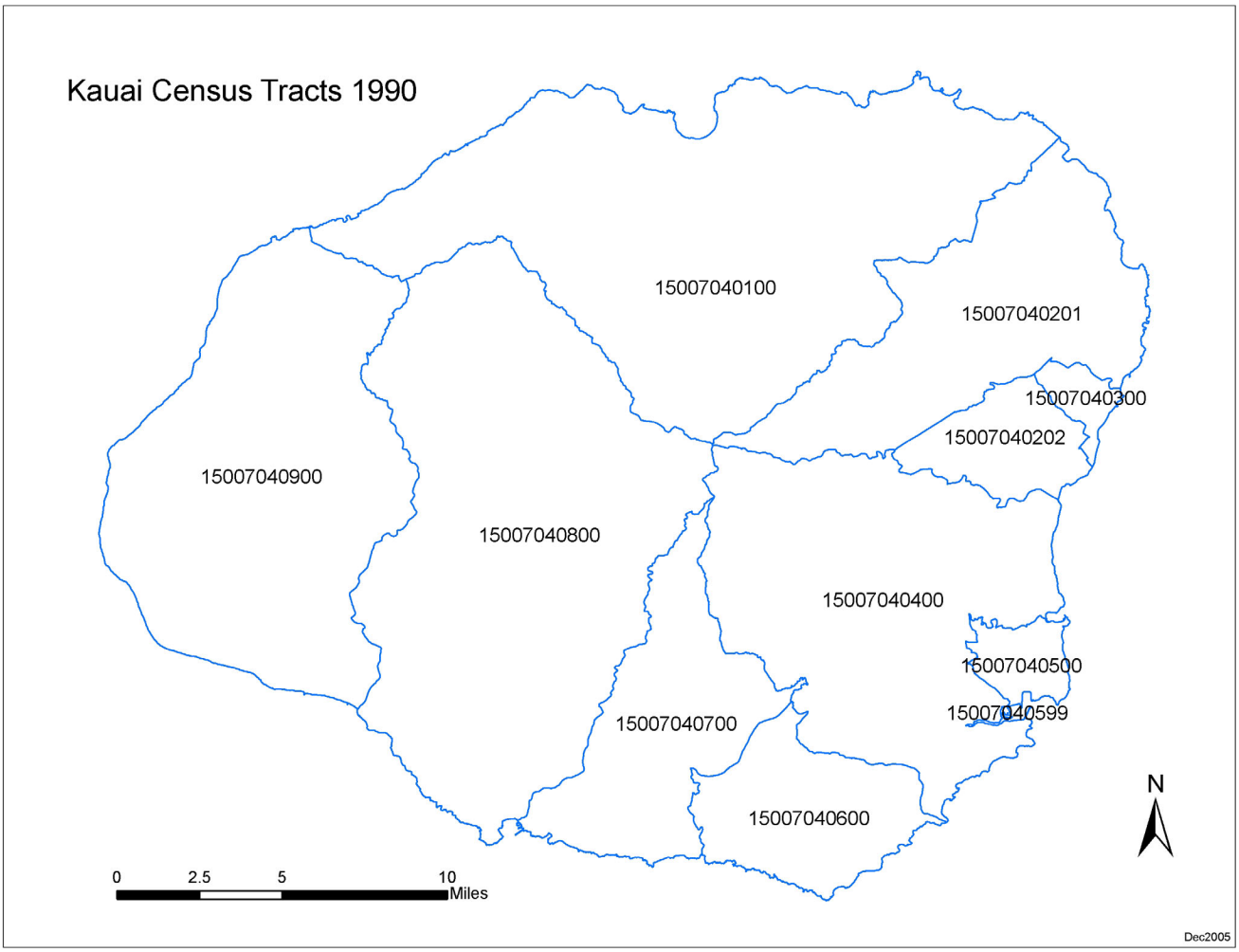


**Figure 5. Census Tracts on Kauai**

The property tax records included indigenous Hawaii residential construction features. Single-wall construction utilizes flat tongue and groove boards placed vertically to form a load-bearing exterior wall without studs. A flat, wood top plate is attached against the vertical siding board to serve as a "supporting" ledger for the roof rafter, and the board is nailed at the bottom to a rim joist and sill beam, transferring its load through vertical shear (see Figure 6). These connections are typically of minimal uplift capacity. Roof construction in single-wall residences is typically light non-engineered framing with composition shingles on tongue and groove (T & G) wood decking, or corrugated metal deck roofing directly attached to rafters. Full plywood sheathing is not provided, and rafters are spaced about four feet apart in the T & G roofed systems. This type of construction is no longer permitted in new construction, but it developed a significant portion of the housing stock due to its low cost and the absence of thermal insulation requirements in Hawaii. Since single-wall construction is less substantial and more vulnerable to wind damage, their proportion was expected to be very significant to hurricane-loss estimation. These proportions differ significantly from island to island in Hawaii and between regions on each island, depending on the development history of a particular community.

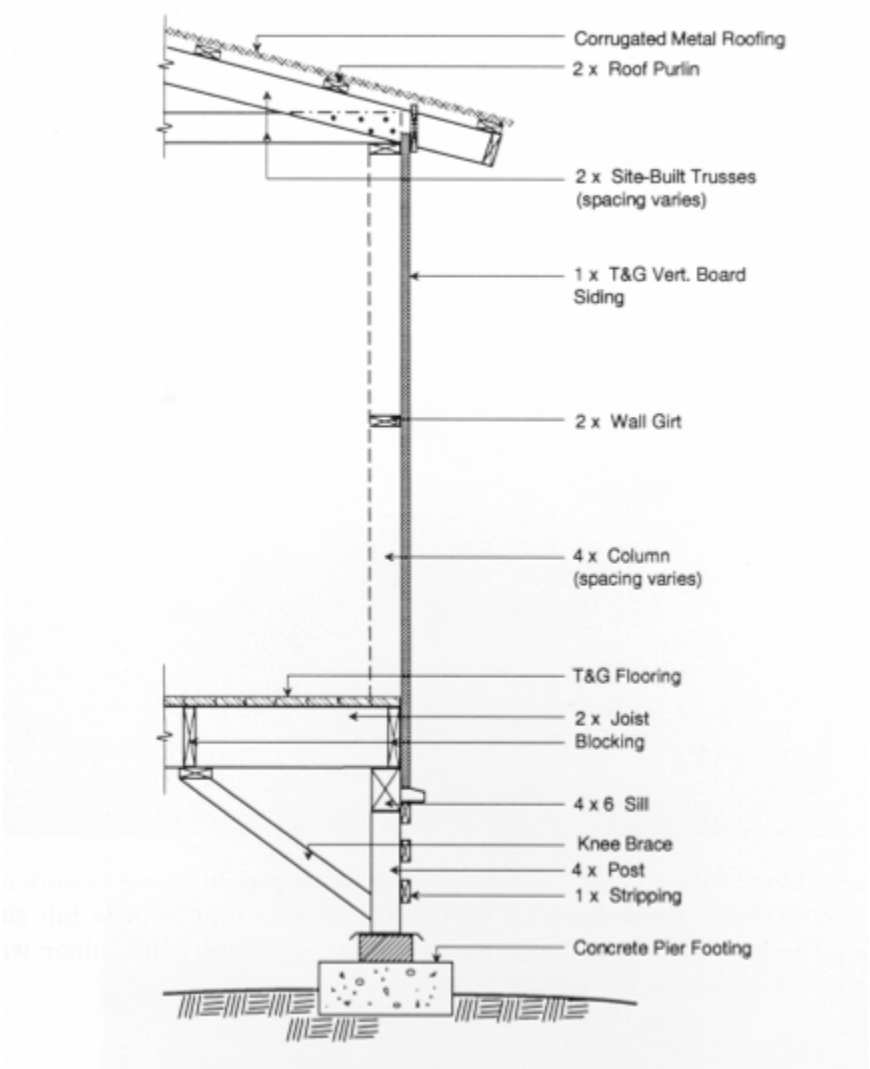


**Figure 6. A Wall Section Of One Of The Typical Forms Of Single Wall Construction**

The single wall residence does not exist as a separate specific building type within HAZUS MH, so it is not practical to isolate loss results in HAZUS MH for this category of structure within a single model region. Since the vulnerability relativity of this construction type is higher than the other forms of conventional construction, it was necessary to develop a separate "single-wall only" building stock model region so that a separate but identical hurricane scenario could be run on this subset of inventory distinctly from the conventionally frame "double-wall" stud-framed construction.

"Double-wall" refers to conventional modern wood frame construction utilizing load-bearing studs and attached wall sheathing. In a portion of recent (~pre 1990) double-wall construction, full plywood sheathing is not provided; shakes and tiles on wood furring strips over rafters with or without roof structural sheathing commonly occur.

The principal building characteristics used by HAZUS are shown in Tables 4 through 11 for specific building types along with the property tax coding identifying the corresponding attributes. Historical (building code) characteristics are also indicated in the following specific building type profiles.

Most Hawaii single family homes were not built with adequate protection against hurricane force winds. Building code requirements for high wind resistance were only implemented in relatively recent times. Single-family residential construction was typically permitted to be built using "conventional construction" provisions based on historical trade practices that did not consider hurricanes. There were no requirements for high wind connectors in single-family residences built up through the late 1980's. The weaknesses of these practices were demonstrated by the unacceptable levels of wind damage to homes during Hurricanes Iwa (1982) and Iniki (1992). After Hurricane Iwa, roof to wall uplift ties were required for new single family residential construction in Kauai County beginning in 1989. Accordingly, prior to just a few years before Hurricane Iniki, single family homes did not have hurricane ties.

**Table 4. HAZUS RES 1 Single Family Dwelling**
**Specific Building Type: WSF1 (Wood Single Family One-Story)**

| | | | Residential Property Tax Database Code |
|---|---|---|---|
| (Occupancy) | Single Family or Ohana | | 1 or 4 |
| (PITT) | | | 100's, or 500's when occupancy = 1 or 4 |
| (Stories) | | | 10 (10 equals 1.0) |
| (Roof Structure) | | | 1 (wood) |
| | | | |
| Roof Shape | Hip | | 2, 3, 4, 5, 6 |
| (roof design) | Gable | | 1 |
| | | | |
| Secondary Water Resistance | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof-Wall Connection | Toe-nail | | Pre 1989 |
| (by year built or effective year built) | Strap | | 1989 and later |
| | | | |
| Shutters | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof Cover Type Hawaii | Shingle | | 1, 2, 3, 4, 7, or 8 |
| (roof material) | Metal | | 5 or 6 |
| | | | |
| Roof Deck Attachment Hawaii | Standard | 100% | |
| | Superior | 0 | |
| | | | |
| Truss Spacing | 2 feet | | |
| | 4 feet | | If interior wall structure = 1 and roof material = 5 |
| | | | |
| Wall Construction Hawaii | Double | | 2 |
| (interior wall structure) | Single | | 1 |
| | | | |
| Uplift Restraint | Yes | | 1 |
| (Foundation) | No | | 2, 3, or 4 |

**Table 5. HAZUS RES 1 Single Family Dwelling**
**Specific Building Type: <u>WSF2 (Wood Single Family Two Stories)</u>**

| | | | Residential Property Tax Database Code |
|---|---|---|---|
| (Occupancy) | Single or Ohana | | 1 or 4 |
| (PITT) | | | 100's, or 500's when occupancy = 1 or 4 |
| (Stories) | | | ≥ 15 |
| (Roof Structure) | | | 1 (wood) |
| | | | |
| Roof Shape | Hip | | 2, 3, 4, 5, 6 |
| | Gable | | 1 |
| | | | |
| Secondary Water Resistance | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof-Wall Connection (by age) | Toe-nail | | Pre-1989 |
| (by year built or effective year built) | Strap | | ≥ 1989 |
| | | | |
| Shutters | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof Cover Type Hawaii | Shingle | | 1, 2, 3, 4, 7, or 8 |
| (roof material) | Metal | | 5 or 6 |
| | | | |
| Roof Deck Attachment Hawaii | Standard | 100% | |
| | Superior | 0 | |

**Table 6. HAZUS RES 3 Multi Family Dwelling [A: Duplex; B: 3 – 4 Units; C: 5 – 9 Units]**
**Specific Building Type: WMUH1 (Wood Marginally or Non-Engineered Multi-Unit Housing One-Story)**

| | | | Residential Property Tax Database Code | Commercial Property Tax Database Code |
|---|---|---|---|---|
| (Occupancy – Residential) | | | 2 or 3 | |
| (PITT) | | | 200's or 700's | 200's |
| (Use Code) | | | | 11 or 12 |
| (Framing Type) | | | | D |
| (Stories) | | | 10 | 10 |
| (Interior Wall Structure) | | | 1 or 2 | 2 |
| (Exterior Wall) | | | Not 5, 7, or 8 | 2 |
| | | | | |
| Roof Shape | Hip | | 2, 5 | |
| | Gable | | 1, 4 | |
| | Flat | | 3, 6 | |
| | | | | |
| Roof Cover Type | BUR | | 1 or 2 | 1 or 2 |
| (roof material) | SPM | | | |
| | | | | |
| Roof Cover Quality | Good | 50% if 4 | If 5, 6, or 7 | |
| (physical condition | Poor | 50% if 4 | If 1, 2, or 3 | |
| | | | | |
| Secondary Water Resistance | Yes | 0 | | 0 |
| | No | 100% | | 100% |
| | | | | |
| Roof Deck Attachment | 6d @ 6/12 | | | |
| | 8d @ 6/12 | | | |
| | 6d/8d mix @ 6/6 | 0% | | 0% |
| | 8d @ 6/6 | 0% | | 0% |
| | | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 | Pre-1989 |
| (by year built or effective year built) | Strap | | 1989 or later | 1989 or later |
| | | | | |
| Shutters | Yes | 0% | | 0% |
| | No | 100% | | 100% |

**Table 7. HAZUS RES 3 Multi Family Dwelling [A: Duplex; B: 3 – 4 Units; C: 5 – 9 Units]**
**Specific Building Type: <u>WMUH2 (Wood Marginally or Non-Engineered Multi-Unit Housing 2-Stories)</u>**

| | | | Residential Property Tax Database Code | Commercial Property Tax Database Code |
|---|---|---|---|---|
| (Occupancy – Residential) | | | | |
| (PITT) | | | 200's or 700's | 200's |
| (Use Code) | | | | 11 or 12 |
| (Framing Type) | | | | D |
| (Stories) | | | 15 or 20 | 15, 20 |
| (Interior Wall Structure) | | | 1 or 2 | 2 |
| (Exterior Wall Structure) | | | Not 5, 7, nor 8 | 2 |
| | | | | |
| Roof Shape | Hip | | 2, 5 | |
| | Gable | | 1, 4 | |
| | Flat | | 3, 6 | |
| | | | | |
| Roof Cover Type | BUR | | 1 or 2 | 1 or 2 |
| | SPM | | | |
| | | | | |
| Roof Cover Quality | Good | 50% if 4 | If 5, 6, or 7 | |
| | Poor | 50% if 4 | If 1, 2, or 3 | |
| | | | | |
| Secondary Water Resistance | Yes | 0 | | 0 |
| | No | 100% | | 100% |
| | | | | |
| Roof Deck Attachment | 6d @ 6/12 | | | |
| | 8d @ 6/12 | | | |
| | 6d/8d mix @ 6/6 | 0 | | 0 |
| | 8d @ 6/6 | 0 | | 0 |
| | | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 | Pre-1989 |
| | Strap | | 1989 or later | 1989 or later |
| | | | | |
| Shutters | Yes | 0 | | 0 |
| | No | 100% | | 100% |

**Table 8. HAZUS RES 3 Multi Family Dwelling [A: Duplex; B: 3 – 4 Units; C: 5 – 9 Units]**
**Specific Building Type: <u>WMUH3 (Wood Marginally or Non-Engineered Multi-Unit Housing 3 or more-Stories)</u>**

| | | | Residential Property Tax Database Code | Commercial Property Tax Database Code |
|---|---|---|---|---|
| (Occupancy – Residential) | | | 2 or 3 | |
| (PITT) | | | 200's or 700's | 200's |
| (Use Code) | | | | 11 or 12 |
| (Framing Type) | | | | D |
| (Stories) | | | ≥ 25 | ≥ 25 |
| (Interior Wall Structure) | | | 1 or 2 | 2 |
| (Exterior Wall) | | | Not 5, 7, nor 8 | 2 |
| | | | | |
| Roof Shape | Hip | | 2, 5 | |
| | Gable | | 1, 4 | |
| | Flat | | 3, 6 | |
| | | | | |
| Roof Cover Type | BUR | | 1 or 2 | 1 or 2 |
| | SPM | | | |
| | | | | |
| Roof Cover Quality | Good | 50% if 4 | If 5, 6, or 7 | |
| | Poor | 50% if 4 | If 1, 2, or 3 | |
| | | | | |
| Secondary Water Resistance | Yes | 0 | | 0 |
| | No | 100% | | 100% |
| | | | | |
| Roof Deck Attachment | 6d @ 6/12 | | | |
| | 8d @ 6/12 | | | |
| | 6d/8d mix @ 6/6 | 0 | | 0 |
| | 8d @ 6/6 | 0 | | 0 |
| | | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 | Pre-1989 |
| | Strap | | 1989 or later | 1989 or later |
| | | | | |
| Shutters | Yes | 0 | | 0 |
| | No | 100% | | 100% |

**Table 9. HAZUS RES 1 Single Family Dwelling**
**Specific Building Type: <u>MSF1 (Masonry Single Family Houses One-Story)</u>**

| | | | Residential Property Tax Database Code |
|---|---|---|---|
| (Occupancy ) | Single Family or Ohana | | 1 or 4 |
| (PITT) | | | 200's, or 500's if occupancy = 1 or 4 |
| (Stories) | | | 10 |
| (Interior Wall Structure) | | | 3 |
| (Exterior Wall) | | | 5, 6, 7, or 8 |
| (Foundation) | | | 1 or 2 |
| | | | |
| Roof Shape | Hip | | 2, 3, 4, 5, 6 |
| | Gable | | 1 |
| | | | |
| Secondary Water Resistance | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 |
| | Strap | | 1989 or later |
| | | | |
| Shutters | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof Cover Type Hawaii | Shingle | | 1, 2, 3, 4, 7, or 8 |
| | Metal | | 5 or 6 |
| | | | |
| Roof Deck Attachment Hawaii | Standard | 100% | |
| | Superior | 0 | |

**Table 10. HAZUS RES 1 Single Family Dwelling**
**Specific Building Type: MSF2 (Masonry Single Family House Two Stories)**

| | | | Residential Property Tax Database Code |
|---|---|---|---|
| (Occupancy) | Single Family or Ohana | | 1 or 4 |
| (PITT) | | | 100's, or 500's if occupancy = 1 or 4 |
| (Stories) | | | ≥ 15 |
| (Interior Wall Structure) | | | 3 |
| (Exterior Wall) | | | 5, 6, 7, or 8 |
| (Foundation) | | | 1 or 2 |
| | | | |
| Roof Shape | Hip | | 2, 3, 4, 5, 6 |
| | Gable | | 1 |
| | | | |
| Roof Shape | Hip | | |
| | Gable | | |
| | | | |
| Secondary Water Resistance | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 |
| | Strap | | 1989 or later |
| | | | |
| Shutters | Yes | 0 | |
| | No | 100% | |
| | | | |
| Roof Cover Type Hawaii | Shingle | | 1, 2, 3, 4, 7, or 8 |
| | Metal | | 5 or 6 |
| | | | |
| Roof Deck Attachment Hawaii | Standard | 100% | |
| | Superior | 0 | |

**Table 11. HAZUS RES 3 Multi Family Dwelling [A: Duplex; B: 3 – 4 Units; C: 5 – 9 Units]**
**Specific Building Type: <u>MMUH1 (Masonry Marginally or Non-Engineered Multi-Unit Housing One-Story)</u>**

| | | | Residential Property Tax Database Code | Commercial Property Tax Database Code |
|---|---|---|---|---|
| (Occupancy ) | | | 2 or 3 | |
| (PITT) | | | 200's or 700's | 200's or 700's |
| (Use Code) | | | | 11 or 12 |
| (Framing Type) | | | | C |
| (Stories) | | | 10 | 10 |
| (Interior Wall Structure) | | | 3 | 1, 3, 4, 5, 6 |
| (Exterior Wall) | | | 5, 6, 7, or 8 | 1, 3, 4, 5, 6, 12 |
| (Foundation) | | | 1 or 2 | |
| | | | | |
| Roof Shape | Hip | 2, 5 | | |
| | Gable | 1, 4 | | |
| | Flat | 3, 6 | | |
| | | | | |
| Roof Cover Type | BUR | 1 or 2 | | |
| | SPM | | | |
| | | | | |
| Roof Cover Quality | Good | 50% if 4 | If 5, 6, or 7 | |
| | Poor | 50% if 4 | If 1, 2, or 3 | |
| | | | | |
| Secondary Water Resistance | Yes | 0 | | 0 |
| | No | 100% | | 100% |
| | | | | |
| Roof Deck Attachment | 6d @ 6/12 | | | |
| | 8d @ 6/12 | | | |
| | 6d/8d mix @ 6/6 | 0 | | 0 |
| | 8d @ 6/6 | 0 | | 0 |
| | | | | |
| Roof-Wall Connection | Toe-nail | | Pre-1989 | Pre-1989 |
| | Strap | | 1989 or later | 1989 or later |
| | | | | |
| Shutters | Yes | 0 | | |
| | No | 100% | | |
| Masonry Reinforcing | Yes | | | |
| | No | | | |

Summary counts of the non-commercial single-ownership low-rise (one and two-story) residential building inventory of up to 9 housing units are given in Table 12 below, excluding condominiums. The Census definition of housing unit is a house, an apartment, a group of rooms, or a single room occupied as separate living quarters, and the 1990 Census figures below include all housing units of up to 9 units, including condominiums and commercial apartments of all heights. There is a very close match of the single family unit counts, which is the predominant occupancy in the modeled inventory. The tabulated figures for the Census are given as a guide to the building inventory's degree of representation of each occupancy classification. In the comparative analysis, the HAZUS and the actual Hurricane Iniki damage building inventories are identical.

