REGIONAL TSUNAMI EVACUATIONS FOR THE STATE OF HAWAII: A FEASIBILITY STUDY BASED ON HISTORICAL RUNUP DATA

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ABSTRACT

Historical runup data for the Hawaiian Islands indicate that evacuations of only limited coastal areas, rather than statewide evacuations, may be appropriate for some small tsunamis originating along the Kamchatka, Aleutian, and Alaskan portion of the circum-Pacific arc. With such limited evacuations most statewide activities can continue with little or no disruptions, saving millions in lost revenues and overtime costs, and maintaining or enhancing credibility in state and federal agencies. However, such evacuations are contingent upon accurate real-time modeling of the maximum expected runup values. Also, data indicate that such evacuations may not be appropriate for small Chilean tsunamis. Furthermore, data from other regions are thus far too limited for an evaluation of the appropriateness of partial evacuations for small tsunamis from those regions.

Introduction

Historical data indicate that tsunami runups are generally greatest along the northern coastlines of the Hawaiian Islands for earthquake originating in that portion of the circum-Pacific arc from Kamchatka through the Aleutians Islands to Alaska. A critical question is whether a statewide warning should be issued if tide gauge, magnitude, and modeling data predict a maximum runup of only 1 meter for some portions of those northern shores. [A one meter tsunami is generally considered by the scientific community and civil defense agencies to be a potentially life threatening phenomenon requiring a warning, if possible, of its arrival and location.] The answer to the question depends on the accuracy of the prediction and how much smaller the runups might be on those other coastlines. If the predictions are fairly accurate, and the runups are significantly smaller along those other coastlines, successful regional evacuations may be possible. Such evacuations would reduce the unnecessary chaos and business losses associated with statewide evacuations, as well as maintain credibility in the warning system. This report examines the relative runup values along differing shorelines for differing source location throughout the Pacific for which historical data is available. The primary data sources are the runup plots compiled for the State of Hawaii's Tsunami Observation Program (2002; and appended to this report); and the secondary data source is Lander and Lockridge (1989).

Analysis of Data from Source Areas Outside the Kamchatka to Alaska Portion of the Circum-Pacific Arc

Chile. The 1960 Chilean earthquake is the only event outside of the Kamchatka to Alaska region that produced a large number of reported runups on all of the major islands. In examining these data (see Appendix), it is clear that comparable values were measured on many coastlines. For example, on the northern, eastern, southern and western shorelines runups as high as: 13.5, 9, 14, and 8 feet, respectively, were reported on Kauai; 12, 9, 9, and 12 feet, respectively, on Oahu; 17, 10, 12, and 10 feet, respectively, on Maui; and 11, 35, 17, and 16 feet, respectively, on the Big Island. No values are reported for Molokai and Lanai – only damage to fishponds and beach houses, presumably on the southern shorelines. The next largest value to the 35' reading on the Big Island's east coast is 22', also in Hilo Bay. Outside of Hilo Bay the largest value on the east coast is 14 feet.

A Chilean earthquake in 1837 produced a tsunami with runups of 6.0, 2.5, and 2.5 meters in Hilo, Lahaina, and Honolulu, respectively. A Chilean earthquake in 1868 produced a tsunami with runups of 4.5, 1.8, and 1.6 meters in Hilo, Kahului, and Honolulu, respectively. A Chilean earthquake in 1877 produced a tsunami with runups of 3.7, 4.5, 1.5, 3.6, and 1.5 meters in Hilo, Kealakekua Bay, Kahului, Lahaina, and Honolulu, respectively. The 1906 Chilean earthquake produced runups of 1.5 and 3.6 meters in Hilo and Maalaea (Maui), respectively.

Data for the 1960 tsunami support the conclusion that aside from high values in Hilo Bay, the largest values along many differing coastlines throughout the State are fairly comparable. This conclusion is suggested by more limited data from other Chilean tsunamis. Thus, any 1 meter runup predicted anywhere in the State for a Chilean earthquake could be expected to produce 1

meter values along many other coastlines. Therefore, any effort to provide regional warnings, rather than a statewide warning, for an expected 1 meter tsunami from Chile would not be appropriate.

Japan. Another source area outside of the Kamchatka to Alaska portion of the circum-Pacific arc is Japan. The 1933 Sanriku earthquake produced values of around 3 meters along the Kona Coast, 0.5m in Hilo, 1.2m at Nawiliwili, and 0.3m in Honolulu. The 1896 Sanriku earthquake produced values of up to 5.5 meters on the Kona Coast, 2.4m in Hilo, 1.5m at Nawiliwili, and 0.5m in Honolulu. [There are only 10 data points for 1933 with 6 from the Big Island; and only 17 data points for 1896 with 11 from the Big Island.] The area of greatest danger would appear to be the Kona Coast. However, until more data is acquired, especially along other western shores, any effort to provide regional warnings, rather than a statewide warning, for an expected 1 meter tsunami from Japan would not be appropriate.

Other Source Areas. Aside from the Kamchatka to Alaska portion of the circum-Pacific arc, there are no other source areas providing sufficient data to test the possibility of regional evacuations. At best there are only a few data points for these other areas and the values are much less than 1 meter (Lander and Lockridge, 1989). The largest number of data points found is for a Kurils earthquake in 1963 (10 data points with the largest value at 0.4 meters). Runups reported for 1901 (3 values: 1.2, 1.2, and 0.1 meters) are probably for a local tsunami (Walker, 2000) and not as reported in Lander and Lockridge as being generated in Tonga.

Analysis of Data from the Kamchatka to Alaska Region

Analysis is now directed to the large quantities of data from the Kamchatka to Alaska portion of the circum-Pacific arc. Data for each island are examined beginning with the 1946 Aleutian event.

Kauai. For the 1946 tsunami, there are no runups at or in excess of 50 feet, 4 are at or in excess of 40’, 13 are at or in excess of 30’ (i.e., the same 4 that are more than 40’ and an additional 9 that are between 30’ and 40’), and 32 are at or in excess of 20’. The 40+’s extend from Haena almost to Nawiliwili with the 3 largest values along the north shore, the 30+’s extend from Barking Sands northward and down the east coast almost to Nawiliwili, and the 20+’s cover the same coastal areas as the 30+’s. Values in other areas of the island (i.e., the south shore) do not exceed 17 feet.

For 1952 (Kamchatka) much damage is reported for the north shore, but there are no reported runup values and there is no other information..

For 1957 (Aleutians) there is 1 runup in excess of 50’ (actually meaning at or in excess of 50’ here and in subsequent discussions of this and other runup heights, but the “at or” will hereafter be deleted), 1 in excess of 40’ (the same one in excess of 50’), 3 in excess of 30’, and 11 in excess of 20’. The 30+’s are all in the Haena to Lumahai area. The 20+’s extend from Hanakapiai to Wailua. Values elsewhere do not exceed 16’. Hanakapiai is about 15 to 20 miles northeast of Barking Sands and Wailua is about 7 miles north of Nawiliwili.

For 1964 (Alaska), there are only 8 values – all less than 10 ft. All are between Hanakapiai and Wailua.

For Kauai a large volume of data indicates that the largest values reported along the north shore are at least twice as large as the largest values along the southern shore from the south of Nawiliwili just to the west of Kekaha (approximately from Kawelikoa Point through Kekaha Beach Park). Thus this area could be excluded from an evacuation if modeling accurately determined that the maximum runups in other areas of the island were no more than 2 meters.

Niihau. There is very little data for Niihau. Until sufficient data becomes available, no shorelines should be excluded from any evacuation plans.

Oahu. For 1946 there are no runups in excess of 40', 6 in excess of 30', and 19 in excess of 20'. The 30+'s are just to the north and south of Kaena Point, and in the Makapuu and Koko Head area. The 20+'s are from Nanakuli up to Kaena Point along the North Shore through Kahuku, the north shore of the Mokapu Peninsula, and in the Makapuu and Koko Head area. Outside of these areas the only double-digit values are 14' or less moving down from Kahuku nearly to Chinaman's Hat, 12' at Diamond Head, and 12' at Barbers Point.

