

Geo-Targeting Performance of Wireless Emergency Alerts in Imminent Threat Scenarios

Volume 2: Earthquake, Tsunami and
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Abbreviations

| | |
|-------|---|
| AFR | Alert Failure Rate |
| AO | Alert Originator |
| CMSP | Commercial Mobile Service Provider |
| DHS | Department of Homeland Security |
| EAC | Earthquake Alert Center |
| EEW | Earthquake Early Warning |
| EMP | Electromagnetic Pulse |
| FCC | Federal Communications Commission |
| FEMA | Federal Emergency Management Agency |
| GTA | Geo-Targeted Area |
| GPS | Global Positioning System |
| GTP | Geo-Targeting Performance |
| IPAWS | Integrated Public Alert and Warning System |
| LDZ | Light Damage Zone |
| MDR | Marina Del Rey |
| MDZ | Moderate Damage Zone |
| MTIL | Maximum Tsunami Inundation Line |
| NBM | National Broadband Map |
| NCR | National Capital Region |
| NOAA | National Oceanic and Atmospheric Administration |
| NWS | National Weather Service |
| RAN | Radio Access Network |
| NTWC | National Tsunami Warning Center |
| OAR | Over-Alerting Rate |
| PEW | Percentage of Event Warned |
| POD | Probability of Detection |
| RF | Radio Frequency |
| SDZ | Severe Damage Zone |
| TEZ | Tsunami Evacuation Zone |
| TWP | Tsunami Warning Polygon |
| USGS | U.S. Geological Survey |
| WEA | Wireless Emergency Alert |

Executive Summary

A significant challenge for emergency managers and Alert Originators (AOs) is how to warn people in danger quickly, and avoid warning people not at risk.¹ Providing effective warning of an imminent threat, such as an earthquake or tsunami, can save lives. People can take shelter or move to higher ground if they have enough warning time. If people frequently receive irrelevant warnings, however, they may choose to ignore later warnings that do apply to them. Several terms have been coined for this — warning fatigue and warning complacency. Over-alerting can lead to warning fatigue. Geo-targeted Wireless Emergency Alerts (WEAs) can help reduce over-alerting and alert failures, and increase warning effectiveness.² This study examines how WEA can be used to warn the public in three potentially deadly scenarios:

- A large destructive earthquake;
- A Tsunami ; and
- A terrorist detonation of nuclear weapon in an urban area.

This report also examines how WEAs can be used to evacuate the public from the threat area in each scenario. It evaluates the benefits of providing advance warning of these threats and the potential performance advantages of using alternative cell antenna selection methods for geo-targeting WEA messages.

WEA Geo-targeting Performance for Earthquake Early Warning

In the U.S. Geological Survey (USGS) ShakeOut Scenario, a large earthquake strikes the San Andreas Fault in southern California. In this case, the WEA earthquake early warning (EEW) message reaches more than 99 percent of all people in the warning area, which includes over 18 million people. The EEW message alert failure rates (AFRs) and over-alerting rates (OARs) are shown in Table S.1.

Table S-1: WEA Geo-Targeting Performance (GTP) for Earthquake Warning

| | OAR (%) | AFR (%) |
|-----------------|---------|---------|
| AT&T | 0.1 | 0 |
| Sprint | 0.3 | 0.1 |
| T-Mobile | 0.1 | 0.1 |
| Verizon | 0.1 | 0 |
| Average | 0.15 | 0.05 |

¹ A range of federal, state, local and tribal government officials can be AOs, including emergency managers, as well as National Weather Service weather forecasters.

² Alert failures result when a person in the warning area is not warned but should be.

A detailed error analysis described in the body of this report indicates that the differences between Tier 1 carrier OAR performance shown in the table are not statistically significant, but that all carriers likely have an OAR that is less than 1 percent of the population to be warned. This is the case in the earthquake scenario because the Tier 1 wireless carriers provide very good coverage to high population areas in southern California.

WEA EEW GTP in Moderately-Sized Earthquakes

In the EEW scenario estimated WEA OARs are small, and may appear unimportant because large earthquakes are rare events. Consequently, there appears to be little risk of alert fatigue.