**Table 12. 1992 Kauai Building Inventory Model and 1990 Census**

| Occupancy | HAZUS Model Building Inventory | 1990 Census Housing Units |
|---|---|---|
| **RES1 Single Family** | 14917 | 15092 |
| **RES3A Duplex** | 228 | 503 |
| **RES3B 3 – 4 Units** | 12 | 550 |
| **RES3C 5 – 9 Units** | 11 | 446 |
| **Island Total** | 15168 | 16591 |
| **% Difference** | | 9.4% |

Tabular summaries of specific occupancy counts by census tract are given in Tables 13 and 14. Table 15 shows the average proportions of construction attributes found for Kaua'i single-family residences at the time of Hurricane Iniki. Based on property tax records, at the time of Hurricane Iniki single-family residential houses were about equally divided on Kaua'i between wood "single-wall" (48%) and wood "double-wall" construction (52%), with a very small minority of homes built with masonry walls. Significant variations from this average profile were found in each community region of Kaua'i. We provide the proportions of building wind resistive parameters in the model inventory for each census tract in Tables 16 through 25.

## Table 13. Single Wall Construction Occupancy Mapping

| Residential buildings with single wall construction | | | | | | |
|---|---|---|---|---|---|---|
| Tract | SPECIFIC OCCUPANCY | WMUH1 | WMUH2 | WSF1 | WSF2 | TOTAL |
| 15007040100 | RES1 | | | 510 | 41 | 551 |
| 15007040100 | RES3A | 5 | | | | 5 |
| 15007040100 | RES3B | | | | | 0 |
| 15007040100 | RES3C | | | | | 0 |
| **TOTAL** | | **5** | **0** | **510** | **41** | **556** |
| 15007040201 | RES1 | | | 315 | 19 | 334 |
| 15007040201 | RES3A | | | | | 0 |
| 15007040201 | RES3B | | | | | 0 |
| 15007040201 | RES3C | | | | | 0 |
| **TOTAL** | | **0** | **0** | **315** | **19** | **334** |
| 15007040202 | RES1 | | | 834 | 24 | 858 |
| 15007040202 | RES3A | 11 | | | | 11 |
| 15007040202 | RES3B | | | | | 0 |
| 15007040202 | RES3C | 1 | | | | 1 |
| **TOTAL** | | **12** | **0** | **834** | **24** | **870** |
| 15007040300 | RES1 | | | 861 | 11 | 872 |
| 15007040300 | RES3A | 6 | 3 | | | 9 |
| 15007040300 | RES3B | | | | | 0 |
| 15007040300 | RES3C | 1 | | | | 1 |
| **TOTAL** | | **7** | **3** | **861** | **11** | **882** |
| 15007040400 | RES1 | | | 787 | 7 | 794 |
| 15007040400 | RES3A | 15 | | | | 15 |
| 15007040400 | RES3B | | | | | 0 |
| 15007040400 | RES3C | | 1 | | | 1 |
| **TOTAL** | | **15** | **1** | **787** | **7** | **810** |
| 15007040500 | RES1 | | | 698 | 9 | 707 |
| 15007040500 | RES3A | 6 | 1 | | | 7 |
| 15007040500 | RES3B | | | | | 0 |
| 15007040500 | RES3C | | | | | 0 |
| **TOTAL** | | **6** | **1** | **698** | **9** | **714** |
| 15007040600 | RES1 | | | 807 | 14 | 821 |
| 15007040600 | RES3A | 13 | | | | 13 |
| 15007040600 | RES3B | 3 | | | | 3 |
| 15007040600 | RES3C | 1 | | | | 1 |
| **TOTAL** | | **17** | **0** | **807** | **14** | **838** |
| 15007040700 | RES1 | | | 825 | 15 | 840 |
| 15007040700 | RES3A | 1 | | | | 1 |
| 15007040700 | RES3B | 1 | | | | 1 |
| 15007040700 | RES3C | | | | | 0 |
| **TOTAL** | | **2** | **0** | **825** | **15** | **842** |
| 15007040800 | RES1 | | | 332 | 7 | 339 |
| 15007040800 | RES3A | 4 | | | | 4 |
| 15007040800 | RES3B | | | | | 0 |
| 15007040800 | RES3C | | | | | 0 |
| **TOTAL** | | **4** | **0** | **332** | **7** | **343** |
| 15007040900 | RES1 | | | 996 | 11 | 1007 |
| 15007040900 | RES3A | 5 | 1 | | | 6 |
| 15007040900 | RES3B | 1 | | | | 1 |
| 15007040900 | RES3C | | | | | 0 |
| **TOTAL** | | **6** | **1** | **996** | **11** | **1014** |
| | | | | | | **7203** |

| Single Wall Construction | Number |
|---|---|
| RES1 Single Family | 7123 |
| RES3A Duplex | 71 |
| RES3B 3 – 4 Units | 5 |
| RES3C 5 – 9 Units | 4 |
| Island Single Wall Total | 7203 |

## Table 14. Double Wall Construction Occupancy Mapping

Residential buildings other than single wall construction

| Tract | SPECIFIC OCCUPANCY | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 | wood TOTAL | Masonry TOTAL | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15007040100 | RES1 | | 9 | | | | | 987 | 273 | 1260 | 9 | 1269 |
| 15007040100 | RES3A | | | | 23 | 5 | | | | 28 | 0 | 28 |
| 15007040100 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040100 | RES3C | | | | 2 | | | | | 2 | 0 | 2 |
| **TOTAL** | | **0** | **9** | **0** | **25** | **5** | **0** | **987** | **273** | **1290** | **9** | **1299** |
| 15007040201 | RES1 | | 3 | | | | | 296 | 44 | 340 | 3 | 343 |
| 15007040201 | RES3A | | | | 1 | 4 | | | | 5 | 0 | 5 |
| 15007040201 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040201 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **0** | **3** | **0** | **1** | **4** | **0** | **296** | **44** | **345** | **3** | **348** |
| 15007040202 | RES1 | | 12 | | | | | 1256 | 124 | 1380 | 12 | 1392 |
| 15007040202 | RES3A | 1 | | | 26 | 4 | | | | 30 | 1 | 31 |
| 15007040202 | RES3B | | | | 2 | 1 | | | | 3 | 0 | 3 |
| 15007040202 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **1** | **12** | **0** | **28** | **5** | **0** | **1256** | **124** | **1413** | **13** | **1426** |
| 15007040300 | RES1 | | 7 | | | | | 897 | 188 | 1085 | 7 | 1092 |
| 15007040300 | RES3A | | | | 18 | 7 | | | | 25 | 0 | 25 |
| 15007040300 | RES3B | | | | 1 | | | | | 1 | 0 | 1 |
| 15007040300 | RES3C | | | | 2 | | | | | 2 | 0 | 2 |
| **TOTAL** | | **0** | **7** | **0** | **21** | **7** | **0** | **897** | **188** | **1113** | **7** | **1120** |
| 15007040400 | RES1 | | 8 | | | | | 549 | 37 | 586 | 8 | 594 |
| 15007040400 | RES3A | | | | 6 | 2 | | | | 8 | 0 | 8 |
| 15007040400 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040400 | RES3C | | | | 1 | | | | | 1 | 0 | 1 |
| **TOTAL** | | **0** | **8** | **0** | **7** | **2** | **0** | **549** | **37** | **595** | **8** | **603** |
| 15007040500 | RES1 | | 16 | | | | | 504 | 39 | 543 | 16 | 559 |
| 15007040500 | RES3A | | | | 13 | 3 | | | | 16 | 0 | 16 |
| 15007040500 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040500 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **0** | **16** | **0** | **13** | **3** | **0** | **504** | **39** | **559** | **16** | **575** |
| 15007040600 | RES1 | | 8 | 2 | | | | 544 | 100 | 644 | 10 | 654 |
| 15007040600 | RES3A | | | | 20 | 7 | | | | 27 | 0 | 27 |
| 15007040600 | RES3B | | | | 1 | | | | | 1 | 0 | 1 |
| 15007040600 | RES3C | | | | 2 | | | | | 2 | 0 | 2 |
| **TOTAL** | | **0** | **8** | **2** | **23** | **7** | **0** | **544** | **100** | **674** | **10** | **684** |
| 15007040700 | RES1 | | 16 | 1 | | | | 1026 | 98 | 1124 | 17 | 1141 |
| 15007040700 | RES3A | | | | 8 | 1 | | | | 9 | 0 | 9 |
| 15007040700 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040700 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **0** | **16** | **1** | **8** | **1** | **0** | **1026** | **98** | **1133** | **17** | **1150** |
| 15007040800 | RES1 | | 2 | | | | | 256 | 7 | 263 | 2 | 265 |
| 15007040800 | RES3A | | | | | | | | | | 0 | 0 |
| 15007040800 | RES3B | | | | | | | | | | 0 | 0 |
| 15007040800 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **0** | **2** | **0** | **0** | **0** | **0** | **256** | **7** | **263** | **2** | **265** |
| 15007040900 | RES1 | | 13 | | | | | 435 | 35 | 470 | 13 | 483 |
| 15007040900 | RES3A | | | | 8 | 2 | | | | 10 | 0 | 10 |
| 15007040900 | RES3B | | | | 1 | | 1 | | | 2 | 0 | 2 |
| 15007040900 | RES3C | | | | | | | | | | 0 | 0 |
| **TOTAL** | | **0** | **13** | **0** | **9** | **2** | **1** | **435** | **35** | **482** | **13** | **495** |
| | | | | | | | | | | | | **7965** |

| Conventional Framing | # |
|---|---|
| RES1 Single Family | 7794 |
| RES3A Duplex | 157 |
| RES3B 3 – 4 Units | 7 |
| RES3C 5 – 9 Units | 7 |
| Island "Double Wall" Total | 7965 |

**Table 15. Kaua'i Principal Building Attribute Profiles – 1992**

| Wall and Foundation Construction | Stories | Roof Design | Roof Material | Incidence |
|---|---|---|---|---|
| Single Wall on Piers | 1 | Hip | Metal | 7.9% |
| Single Wall on Piers | 1 | Gable | Metal | 8.6% |
| Single Wall on Slab | 1 | Gable | Composition or Shake/Shingle | 6.8% |
| Single Wall on Piers | 1 | Hip | Composition or Shake/Shingle | 6.2% |
| Single Wall on Slab | 1 | Hip | Metal | 4.4% |
| Single Wall on Slab | 1 | Hip | Composition or Shake/Shingle | 5.1% |
| Double Wall on Slab | 1 | Gable | Composition or Shake/Shingle | 16.1% |
| Double Wall on Slab | 1 | Hip | Composition or Shake/Shingle | 16.0% |
| Double Wall on Piers | 1 | Gable | Composition or Shake/Shingle | 5.3% |
| Double Wall on Slab | 2 | Gable | Composition or Shake/Shingle | 2.7% |
| Double Wall on Slab | 2 | Hip | Composition or Shake/Shingle | 2.6% |
| All others | | | | 18.0% |

Note: Masonry wall construction was very uncommon in single family residences, less than 1%

| Wall Construction Combinations | |
|---|---|
| Double Wall 1-story | 46.0% |
| Double Wall 2-story | 6.5% |
| Single wall on Wood Piers | 28.5% |
| Single wall on Concrete or Masonry Foundation | 19.0% |

| Roofing Material | |
|---|---|
| Built-up or Composition | 51.6% |
| Shake or Shingle | 15.7% |
| Metal Roofs | 27.6% |
| Tile | 5.1% |

| Roof Design | |
|---|---|
| Hip Roofs | 49.2% |
| Gable Roofs | 50.8% |
| Others | less than 1% |

| Pre-1993 Age Distribution | |
|---|---|
| Pre-1970 | 35.7% |
| 1971-1982 | 29.4% |
| 1983-1992 | 34.9% |

**Table 16. Distribution of Roof Shapes for Single Wall Construction**

**Roof Shape Distributions in Percentages** Single wall constru

| | | Specific Building Types | | | |
|---|---|---|---|---|---|
| Tract | ROOF SHAPE | WMUH1 | WMUH2 | WSF1 | WSF2 |
| 15007040100 | Gable | 60 | | 60 | 66 |
| 15007040100 | HIP | 40 | | 40 | 34 |
| 15007040201 | GABLE | | | 67 | 68 |
| 15007040201 | HIP | | | 33 | 32 |
| 15007040202 | FLAT | 8 | | 0 | 0 |
| 15007040202 | Gable | 25 | | 50 | 54 |
| 15007040202 | HIP | 67 | | 50 | 46 |
| 15007040300 | Gable | 71 | 67 | 53 | 64 |
| 15007040300 | HIP | 29 | 33 | 47 | 36 |
| 15007040400 | FLAT | 7 | 0 | 0 | 0 |
| 15007040400 | Gable | 40 | 100 | 33 | 43 |
| 15007040400 | HIP | 53 | 0 | 67 | 57 |
| 15007040500 | Gable | 50 | 0 | 38 | 78 |
| 15007040500 | HIP | 50 | 100 | 62 | 22 |
| 15007040600 | FLAT | 6 | | 0 | 0 |
| 15007040600 | Gable | 59 | | 55 | 64 |
| 15007040600 | HIP | 35 | | 45 | 36 |
| 15007040700 | Gable | 100 | | 43 | 40 |
| 15007040700 | HIP | 0 | | 57 | 60 |
| 15007040800 | Gable | 100 | | 43 | 29 |
| 15007040800 | HIP | 0 | | 57 | 71 |
| 15007040900 | FLAT | 17 | 0 | 0 | 0 |
| 15007040900 | Gable | 67 | 100 | 57 | 27 |
| 15007040900 | HIP | 17 | 0 | 43 | 73 |

## Table 17. Distributions of Roof Shapes for Other Than Single Wall Construction

**Roof Shape Distributions in Percentages** Other than single wall construction

| | | Specific Building Types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tract | ROOF SHAPE | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 |
| 15007040100 | FLAT | | 0 | | 16 | 0 | | 0 | 0 |
| 15007040100 | GABLE | | 33 | | 52 | 60 | | 35 | 38 |
| 15007040100 | HIP | | 67 | | 32 | 40 | | 65 | 62 |
| 15007040201 | GABLE | | 67 | | 100 | 75 | | 55 | 57 |
| 15007040201 | HIP | | 33 | | 0 | 25 | | 45 | 43 |
| 15007040202 | FLAT | 0 | 0 | | 7 | 0 | | 0 | 0 |
| 15007040202 | GABLE | 0 | 42 | | 46 | 20 | | 48 | 42 |
| 15007040202 | HIP | 100 | 58 | | 46 | 80 | | 52 | 58 |
| 15007040300 | GABLE | | 43 | | 24 | 43 | | 64 | 82 |
| 15007040300 | HIP | | 57 | | 76 | 57 | | 36 | 18 |
| 15007040400 | GABLE | | 25 | | 43 | 50 | | 59 | 32 |
| 15007040400 | HIP | | 75 | | 57 | 50 | | 41 | 68 |
| 15007040500 | GABLE | | 13 | | 46 | 33 | | 42 | 64 |
| 15007040500 | HIP | | 88 | | 54 | 67 | | 58 | 36 |
| 15007040600 | FLAT | | 0 | 0 | 13 | 0 | | 0 | 0 |
| 15007040600 | GABLE | | 63 | 50 | 52 | 29 | | 42 | 30 |
| 15007040600 | HIP | | 38 | 50 | 35 | 71 | | 58 | 70 |
| 15007040700 | GABLE | | 38 | 100 | 63 | 0 | | 56 | 48 |
| 15007040700 | HIP | | 63 | 0 | 38 | 100 | | 44 | 52 |
| 15007040800 | GABLE | | 100 | | | | | 87 | 71 |
| 15007040800 | HIP | | 0 | | | | | 13 | 29 |
| 15007040900 | GABLE | | 31 | | 33 | 100 | 100 | 71 | 51 |
| 15007040900 | HIP | | 69 | | 67 | 0 | 0 | 29 | 49 |

## Table 18. Distributions of Roof to Wall Connections in Single Wall Construction

**Roof-Wall Connection Distributions in Percentages** Single wall constructio

| | | Specific Building Types | | | |
|---|---|---|---|---|---|
| Tract | ROOF WALL CONNECTION | WMUH1 | WMUH2 | WSF1 | WSF2 |
| 15007040100 | STRAP | | | 9 | |
| 15007040100 | TOE-NAIL | 5 | | 501 | 41 |
| 15007040201 | STRAP | | | 4 | |
| 15007040201 | TOE-NAIL | | | 311 | 19 |
| 15007040202 | STRAP | | | 10 | 2 |
| 15007040202 | TOE-NAIL | 12 | | 824 | 22 |
| 15007040300 | STRAP | | | 7 | |
| 15007040300 | TOE-NAIL | 7 | 3 | 854 | 11 |
| 15007040400 | STRAP | | | 4 | |
| 15007040400 | TOE-NAIL | 15 | 1 | 783 | 7 |
| 15007040500 | STRAP | | | 3 | |
| 15007040500 | TOE-NAIL | 6 | 1 | 695 | 9 |
| 15007040600 | STRAP | | | 2 | |
| 15007040600 | TOE-NAIL | 17 | | 805 | 14 |
| 15007040700 | STRAP | | | 3 | |
| 15007040700 | TOE-NAIL | 2 | | 822 | 15 |
| 15007040800 | STRAP | | | 1 | |
| 15007040800 | TOE-NAIL | 4 | | 331 | 7 |
| 15007040900 | STRAP | | | 6 | |
| 15007040900 | TOE-NAIL | 6 | 1 | 990 | 11 |

**Table 19. Distributions of Roof to Wall Connections In Other than Single Wall Construction**

| **Roof-Wall Connection Distributions in Percentages** | | Other than single wall construction | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Specific Building Types | | | | | | | |
| Tract | ROOF WALL CONNECTION | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 |
| 15007040100 | STRAP | | 44 | | 40 | 0 | | 42 | 14 |
| 15007040100 | TOE-NAIL | | 56 | | 60 | 100 | | 58 | 86 |
| 15007040201 | STRAP | | 67 | | 0 | 50 | | 25 | 11 |
| 15007040201 | TOE-NAIL | | 33 | | 100 | 50 | | 75 | 89 |
| 15007040202 | STRAP | 100 | 42 | | 36 | 100 | | 32 | 42 |
| 15007040202 | TOE-NAIL | 0 | 58 | | 64 | 0 | | 68 | 58 |
| 15007040300 | STRAP | | 0 | | 48 | 57 | | 33 | 74 |
| 15007040300 | TOE-NAIL | | 100 | | 52 | 43 | | 67 | 26 |
| 15007040400 | STRAP | | 13 | | 29 | 50 | | 68 | 65 |
| 15007040400 | TOE-NAIL | | 88 | | 71 | 50 | | 32 | 35 |
| 15007040500 | STRAP | | 13 | | 46 | 33 | | 22 | 49 |
| 15007040500 | TOE-NAIL | | 88 | | 54 | 67 | | 78 | 51 |
| 15007040600 | STRAP | | 0 | 50 | 9 | 43 | | 31 | 38 |
| 15007040600 | TOE-NAIL | | 100 | 50 | 91 | 57 | | 69 | 62 |
| 15007040700 | STRAP | | 19 | 0 | 25 | 100 | | 25 | 31 |
| 15007040700 | TOE-NAIL | | 81 | 100 | 75 | 0 | | 75 | 69 |
| 15007040800 | STRAP | | 0 | | | | | 83 | 14 |
| 15007040800 | TOE-NAIL | | 100 | | | | | 17 | 86 |
| 15007040900 | STRAP | | 0 | | 56 | 0 | 0 | 26 | 14 |
| 15007040900 | TOE-NAIL | | 100 | | 44 | 100 | 100 | 74 | 86 |

## Table 20. Distributions of Roofing Cover in Single Wall Construction

**Roofing Distributions in Percentages** Single wall construction

| | | Specific Building Types | | | |
|---|---|---|---|---|---|
| Tract | ROOF COVER TYPE HI | WMUH1 | WMUH2 | WSF1 | WSF2 |
| 15007040100 | BUR | 80 | | 0 | 0 |
| 15007040100 | METAL | 0 | | 54 | 22 |
| 15007040100 | SHINGLE | 0 | | 46 | 78 |
| 15007040100 | SPM | 20 | | 0 | 0 |
| 15007040201 | METAL | | | 62 | 21 |
| 15007040201 | SHINGLE | | | 38 | 79 |
| 15007040202 | BUR | 83 | | 0 | 0 |
| 15007040202 | METAL | 0 | | 31 | 13 |
| 15007040202 | SHINGLE | 0 | | 69 | 88 |
| 15007040202 | SPM | 17 | | 0 | 0 |
| 15007040300 | BUR | 14 | 33 | 0 | 0 |
| 15007040300 | METAL | 0 | 0 | 49 | 27 |
| 15007040300 | SHINGLE | 0 | 0 | 51 | 73 |
| 15007040300 | SPM | 86 | 67 | 0 | 0 |
| 15007040400 | BUR | 40 | 0 | 0 | 0 |
| 15007040400 | METAL | 0 | 0 | 63 | 29 |
| 15007040400 | SHINGLE | 0 | 0 | 37 | 71 |
| 15007040400 | SPM | 60 | 100 | 0 | 0 |
| 15007040500 | BUR | 33 | 0 | 0 | 0 |
| 15007040500 | METAL | 0 | 0 | 33 | 22 |
| 15007040500 | SHINGLE | 0 | 0 | 67 | 78 |
| 15007040500 | SPM | 67 | 100 | 0 | 0 |
| 15007040600 | BUR | 35 | | 0 | 0 |
| 15007040600 | METAL | 0 | | 44 | 14 |
| 15007040600 | SHINGLE | 0 | | 56 | 86 |
| 15007040600 | SPM | 65 | | 0 | 0 |
| 15007040700 | BUR | 50 | | 0 | 0 |
| 15007040700 | METAL | 0 | | 63 | 7 |
| 15007040700 | SHINGLE | 0 | | 37 | 93 |
| 15007040700 | SPM | 50 | | 0 | 0 |
| 15007040800 | BUR | 75 | | 0 | 0 |
| 15007040800 | METAL | 0 | | 49 | 43 |
| 15007040800 | SHINGLE | 0 | | 51 | 57 |
| 15007040800 | SPM | 25 | | 0 | 0 |
| 15007040900 | BUR | 67 | 100 | 0 | 0 |
| 15007040900 | METAL | 0 | 0 | 58 | 45 |
| 15007040900 | SHINGLE | 0 | 0 | 42 | 55 |
| 15007040900 | SPM | 33 | 0 | 0 | 0 |