For 1952, there are no runups in excess of 30', 1 in excess of 20' just to the northeast of Haleiwa, and 16 in excess of 10' from Nanakuli to Kaena Point to Kahuku down past Hauula, and at Koko Head. The largest values are in the Waialua and Haleiwa areas.

In 1957 there are no runups in excess of 40', 1 in excess of 30' at Kaena Point, 8 in excess of 20' in the Kaena Point to Kahuku Point area, 24 in excess of 10' from Kahe Point north to Kaena, east to Kahuku, down the east coast almost to Chinaman's Hat, and in the Hanauma Bay area.

In 1964 values range from 6' to 16' along the north shore with the highest value at Waimea Bay, and the only other values being 4' at Hauula and 3' at Waiahole.

For Oahu, a large volume of data indicates that the largest values are at least twice as large as values along the Windward Coast from Chinaman's Hat to Waimanalo, excluding the shorelines of the Marine Corps Air Station, and along the south shore from Hawaii Kai just to the west of Ewa Beach, (through Oneula Beach) excluding Diamond Head. Thus these areas could be excluded from an evacuation if modeling accurately determined that the maximum runups in other areas of the island were no more than 2 meters.

Molokai. For 1946, there is one runup in excess of 50' and 5 in excess of 40'. These are on the northern shore. There are 16 runups in excess of 30' and 26 in excess of 20'. These values are on the northern, western, and eastern shores. Values west of Waialua through Kaunakakai are far less than half of the largest values reported. No measurements are available for the Hale o Lono Harbor area. The only other tsunami from the Kamchatka to Alaska area reported on Molokai was a 9' runup at Halawa Valley for the 1957 Aleutian event.

For Molokai, sufficient data indicates that the largest values are more than twice as large as the values from Waialua through Kaunakakai and Coconut Grove. Thus these areas could be excluded from an evacuation if modeling accurately determined that the maximum runups in other areas of the island were no more than 2 meters.

Maui. For 1946, there are no values in excess of 40', 3 are in excess of 30' (2 at Kahakuloa and 1 near Nahiku), and 25 are in excess of 20' from north of Kapalua around to Kahului to Hana and to Kaupo. All of the values past Malama Bay, west of Kaupo, and through the western shores just past Lahaina are less than half of the largest recordings along the northern shores.

For 1952, the tsunami is reported only as observed with most of the damage in the Kahului area.

For 1957, there are no runups in excess of 20', and 15 are reported in excess of 10'. One of the 15 is at Napili Bay north of Kapalua and the other 14 are in the Kahului area from the Waihee River to Maliko Bay. With the exception of a single 9' reading at Kealia Pond, all of the runups past Malama Bay through the western shores to just past Lahaina are less than or equal to half the largest recordings along the northern shores (i.e., 17', 16', 16').

For 1964, there are only single and low double-digit (10' to 12') readings in the Waihee River to Kahului area. The only other readings outside of the Waihee River to Kahului area were two 5' readings midway between Maliko Bay and Hana.

For Maui, a large volume of data indicates that the largest values are twice, or in one instance nearly twice, as large as values from Mamalu Bay, west of Kaupo, westward through Makena, Wailea, and Kihei to north of Lahaina. It should be noted, however, that from Mamalu Bay to La Peruse Bay there is only one reading of 10'. The area north of La Peruse Bay (i.e., Makena, Wailea, and Kihei), west through Maalaea and Olowalu, and on to the north of Lahaina, (Kuunoa Point), could be excluded from an evacuation if modeling accurately determined that the maximum runups in other areas of the island were no more than 2 meters.

Lanai. For 1946, there are only two readings – 7' at Manele Bay and 7' at Kamaulapau Harbor. There are no other readings for tsunamis from the Kamchatka to Alaska region. Tsunamis from the Kamchatka to Alaska region expected to have values no larger than 2 meters elsewhere in the Hawaiian Island should not require an evacuation of the southern shores of Lanai.

Kahoolawe. There is no data for this island. Until sufficient data becomes available, no shorelines should be excluded from any evacuation plans.

Hawaii. For 1946, there is one reading of 50+' and 3 of 40+'. All are in the Waipio and Pololu Valley areas. There are 16 values of 30+' extending from Pololu down to the Hilo Bay area. There are 39 values of 20+' in these same coastal areas and extending further south to Kaimu and west from Pololu to just past Upolu Point. A single value of 20' is at South Point.

For 1952, values from 9' to 11' are reported in the Hilo area. The only other values are 3' at Kaimu, 2' at Kawaihai, and 2' to 4' along the Kona coast.

For 1957, there was one reading in excess of 30', 3 in excess of 20', and 26 in excess of 10'. These had the same distribution as the 1946 values.

For 1964, there were small readings except for three 6' readings near Mahukona, Upolu Point, and near Pololu Valley.

For the Big Island, a large volume of data indicates that the largest values are at least twice as large as values west of Kaimu along the Puna and Kau coastlines, with the exception of South Point, and up through the Kona and Kohala coasts just past Kawaihae. Thus, these areas could be excluded from an evacuation if modeling accurately determined that the maximum runup in other areas of the island were no more than 2 meters.

Tsunami Periods

It is generally believed that the period of the 1960 tsunami was longer than the period of the 1946 tsunami. Therefore, one might speculate that tsunamis from the north Pacific with longer periods could have comparable values on all coasts like the 1960 tsunami; and, conversely, Chilean tsunamis with shorter periods might have much larger values on southern or eastern shores. Table 1 gives historical data on the periods measured for the tsunamis described in this report. Not all of the 1960 tsunami's periods were long, nor were all of the periods from the north Pacific short. Modeling studies could determine the periods from differing regions of the Pacific, the possible variability in periods from differing regions for differing source mechanisms, and whether these differences would substantially alter the relative distribution of runups along differing shorelines in the Hawaiian Islands.

Conclusions

When modeling is capable of accurately predicting maximum runups in the Hawaiian Islands, marginal warnings may be improved to either reduce the number of warnings perceived to be false or the number of small, but potentially destructive tsunamis for which no warning may be issued. Although tsunamis just over one meter may occur only at one location or a small number of locations, existing State Civil Defense procedures require a statewide evacuation of all low lying coastal areas. Such warnings are not only expensive in business and tourism losses, work stoppages, and overtime costs, but are also the type of tsunamis expected to occur most frequently. Because of the small runups of these tsunamis and their personal and economic disruptions, credibility in the warning system and civil defense agencies will rapidly erode with the potential for major loss of life when a large tsunami does occur. One way to reduce the negative effects of warnings for these small ("gray") tsunamis is to eliminate statewide evacuations and evacuate only those areas expected to have runups of 1 meter or more. In this study historical data has been used to determine those areas most likely to be inundated by small tsunamis, thereby identifying those areas of the State that need not be evacuated and can continue with uninterrupted activities.

The results are as follows. Regional evacuations are possible for tsunamis originating in the Kamchatka to Alaska portion of the circum-Pacific Arc. Runups for the 1960 Chilean tsunami are somewhat uniformly distributed along all the coastlines of the Hawaiian Islands. Therefore a one meter runup from Chile type tsunamis on any coast could appear on many other coasts, negating the possibility of regional evacuations. Also, insufficient data prevents conclusions regarding regional evacuations for other source areas in the Pacific including the Japan region. For the Kamchatka to Alaska portion of the circum-Pacific arc, regional evacuations appear to be possible for Kauai, Oahu, Molokai, Maui, Lanai, and the Big Island. Insufficient data prevents any conclusions regarding regional evacuations of Niihau and Kahoolawe. Coastal areas not required to evacuate for marginal tsunamis appear to be the following: Kauai – from west of Nawiliwili through Kekaha; Oahu – along the windward coast from Chinaman's Hat to Waimanalo, exclusive of the Marine Corps Air Station, and from Hawaii Kai through Ewa Beach, exclusive of the Diamond Head area; Molokai – from Waialua west through Kaunakakai; Maui – from the north of La Peruse Bay through Makena, Wailua, and Kihei through Lahaina; Lanai – the south shore; the Big Island – west of Kaimu along the Puna, Kau, Kona, and Kohala coasts through Kawaihae, with the exception of South Point.