As noted earlier, however, earthquakes are not rare events in California. Past studies of earthquake frequency in southern California reveal the area could experience almost a dozen large to moderate-sized earthquakes each year. These estimates indicate that WEA EEW messages will be rare only if the EEW system is used to warn of large earthquakes of magnitude 6 or higher. If WEA EEW messages are sent for mid-size or moderately-sized earthquakes, a significant number of WEA EEW messages would be transmitted each year in southern California. Consequently, the use of WEA in moderate or mid-size earthquakes could render OARs important.

A related issue is how large the warning polygons would be for smaller earthquakes. For moderately-sized earthquakes, the warning polygons should be much smaller because the damage zone will be much smaller. If the warning polygons used are larger than necessary this could lead to higher OARs than those estimated in this report for a large, magnitude 7.8 quake. It is beyond the scope of the current study to recommend thresholds for the two parameters that will be crucial in determining EEW OARs: (1) the minimum size of earthquake for which a WEA message would be sent; and (2) the size of warning polygons for moderately sized earthquakes. Further study is needed to determine an optimal EEW warning strategy that limit OARs using WEA.

WEA EEW Message Delays

It may be possible to provide more than 100 seconds of warning time to people in the metro Los Angeles area before significant shaking begins in the ShakeOut scenario — but only if the EEW warning can be transmitted to the public with a transmit delay of 20 seconds or less.³

A critical question for the WEA service is whether it can provide the timeliness needed to provide EEW before significant shaking starts in the entire warning area. For a large earthquake such as the one considered in the ShakeOut scenario, it is technically feasible to provide early warning of the earthquake to people in areas far from the epicenter. Seismic sensor networks require approximately 10 seconds to

³ The prototype California Integrated Seismic Network (CISN) requires approximately 10 seconds to process the first signals detected by its seismic sensors and to issue a warning. Previous studies assumed the EEW message would be sent to the public with a delay of 10 seconds or less.

determine the location and strength of the earthquake and to generate the warning message.⁴ If a communications system can deliver the EEW message in 10 seconds or less, it would provide approximately 100 seconds of warning time (for an earthquake similar to the one in the Shakeout scenario).

An EEW system is not yet operational in California, however such a system is under development. Cell phone industry technical experts have studied whether it is feasible for the current version of the WEA service to provide EEW messages to the public. This study found it was not feasible to use the current WEA service for EEW. The report implies the current WEA service transmits WEA messages with substantial time delays that may be as high as 12 minutes.⁵ It is important to note, however, that the current WEA service has never been tested on live carrier networks and that government officials do not have a good understanding of the time delays incurred when using the current WEA service.

Cell phone-based EEW capabilities are currently operational in a number of other countries that use 3G and 4G networks, including Turkey, Mexico, Japan, Romania and Taiwan.⁶ The Japanese and Mexican EEW systems have demonstrated they can provide EEW messages to cell phones with only seconds of delay. Furthermore, the Japanese EEW system uses the same underlying technology as the U.S. WEA service (cell broadcast), so in principal it should be possible to modify the current implementation of the U.S. WEA service so it can provide timely EEW messages.

WEA Tsunami Warning GTP

Three potential tsunami inundation zones in Los Angeles County, California, were examined in this study. These zones are: Marina del Rey, Long Beach Harbor and the Naples Island area just south of Long Beach Harbor. Elsewhere in Los Angeles County tsunami inundation zones are relatively narrow and only a small number of people would be affected.

The study focused on a Tsunami Warning Polygon (TWP) that includes these three densely populated areas. Tier 1 wireless carrier networks provide excellent coverage in the TWP, as long as their networks are not damaged. It is assumed this would be the case, up until the time the tsunami strikes. Analysis of WEA geo-targeting capabilities reveals the tsunami warning AFRs are zero for all four Tier 1 carriers.

OARs are somewhat higher. The average OAR for all three areas and for all carriers is 3.3 percent. In a separate calculation the OAR error rate for the TWP is estimated to be approximately 5 percent. The

⁴ David Talbot, "80 Seconds of Warning for Tokyo," *MIT Technology Review*, 2011, <https://www.technologyreview.com/s/423274/80-seconds-of-warning-for-tokyo/>.

⁵ "Joint ATIS/TIA CMAS Federal Alert Gateway To CMSP Gateway Interface Specification" (Washington DC: Alliance for Telecommunications Industry Solutions and the Telecommunications Industry Association, 2009), https://global.ihs.com/doc_detail.cfm?document_name=ATIS%20J-STD-101.