## Table 21. Distributions of Roofing Cover in Other than Single Wall Construction

**Roofing Distributions in Percentages** Other than single wall construction

| | | Specific Building Types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tract | ROOF COVER TYPE HI | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 |
| 15007040100 | BUR | | 0 | | 84 | 80 | | 0 | 0 |
| 15007040100 | METAL | | 11 | | 0 | 0 | | 8 | 4 |
| 15007040100 | SHINGLE | | 89 | | 0 | 0 | | 92 | 96 |
| 15007040100 | SPM | | 0 | | 16 | 20 | | 0 | 0 |
| 15007040201 | BUR | | 0 | | 100 | 100 | | 0 | 0 |
| 15007040201 | METAL | | 33 | | 0 | 0 | | 33 | 14 |
| 15007040201 | SHINGLE | | 67 | | 0 | 0 | | 67 | 86 |
| 15007040202 | BUR | 100 | 0 | | 71 | 80 | | 0 | 0 |
| 15007040202 | METAL | 0 | 0 | | 0 | 0 | | 4 | 3 |
| 15007040202 | SHINGLE | 0 | 100 | | 0 | 0 | | 96 | 97 |
| 15007040202 | SPM | 0 | 0 | | 29 | 20 | | 0 | 0 |
| 15007040300 | BUR | | 0 | | 86 | 100 | | 0 | 0 |
| 15007040300 | METAL | | 0 | | 0 | 0 | | 7 | 2 |
| 15007040300 | SHINGLE | | 100 | | 0 | 0 | | 93 | 98 |
| 15007040300 | SPM | | 0 | | 14 | 0 | | 0 | 0 |
| 15007040400 | BUR | | 0 | | 71 | 100 | | 0 | 0 |
| 15007040400 | METAL | | 38 | | 0 | 0 | | 2 | 0 |
| 15007040400 | SHINGLE | | 63 | | 0 | 0 | | 98 | 100 |
| 15007040400 | SPM | | 0 | | 29 | 0 | | 0 | 0 |
| 15007040500 | BUR | | 0 | | 77 | 67 | | 0 | 0 |
| 15007040500 | METAL | | 44 | | 0 | 0 | | 2 | 5 |
| 15007040500 | SHINGLE | | 56 | | 0 | 0 | | 98 | 95 |
| 15007040500 | SPM | | 0 | | 23 | 33 | | 0 | 0 |
| 15007040600 | BUR | | 0 | 0 | 43 | 71 | | 0 | 0 |
| 15007040600 | METAL | | 25 | 0 | 0 | 0 | | 7 | 3 |
| 15007040600 | SHINGLE | | 75 | 100 | 0 | 0 | | 93 | 97 |
| 15007040600 | SPM | | 0 | 0 | 57 | 29 | | 0 | 0 |
| 15007040700 | BUR | | 0 | 0 | 75 | 100 | | 0 | 0 |
| 15007040700 | METAL | | 13 | 0 | 0 | 0 | | 15 | 4 |
| 15007040700 | SHINGLE | | 88 | 100 | 0 | 0 | | 85 | 96 |
| 15007040700 | SPM | | 0 | 0 | 25 | 0 | | 0 | 0 |
| 15007040800 | METAL | | 50 | | | | | 2 | 14 |
| 15007040800 | SHINGLE | | 50 | | | | | 98 | 86 |
| 15007040900 | BUR | | 0 | | 89 | 100 | 100 | 0 | 0 |
| 15007040900 | METAL | | 15 | | 0 | 0 | 0 | 9 | 14 |
| 15007040900 | SHINGLE | | 85 | | 0 | 0 | 0 | 91 | 86 |
| 15007040900 | SPM | | 0 | | 11 | 0 | 0 | 0 | 0 |

## Table 22. Distributions of Roof Truss Spacing in Single Wall Construction

**Truss Spacing Distributions in Percentages** Single wall construction

| | | Specific Building Types | | | |
|---|---|---|---|---|---|
| Tract | TRUSS SPACING | WMUH1 | WMUH2 | WSF1 | WSF2 |
| 15007040100 | 2 | 100 | | 57 | 88 |
| 15007040100 | 4 | 0 | | 43 | 12 |
| 15007040201 | 2 | | | 46 | 84 |
| 15007040201 | 4 | | | 54 | 16 |
| 15007040202 | 2 | 92 | | 75 | 92 |
| 15007040202 | 4 | 8 | | 25 | 8 |
| 15007040300 | 2 | 57 | 67 | 63 | 73 |
| 15007040300 | 4 | 43 | 33 | 37 | 27 |
| 15007040400 | 2 | 47 | 100 | 43 | 71 |
| 15007040400 | 4 | 53 | 0 | 57 | 29 |
| 15007040500 | 2 | 67 | 0 | 71 | 78 |
| 15007040500 | 4 | 33 | 100 | 29 | 22 |
| 15007040600 | 2 | 53 | | 62 | 93 |
| 15007040600 | 4 | 47 | | 38 | 7 |
| 15007040700 | 2 | 50 | | 45 | 93 |
| 15007040700 | 4 | 50 | | 55 | 7 |
| 15007040800 | 2 | 75 | | 57 | 57 |
| 15007040800 | 4 | 25 | | 43 | 43 |
| 15007040900 | 2 | 67 | 100 | 50 | 64 |
| 15007040900 | 4 | 33 | 0 | 50 | 36 |

## Table 23. Distributions of Roof Truss Spacing in Other than Single Wall Construction

**Truss Spacing Distributions in Percentages** Other than single wall construction

| | | Specific Building Types | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tract | TRUSS SPACING | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 |
| 15007040100 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040201 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040202 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040300 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040400 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040500 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040600 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040700 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040800 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15007040900 | 2 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

## Table 24. Distributions of Foundation Uplift Restraint in Single Wall Construction

**Foundation Uplift Restraint Distributions in Percentages** Single wall construction

| | | Specific Building Types | | | |
|---|---|---|---|---|---|
| Tract | UPLIFT RESTRAINT | WMUH1 | WMUH2 | WSF1 | WSF2 |
| 15007040100 | NO | 100 | | 89 | 78 |
| 15007040100 | YES | 0 | | 11 | 22 |
| 15007040201 | NO | | | 86 | 68 |
| 15007040201 | YES | | | 14 | 32 |
| 15007040202 | NO | 83 | | 87 | 63 |
| 15007040202 | YES | 17 | | 13 | 38 |
| 15007040300 | NO | 86 | 67 | 88 | 73 |
| 15007040300 | YES | 14 | 33 | 12 | 27 |
| 15007040400 | NO | 47 | 100 | 59 | 86 |
| 15007040400 | YES | 53 | 0 | 41 | 14 |
| 15007040500 | NO | 67 | 100 | 68 | 89 |
| 15007040500 | YES | 33 | 0 | 32 | 11 |
| 15007040600 | NO | 82 | | 83 | 71 |
| 15007040600 | YES | 18 | | 17 | 29 |
| 15007040700 | NO | 0 | | 93 | 67 |
| 15007040700 | YES | 100 | | 7 | 33 |
| 15007040800 | NO | 100 | | 90 | 71 |
| 15007040800 | YES | 0 | | 10 | 29 |
| 15007040900 | NO | 83 | 0 | 86 | 73 |
| 15007040900 | YES | 17 | 100 | 14 | 27 |

## Table 25. Distributions of Foundation Uplift Restraint In Other than Single Wall Construction

| **Foundation Uplift Restraint Distributions in Percentages** | | | Other than single wall construction<br>Specific Building Types | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tract | UPLIFT RESTRAINT | MMUH1 | MSF1 | MSF2 | WMUH1 | WMUH2 | WMUH3 | WSF1 | WSF2 |
| 15007040100 | NO | | 11 | | 56 | 40 | | 50 | 38 |
| 15007040100 | YES | | 89 | | 44 | 60 | | 50 | 62 |
| 15007040201 | NO | | 67 | | 100 | 50 | | 65 | 45 |
| 15007040201 | YES | | 33 | | 0 | 50 | | 35 | 55 |
| 15007040202 | NO | 0 | 42 | | 32 | 40 | | 44 | 34 |
| 15007040202 | YES | 100 | 58 | | 68 | 60 | | 56 | 66 |
| 15007040300 | NO | | 14 | | 14 | 43 | | 39 | 14 |
| 15007040300 | YES | | 86 | | 86 | 57 | | 61 | 86 |
| 15007040400 | NO | | 13 | | 43 | 50 | | 17 | 22 |
| 15007040400 | YES | | 88 | | 57 | 50 | | 83 | 78 |
| 15007040500 | NO | | 25 | | 23 | 0 | | 30 | 21 |
| 15007040500 | YES | | 75 | | 77 | 100 | | 70 | 79 |
| 15007040600 | NO | | 38 | 50 | 57 | 71 | | 48 | 28 |
| 15007040600 | YES | | 63 | 50 | 43 | 29 | | 52 | 72 |
| 15007040700 | NO | | 44 | 0 | 50 | 100 | | 64 | 50 |
| 15007040700 | YES | | 56 | 100 | 50 | 0 | | 36 | 50 |
| 15007040800 | NO | | 50 | | | | | 21 | 43 |
| 15007040800 | YES | | 50 | | | | | 79 | 57 |
| 15007040900 | NO | | 23 | | 44 | 0 | 0 | 50 | 40 |
| 15007040900 | YES | | 77 | | 56 | 100 | 100 | 50 | 60 |

## V. Assembling Damage Data and Analysis

Information on Hurricane Iniki damage to Hawaii buildings of residential occupancy had previously been gathered and geo-referenced on GIS. Comprehensive reconstruction cost documentation had been cross-checked with post-hurricane aerial photography and then linked to the property tax database of construction type attributes and property valuation. The investigation previously had obtained available data from NOAA Storm Data reports [5, 6}, American Red Cross surveys [7], FEMA damage/claim reports and State Civil Defense initial data on building damage, State hurricane impact economic reports, a Structural Engineers Association of Hawaii post-disaster report, National Research Council, and National Science Foundation studies [8], National Weather Service[9], Hawaii Insurance Bureau [10], and most importantly, the Kaua'i County permit database for post-hurricane reconstruction.

Comprehensive building damage data was primarily based on post-Iniki reconstruction permit applications that had been input into a database by the former Office of Emergency Permitting (OEP), which was temporarily established by FEMA after Hurricane Iniki. Pertinent data fields of this special hurricane reconstruction database included, among other information: Tax Map Key Code or TMK, a unique identification coding for each property in Hawaii; Land Use Zonation; Structure Number or Unit Number; Type of Permit; Post-Hurricane Damage Tagging; Description of Structure; Roof Repairs; Roof Structure Repairs; Wall Repairs; Whether 50% Damaged or Greater, any Demolition; Whether Rebuilt; Estimated Value of Permitted Work; Permit Date. The linked building permit database included over 20,000 permit records. Recorded loss data for Kauai was assembled and compiled according to census tract mapping and HAZUS-compatible specific building types to produce damage data summaries in damage categories that were comparable to HAZUS MH output. Thus, HAZUS MH results for Hurricane Iniki could be compared to the actual recorded damage data for *equivalent* building inventory representations aggregated by census tracts.

Extensive data processing tasks related to the sorting and analysis of this data included:

- elimination of void and superseded permits,
- elimination of permits for detached temporary housing,
- assembling residential, single-family structure records from parcels across a variety of land use zonings,
- identification of multiple, detached structures, each with a different damage state, on a single parcel,
- identification of multiple separated structures with identical damage states on single parcels,
- separation of principal structures from minor structures such as detached carports and sheds,
- location of damage zones within separate multiple-unit buildings within a single parcel,
- correction of miscoded OEP TMK and Tax database fields
- matching of initial demolition costs with reconstruction costs of the later work permit,

- destroyed structures identified with a demolition permit which were not subsequently rebuilt,
- aggregation of cumulative-cost data from several permits issued for a structure, and identification of its highest damage state,
- quality control checks utilizing random sample queries of third-party tax record information for verification of available data for area, year built date, use (specific occupancy), structural material, and tax valuation,
- additional data screening performed as a part of the quality control of data to eliminate outlier entries in the tax records, and
- accounting for a lack of complete documentation of reconstruction, resulting in a number of structures without definitive damage assessment or reconstruction estimated values.

In addressing this last item, other data fields were first used to determine the best match of damage characteristics to place these structures in the appropriate categories. For example, matching permits for temporary, detached shelters would indicate loss of roof. Permits for certain types of nonstructural work only would indicate water damage without structural damage. The OEP also performed field tagging of structures that exhibited damage expected to need structural repairs. Residences without structural damage could also be exempted from most permitting requirements after a verifying inspection by the Office of Emergency Permitting. A table of post-hurricane field inspection logs was utilized to clarify the status of properties without subsequent building permits.

Then, the permit records of demolition and reconstruction were separated within each occupancy classification. The reconstruction permit records were subsequently sorted into mutually exclusive damage level groupings based on the OEP scope of repair and damage severity rating (see Table 26). Each individual parcel was then categorized based on its most severe damage state (there can be a successive number of permits issued for a property, as well as multiple structures on a parcel). The reconstruction permit database table was then linked to the Kaua'i tax assessor files of 1994 vintage. Existing damage and loss data was then re-aggregated within census tracts according to geocoded property selection by GIS and property tax data fields

**Table 26. Raw Data Building Counts By Area And Census Tract**

**Residential Areas**

| Regions | Rnp | Rx | Rnr | Rr | R50 | R50d | RD | Total |
|---|---|---|---|---|---|---|---|---|
| Anahola | 78 | 271 | 12 | 46 | 5 | 21 | 7 | *440* |
| Hanalei | 1028 | 172 | 42 | 434 | 41 | 91 | 12 | *1820* |
| Hanamaulu | 358 | 156 | 18 | 202 | 8 | 31 | 4 | *777* |
| Hanapepe | 699 | | 15 | 205 | 10 | 42 | 12 | *983* |
| Kalaheo | 1020 | 853 | 47 | 446 | 26 | 143 | 29 | *2564* |
| Kapaa | 1750 | 1705 | 105 | 704 | 58 | 217 | 33 | *4572* |
| Lihue | 839 | 546 | 29 | 357 | 28 | 105 | 24 | *1928* |
| Poipu | 224 | 167 | 21 | 75 | 9 | 45 | 13 | *554* |
| Waimea | 609 | 357 | 36 | 409 | 13 | 82 | 24 | *1530* |
| Total | *6605* | *4227* | *325* | *2878* | *198* | *777* | *158* | ***15168*** |

**Census Tracts**

| Tracts | Rnp | Rx | Rnr | Rr | R50 | R50d | RD | Total |
|---|---|---|---|---|---|---|---|---|
| 040100 | 1043 | 182 | 43 | 435 | 42 | 93 | 17 | *1855* |
| 040201 | 125 | 425 | 13 | 78 | 10 | 27 | 4 | *682* |
| 040202 | 1031 | 653 | 64 | 381 | 31 | 122 | 13 | *2295* |
| 040300 | 657 | 888 | 39 | 290 | 21 | 87 | 20 | *2002* |
| 040400 | 624 | 398 | 27 | 306 | 14 | 36 | 8 | *1413* |
| 040500 | 573 | 304 | 20 | 253 | 22 | 100 | 17 | *1289* |
| 040600 | 542 | 630 | 41 | 195 | 11 | 80 | 22 | *1521* |
| 040700 | 989 | 390 | 34 | 419 | 24 | 115 | 21 | *1992* |
| 040800 | 415 | 17 | 8 | 113 | 10 | 35 | 10 | *608* |
| 040900 | 606 | 340 | 36 | 408 | 13 | 82 | 24 | *1509* |
| * Unknown | | | | | | | 2 | *2* |
| Total | *6605* | *4227* | *325* | *2878* | *198* | *777* | *158* | ***15168*** |

Database tables of Tax Map Key (TMK) indexed site locations sorted by various damage levels were geocoded onto GIS, for geographic comparison at parcel-level resolution with matching aerial photographs of the north coast region of Kaua'i. Hurricane Iniki (September, 1992) winds have previously been qualitatively interpreted and wind directionality vectors mapped by T. Fujita based on low-level aerial photography taken by Air Survey Hawaii. The raw photographs were acquired for several flight lines and geo-referenced so that building damage could be examined. These low-level photographs were relatively cloud-free, and they were at a scale and size that retained adequate resolution for examination of individual structures on parcels. This GIS overlay provided a means verifying damage states for individual properties lacking detailed building permit or precise field tagging inspection information. To prorate the correct proportion of remaining single-family, parcels where the damage data was incomplete, random samples were taken for detailed aerial photograph assessment for parcel damage identification. Querying

of available field inspection records was used to select the parcels actually needing clarification of damage states. Random numbers were assigned to this group of TMK records and a sample was selected by sorting of the random numbers. The number of samples was determined to yield a 99% confidence level of no more than a 10% error in the determined proportion of damage states of single-family residences. Damage categorization of the randomly selected sites was then performed by individual inspection of aerial photography. The proportions thus determined were used to distribute the larger population of sites lacking detailed, building-permit data.

The damage states are also re-classified to the HAZUS output in accordance with Table 27. The combined Property Tax-Derived Database and Building Damage Database was expanded to add the HAZUS building type, wind resistive characteristics, and occupancy classification fields to all 15168 records (See Figure 7).

Microsoft Access - [Residential_Damage_Iniki : Table]

File Edit View Insert Tools Window Help

| Field Name | Data Type | |
|---|---|---|
| TMKConvert | Text | |
| TMK-Tax | Text | |
| Category | Text | |
| Residential | Text | |
| RES ID | Text | |
| FR ID | Text | |
| Tract | Text | |
| Tract2 | Text | |
| TMK | Number | |
| CARD | Number | |
| BLDG | Number | |
| Est_Value | Text | |
| $Est_Value | Number | |
| 94BldgValue | Number | |
| BldgLivArea | Number | |
| Street | Number | |
| STREET_NAM | Text | |
| YEAR_BUILT | Number | |
| EffectYrBuilt | Number | |
| PITT | Number | |
| OCCUPANCY | Number | |
| Physcl_Condtn | Number | |
| ROOF_DESIG | Number | |
| ROOF_MATER | Number | |
| ROOF_STRUC | Number | |
| EXT_Wall | Number | |
| Int_Wall_Strctr | Number | |
| Floor_Const | Number | |
| FOUNDATION | Number | |
| STORIES | Number | |
| GrossBldgArea | Number | |
| STRUCTURE | Number | |
| BUILDING TYPE | Text | |
| SPECIFIC OCCUPANCY | Text | |
| SPECIFIC BUILDING TYPE | Text | |
| ROOF SHAPE | Text | |
| ROOF WALL CONNECTION | Text | |
| ROOF COVER TYPE HI | Text | |
| TRUSS SPACING | Number | |
| UPLIFT RESTRAINT | Text | |
| ROOF COVER QUALITY | Number | |
| CONTENT VALUE | Number | |
| DamageCategory | Text | |
| HurricaneCategory | Number | |
| CostDataCategory | Number | |
| DamageValueCAT | Number | |
| ifOneStory | Number | |
| ifMetalRoof | Number | |
| taxValueCAT | Number | |
| ifSingleWall | Number | |
| ifPreCode | Number | |
| ifWoodPier | Number | |
| ifGable | Number | |
| $Est_ValuePerSF | Number | Divide Field "$Est_Value" by the field of "BldgLivArea" |
| reConstructionCost | Number | Damage economic loss in $ |
| reConstructionCostPerSF | Number | Damage economic loss in $ per square foot |

**Figure 7. Combined Database Fields**

## Table 27. Damage State Classifications for Residential Construction

| Damage State | **HAZUS-MH Damage State Description** | **Kauai Database Damage State Description** | Average % loss range of total value | Roof Cover Failure | Window / Door Failures | Roof Deck | Missile Impacts on Walls | Roof Frame Failure | Wall Structure Failure |
|---|---|---|---|---|---|---|---|---|---|
| 0 | **No Damage or Very Minor Damage** Little or no visible damage from the outside. No broken windows, or failed roof deck. Minimal loss of roof over, with no or very limited water penetration. | **Rnp** Residential, OEP record, **n**o subsequent **p**ermit information | | <2% | No | No | No | No | No |
| 1 | **Minor Damage** Maximum of one broken window, door or garage door. Moderate roof cover loss that can be covered to prevent additional water entering the building. Marks or dents on walls requiring painting or patching for repair. | **Rnr** Residential, repairs (**n**ot to **r**oof), <50% damage | **20% to 30%** | >2% to <15% | One window, door, or garage door failure | No | <5 | No | No |
| 2 | **Moderate Damage** Major roof cover damage, moderate window breakage. Minor roof sheathing failure. Some resulting damage to interior of building from water. | **Rr** Residential, repairs including **r**oof, but <50% damage | **30% to 50%** | >15% to <50% | ≥ one, but ≤ the greater of 15% or 3 | One or two panels | Typically 5 to 10 impacts | No | No |
| 3 | **Severe Damage** Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water. | **R50** Residential, **>50%** damage with rebuilding | **50% to 75%** | >50% | <15% (or 3) up to 50% | ≥3 panels, but less than 25% | Typically 10 to 20 impacts | No | No |
| 4 | **Destruction** Complete roof failure and/or, failure of wall frame. Loss of more than 50% of roof sheathing. | **R50d** Residential, **>50%** damage rebuilding after **d**emolition | **75% to 100%** | Typically >50% | >50% | ≥25% failed panels | Typically more than 20 impacts | Yes | Yes |
| | | **RD** Residential, total **D**emolition, no rebuild | **Greater than 100%** | | | | | | |

In Tables 28, 29, and 30, summary statistics are given on the number of buildings in each HAZUS damage state for single wall, conventional framing, and for the total building inventory by census tract.