With such limited evacuations, major segments of the State's activities can continue with little or no disruptions, saving millions in lost revenues, overtime costs, and maintaining or enhancing credibility in Civil Defenses agencies and the Pacific Tsunami Warning Center. However, such regional evacuations are contingent upon accurate real-time modeling of maximum expected runup values. Finally, since those areas to be evacuated in the event of a small tsunami would be expected to have runups of less than two meters, practical considerations might suggest a reexamination of existing evacuation plans and road closures for some areas.

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References

Lander, J. F., and P.A. Lockridge (1989). United States Tsunamis (including United States possessions) 1690 – 1988, National Geophysical Data Center, Publication 41-2, Boulder, Colorado, 265 pp.

Tsunami Technical Review Committee (2002). Field Guide for Measuring Tsunami Runups and Inundations, State of Hawaii, Department of Defense, Civil Defense Division, 23 pp + appendices.

Walker, D.A. (2000). Twentieth Century Ms and Mw values as tsunamigenic indicators for Hawaii, Sci. of Tsunami Hazards, 18-2, 69-76.

Table 1. Periods of Tsunamis Discussed in This Report *

		Period in Minutes				
Year	Origin	Hilo	Honolulu	Kahului	Nawiliwili	Other
1837	Chile	15	28	---	---	---
1868	Chile	10	---	---	---	20 min. for Molokai
1877	Chile	8	20	---	---	---
1896	Japan	6	20	---	---	10 min. for Kailua-Kona
1906	Chile	---	25	---	---	---
1923	Kamchatka	---	23	---	---	---
1933	Japan	15	15	---	---	10 min. for Kawaihae, Kailua-Kona, and Napoopoo
1946	Aleutians	15	15	---	---	15 min. for Waikiki; 10 min. for Waimea Bay, Kauai
1952	Kamchatka	27	38	21	---	20 min. for Pearl Harbor; 15 min. for Port Allen
1957	Aleutians	19	14	22	12	---
1960	Chile	30	33	18	15	27 min. for Coconut Is. (Oahu)
1964	Alaska	19	21	23	13	---

* Taken from Lander and Lockridge (1989).

Appendix: Sources of Historical Data and Documentation of Discrepancy Resolutions

Primary references, if available, were maps found in the tsunami archives at the University of Hawaii at Manoa in the School of Ocean, Earth Science, and Technology (SOEST). Data from field notes were originally put on to these maps that have scales of 1:62,500 (Kauai and the Big Island) and 1:24,000 (Oahu, Maui, and Molokai). These maps will, hereafter, for convenience sake be referred to as "quads". Some of the quads may not be originals. Some may be second or even third generations of the original quads. However, these data are the closest to the original field notes (also missing) that could be found. The data on the available quads have been color coded for the differing major tsunamis of 46, 52, 57, 60, and 64. Although some of the colors are fading, all are still readable. The values on the quads, as well as the values in all of the references cited, have been corrected to mean lower low water. Secondary references, hereafter referred to as A, B, and C, respectively, follow.

(A) Shepard, F. P., G. A. Macdonald, and D. C. Cox (1950). The Tsunami of April 1, 1946, Bull. Scripps Inst. Oceanog., Univ. of Calif. Press, 5 – 6. 391-528.
(B) Macdonald, G. A., F. P. Shepard, and D. C. Cox (1947). The Tsunami of April 1, 1946 in the Hawaiian Islands, Pacific Science, 1, 21-37.
(C) Loomis, H. G. (1976*). Tsunami Wave Runup Heights in Hawaii, Hawaii Institute of Geophysics, HIG-76-5, (*corrected and reissued January 1980), 95 pp.

Additional references follow.

Macdonald, G. A., and C. K. Wentworth (1954). The Tsunami of November 4, 1952, on the Island of Hawaii, Bull. Seismol. Soc. Amer., 44-3, 463 -469.

Fraser, G. D., J. P. Eaton, and C. K. Wentworth (1959). The Tsunami of March 9, 1957, on the Island of Hawaii, Bull. Seismol. Soc. Amer., 49-1. 79 - 90.

Eaton, J. P., D. H. Richter, and W. U. Ault, (1961). The Tsunami of May 23, ,1960, on the Island of Hawaii, Bull. Seismol. Soc. Amer., 51-2, 135 - 157.

Cox, D. C., and J. F. Mink (1963). The Tsunami of 23 May 1960 in the Hawaiian Islands, Bull. Seismol. Soc. Amer., 53 -6. 1191 - 1209.

Loomis, H. G., (1972). "The Major Tsunami in the Hawaiian Islands" in The Great Alaskan Earthquake of 1964 – Oceanography and Coastal Engineering, Nat. Academy of Sciences, Washington, D. C., 181 - 190.

Lander, J. F., and P. A. Lockridge (1989). United States Tsunamis (Including United States Possessions) 1690 – 1988, National Geophysical Data Center, Publication 41-2, Boulder, Colorado, 265 pp.

There are no missing quads for Kauai or Molokai. Four of 14 quads with data are missing for Oahu (Kahana, Kaneohe, Mokapu, and Ewa). Three of 14 quads with data are missing for Maui (Kahakuloa, Kipahulu, and Kaupo). Five of the 16 quads with data are missing for the Big Island (Honokaa, Kukaiau, Papaaloa, Papaikou, and Hilo). The "new" quad names may not be the same as the names of the missing old maps. [The existing old quads do not always have the same names as the new quads.]

Only data for 1946 is available for Molokai and Lanai. The Lanai quads, if they ever existed, are missing; but only two values were reported for this island (7' at Manele Bay and 7' at Kaumalapau Harbor). Niihau quads, if they ever existed, are also missing. Values of about 20' and 10' were reported for the 46 and 57 tsunamis, respectively. The locations for those readings is unknown.

There was much damage reported along the north shore of Kauai for the 52 tsunami. However, the only reported values were 10' at Wahiawa Bay and 1' at Port Allen (Lander and Lockridge, 1989). [Since Wahiawa Bay is on the south shore of Kauai right next to the 1' reading at Port Allen, the 10' value may be a typo, and possibly should be 1'.] There are no values reported for Maui for 52, but the greatest damage was reported in the Kahului – Spreckelsville area where the tide gauge went off scale (Lander and Lockridge, 1989). All of the quads and references were cross-checked for evidence of discrepancies. Greatest weight was given to the quads, then the secondary references, and finally the additional references. The following is a list of discrepancies, considerations and decisions.

General Observations. In the secondary references, a total of 472 locations statewide were found where runup measurements have been made for the 46, 52, 57, 60, and 64 tsunamis. Of these, 356 are for the 1946 tsunamis. Many of the locations for the 52, 57, 60, and 64 tsunamis (in C) are plotted as being the same as for the 1946 tsunami, and many are not. This seems to differ from island to island. For example, Kauai has many (51 out of 126) locations other than 1946 locations for the other tsunamis, while data for Oahu for all of the tsunamis is nearly exclusively plotted at 1946 locations. Only 2 of the 95 locations for Oahu were non-1946 locations. I don't believe it is possible for readings in 52, 57, 60, and 64 to have been taken at the same locations as in 1946 to the extent possibly inferred by anyone looking at the data in C. Some sort of clumping must have occurred, as Doak Cox and George Curtis have suggested (personal communication); and it is logical to do this for plotting and comparison purposes. Also, there is no point in trying to "unclump" the data. It may not be possible, the process would have its own errors, and there is no clear reason why it should be done.

Kauai

- There is a little bit of "clumping" for Hanalei Bay in C. These values have been "unclumped" using values on the quad.
- There is a value of 33' (1946) north of Mana in A. On the quad, in B, and in C it is 34'. [Decision: Change to 34'.]
- On the original quad, in A, and in C there is a single reading of 45'(1946) at Haena, but in B there are 2 distinct readings of 45' at Haena. [Decision: Ignore the 2nd reading.]