⁶ Mark Johnson, "California Earthquake Early Warning System," 2015, <http://www.atis.org/newsandevents/webinar-pptslides/EEWSSlides-8252015.pdf>.

source of OAR error is the possible spillover of the WEA radio frequency (RF) signal into nearby cells of the wireless network. Therefore, the differences in OAR estimates for the Tier 1 carriers are not statistically significant. Given this error, the average OAR lies somewhere in the range indicated below:

$$\text{OAR}_{\text{ave}}(\text{TWP}) \approx (3.3\% \text{ to } 8.3\%)$$

The TWP would include 252,156 people. Even with potential RF signal spillover, the number of people that could suffer over-alerting (about 21,500 in the worst case) is far less than would be the case if the tsunami alert were sent to the entire National Weather Service (NWS) CA041 warning area (which includes about onethird of Los Angeles County). This is the warning area that could be used to send a tsunami warning, if standard NWS warning practices were used. More than 4.2 million people live in NWS CA041. They would be alerted of the tsunami, but the vast majority of these people would not be in danger. One can only imagine the economic disruption, traffic and dislocation that would result if over 4 million people were warned of a tsunami and if a significant fraction of these people left work or their home in search of higher ground. The geo-targeting capabilities of the WEA service would prevent this from happening.

Tsunami Evacuation Warning

This study examined how WEA could be used to facilitate the evacuation of Naples Island, which is located on an inland waterway just south of Long Beach Harbor in the event of a tsunami. It would be entirely inundated in a large tsunami. This island is connected to the mainland by three bridges. More than 3,400 people live on the island. In the scenario considered, residents would only have 10 to 15 minutes to evacuate the island. Three zones were defined in the Naples Island Tsunami Evacuation Zone (TEZ) and three geo-targeted WEA messages were sent that directed the population in each sector to evacuate the island using the bridge in each sector.

This is perhaps one of the most challenging scenarios for WEA, as it would require transmission of geo-targeted evacuation messages to very small areas, each less than one-half mile across. We examined the performance of two of the Tier 1 wireless carriers networks for this scenario. The average AFRs for the three zones were found to be 23 percent, 16 percent and 4 percent. The average AFR over the entire island, or TEZ, was estimated to be 13 percent. The error in the AFR estimate, which is due to spillover of the cell broadcast signal, is very small so the average AFR estimate is:

$$\text{AFR}_{\text{ave}}(\text{TEZ}) = 13\%$$

The average OARs for the three evacuation zones were found to be 13 percent, 16 percent and 8.5 percent. The average OAR over the entire island, or TEZ, was estimated to be 14.5 percent. Given the OAR error induced by RF spillover effects, the average OAR could be anywhere in the range below.

$$\text{OAR}_{\text{ave}}(\text{TEZ}) \approx (14.5\% \text{ to } 19.5\%)$$

In this case the individual evacuation warning polygons are small and perimeter RF spillover effects are significant. Despite these errors, the results suggest the WEA service could play a positive role in the evacuation of Naples Island and could help the majority of the island's population evacuate efficiently.

WEA Message Delay Can Impact Tsunami Warning Effectiveness

A separate concern in this scenario is the responsiveness of the WEA service. If it would take 10 minutes for the WEA tsunami warning message to be received by the population under threat, there would not be enough time for the orderly evacuation of these low lying areas. On the other hand, if the WEA message could be delivered within 10 to 20 seconds after the initial tsunami is detected, it may be possible to evacuate these areas in an orderly fashion (this assumes the tsunami warning had already been created ahead of time by local emergency managers so they could be sent at the push of button). This example highlights the need for emergency managers and AOs to better understand the responsiveness of the WEA service so that they can plan to use WEA in an effective way.

GTP for WEA Radiation Hazard and Evacuation Warning

The third imminent threat scenario began with a nuclear terrorist attack in Washington, D.C. This study focused on WEA use after the attack to minimize the exposure of the surviving population to hazardous fallout and radiation. The details of the scenario are taken from the Department of Homeland Security (DHS) study “Key Response Planning Factors for the Aftermath of Nuclear Terrorism”. The scenario includes a dangerous fallout zone that extends up to 40 miles away from the center of Washington, D.C. A larger “Hot” or hazardous radiation zone would exist for up to 12 hours after the attack and would extend hundreds of miles away and cover several states, including a small part of New Jersey. This report examines how WEA could be used to send shelter-in-place instructions to people in both warning areas.