**Table 28. Processed Single Wall Building Damage Count Data by Census Tract**

Single wall

| Census Tracts | None | slight | moderate | severe | complete | Total |
|---|---|---|---|---|---|---|
| 15007040100 | 239 | 14 | 199 | 41 | 63 | 556 |
| 15007040201 | 235 | 6 | 58 | 12 | 23 | 334 |
| 15007040202 | 470 | 37 | 233 | 48 | 82 | 870 |
| 15007040300 | 522 | 29 | 208 | 39 | 84 | 882 |
| 15007040400 | 410 | 21 | 287 | 50 | 42 | 810 |
| 15007040500 | 326 | 16 | 216 | 47 | 109 | 714 |
| 15007040600 | 543 | 24 | 170 | 36 | 65 | 838 |
| 15007040700 | 391 | 18 | 263 | 54 | 116 | 842 |
| 15007040800 | 150 | 8 | 109 | 36 | 40 | 343 |
| 15007040900 | 478 | 28 | 368 | 48 | 92 | 1014 |
| Total | 3764 | 201 | 2111 | 411 | 716 | 7203 |
| Percentage | 52.3% | 2.8% | 29.3% | 5.7% | 9.9% | |

**Table 29. Processed Other than Single Wall Building Damage Count Data by Census Tract**

Other than single wall

| Census Tracts | None | slight | moderate | severe | complete | Total |
|---|---|---|---|---|---|---|
| 15007040100 | 679 | 36 | 389 | 120 | 75 | 1299 |
| 15007040201 | 278 | 8 | 38 | 12 | 12 | 348 |
| 15007040202 | 911 | 34 | 299 | 100 | 82 | 1426 |
| 15007040300 | 830 | 14 | 179 | 57 | 40 | 1120 |
| 15007040400 | 429 | 10 | 111 | 35 | 18 | 603 |
| 15007040500 | 383 | 8 | 121 | 40 | 23 | 575 |
| 15007040600 | 470 | 20 | 105 | 37 | 52 | 684 |
| 15007040700 | 697 | 22 | 302 | 83 | 46 | 1150 |
| 15007040800 | 160 | 3 | 65 | 21 | 16 | 265 |
| 15007040900 | 290 | 12 | 129 | 34 | 30 | 495 |
| Total | 5127 | 167 | 1738 | 539 | 394 | 7965 |
| Percentage | 64.4% | 2.1% | 21.8% | 6.8% | 4.9% | |

**Table 30. Processed Building Damage Count Data by Census Tract**

| | Rx | Rnr | Rr | R50 | R50d | RD | Total |
|---|---|---|---|---|---|---|---|
| Census Tracts | **None** | **Slight** | **Moderate** | **Severe** | **Complete** | | |
| 15007040100 | 918 | 50 | 588 | 161 | 114 | 24 | 1855 |
| 15007040201 | 513 | 14 | 96 | 24 | 30 | 5 | 682 |
| 15007040202 | 1381 | 71 | 532 | 148 | 143 | 21 | 2296 |
| 15007040300 | 1352 | 43 | 387 | 96 | 100 | 24 | 2002 |
| 15007040400 | 839 | 31 | 398 | 85 | 48 | 12 | 1413 |
| 15007040500 | 709 | 24 | 337 | 87 | 111 | 21 | 1289 |
| 15007040600 | 1013 | 44 | 275 | 73 | 91 | 26 | 1522 |
| 15007040700 | 1088 | 40 | 565 | 137 | 135 | 27 | 1992 |
| 15007040800 | 310 | 11 | 174 | 57 | 43 | 13 | 608 |
| 15007040900 | 768 | 40 | 497 | 82 | 94 | 28 | 1509 |
| **Total** | **8891** | **368** | **3849** | **950** | **909** | **201** | **15168** |
| **Percentage** | **58.6%** | **2.4%** | **25.4%** | **6.3%** | **6.0%** | **1.3%** | **100%** |

For comparison, a rapid evaluation "drive-by" street survey of damage conducted of the exteriors of structures by the American Red Cross across the island in the days after Hurricane Iniki estimated that 51.5% of the single family homes had minor or no damage, 38.2% had major damage, and 10.3% were destroyed. The database island-wide summary statistics appear similar (but somewhat less severe) relative to the ARC Disaster Operations Center report [7] from the initial (and less rigorous) Red Cross surveys.

Figures 8 through 16 present maps of each census tract indicating the color-coded parcels categorized by damage state. Note that these maps indicate the non-commercial low-rise residential housing structures only, and not the entire Kauai building inventory. Accordingly, there will be parcels that do not have a damage state indicated.