- At Haena there are values of 9’ and 14’ (1946) on the quad and in B. These are reversed in C. [Decision: Use the values on the quad.]
- The reading of 21’ (1946) at Kilauea Bay in C is not on the quad. [Decision: Delete.]
- The reading of 29’ (1946) south of Kilauea Bay in C is actually 32’ on the quad. [Decision: Use 32’.]
- At Moloaa there are readings of 30’(1946) in A, 30’ and 40’ in B, and 45’ (inland), 30’ (at shore), and 35’ on the quad and in C. [Decision: Use 45’. The designations “inland” and “at shore” are confusing. Do not use.]
- A value of 30’ (1946) south of Moloaa in A does not appear on the quad or in B or C. [Decision: Do not use.]
- For Kepuhi Point there are readings of 32’ (1946) in B, 32’(at shore) and 38’(inland) on the quad and in C. [Decision: Use 38’ and delete “inland”.]
- At Kalihiwai the value of 21’ (1957) in C was found to be 22’ on the quad. [Decision: Use 22’]
- In map 11 of C the 9 ½’ reading (1960) should be blank as it goes with the 2nd reading in map 1 of C. This is confirmed by the quad. [Decision: Blank it.]
- The 6’ reading (1960) on the north side of Anahola Bay in (C) is not on the quad. [Decision: Delete.]
- Three values south of Kapaa of 7” (1960) are on the quad, but one of these is 8’ in C. [Decision: Use 7’.]
- A value of 14’ (1960) at Hanapepe Bay in C is not on the quad. [Decision: Delete.]
- The value of 6 ½’ (1960) near the middle of map 8 in C is 9’ in Cox and Mink, but 6 ½’ on the original quad. Could have been rounded up to 7’, then a handwritten 7’ was misplotted as 9’. [Decision: Use 6.5’.]
- The value of 8’ (1960) near Kukuiula Bay in map 6 of C also appears on the original quad but shows up as a 7’ reading in Cox and Mink. [Decision: Use 8’.]
- Plotting from the original quad onto figures in C is extremely accurate for Kauai with no corrections for locations required.

Oahu

- Two values (1946) in Pearl Harbor are shown on quads and in A and B, but not in C (maps don’t go there). [Decision: Add these points.]

- A 12’ (1946) value near Maile Point on the quad and in A and B is not in C. [Decision: Add this data point which lies between values of 14’ and 16’.]
- There are 27’ (1946) and 6’ (1952) readings near Kahuku on the quad and in A and B but not in C. [Decision: Add these data points.]
- There is a 2’ (1946) reading on the east side of Kaneohe Bay in A and B but not in C. The quad map is missing. [Decision: Add this data point.]
- There are some duplicate readings in C east of Niu Valley not on the quad nor in other publications. [Decision: Delete these values.]
- There is no 3’ (1946) value for the Ewa Beach area in A or B but is in C. The quad is missing. Scale may be too small for plotting in A and B, or value thought to be too insignificant at the time, or a neighboring value of 3’already plotted may have suggested that plotting not necessary. [Decision: Put in the 3’ value.]

- In C (map 2) the 12’ (1960) north of Punaluu Stream is 7’ in Cox and Mink.The 12’ doesn’t fit with surrounding values. Also, 12’ would be the largest value on the entire eastern and southern coastlines. Perhaps a handwritten comma and a 7 was misplotted as a 12. Quad is missing. [Decision: Use 7’.]
- The 5’ (1960) value next to Koko Head in Cox and Mink is missing in C but is in the original quad but not in a secondary quad. [Decision: Use 5’.]
- A 5’ (1960) reading east of Diamond Head in Cox and Mink is missing in C and in the quad. [Decision: Do not use this 5’ value.]
- A 2’ (1960) reading on the west side of Kaneohe Bay in Cox and Mink is missing in C. Quadrangle map is missing. [Decision: Use 2’ value.]
- All locations in C follow the locations on the available quad maps with the exception of Hanauma Bay. They are on the northern edge in C and more toward the center of the bay on the quad. [Decision: Use the quad location

Molokai

- On the quad the 36’ value north of Kepuhi Bay is about 1 mile further north and the 13’ at Halena is about 1 mile further east than in C. [Decision: Move values to location indicated on quad.]
- There is an additional 9’ reading on the quad on the west side of Kalaupapa Peninsula not found in A, B, or C. [Decision: Add this value.]
- There are 7 additional values in B and C around Kalaupapa and 7 additional values in B and C along the southeastern coast that are not on the quads. These values may not have been plotted on the smaller scale map in A because of a lack of space. [Decision: Include these values.]
- A 36’ reading in B and C at the eastern edge of Molokai is 35’ on the quad. [Decision: use 35’.]
- A 30’ reading in C below the 36’ reading is 39’ on the quad and in A and B. [Decision: Use 39’].

Maui

- On the quad and in A and B, the value for Hana Bay is 13’ (1946). In C the value is 30’ [Decision: Use 13’]
- A and B have 24’ (1946) at Puuiki (South of Hamoa) but this value is not in C and the quad map is missing. [Decision: Add this value.]
- A value of 7’ (1960) is missing in C but is on the quad. [Decision: Add this value.]
- No values at Honokohau Bay or Nakalele Point on the quad, yet are in A, B, and C. Also a quad is missing for Kahakuloa that could have the missing values for Honokohau and Nakalele. This lost quad appears to be an odd one with borders overlapping the existing quads, probably including the Honokohau , Nakalele , and Kahakuloa areas. [Decision: Keep the values that are given in A, B, and C.]

- In addition, quad maps are missing from south of Hamoa south and eastward to La Perouse Bay. Data from C were checked against all original published sources for this area for the 46, 57, 60, and 64 tsunamis (there is little or no data for the 52 tsunami for Maui or Kauai). No discrepancies were found and the data from C were used for these areas of the coast.
- The 7' (1960) for Honolua Bay in Cox and Mink and on the quad is missing in C. [Decision: Add the 7' reading.]
- Plotting from the original quads onto figures in C is extremely accurate for Maui with no corrections for locations required.

Hawaii

- The 25' (1946) reading near Leleiwi Point in A and B is 20' on the quad and in C. Perhaps handwritten 0 was read as 5 in drafting. [Decision: Use 20'.]
- Readings of 7' and 11' (both 1946) for Kailua-Kona on the quad and in A and B are missing in C (no map for this area). [Decision: Use the 7' and 11' readings, and add a map that covers this region.]
- The 11' (1952) for Reeds Bay in Macdonald and Wentworth is missing in C, but is very close to a 9' reading in C consistent with other nearby
- readings. Quadrangle map is missing. [Decision: Not critical to add the 11' reading.]
- Just north of Keaukaha the 13' for 1952 in Loomis should be for 1957 as indicated in Fraser et. al. There is no 13' value in Macdonald and Wentworth for this location. Quad is missing. [Decision: Make 13' for 57 not 52.]
- The 2' (1952) reading for Kailua-Kona in Macdonald and Wentworth is missing in C (no map). [Decision: Add map and value.]
- At Kauhola Point the 10' and 27' (both 1957) readings in C are indicated as values for 1946 on the quad but are not in A or B (the papers for 1946 - on this small map not every data point could be shown, so they may have been deliberately deleted to reduce the visual clutter). They are in Fraser, Eaton, & Wentworth; and Eaton, Richter, and Ault (the papers for 1957 – but the 57,52,46 order may have gotten reversed). [Decision: Consider the primary source as valid, i.e., the 10' and 27' are 1946 values.]
- The 5' (1957) value for Kailua-Kona is on the quad but missing in Loomis (no map). [Decision: Add map and value.]
- For the two 7' (1957) readings in the Hilo map in Fraser et. al., no values can be found in Loomis but there are other larger values for 57 close to the same general area. Quad is missing. [Decision: Use C.]
- A 6' (1960) reading east of Upolu Point near Keawaeli Bay in C is not on the quad or in Cox and Mink. It is the same value and is at the same location as was reported in Loomis for the 1964 tsunami. [Decision: Do not use for 1960 and add for 1964.]
- A 12' (1960) reading at Pololu in Cox and Mink adjacent to values of 10' and 11' also in Cox and Mink, is not in C and does not appear on the quad. [Decision: Do not use.]
- The 8' (1960) reading in C near the fish pond at Waipio is not on the quad and may be carried over from an 8' value already indicated just to the west of the pond. [Decision: Do not use.]
- There is no map for Kailua values in C. There is an 8' (1960) value in Cox and Mink, and on the quad. [Decision: Add maps and value.]