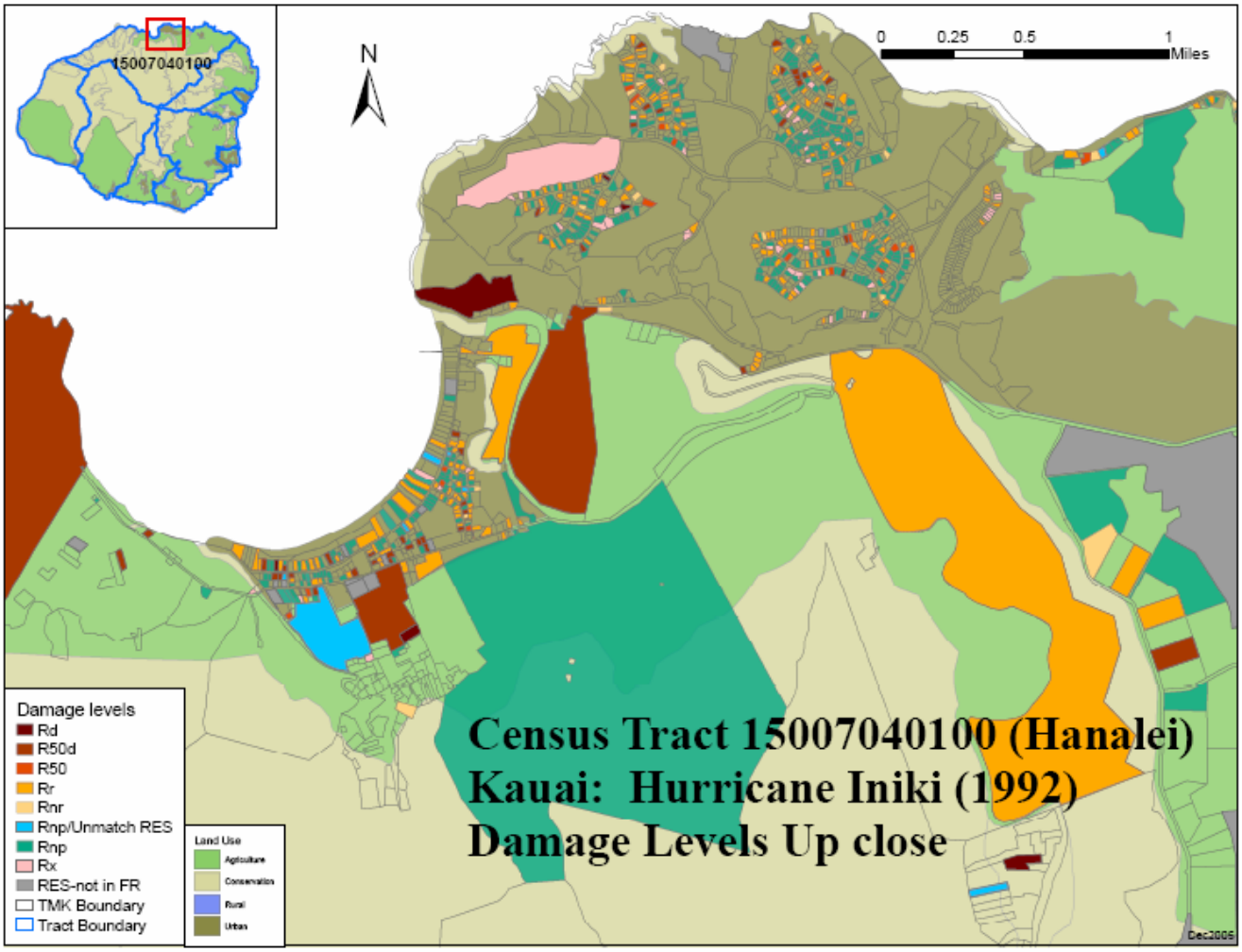


**Figure 8. Census Tract 15007040100 (Hanalei) Hurricane Iniki Damage Levels**

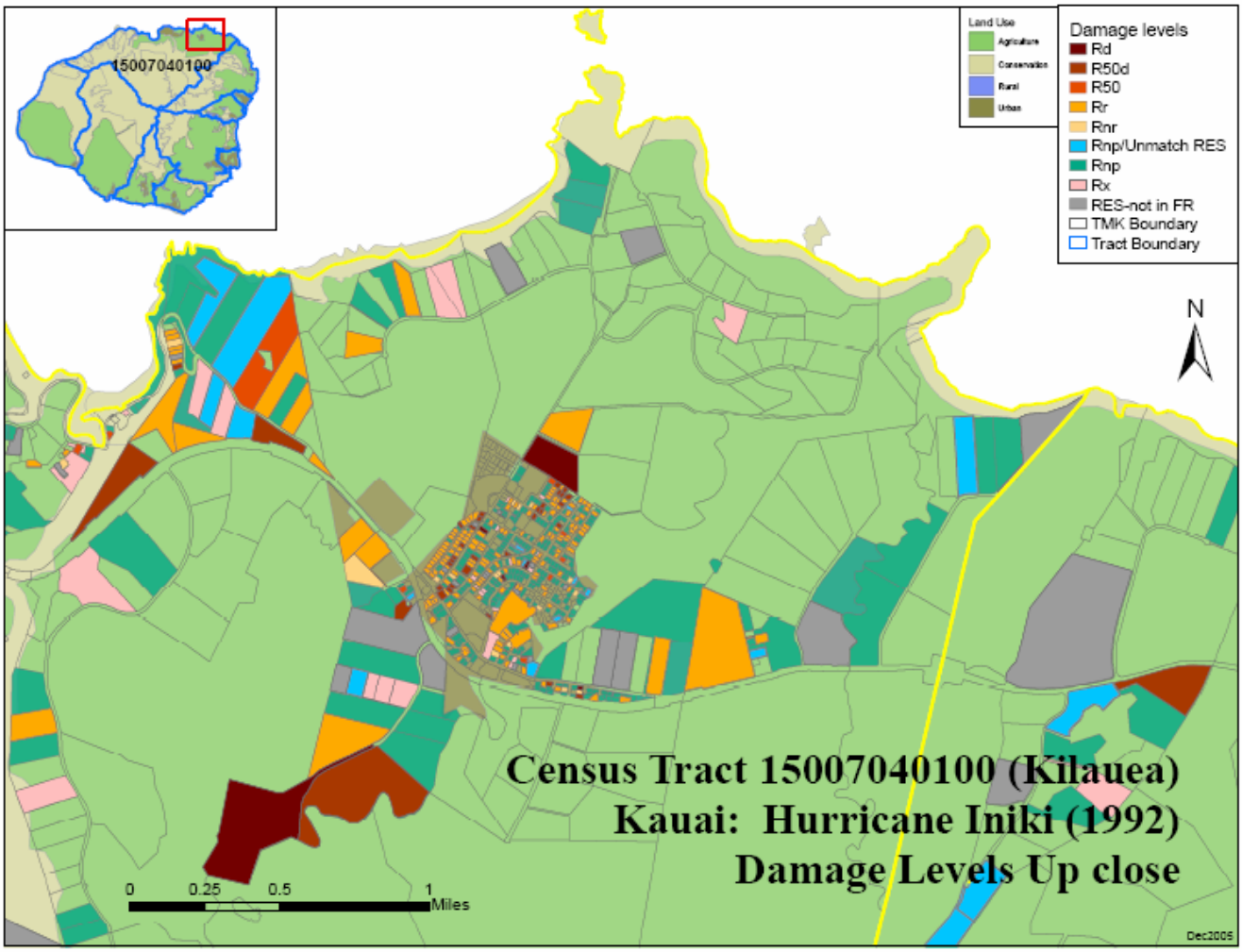


**Figure 9. Census Tract 15007040100 (Kilauea) Hurricane Iniki Damage Levels**

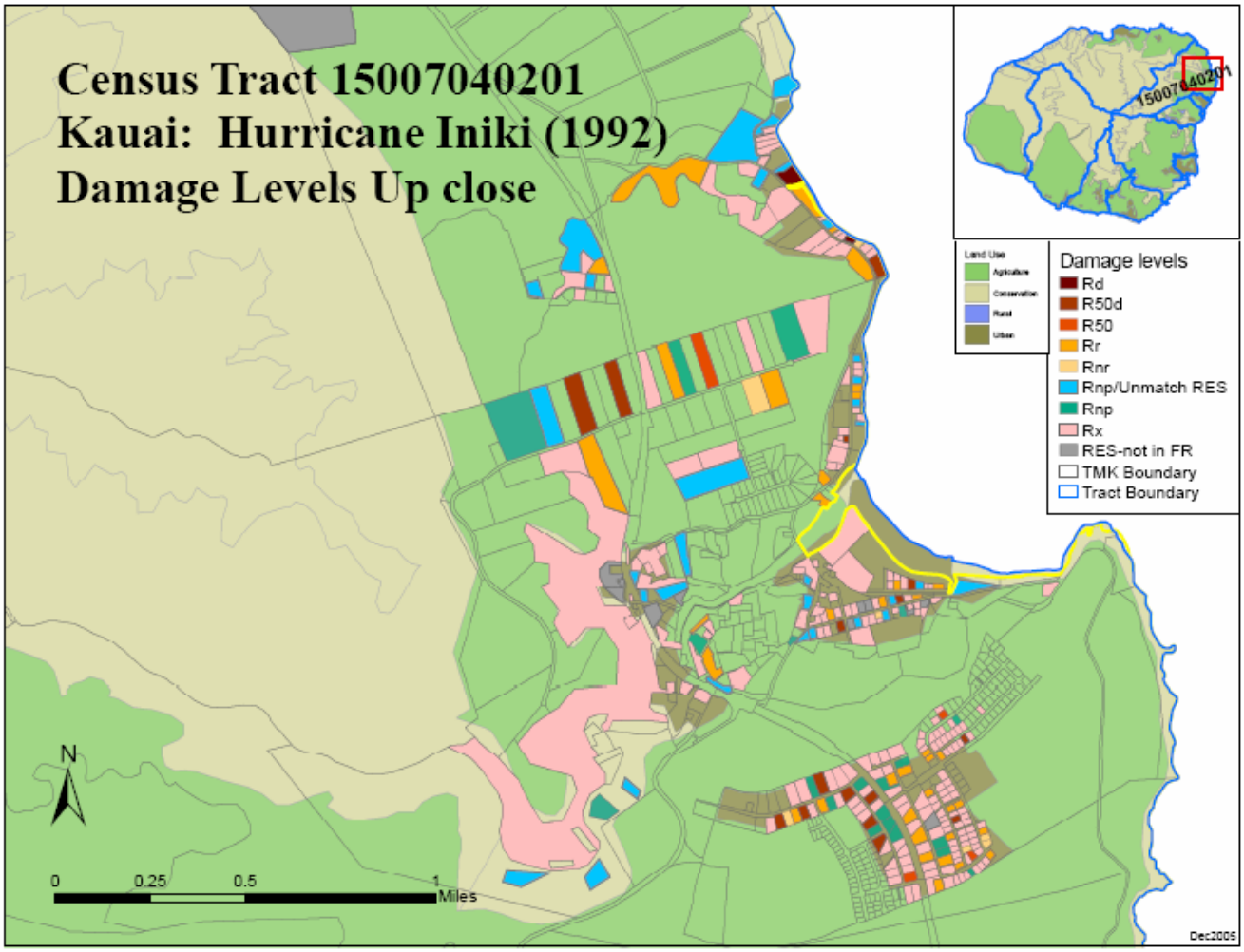


**Figure 10. Census Tract 15007040201 Hurricane Iniki Damage Levels**

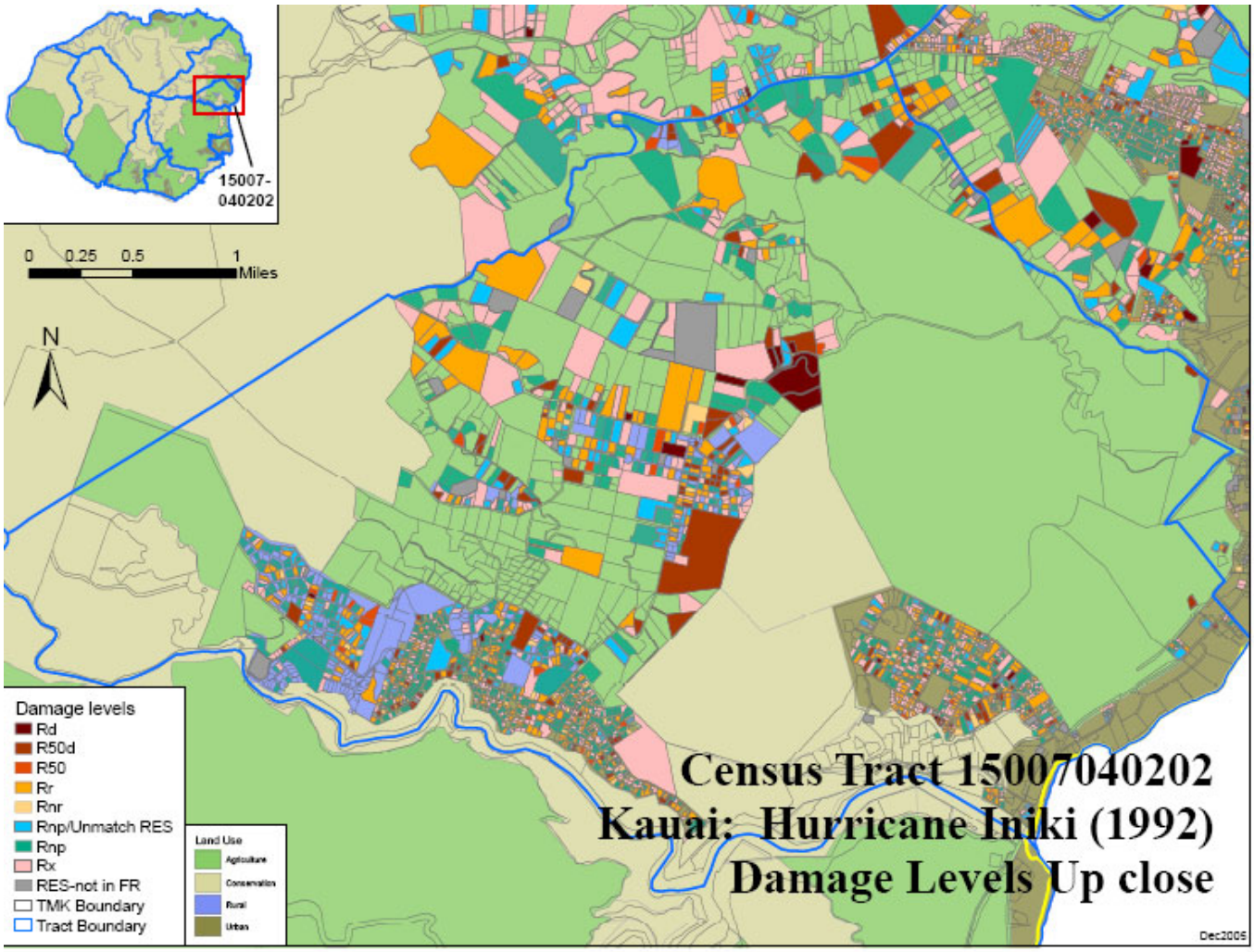


**Figure 11. Census Tract 15007040202 Hurricane Iniki Damage Levels**

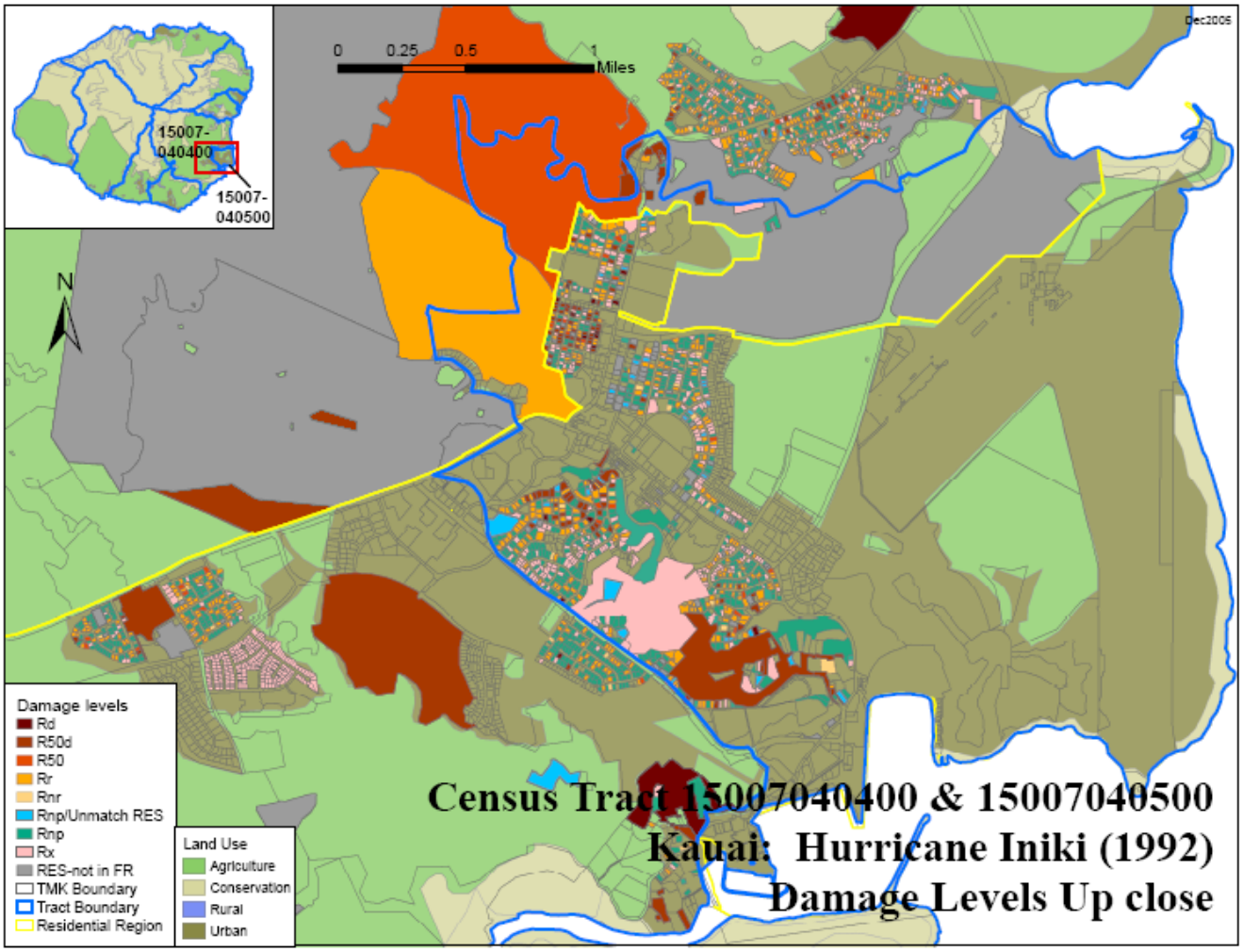


**Figure 12. Census Tract 15007040400 & 15007040500 Hurricane Iniki Damage Levels**

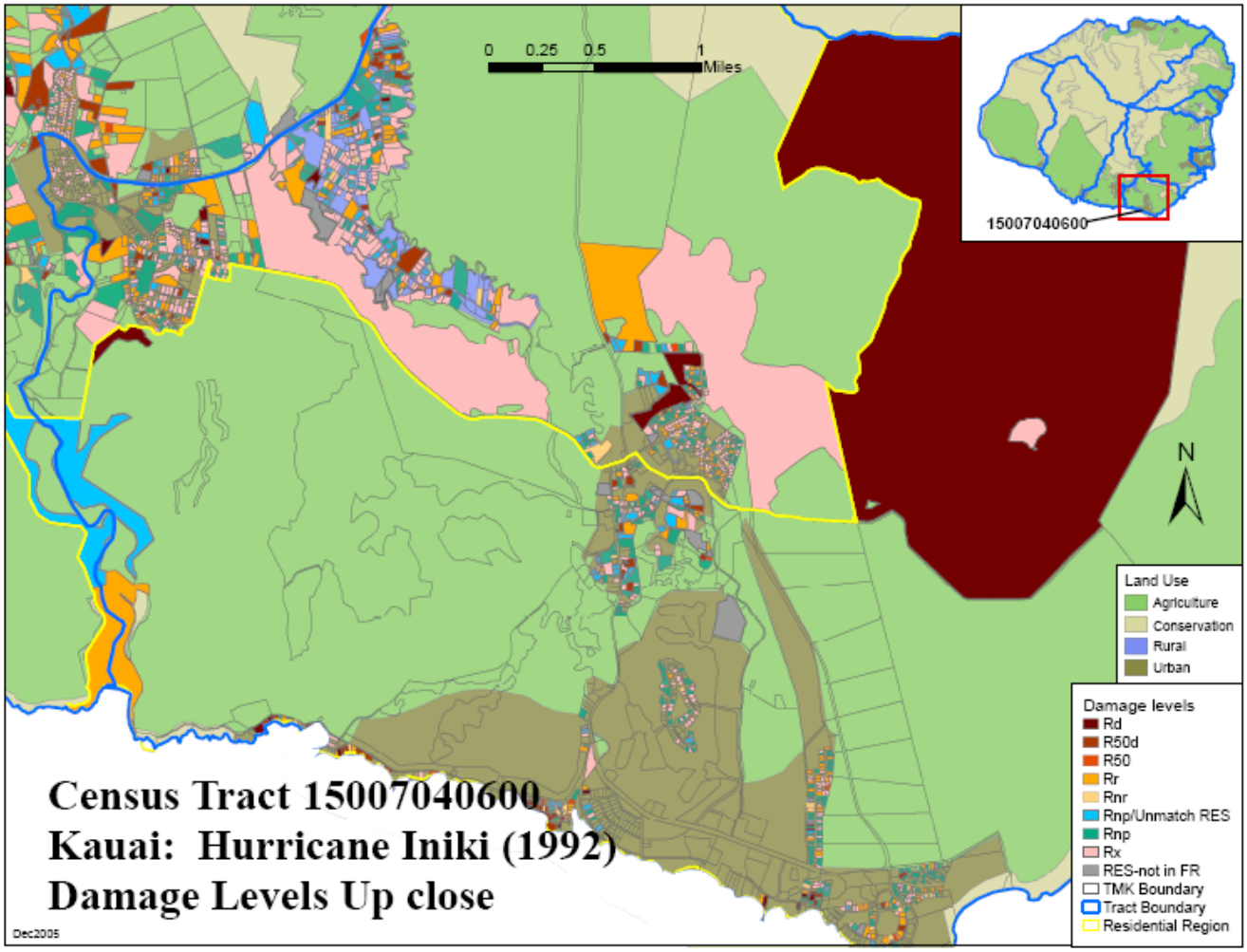


**Figure 13. Census Tract 15007040600 Hurricane Iniki Damage Levels**

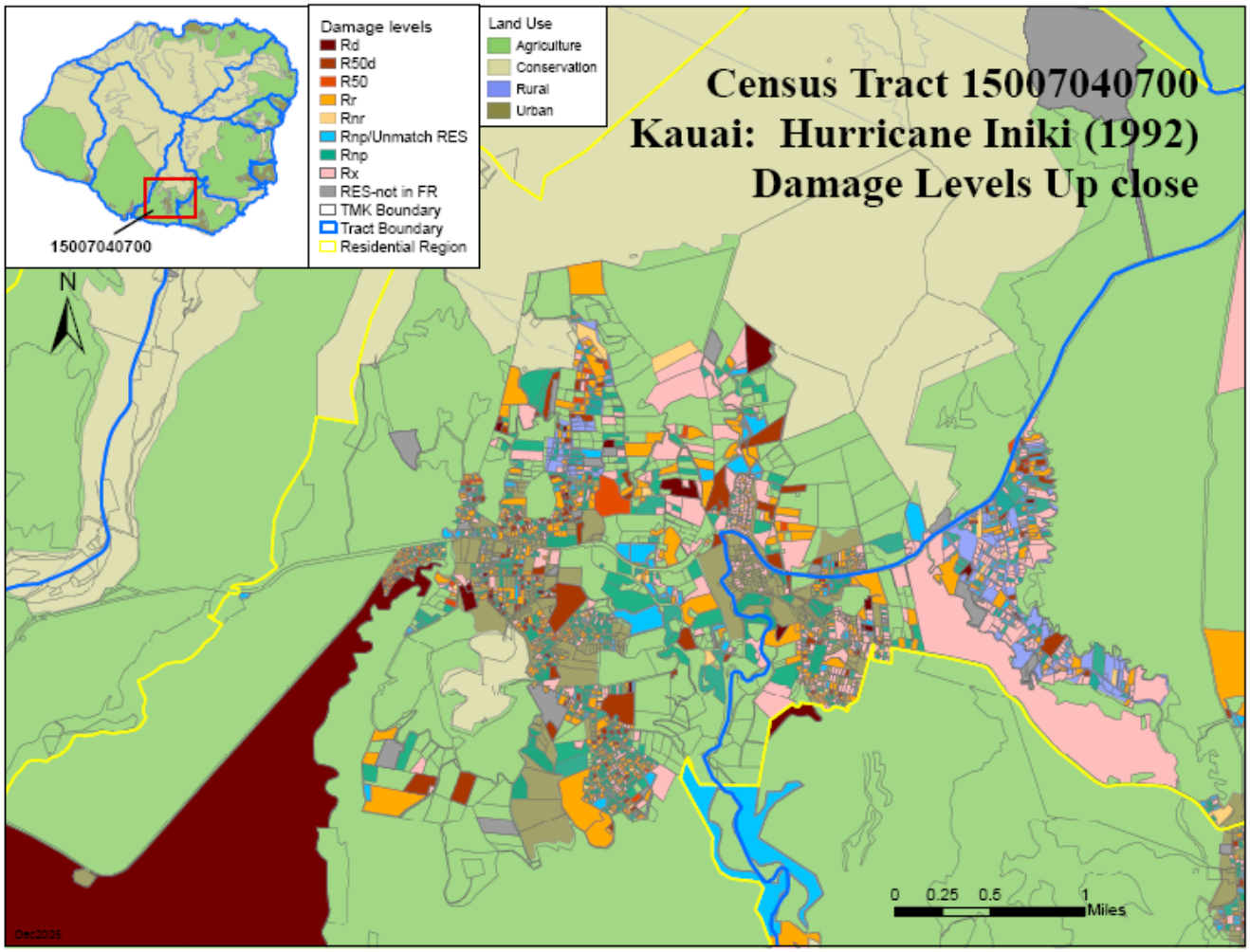


**Figure 14. Census Tract 15007040700 Hurricane Iniki Damage Levels**

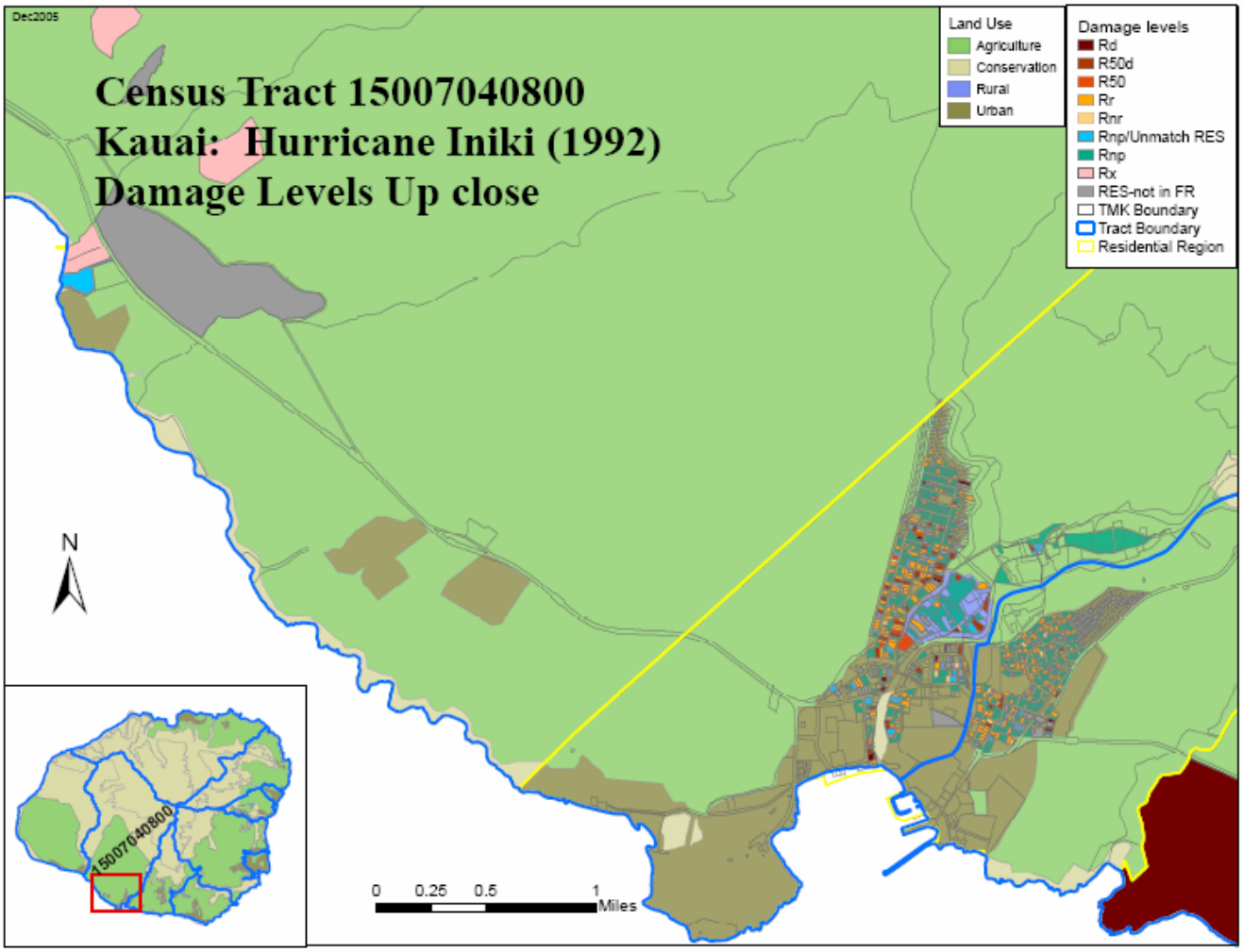


**Figure 15. Census Tract 15007040800 Hurricane Iniki Damage Levels**

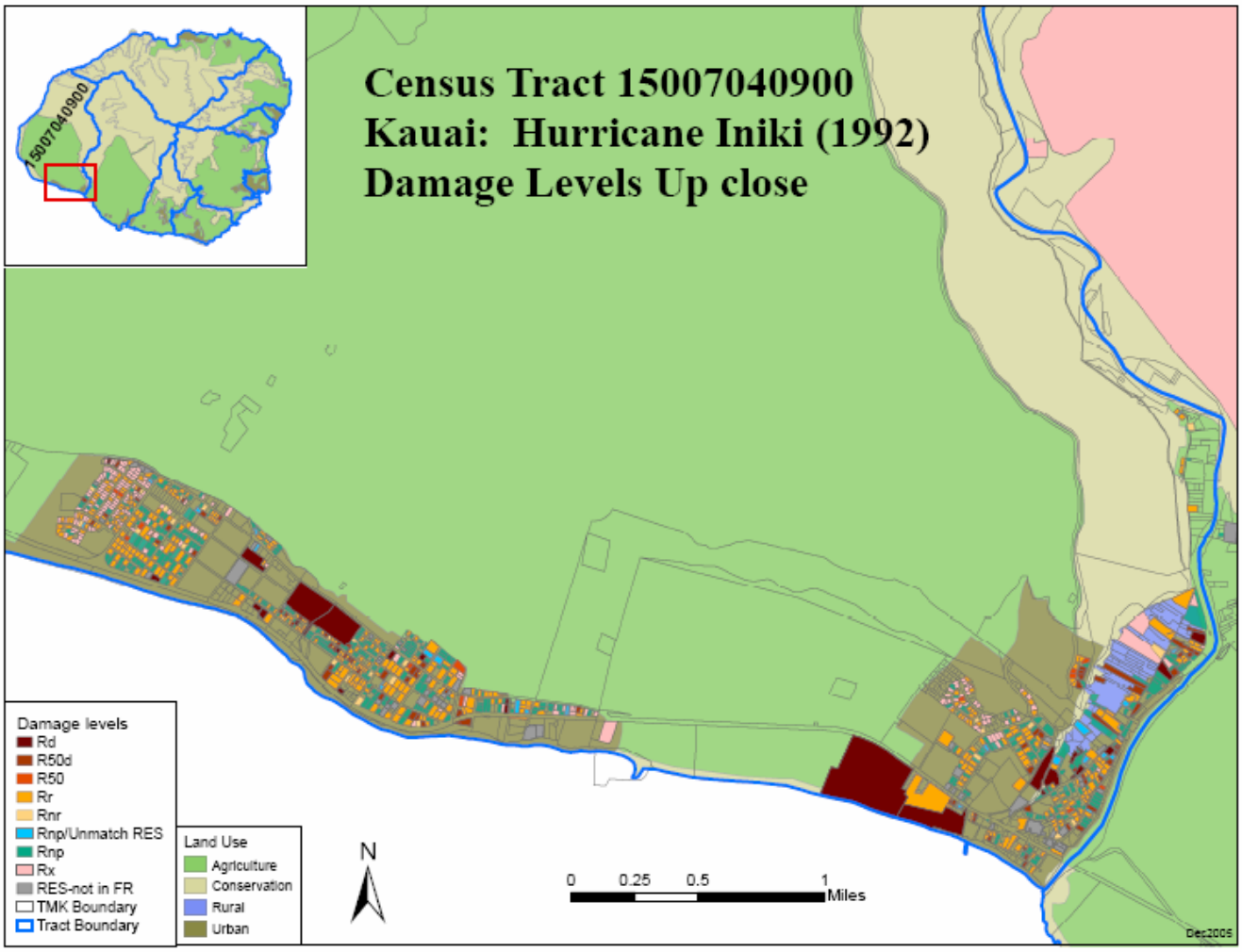


**Figure 16. Census Tract 15007040900 Hurricane Iniki Damage Levels**

## VI. HAZUS MH Damage and Direct Losses for Hurricane Iniki Compared To Actual Losses

The HAZUS MH Hurricane Module was run using the given windfield parameters for Hurricane Iniki based on published data for central pressure and track.

Since the single wall residence does not exist as a separate specific building type, separate regions in HAZUS MH for "single" and "double" wall categories of structure were run for identical storms.

We adjusted construction cost parameters to the 1990's for this region based on valuations and post-Iniki-era cost data for specific building types in Hawaii, similar to studies previously conducted by the Hawaii State Earthquake Advisory Committee to Hawaii State Civil Defense. The aggregate replacement cost valuation was $734 million for the single wall building inventory of 7,203, and it was $1,088 million for the non-single wall building inventory of 7,965. The total inventory included in this study region thus had an exposure of about $1.82 billion.

The total value of contents as a percentage of building replacement value was adjusted to 20% of building value, since the value of Hawaii homes is typically higher than national averages, but smaller in size, and the cost of goods is higher while average income levels (and household budgets) are not commensurately higher.

The population was adjusted to 1990 Census figure of 51,200 and distributed in census tract aggregations. Centroids of each tract were adjusted to the population centroid rather than the geometric centroid of the tract as indicated in Figure 17. In Hawaii, it is typical that a large portion of a census tract is uninhabited due to the mountainous terrain and land use zoning restrictions.

The peak gusts of 143 mph recorded at Makahuena Point, located at the southeast corner of the island about 20 km distant from the center of the storm, and 130 mph recorded at Lihue, about 25 km from the center, are considered representative surface windspeeds at landfall to the east of the eyewall in the right forward quadrant of the hurricane, in areas that were relatively free of the topographic effects of the island's principal mountain ranges. These two sites are generally considered the most reliable sites of surface windspeed measurement during this event. Bussinger estimated 150 mph peak gust windspeeds at landfall at the right forward quarter of the windfield. Peterka and Banks [11] produced a Hurricane Iniki re-created windfield which is shown in Figure 18 along with the HAZUS MH produced speeds. The CPP values for Poipu and Lihue are 152 mph and 130 mph, respectively. The HAZUS MH produced windfield values of 163 mph and 139 mph appears to be about 10 mph or more higher than these values at the southeastern locations on the island subject to the highest winds at landfall, and are higher than the instrumental records. The Kalaheo windspeeds produced by HAZUS are also about 10 mph than the CPP windfield that has a better fit to Hurricane Iniki. Therefore, the HAZUS windfield [12, 13] appears to have a 10+ mph upward bias in this particular case for the identical parameters than the CPP windfield and the records, and this Iniki scenario suggests that some downward adjustment of the parameters may be necessary to achieve a closer match to peak windspeeds in actual storms.

The Hawaii HAZUS model also contains the topographic speed-up model developed for the Hawaii Hurricane Relief Fund (HHRF) mitigation study. The topographic effects are averaged over time and spatially over the entire census tract distribution of buildings to an average value at the centroid of the census tract, and then this average value is used with a lognormal distribution scheme to all structures aggregated in the census tract. A specific difficulty within HAZUS is that the spatial averaging is probably not appropriate for Hawaii and Pacific hurricane hazard loss estimation, since the census tracts normally extend perpendicularly from coastline to the ends of valley and mountain ridges. The scheme used by HAZUS_MH is subject to question in areas where topography varies very significantly within a census tract as it is in many parts of Hawaii, and where the census tracts are larger. An excessive range of topographic wind speed-up would therefore be exhibited within each census tract. The averaging would include large areas of unpopulated terrain. Figure 19 provides a comparison of the windspeeds topographically altered by HAZUS MH. The values in Hanalei (tract 40100) are decreased by about 15 mph, which does not appear to reflect the downslope acceleration that was reported. The Kapaa-Wailua (tracts 40300 and 40202) speed values are diminished or increased by about 5 mph, which is not arguable considering the ravines and hills in this area that make for a complex and variable region with accelerations and shielding. The HAZUS windspeed values for the Lihue-Hanamaulu area (tracts 40400 and 40500)are particular anomalies of concern, in that the speeds in this region that has relatively flat terrain are about 30 mph greater than the instrumental record. The Poipu (40600) windspeed is reduced from 163 mph down to 151 mph, which may be a coincidental effect of the HAZUS spatial averaging scheme in this case. In general, it appears that the accuracy of the HAZUS scheme is not aided by the spatial averaging scheme, especially in Hawaii where the population is hardly ever uniformly distributed over a census tract that covers both uninhabited conservation land with mountainous terrain and inhabited coastal areas. It is not clear whether the topographic speed-up scheme improves the windfield data, especially in the Lihue-Hanamaulu area. In other areas, it appears that the topographic speeds are lower than the flat land speeds.

In Hawaii, because its very steep mountainous terrain and essential watershed function, building development is typically disallowed by means of zoning restrictions. Most often, and almost invariably outside of urban core areas, Hawaii census tracts span from mountain to sea, leading to building population centroids that are closer to the coast. Both of these factors are not modeled well by the spatial averaging methodology of HAZUS MH.

**An Alternative Topographic Speed-Up Factor Methodology**

A 2002 NASA-sponsored hurricane risk project directed by Gary Chock produced new methodologies pertaining to modeling of island topographic effects [14, 15]. To determine speed-up factors for Oahu and Kauai, terrain models of portions of the island terrain were constructed and tested in the wind tunnel. Wind speed-ups or reductions were measured at several hundred locations; data of the 358 sites of Oahu and Kauai for 16 directions of wind comprised 5728 records. Velocity measurements were made with a hot-film anemometer. Martin & Chock, Inc. then constructed a phenomenological model to fit the measured data, and used that model to predict the wind speedup in all areas of Oahu. The Chock empirical speed-up functions have been validated fit with a $R^2$ of 0.500 to wind speed-up data measured in a

boundary layer wind-tunnel. The project developed empirical predictive models for peak gust, mean speed, and peak/mean speed ratio based on the complex interaction of site location within landforms and nonlinear transformations of terrain parameters. The methodology used multiple terrain analysis techniques performed on a 30M DEM raster grid, incorporating a large area of the surface topography both upwind and downwind of each site. Downslope acceleration effects were captured in this methodology. This alternative methodology has been adopted for contour maps of speed-up generated for building code provisions in the State of Hawaii.

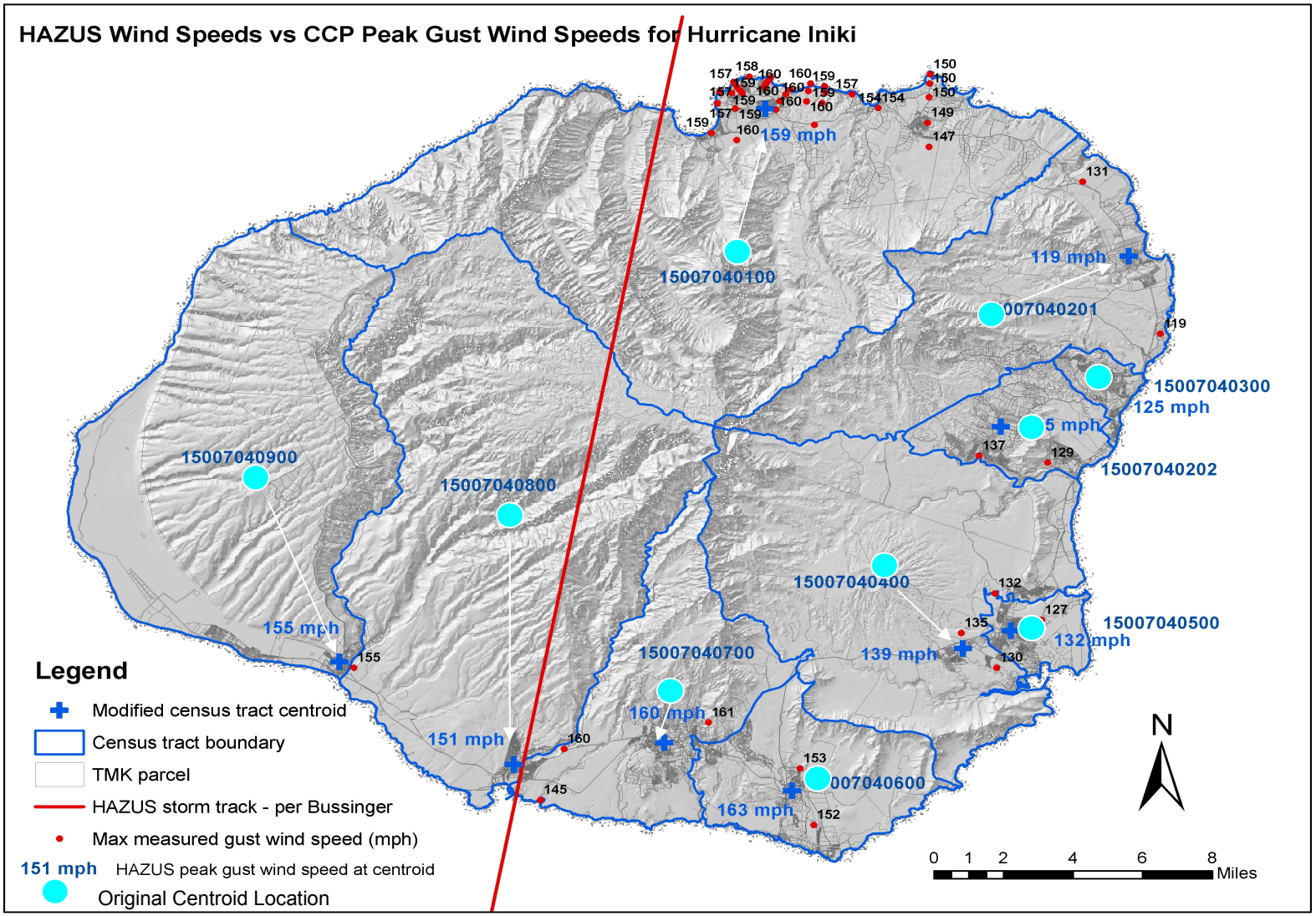


**Figure 17. Shifting of Model Centroids to Population Centers**

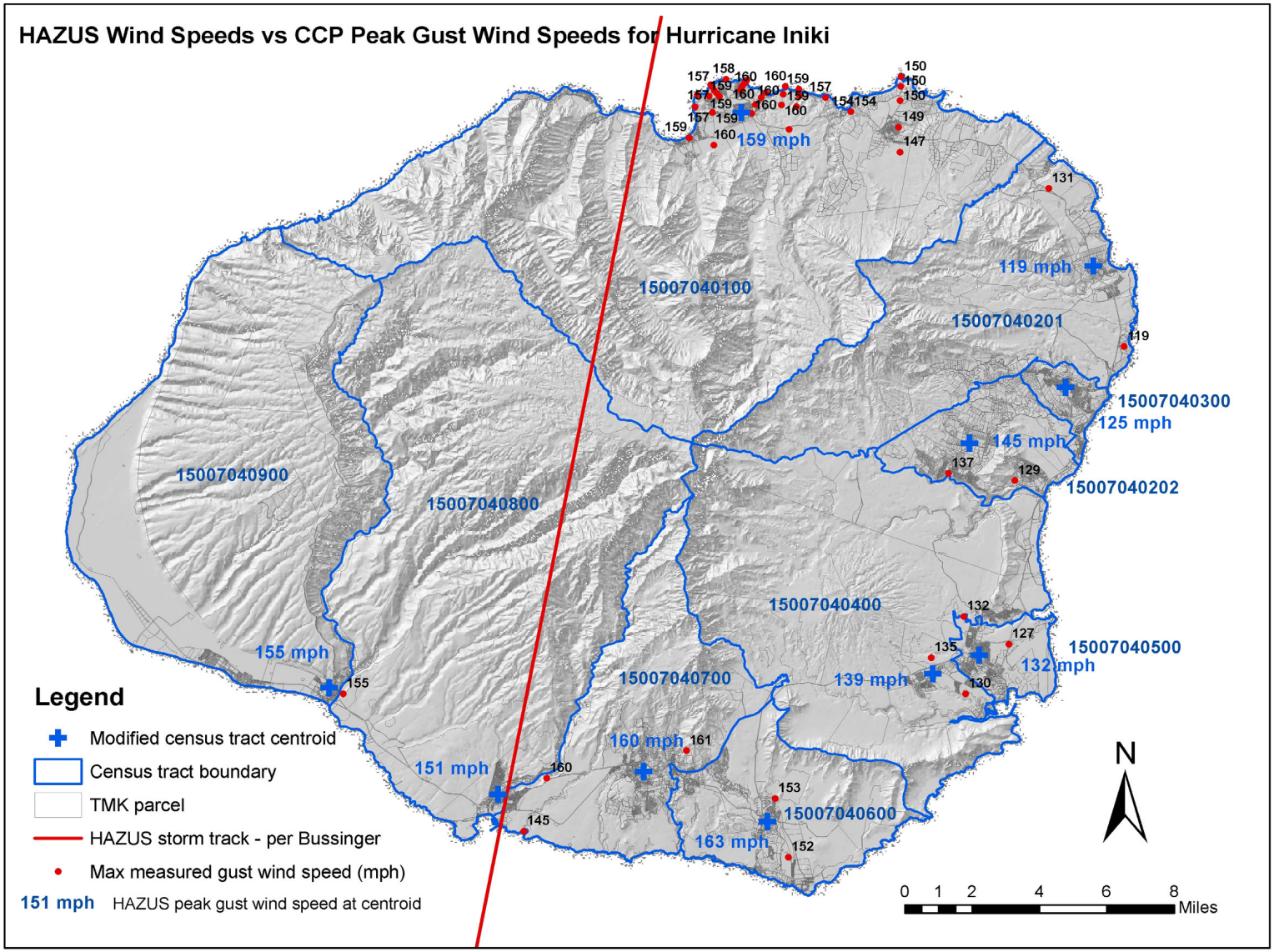


**Figure 18. HAZUS Wind Speeds at Centroids**

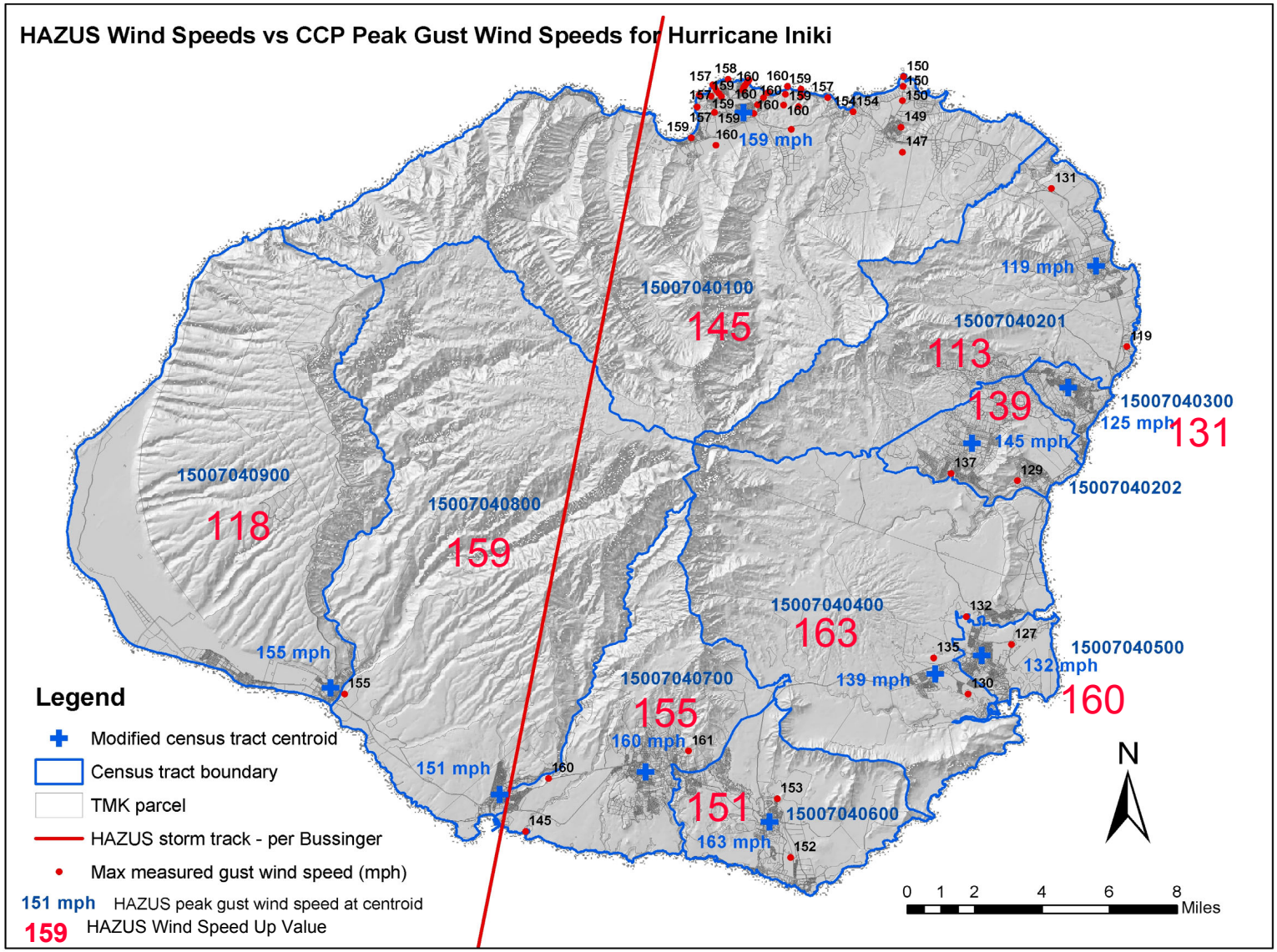


**Figure 19. Topographically Altered Windspeeds (Red Text) by HAZUS MH for each Census Tract**

A comparison of damage levels and direct losses was categorized by census tract and by specific building type. Relative damage level descriptive and reconstruction cost statistics were compared to summaries re-parsed from the original damage and reconstruction cost database. Since the vulnerability relativity of the "single wall" construction type is higher than the other forms of conventional construction, damage level incidence and repair cost are compared separately from the conventional "double" wall construction. Table 31 and Figures 20 and 21 present the comparisons for "single-wall" construction and Table 32 and Figures 22 and 23 show the comparative results for double wall construction. Table 33 shows the comparison for masonry wall; due to the low count of masonry wall structures, map presentations are not provided. The numbers of severely and completely damaged single and double wall homes predicted by HAZUS MH are 2 to 8 times greater than observed, and the trend is similar for all census tracts. The level of damage to masonry wall homes is also greater in HAZUS, with 10 times as many destroyed masonry homes.

The difference in modeled and actual debris was studied.

HAZUS Results
Single Wall = 111,000 Tons of Debris
Non Single Wall = 120,000 Tons of Debris
Total = 230,000 Tons of Debris

Observed Debris (cited in the County of Kauai Disaster Debris Action Manual)
Total = 220,000 to 500,000 Tons of Debris

However, these results are not easily compared, since the debris tally on Kauai included debris from *all sources*, and not solely single and multi-family detached one and two story homes. HAZUS Building damage debris calculations include only structural material tonnage and not the nonstructural materials such as roofing, cladding and glazing, wall and floor finishes, gypsum wallboard, electrical and plumbing fixtures, furnishings, appliances, and personal contents. These are major components of total debris volume and should be included in the model. However, if the level of damage predicted by HAZUS is much higher than what occurred, the amount of debris would be expected to also be over-estimated from that source.

## Table 31. Single Wall Construction Estimated Damage versus Observed

Damage Probabilities estimated by HAZUS

Single wall
WOOD

| Census tract | No damage | Minor | Moderate | Severe | Destruction |
|---|---|---|---|---|---|
| 15007040100 | 0.09 | 0.03 | 0.08 | 0.08 | 0.72 |
| 15007040201 | 0.37 | 0.07 | 0.18 | 0.12 | 0.27 |
| 15007040202 | 0.09 | 0.07 | 0.14 | 0.14 | 0.56 |
| 15007040300 | 0.26 | 0.10 | 0.20 | 0.15 | 0.29 |
| 15007040400 | 0.20 | 0.05 | 0.12 | 0.10 | 0.54 |
| 15007040500 | 0.13 | 0.09 | 0.17 | 0.14 | 0.47 |
| 15007040600 | 0.04 | 0.03 | 0.06 | 0.07 | 0.80 |
| 15007040700 | 0.03 | 0.01 | 0.05 | 0.06 | 0.84 |
| 15007040800 | 0.10 | 0.05 | 0.11 | 0.11 | 0.64 |
| 15007040900 | 0.13 | 0.03 | 0.09 | 0.09 | 0.66 |

Single wall
WOOD

| Census tract | No damage | | Minor | | Moderate | | Severe | | Destruction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default |
| 15007040100 | 239 | 50 | 14 | 17 | 199 | 44 | 41 | 44 | 63 | 400 |
| 15007040201 | 235 | 124 | 6 | 23 | 58 | 60 | 12 | 40 | 23 | 90 |
| 15007040202 | 470 | 78 | 37 | 61 | 233 | 122 | 48 | 122 | 82 | 487 |
| 15007040300 | 522 | 229 | 29 | 88 | 208 | 176 | 39 | 132 | 84 | 256 |
| 15007040400 | 410 | 162 | 21 | 41 | 287 | 97 | 50 | 81 | 42 | 437 |
| 15007040500 | 326 | 93 | 16 | 64 | 216 | 121 | 47 | 100 | 109 | 336 |
| 15007040600 | 543 | 34 | 24 | 25 | 170 | 50 | 36 | 59 | 65 | 670 |
| 15007040700 | 391 | 25 | 18 | 8 | 263 | 42 | 54 | 51 | 116 | 707 |
| 15007040800 | 150 | 34 | 8 | 17 | 109 | 38 | 36 | 38 | 40 | 220 |
| 15007040900 | 478 | 132 | 28 | 30 | 368 | 91 | 48 | 91 | 92 | 669 |
| Total | ***3764*** | ***961*** | ***201*** | ***375*** | ***2111*** | ***843*** | ***411*** | ***758*** | ***716*** | ***4273*** |
| Difference | | 26% | | 187% | | 40% | | 184% | | 597% |