- Values for 1964 are not plotted on any of the quads for the Big Island. Therefore, the primary data sources are the Loomis reports of 72 and 76.]
- In maps 9 and 10 of C, there is duplicate data for 46, 57, and 60. Map 9 has no value for 64, but map 10 has 3' for 64. The 3' value is in Loomis (1972). [Decision: Use the 3' value.]
- A reading of 2' (1964) at Puako Bay is in C but not in Loomis (1972) There is no map for this area in C. [Decision: Add map and 2' value.]
- On the quads, there are no values for Honuapo and only some values down to South Point. However, values are present at Honuapo and at other locations extending to South Point in C and in other publications. All of these addition points are in C. [Decision: Use these additional data points.]
- Plotting from original quads onto figures in Loomis extremely accurate for Hawaii. Only two locations had to be moved slightly (near Limukoko Point and Honomalino Bay).

Other data. The only other values for the above tsunamis in the Hawaiian Islands are for Midway: 6.2' in 1952, 1.6' in 1957, 2.0' in 1960, and 0.3' in 1964 (Lander and Lockridge, 1989). Also, flooding was reported at French Frigate Shoals in 1946 (personal communication, Pacific Tsunami Museum). There are no values from Midway for 1946. Thus far, the only other areas of the Pacific Rim (i.e., other than Kamchatka, the Aleutians, Alaska, and South America) producing double-digit runups in Hawaii were from the Japan earthquakes of 1896 and 1933. Values in excess of 5' were only observed in Hilo in 1896 and along the west coast of the Big Island with a maximum reported value of 18' in Keauhou for the 1896 tsunami (Lander and Lockridge, 1989).

Addendum:
Subsequent to completion of the above, field notes of Mink and Takasaki for the 1952 tsunami on Oahu were found in the SOEST archives, consisting of an 8 ½" X 11" map of Oahu on which 54 runups or water levels are indicated. Six of the values on that map are missing in C; but two values in C are not on Mink and Takasaki's map. However, the two additional values in C are identical to immediately adjacent values that do appear on Mink and Takasaki's map. Since a larger scale map may have been available for Loomis to work with in C, these values are retained in the new maps. Regarding the 6 missing values: (1) an 8' reading east of Kaena Pt. near the site of a 31' reading for 1946 has been added; (2) an 8' value in Waialua Bay immediately adjacent to a 13' value for 1952 was considered superfluous and not added; (3) a 10' value near Waialee and Sunset Beach between 13' and 10' values for 1952 was also considered superfluous and not added; (4) an 11' value just south of Hauula was larger than adjacent values for 1952 and was added; (5) a 1' value in Kaneohe Bay was considered superfluous and not added; and (6) a 5' value east of Diamond Head which was larger than surrounding values for 1952 was added. In C the only single values plotted were for the 1946 tsunami. Apparently, if any other tsunami had a unique location where the reading was taken, that value was either not plotted in C or was clustered at another location with other values for other tsunamis. Items (4) and (6) above are the only known remaining values that were not plotted in C because of their unique location.

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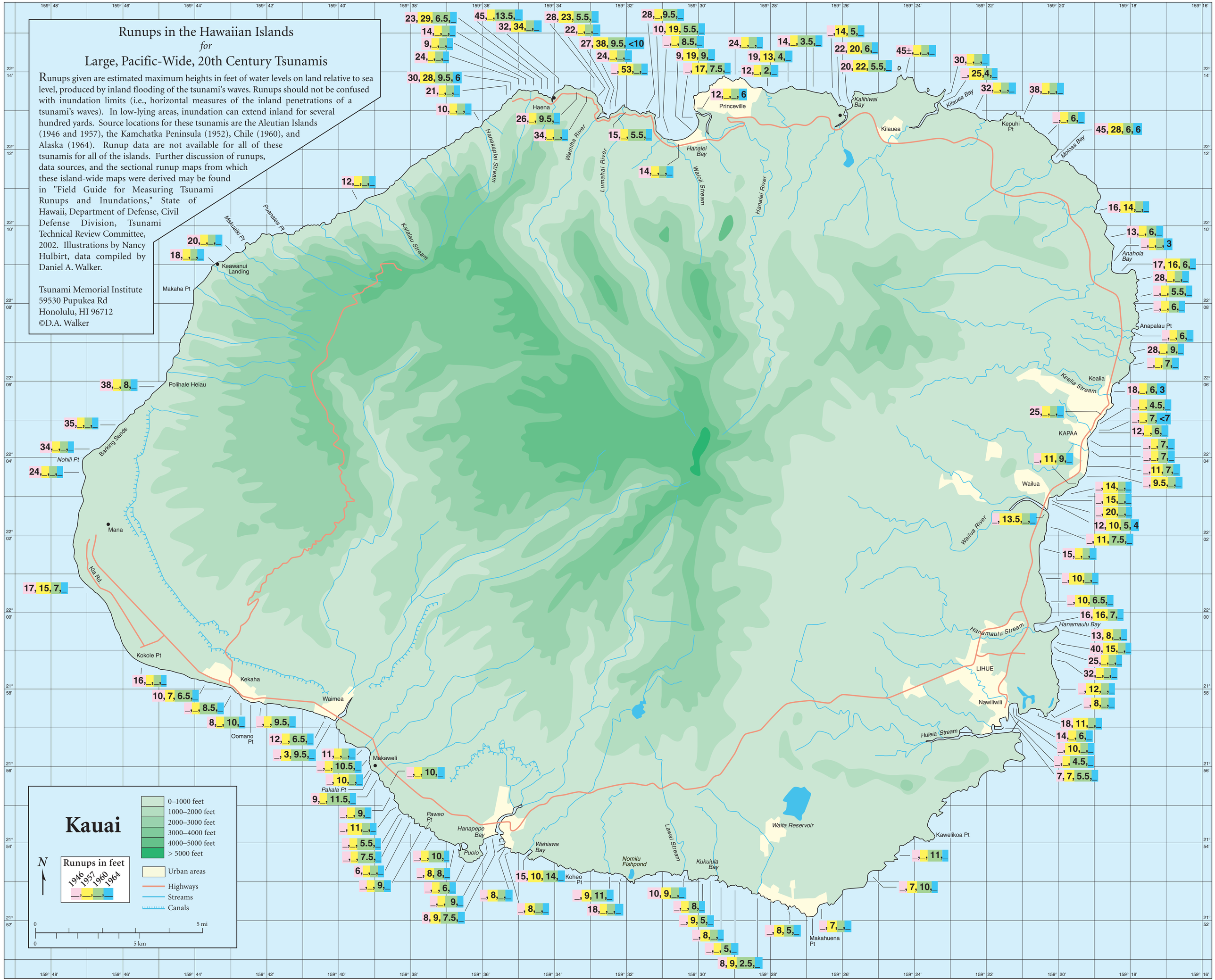