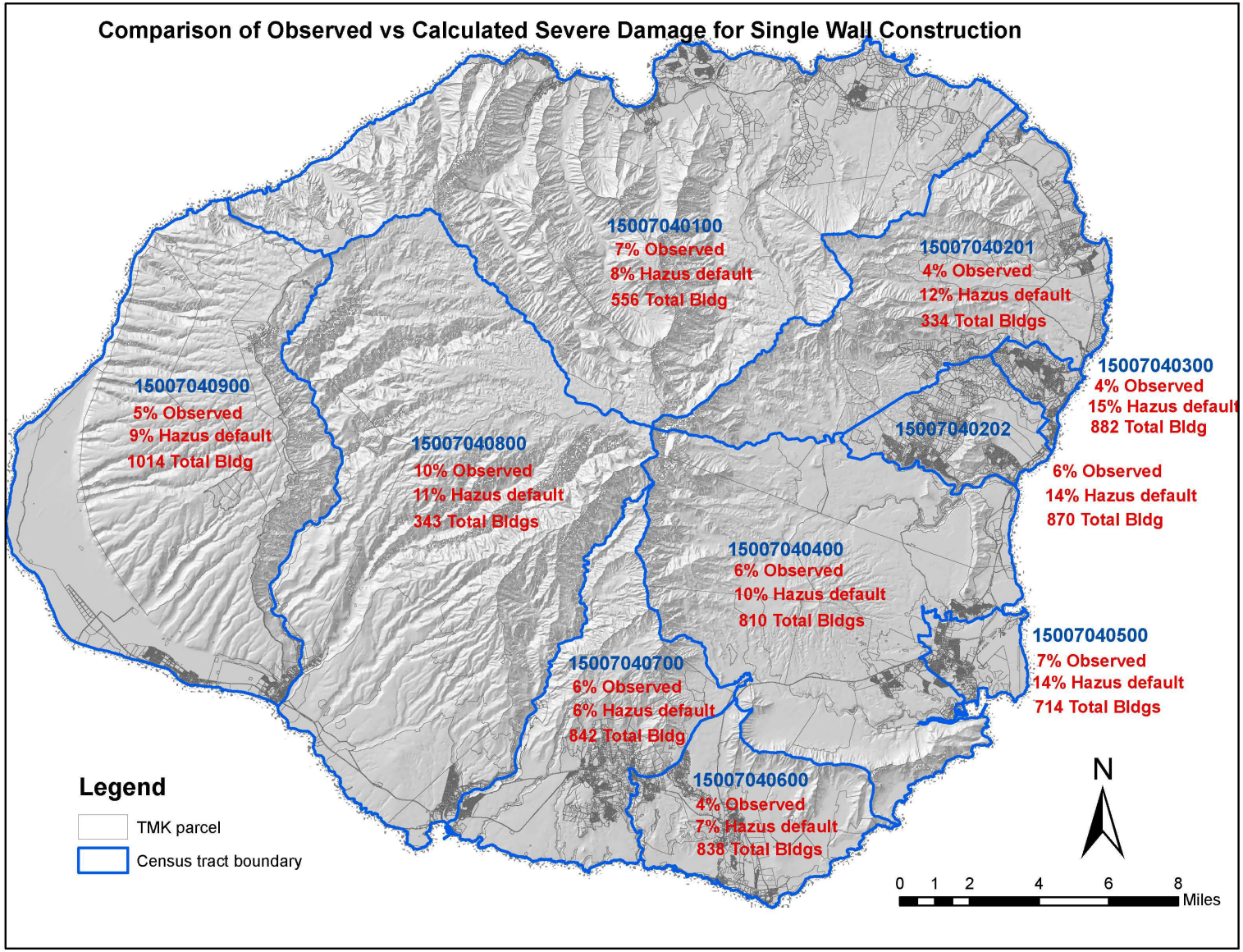


**Figure 20. Comparison of Severe Damage for Single Wall Construction**

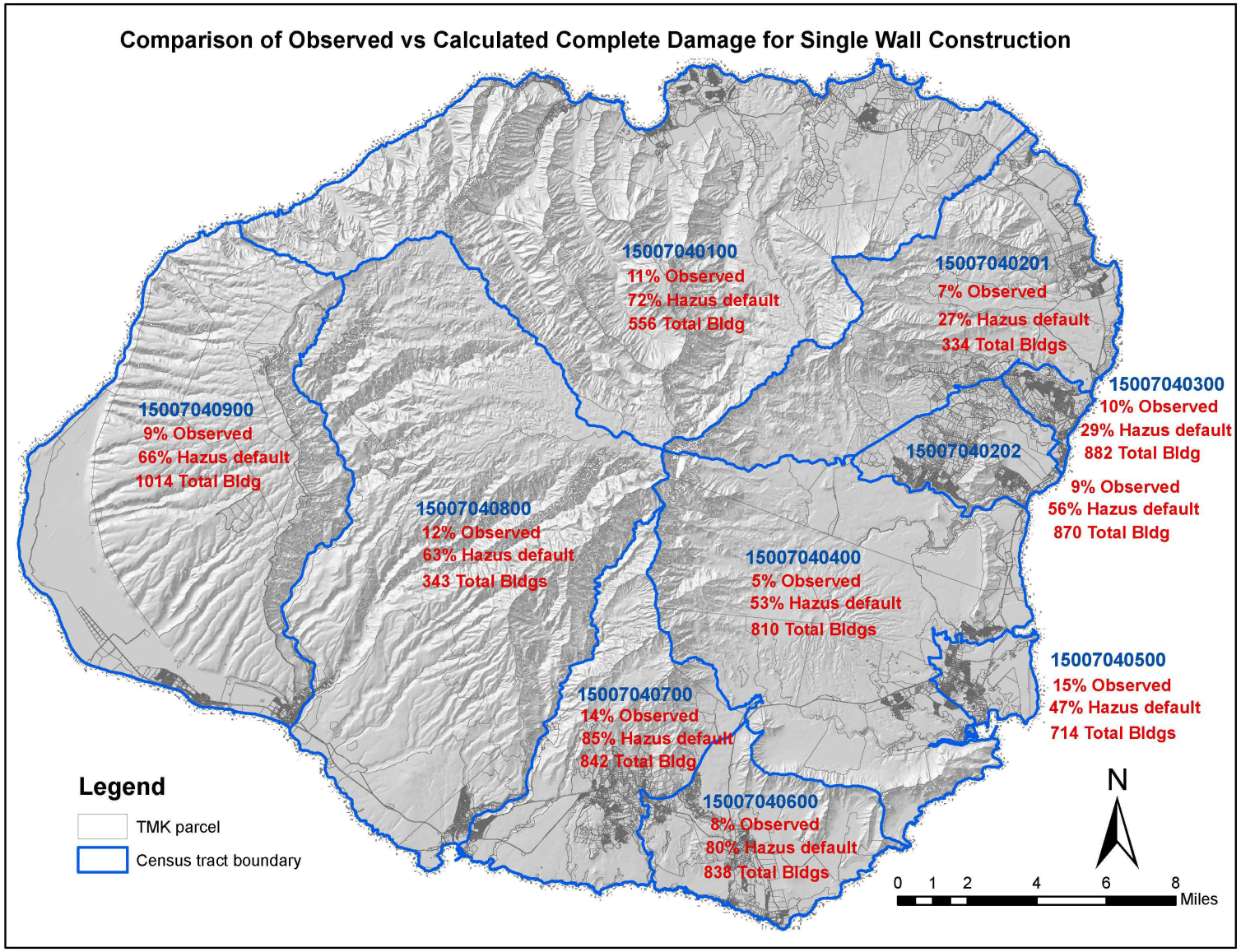


**Figure 21. Comparison of Complete Damage for Single Wall Construction**

## Table 32. Double Wall Construction Estimated Damage versus Observed

Damage state probabilities from HAZUS default run
Other than single wall
WOOD

| Census tract | No damage | Minor | Moderate | Severe | Destruction |
|---|---|---|---|---|---|
| 15007040100 | 0.08 | 0.1 | 0.13 | 0.12 | 0.56 |
| 15007040201 | 0.39 | 0.18 | 0.19 | 0.1 | 0.13 |
| 15007040202 | 0.09 | 0.17 | 0.21 | 0.17 | 0.35 |
| 15007040300 | 0.25 | 0.26 | 0.24 | 0.13 | 0.12 |
| 15007040400 | 0.15 | 0.18 | 0.21 | 0.16 | 0.31 |
| 15007040500 | 0.12 | 0.23 | 0.25 | 0.15 | 0.25 |
| 15007040600 | 0.04 | 0.08 | 0.12 | 0.13 | 0.65 |
| 15007040700 | 0.02 | 0.05 | 0.11 | 0.14 | 0.67 |
| 15007040800 | 0.09 | 0.14 | 0.21 | 0.18 | 0.38 |
| 15007040900 | 0.11 | 0.12 | 0.15 | 0.13 | 0.5 |

WOOD Conventional Stud Wall Framing

| Census tract | No damage | | Minor | | Moderate | | Severe | | Destruction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default |
| 15007040100 | 676 | 103 | 35 | 129 | 386 | 168 | 118 | 155 | 75 | 722 |
| 15007040201 | 276 | 135 | 8 | 62 | 38 | 66 | 11 | 35 | 12 | 45 |
| 15007040202 | 900 | 127 | 33 | 240 | 299 | 297 | 100 | 240 | 81 | 495 |
| 15007040300 | 825 | 278 | 14 | 289 | 177 | 267 | 57 | 145 | 40 | 134 |
| 15007040400 | 423 | 89 | 9 | 107 | 111 | 125 | 34 | 95 | 18 | 184 |
| 15007040500 | 375 | 67 | 8 | 129 | 116 | 140 | 37 | 84 | 23 | 140 |
| 15007040600 | 462 | 27 | 20 | 54 | 104 | 81 | 36 | 88 | 52 | 438 |
| 15007040700 | 687 | 23 | 22 | 57 | 298 | 125 | 83 | 159 | 43 | 759 |
| 15007040800 | 159 | 24 | 3 | 37 | 64 | 55 | 21 | 47 | 16 | 100 |
| 15007040900 | 283 | 53 | 11 | 58 | 126 | 72 | 32 | 63 | 30 | 241 |
| Total | ***5066*** | ***926*** | ***163*** | ***1162*** | ***1719*** | ***1395*** | ***529*** | ***1109*** | ***390*** | ***3258*** |
| Difference | 18% | | 713% | | 81% | | 210% | | 835% | |

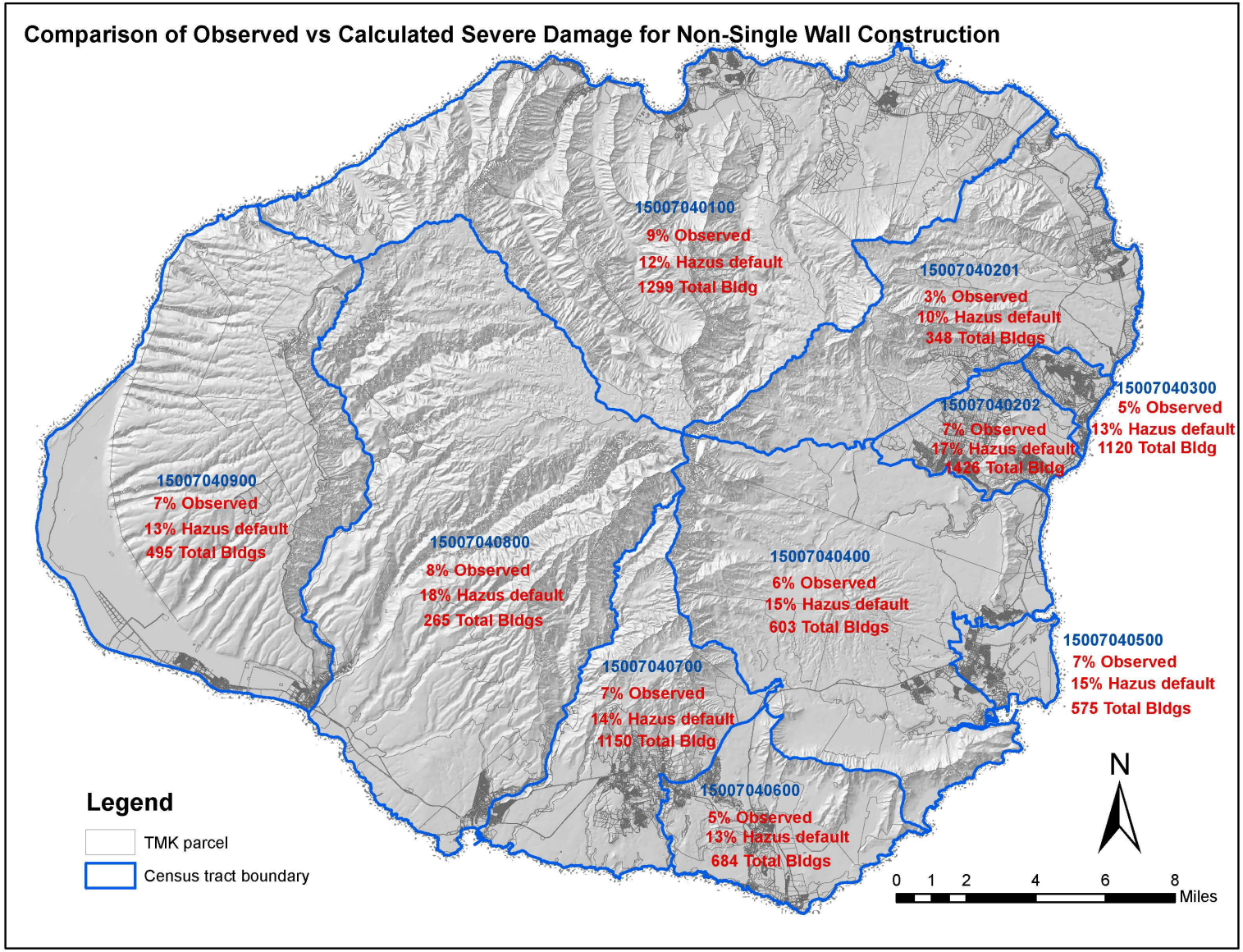


**Figure 22. Comparison of Severe Damage for Double Wall Construction**

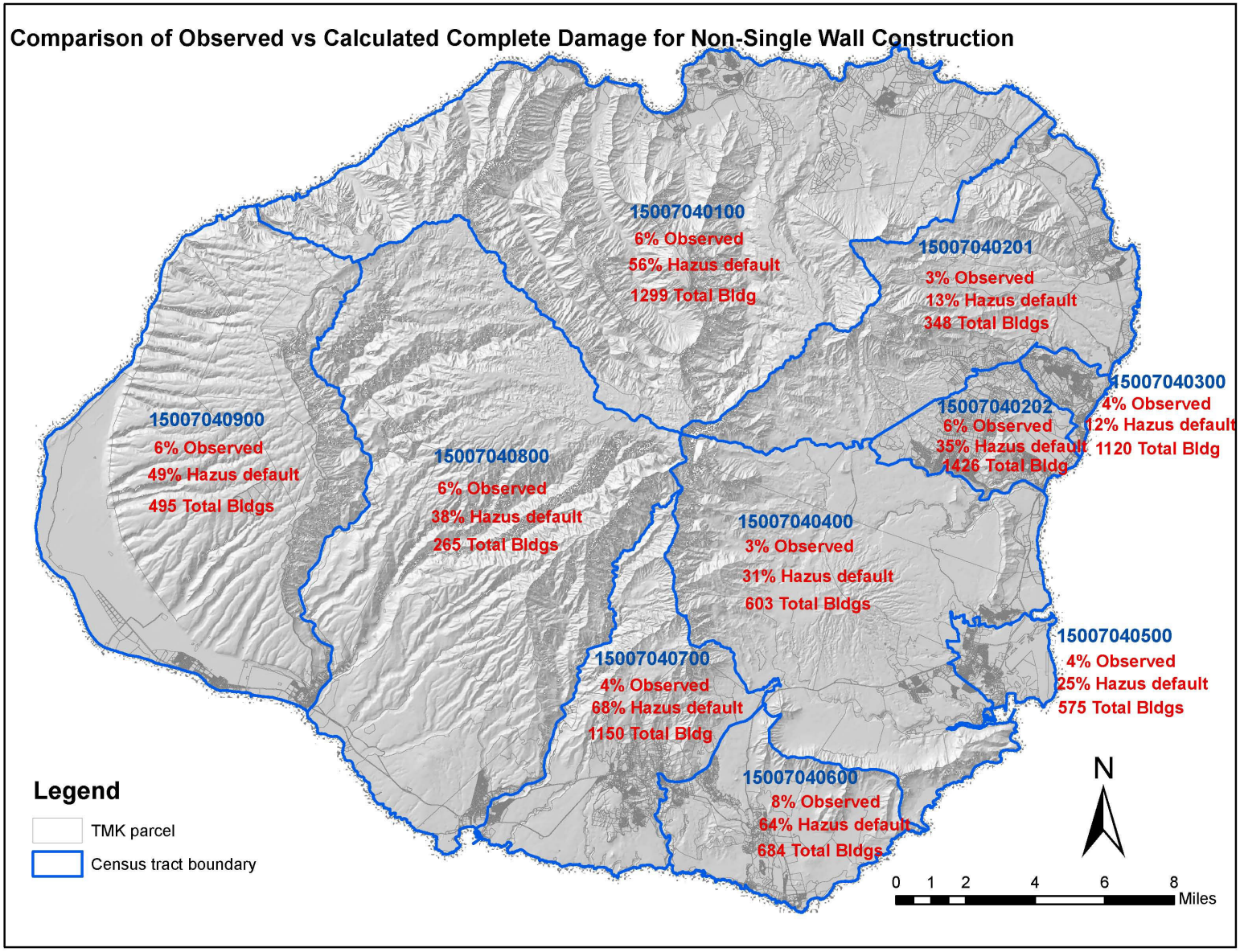


**Figure 23. Comparison of Complete Damage for Double Wall Construction**

## Table 33. Masonry Wall Construction Estimated Damage versus Observed

| MASONRY | | | | | |
|---|---|---|---|---|---|
| Census tract | No damage | Minor | Moderate | Severe | Destruction |
| 15007040100 | 0.12 | 0.12 | 0.15 | 0.12 | 0.49 |
| 15007040201 | 0.47 | 0.19 | 0.19 | 0.08 | 0.08 |
| 15007040202 | 0.12 | 0.22 | 0.24 | 0.17 | 0.26 |
| 15007040300 | 0.31 | 0.32 | 0.22 | 0.07 | 0.08 |
| 15007040400 | 0.23 | 0.14 | 0.17 | 0.09 | 0.37 |
| 15007040500 | 0.26 | 0.17 | 0.2 | 0.09 | 0.28 |
| 15007040600 | 0.05 | 0.06 | 0.1 | 0.09 | 0.7 |
| 15007040700 | 0.04 | 0.08 | 0.14 | 0.13 | 0.61 |
| 15007040800 | 0.12 | 0.08 | 0.16 | 0.11 | 0.53 |
| 15007040900 | 0.16 | 0.14 | 0.15 | 0.09 | 0.46 |

MASONRY

| Census tract | No damage | | Minor | | Moderate | | Severe | | Destruction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default | Observed | HAZUS default |
| 15007040100 | 3 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 0 | 4 |
| 15007040201 | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| 15007040202 | 11 | 2 | 1 | 3 | 0 | 3 | 0 | 2 | 1 | 3 |
| 15007040300 | 5 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 1 |
| 15007040400 | 6 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 3 |
| 15007040500 | 8 | 4 | 0 | 3 | 5 | 3 | 3 | 1 | 0 | 4 |
| 15007040600 | 8 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 7 |
| 15007040700 | 10 | 1 | 0 | 1 | 4 | 2 | 0 | 2 | 3 | 10 |
| 15007040800 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 15007040900 | 7 | 2 | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 6 |
| Total | ***61*** | ***16*** | ***4*** | ***15*** | ***19*** | ***17*** | ***10*** | ***11*** | ***4*** | ***40*** |

The total building loss estimated by HAZUS is approximately 2-1/2 times the losses reported either through insurance claims and building reconstruction permits.

- Claims Information cited from the State of Hawaii Department of Insurance:
  Personal Line Economic Loss (Building loss and Content Loss)
  **888 Million Dollars**
- Database of Total Reconstruction Costs
  (Building loss and Assumed Proportionate Content Losses)
  302.3 Million Dollars + 60 Million Dollars (single wall)
  \+ 418.7 Million Dollars + 84 Million Dollars (double wall)
  = 721.0 Million Dollars + 144 Million Dollars (total inventory)
  = **865 Million Dollars**
- HAZUS Estimated Losses to Buildings and Contents :
  (Building loss and Estimated Content Losses)
  669.4 Million Dollars + 242.4 Million Dollars (single wall)
  \+ 1,043 Million Dollars + 260.8 Million Dollars (double wall)
  1,712 Million Dollars + 503.2 Million Dollars (total inventory)
  = **2,215 Million Dollars**

**Table 34. Comparison of Direct Economic Losses**

Comparison of Estimated to Actual Building Direct Economic Loss by Census Tract by Construction Archetype

**Single Wall**

| Census tract | Economic loss (Thousands of dollars) | | Difference |
|---|---|---|---|
| | Observed | HAZUS default estimate | |
| 15007040100 | 25,201 | 58,186 | 231% |
| 15007040201 | 9,945 | 14,966 | 150% |
| 15007040202 | 35,282 | 84,575 | 240% |
| 15007040300 | 29,438 | 45,860 | 156% |
| 15007040400 | 37,077 | 76,642 | 207% |
| 15007040500 | 34,881 | 66,427 | 190% |
| 15007040600 | 33,263 | 97,569 | 293% |
| 15007040700 | 40,663 | 99,538 | 245% |
| 15007040800 | 17,240 | 33,535 | 195% |
| 15007040900 | 39,392 | 92,140 | 234% |
| County-wide Total | ***302,382*** | ***669,438*** | 221% |

**Other Than Single Wall**

| Census tract | Economic loss (Thousands of dollars) | | Difference |
|---|---|---|---|
| | Observed | HAZUS default estimate | |
| 15007040100 | 90,099 | 234,471 | 260% |
| 15007040201 | 12,140 | 16,850 | 139% |
| 15007040202 | 74,309 | 173,774 | 234% |
| 15007040300 | 43,921 | 58,861 | 134% |
| 15007040400 | 27,750 | 61,637 | 222% |
| 15007040500 | 32,128 | 59,641 | 186% |
| 15007040600 | 38,257 | 138,785 | 363% |
| 15007040700 | 60,569 | 207,462 | 343% |
| 15007040800 | 12,927 | 27,616 | 214% |
| 15007040900 | 26,596 | 64,090 | 241% |
| County-wide Total | ***418,696*** | ***1,043,187*** | 249% |

## Table 35. Single Wall Losses with HAZUS Comparisons

WSF1

| Tract | Economic loss | |
|---|---|---|
| | Observed | HAZUS default |
| 15007040100 | 22,982,448 | 39,737,000 |
| 15007040201 | 9,745,049 | 9,191,000 |
| 15007040202 | 33,880,672 | 55,371,000 |
| 15007040300 | 28,677,840 | 28,719,000 |
| 15007040400 | 35,697,569 | 38,623,000 |
| 15007040500 | 33,933,520 | 35,393,000 |
| 15007040600 | 31,356,033 | 53,771,000 |
| 15007040700 | 40,036,044 | 63,143,000 |
| 15007040800 | 16,495,568 | 15,790,000 |
| 15007040900 | 37,758,086 | 169,483,000 |
| Total | ***290,562,830*** | ***509,221,000*** |

WSF2

| Tract | Economic loss |
|---|---|
| 15007040100 | 1,972,162 |
| 15007040201 | 199,760 |
| 15007040202 | 763,422 |
| 15007040300 | 456,754 |
| 15007040400 | 261,567 |
| 15007040500 | 579,868 |
| 15007040600 | 758,095 |
| 15007040700 | 501,924 |
| 15007040800 | 584,414 |
| 15007040900 | 1,197,502 |
| | ***7,275,468*** |