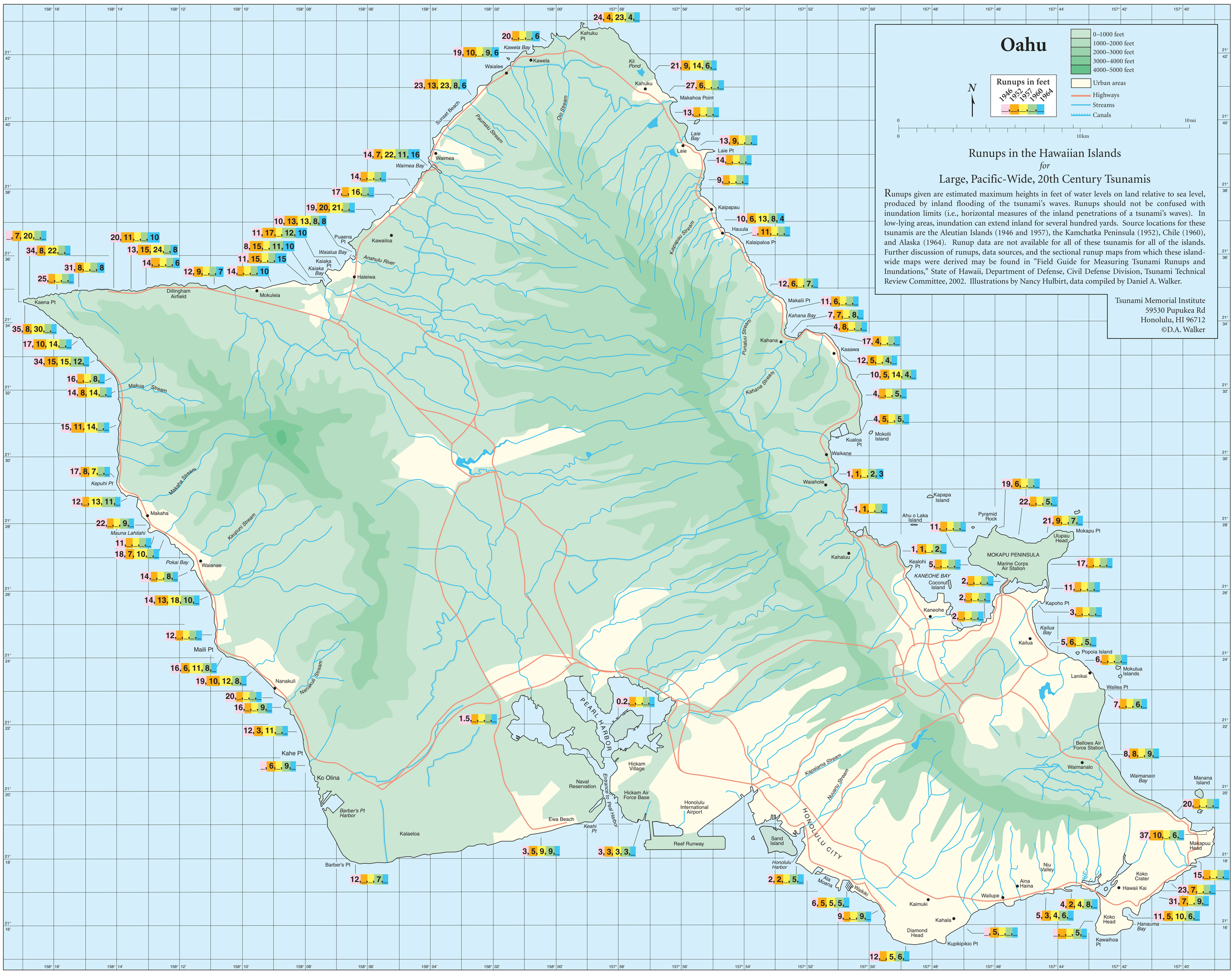
Oahu
0–1000 feet
1000–2000 feet
2000–3000 feet
3000–4000 feet
4000–5000 feet
Urban areas
Highways
Streams
Canals
N
Runups in feet
1946 1952 1957 1960 1964
0 10 mi
0 10 km
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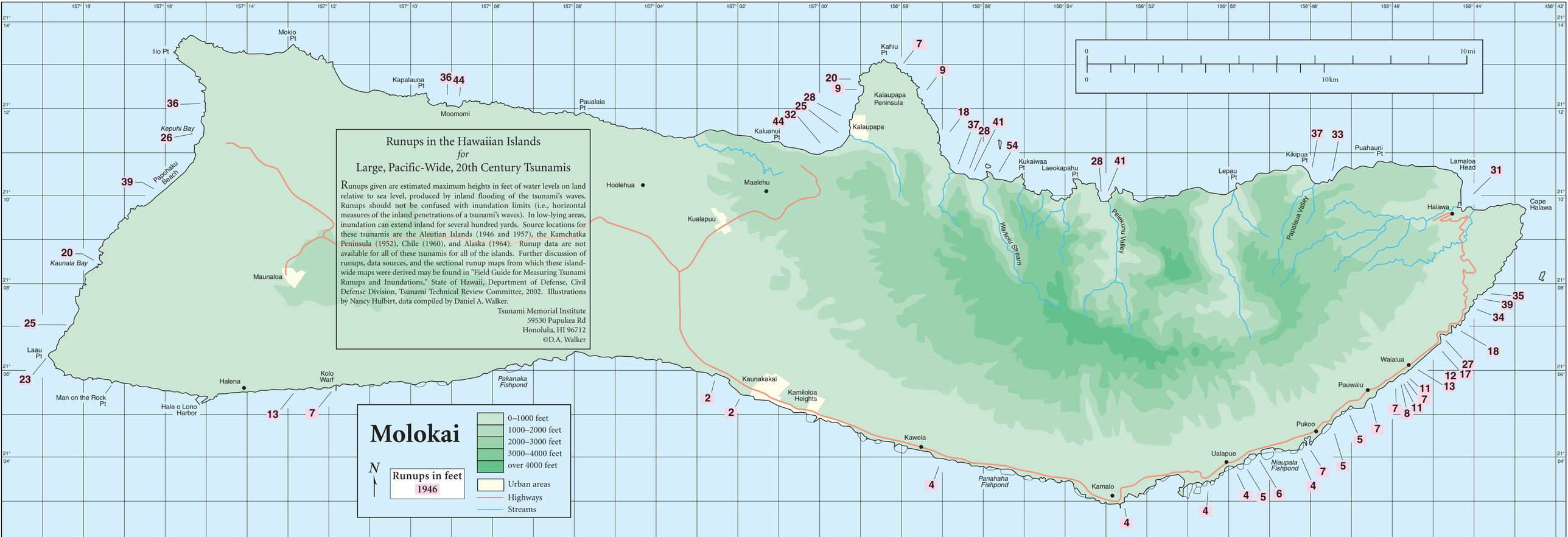
24, 4, 23, 4,_
Kahuku Pt
20,_,_,_, 6
Kawela Bay
19, 10,_, 9, 6
Kawela
Waialee
Kii Pond
Kahuku
21, 9, 14, 6,_
23, 13, 23, 8, 6
27, 6,_,_,_
Makahoa Point
Sunset Beach
Paumalu Stream
Old Stream
13,_,_,_,_
Laie Bay
13, 9,_,_,_
Laie
Laie Pt
14, 7, 22, 11, 16
Waimea
Waimea Bay
14,_,_,_,_
14,_,_,_,_
17,_, 16,_,_
9,_,_,_,_
19, 20, 21,_,_
Kaipapau
10, 6, 13, 8, 4
Hauula
Kaipapau Stream
10, 13, 13, 8, 8
11, 17,_, 12, 10
Puaena Pt
Kawailoa
_, 11,_,_,_
Kalaipaloa Pt
_, 7, 20,_,_
20, 11,_,_, 10
34, 8, 22,_,_
13, 15, 24,_, 8
8, 15,_, 11, 10
Waialua Bay
Anahulu River
31, 8,_,_, 8
14,_,_,_, 6
11, 15,_,_, 15
Kaiaka Pt
Kaiaka Bay
25,_,_,_,_
12, 9,_,_, 7
14,_,_,_, 10
Haleiwa
Dillingham Airfield
Mokuleia
Kaena Pt
12, 6,_, 7,_
Makalii Pt
11, 6,_,_,_
Kahana Bay
7, 7,_, 8,_
4, 8,_,_,_
35, 8, 30,_,_
17, 10, 14,_,_
Kahana
17, 4,_,_,_
Kaaawa
Punaluu Stream
34, 15, 15, 12,_
12, 5,_, 4,_
16,_,_, 8,_
Makua Stream
14, 8, 14,_,_
10, 5, 14, 4,_
Kahana Stream
4,_,_,_, 5,_
15, 11, 14,_,_
4, 5,_, 5,_
Kualoa Pt
Mokolii Island
Waikane
17, 8, 7,_,_
Kepuhi Pt
Makaha Stream
Waiahole
1, 1,_, 2, 3
12,_, 13, 11,_
Makaha
Kaupuni Stream
Kapapa Island
19, 6,_,_,_
22,_,_, 5,_
Ahu o Laka Island
Pyramid Rock
22,_,_, 9,_
Mauna Lahilahi
11,_,_,_,_
21, 9,_, 7,_
Mokapu Pt
Ulupau Head
11,_,_,_,_
18, 7, 10,_,_
Pokai Bay
Waianae
1, 1,_, 2,_
MOKAPU PENINSULA
Marine Corps Air Station
Kahaluu
Kealohi Pt
5,_,_,_,_
17,_,_,_,_
14,_,_, 8,_
KANEOHE BAY
Coconut Island
2,_,_,_,_
11,_,_,_,_
14, 13, 18, 10,_
2,_,_,_,_
Kaneohe
Kapoho Pt
3,_,_,_,_
2,_,_,_,_
Kailua Bay
12,_,_,_,_
Kailua
5, 6,_, 5,_
Maili Pt
Popoia Island
6,_,_,_,_
16, 6, 11, 8,_
Mokulua Islands
Lanikai
19, 10, 12, 8,_
Nanakuli
Nanakuli Stream
Wailea Pt
20,_,_,_,_
16,_,_, 9,_
7,_,_, 6,_
0.2,_,_,_,_
1.5,_,_,_,_
12, 3, 11,_,_
PEARL HARBOR
Bellows Air Force Station
8, 8,_, 9,_
Kahe Pt
_, 6,_, 9,_
Hickam Village
Waimanalo
Kapalama Stream
Waimanalo Bay
Manana Island
Ko Olina
Naval Reservation
Entrance to Pearl Harbor
Hickam Air Force Base
Nuuanu Stream
20,_,_,_,_
Honolulu International Airport
Barber's Pt Harbor
Ewa Beach
Keahi Pt
HONOLULU CITY
Kalaeloa
Reef Runway
Sand Island
37, 10,_, 6,_
Makapuu Head
3, 5, 9, 9,_
3, 3, 3, 3,_
Barber's Pt
Honolulu Harbor
Niu Valley
15,_,_,_,_
12,_,_, 7,_
2, 2,_, 5,_
Ala Moana
Waikiki
Aina Haina
Koko Crater
Hawaii Kai
23, 7,_,_,_
Wailupe
31, 7,_, 9,_
6, 5, 5, 5,_
Kaimuki
4, 2, 4, 8,_
9,_,_, 9,_
Kahala
5, 3, 4, 6,_
11, 5, 10, 6,_
Koko Head
Hanauma Bay
Diamond Head
_, 5,_,_,_
_,_,_, 5,_
Kupikipikio Pt
Kawaihoa Pt
12,_, 5, 6,_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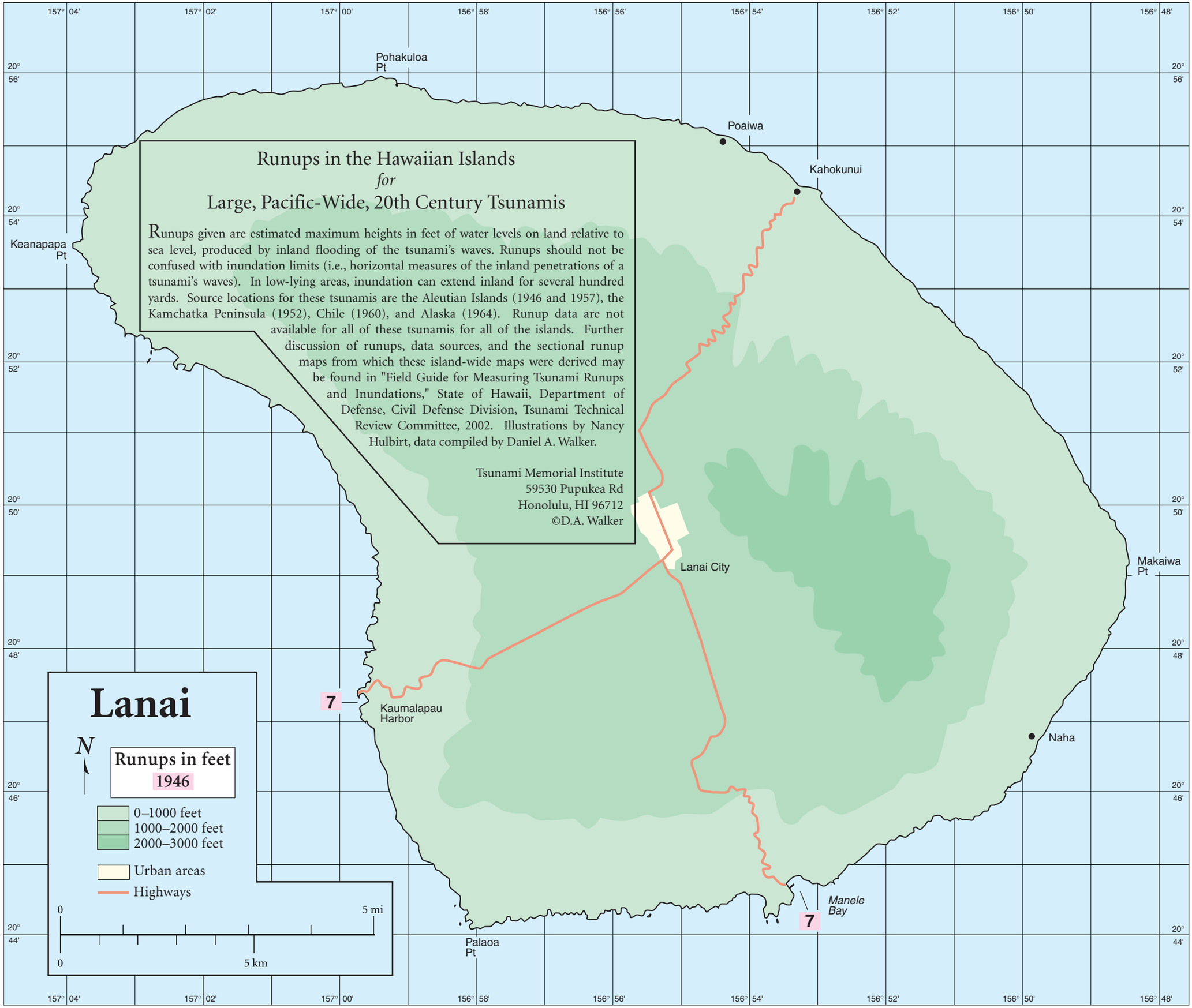
Molokai
N
Runups in feet
1946
0–1000 feet
1000–2000 feet
2000–3000 feet
3000–4000 feet
over 4000 feet
Urban areas
Highways
Streams
0
10 mi
0
10 km
Mokio Pt
Ilio Pt
Kapalauoa Pt
Moomomi
Paualaia Pt
Kepuhi Bay
Papohaku Beach
Kaunala Bay
Laau Pt
Man on the Rock Pt
Hale o Lono Harbor
Halena
Kolo Warf
Maunaloa
Hoolehua
Kualapuu
Maalehu
Kaluanui Pt
Kahiu Pt
Kalaupapa Peninsula
Kalaupapa
Pakanaka Fishpond
Kaunakakai
Kamiloloa Heights
Kawela
Panahaha Fishpond
Kamalo
Ualapue
Pukoo
Niaupala Fishpond
Pauwalu
Waialua
Halawa
Cape Halawa
Lamaloa Head
Puahauni Pt
Kikipua Pt
Lepau Pt
Papalaua Valley
Palekuni Valley
Wakolu Stream
Laeokapahu Pt
Kukaiwaa Pt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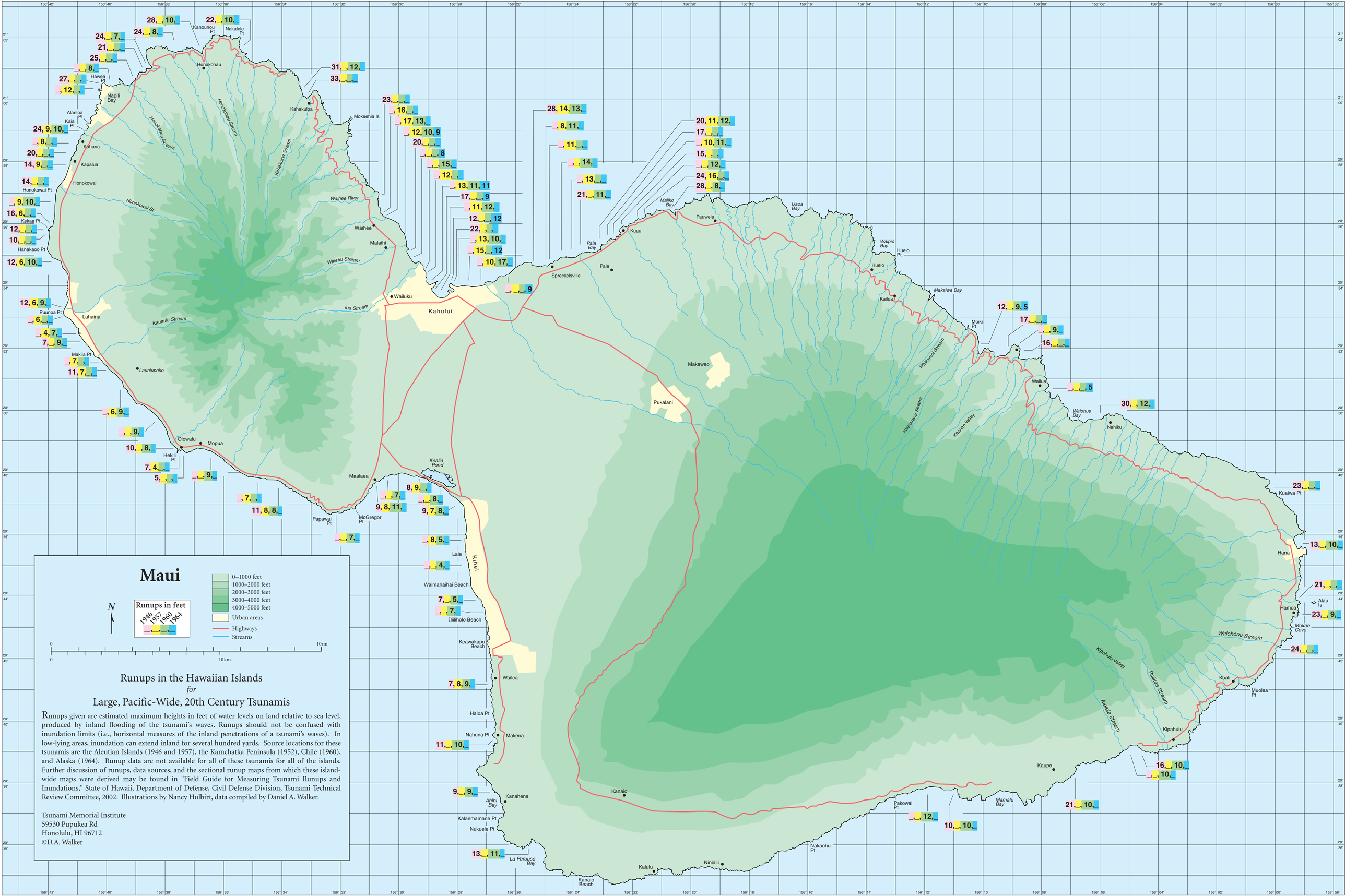
Lanai
N
Runups in feet
1946
0–1000 feet
1000–2000 feet
2000–3000 feet
Urban areas
Highways
0
5 mi
0
5 km
Pohakuloa Pt
Poaiwa
Kahokunui
Keanapapa Pt
Lanai City
Makaiwa Pt
Kaumalapau Harbor
7
Naha
Manele Bay
7
Palaoa Pt
157° 04'
157° 02'
157° 00'
156° 58'
156° 56'
156° 54'
156° 52'
156° 50'
156° 48'
20° 56'
20° 54'
20° 52'
20° 50'
20° 48'
20° 46'
20° 44'