WMUH1

| Tract | Economic loss |
|---|---|
| 15007040100 | 246,384 |
| 15007040202 | 637,695 |
| 15007040300 | 259,130 |
| 15007040400 | 1,111,615 |
| 15007040500 | 295,147 |
| 15007040600 | 1,148,622 |
| 15007040700 | 125,366 |
| 15007040800 | 160,221 |
| 15007040900 | 424,657 |
| | ***4,408,837*** |

WMUH2

| Tract | Economic loss |
|---|---|
| 15007040300 | 44,172 |
| 15007040400 | 5,824 |
| 15007040500 | 72,516 |
| 15007040900 | 12,096 |
| | ***134,608*** |

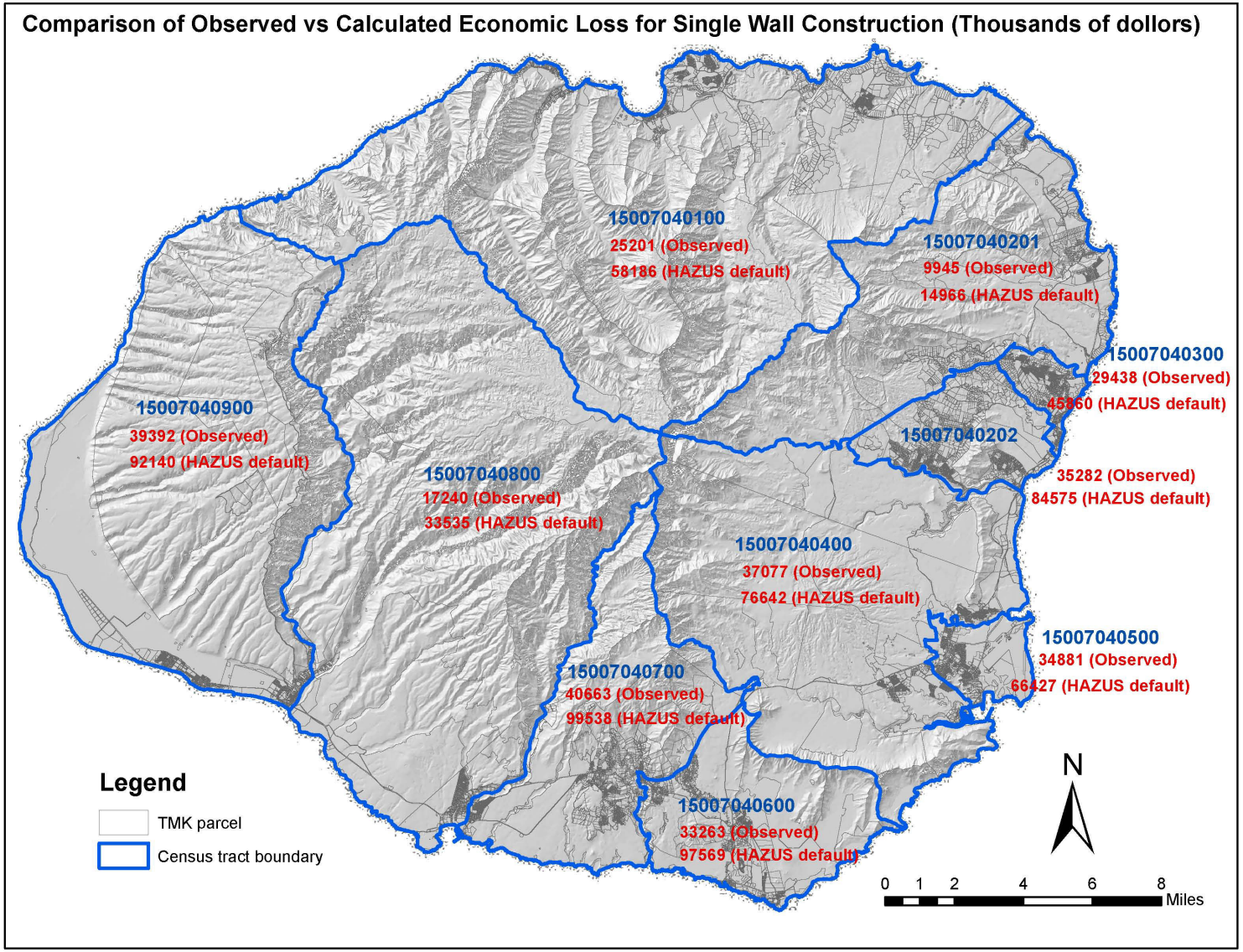


**Figure 24. Comparison of Economic Loss for Single Wall Construction**

## Table 36. Other Than Single Wall Residential Losses With HAZUS Comparisons

WSF1

| Tract | Economic loss | |
|---|---|---|
| | Observed | HAZUS default |
| 15007040100 | 64,959,874 | 111,366,000 |
| 15007040201 | 10,127,540 | 8,345,000 |
| 15007040202 | 63,543,759 | 91,673,000 |
| 15007040300 | 32,932,073 | 20,823,000 |
| 15007040400 | 23,866,602 | 30,196,000 |
| 15007040500 | 27,807,236 | 24,344,000 |
| 15007040600 | 28,616,883 | 69,362,000 |
| 15007040700 | 51,395,871 | 101,644,000 |
| 15007040800 | 12,345,865 | 13,228,000 |
| 15007040900 | 22,549,160 | 45,310,000 |
| Total | ***338,144,862*** | ***516,291,000*** |

WSF2

| Tract | Economic loss |
|---|---|
| 15007040100 | 21,453,993 |
| 15007040201 | 1,691,632 |
| 15007040202 | 7,724,560 |
| 15007040300 | 8,761,144 |
| 15007040400 | 2,624,935 |
| 15007040500 | 1,947,294 |
| 15007040600 | 7,003,189 |
| 15007040700 | 7,105,297 |
| 15007040800 | 465,664 |
| 15007040900 | 2,171,112 |
| | ***60,948,819*** |

MMUH1

| Tract | Economic loss |
|---|---|
| 15007040202 | 18,416 |
| | ***18,416*** |

WMUH1

| Tract | Economic loss |
|---|---|
| 15007040100 | 2,593,403 |
| 15007040201 | 67,592 |
| 15007040202 | 2,034,390 |
| 15007040300 | 1,505,156 |
| 15007040400 | 672,005 |
| 15007040500 | 1,032,367 |
| 15007040600 | 1,554,322 |
| 15007040700 | 890,316 |
| 15007040900 | 535,596 |
| | ***10,885,146*** |

WMUH2

| Tract | Economic loss |
|---|---|
| 15007040100 | 308,586 |
| 15007040201 | 138,513 |
| 15007040202 | 209,346 |
| 15007040300 | 505,727 |
| 15007040400 | 182,142 |
| 15007040500 | 161,352 |
| 15007040600 | 516,281 |
| 15007040700 | 74,908 |
| 15007040900 | 199,662 |
| 15007040900 | 52,927 |
| | ***2,349,444*** |

MSF1

| Tract | Economic loss |
|---|---|
| 15007040100 | 782,715 |
| 15007040201 | 114,654 |
| 15007040202 | 778,296 |
| 15007040300 | 216,684 |
| 15007040400 | 404,357 |
| 15007040500 | 1,179,712 |
| 15007040600 | 303,555 |
| 15007040700 | 948,944 |
| 15007040800 | 115,928 |
| 15007040900 | 1,087,473 |
| | ***5,932,318*** |

MSF2

| Tract | Economic loss |
|---|---|
| 15007040600 | 262,465 |
| 15007040700 | 154,136 |
| | ***416,601*** |

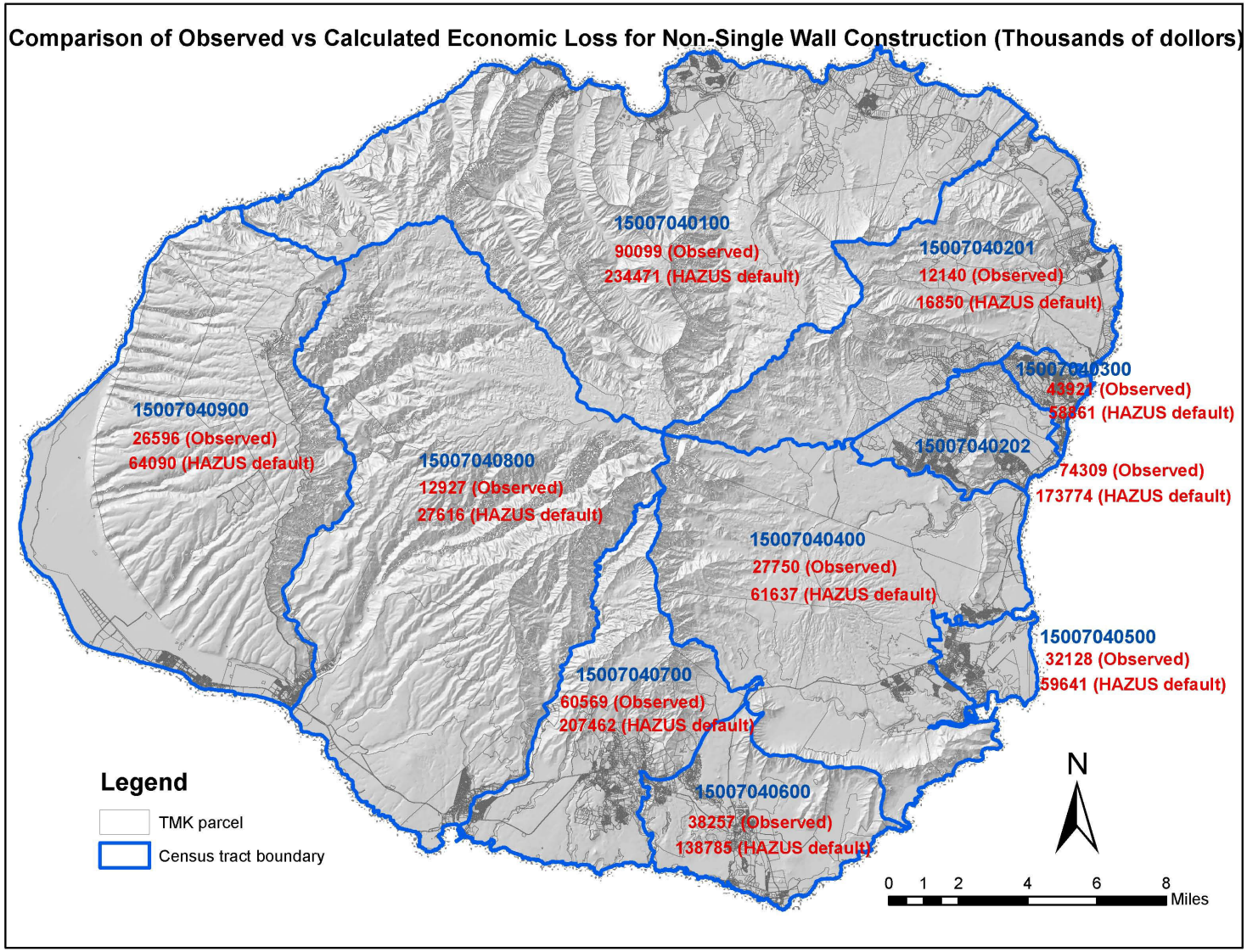


**Figure 25. Comparison of Economic Loss for Double Wall Construction**

**Model Sensitivity**

As a test of sensitivity the fragility curve matrix file in HAZUS was altered by a 20 mph shift fpr single wall construction and re-run (User input of custom fragility and loss functions is not directly allowed within the HAZUS MH GUI menus). This replicates a result based on a uniform 20 mph reduction in windspeed values while keeping the relative speed differentials between census tracts the same. This could also be considered a hypothetical reduction of maximum peak gust speed at landfall from 155 mph (upper Category 3) in the initial model to 135 mph (lower Category 3) in this subsequent storm scenario model. The peak gusts of 143 mph recorded at Makahuena Point, located at the southeast corner of the island about 12-1/2 miles distant from the center of the storm, and 130 mph recorded at Lihue, about 15-1/2 miles from the center, are considered representative surface windspeeds at landfall to the east of the eyewall in the right forward quadrant of the hurricane. When detailed dropsonde data was studied with consideration of the translational velocity, Schroeder [16] estimated sustained winds at landfall of approximately 113 to 120 mph at the forward quadrant of the storm, equivalent to peak gusts of 139 to 148 mph (per references [17 and 18]). In this context, while consistent he initial with the central pressure and location data of the storm track, the earlier scenario might be considered a upper bound to the intensity of Iniki. The altered scenario was thus run to replicate a lower bound to Iniki windspeed intensity to explore the effect of windspeed and windspeed fragility on the results.

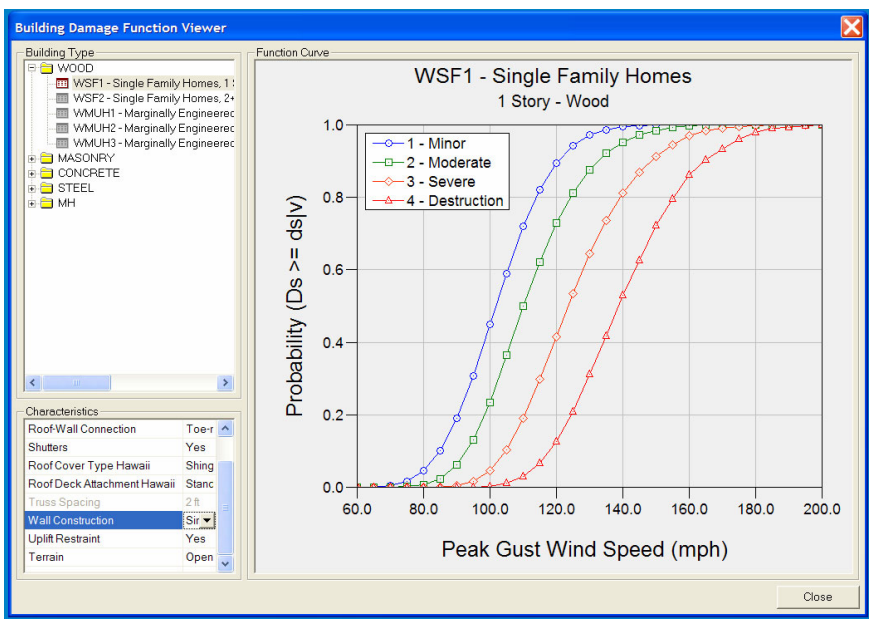


**Figure 26. Example Fragility Curves**

**Table 37. Single Wall Damage When The Fragility Curve Is Altered To Effectively Reduce the windfield Values By 20 Mph**

| Single wall | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| WOOD | | | | | | | | | | |
| Census tract | No damage | | Minor | | Moderate | | Severe | | Destruction | |
| | Observed | HAZUS MOD | Observed | HAZUS MOD | Observed | HAZUS MOD | Observed | HAZUS MOD | Observed | HAZUS MOD |
| 15007040100 | 239 | 191 | 14 | 3 | 199 | 179 | 41 | 23 | 63 | 49 |
| 15007040201 | 235 | 188 | 6 | 1 | 58 | 52 | 12 | 7 | 23 | 18 |
| 15007040202 | 470 | 376 | 37 | 7 | 233 | 210 | 48 | 26 | 82 | 63 |
| 15007040300 | 522 | 418 | 29 | 6 | 208 | 187 | 39 | 21 | 84 | 65 |
| 15007040400 | 410 | 328 | 21 | 4 | 287 | 258 | 50 | 28 | 42 | 32 |
| 15007040500 | 326 | 261 | 16 | 3 | 216 | 194 | 47 | 26 | 109 | 84 |
| 15007040600 | 543 | 434 | 24 | 5 | 170 | 153 | 36 | 20 | 65 | 50 |
| 15007040700 | 391 | 313 | 18 | 4 | 263 | 237 | 54 | 30 | 116 | 89 |
| 15007040800 | 150 | 120 | 8 | 2 | 109 | 98 | 36 | 20 | 40 | 31 |
| 15007040900 | 478 | 382 | 28 | 6 | 368 | 331 | 48 | 26 | 92 | 71 |
| Total | *3764* | *3011* | *201* | *40* | *2111* | *1900* | *411* | *226* | *716* | *551* |

In this test case, the counts of damaged buildings in each category show a more consistent trend with the observed damage data, suggesting that the initial overprediction of windspeed by the HAZUS parametric windfield model (approximately 155 – 143 average = 12 mph) had a significant effect. The effect of the topographic adjustments also appear to create higher windspeeds in populated areas where such effects were not recorded (such as Lihue), and this may be contributing to higher losses. .It also confirms that the fragility curves of HAZUS MH are very sensitive to windspeed, and that dramatic changes in damage estimates can be expected to result from a 10+ mph difference in modeled peak gust windspeed for a scenario. Since this test case is based on a 20 mph shift between an upper bound and lower bound of Hurricane Iniki intensity, it is expected that less overprediction of damage would be exhibited with a adjustment of the input storm parameters to create a 10 mph correction to better match the estimated surface windspeeds of Hurricane Iniki (as opposed to matching its reported central pressures). However, this technique may not be possible in actual storm scenarios if damage estimates need to be made before landfall based on parameters available from the Central Pacific Hurricane Center.

## VII. Conclusions

- The HAZUS-MH wind field model (over flat land) resulted in modeled Iniki wind speeds about 10 to 15 mph greater than the observed surface wind speeds before application of the topographic modifier procedure. However, that difference may be too great for loss estimation purposes; a +- 5 mph match may be necessary in order to produce accurate loss estimates for an actual event.

- The HAZUS-MH wind speed-up calculations appear to need improvement and its spatial averaging technique does not appear to produce results that are appropriate in Hawaii where the building inventory is not uniformly distributed over the terrain. The effect of the topographic adjustments also appear to create higher windspeeds in populated areas where such effects were not recorded and reduced windspeeds in areas where downslope accelerations were exhibited. The application of the topographic speed-up procedure appears to contribute to a loss of accuracy in the prediction of windspeed, and does not appear to aid the accuracy of estimated losses for this scenario.

- When HAZUS-MH was run using an estimate of Hurricane Iniki intensity derived strictly from central pressure and location data from the official storm track, it grossly over-estimated the physical damage to residential buildings by a factor of 2 to 8.

- HAZUS MH fragility modeling of building damage is be very sensitive to the windspeed. This sensitivity was verified by a trial adjustment of 10 mph below the observed peak gust windspeeds which yielded much better matching of building counts in each damage category for the single wall wood construction type.

- For the upper bound Iniki scenario, HAZUS-MH results for debris calculations would initially appear to be within acceptable values compared with existing data. However, these predictions may be underestimating amount of debris since HAZUS overestimated the damage levels using the upper bound storm.

- When run using an estimate of Hurricane Iniki intensity derived strictly from central pressure and location data, HAZUS-MH overestimated economic losses to buildings by a factor of greater than 2. This level of overprediction is not as great as the damage counts. It is our understanding that the economic loss procedure is a parallel calculation that is not directly related to the predicted number of damaged structures in each category of loss.

- Accurate modeling of the building inventory including indigenous construction types is an essential step before using HAZUS MH for making hurricane loss estimates in Hawaii.

- After a storm, when more detailed analysis of surface wind and windfield data may be available, HAZUS MH may be capable of producing similar damage if the building inventory is appropriately modeled and if the building inventory is dispersed over an entire census tract. The topographic effects procedure may be detrimental to accuracy is the actual

building distribution does not fully populate the planar extent of a census tract that has significant topographic features.

- It appears that better results were obtained in this study by using a lower bound of storm intensity, equivalent to a "half-category" downward modulation from the best estimate of storm central pressure or windspeed data.

- For an actual approaching storm, several modulated intensity scenarios may be needed to attempt to bracket possible expected damage. It is possible that the upper bound storm assumptions may yield significant overestimates of damage and economic loss. During an actual storm, it may be difficult to determine what parameters would constitute the upper and lower bounds to be used.

## VIII. Recommendations

We would recommend further parametric study of the sensitivity of windspeed and fragility to better define the range of accuracy that HAZUS MH may be able to produce for this Iniki event and others. In addition, we would recommend performing scenario runs with and without the topographic speed-up procedure embedded in HAZUS MH to better determine whether this feature might possibly be a hindrance to accurate loss estimates, due to its spatial averaging technique that does not appear to yield appropriate results when the building inventory is not uniformly distributed over a census tract. The HAZUS-MH wind speed up calculations may need to be reexamined and eventually re-programmed to produce more suitable results for Hawaii topography and reflect a more accurate spatial distribution of buildings. It is also possible that modifications to HAZUS-MH fragility curves for physical damage and economic loss may need to be reexamined and calibrated for building inventory in the Pacific Region.

Through further work, we believe it will be possible to define better guidelines for the use of HAZUS MH in Hawaii. A means of producing credible loss estimates is definitely needed for emergency planning and response.

It is also recommended that a Hawaii Building Inventory Database be created for use with the HAZUS MH Hurricane and Flood module. It will be possible to utilize some of the information obtained from past SCD-sponsored projects that have gathered and analyzed a Building Inventory Database for earthquake loss estimation of Hawaii and Maui counties. Data fields of relevance to earthquake, hurricane, and flood hazards would to be gathered. All data would be referenced to tax map key. This data collection scheme should use existing building and property databases and identify data fields where field survey sampling may be required. The data-gathering scheme should utilize clustered sampling techniques that would optimize the benefits of inventory gathering and minimize fieldwork.

This final report (Contract Project Scope Paragraph 6) and Powerpoint draft report briefings have documented the procedure and compared the loss results for validation evaluation by the Office of Planning CZM Program and the NOAA Pacific Services Center, State Civil Defense, the State Insurance Division of the Department of Commerce and Consumer Affairs, and the Central Pacific Hurricane Center.

## IX. Project Funding and Acknowledgements

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