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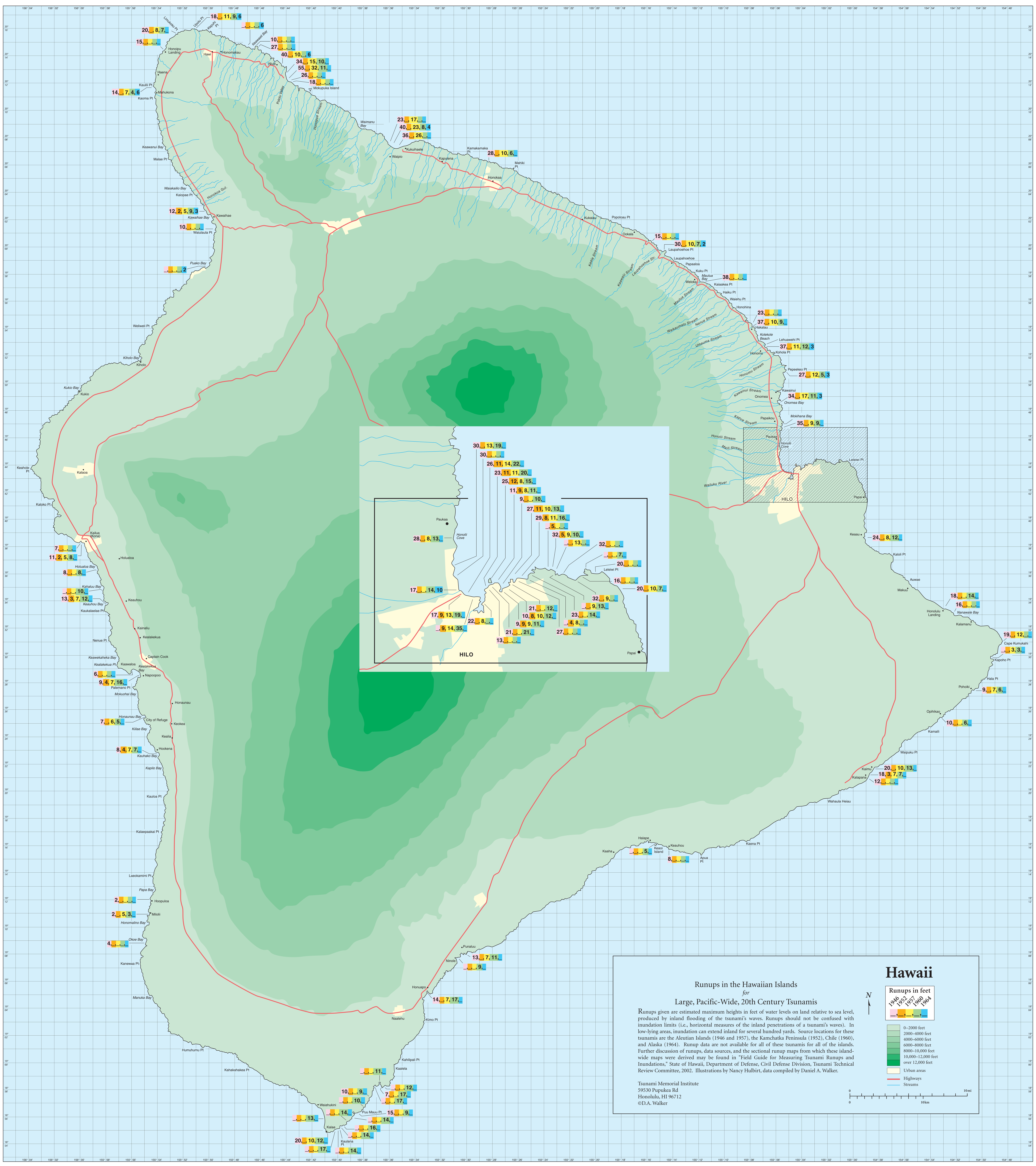

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