More than 2.4 million people are located in the hot zone. If the Tier 1 wireless networks remain largely intact outside of the blast damage area, the WEA hot zone alert would be received by 98 percent of the people in the warning area. Only those located closest to the blast would not receive message, either because their phones no longer worked or because of damage to the wireless network infrastructure.

More than 587,000 people would be located in the dangerous fallout warning area. About 90 percent of the population in the dangerous fallout zone would be warned. Approximately 10 percent of the population in this smaller warning area would not receive the message, either because their phones would not work or because of damage to the wireless networks nearby and inside the blast zone.

WEA GTP for Evacuation Warning

WEA GTP was examined in the terrorist nuclear attack scenario when evacuation warnings are issued to an area that suffers heavy damage and lacks power and other essential services. Consistent with the findings of the earlier DHS study of this scenario, it is assumed that most of the wireless network would still be working in the evacuation zone. Given this assumption, Tier 1 carrier AFRs are estimated to be zero, even when errors due to RF spillover effects are included. The average OAR for the evacuation scenario was found to be small — 2.2 percent — although it could be as high as 7.2 percent when potential errors in our estimation technique are taken into account.

Relationship Between WEA GTP and Warning Area Size

Analysis of the three scenarios above shows there is a tradeoff between the size of the warning area or polygon and WEA GTP. WEA geo-targeting accuracy is higher for larger warning areas, as is the case in the EEW scenario. On the other hand, WEA geo-targeting accuracy is lower for smaller warning areas. OARs increase for small warning polygons, such as those used for tsunami and damage zone evacuation orders.

WEA antenna selection method 1 provides better performance than method 2 for the case where evacuation warning messages are issued in a small densely populated urban area. This assessment is based on OAR differences as both methods yield an AFR of zero in this case. The evacuation warning areas considered in this study are relatively small. For larger areas we did not find a statistically significant difference in performance between methods 1 and 2.

Recommendations

WEA and EEW

This study found that WEA can effectively geo-target EEW messages. Industry studies imply that EEW message time delay may be too large to provide effective warning using the current WEA service, however. In light of these findings it is recommended that DHS, the state of California, the state of Oregon (where an EEW system is also under development) and the USGS investigate whether there are relatively inexpensive ways to modify the current WEA service to improve its responsiveness.

Consistent with this objective, it is recommended that the WEA service be tested on the West Coast and in the National Capital Region to measure WEA message delays. If there is a significant time difference in message latency between East Coast and West Coast WEA messages, it may make sense to establish a second Integrated Public Alert and Warning System (IPAWS) aggregator on the West Coast to support WEA messaging and which would be dedicated to EEW.

An EEW specific WEA test should be conducted on the West Coast to determine if the current WEA service could be useful for EEW even without improvements. If testing determines it is necessary, DHS, the Federal Communications Commission (FCC), and the Tier 1 wireless carriers should explore technical solutions that can reduce WEA message transmission time delays from minutes to seconds to make WEA EEW feasible in 4G networks. If instrumented properly, such a test could determine the source of the largest time delays in the system.

A new IPAWS aggregator backup node could be located on the West Coast and would provide resilience to the IPAWS architecture. This IPAWS aggregator backup node would be designated as the primary node for issuing WEA EEW messages. This would reduce delays in the WEA EEW message transmission process, relieving the primary IPAWS aggregator of the very short EEW message timeliness requirements

and, most importantly, would enable existing WEA capable handsets currently used by millions of Californians to receive WEA messages.

A separate study may be required (depending upon the WEA service test results) to determine whether modifications would be needed in Tier 1 wireless carrier networks to reduce WEA time delays in carrier networks for EEW.

The cell phone industry is studying how to improve the next version of the WEA service, which will be implemented on advanced 4G Long Term Evolution (LTE) networks. A recent wireless industry study assumed that WEA would not be used for transmitting EEW messages to cell phones, i.e., that EEW messages would not be sent to the IPAWS aggregator (which is located near Washington, D.C.) and instead would be sent to the Tier 1 wireless carriers from a new special purpose Earthquake Alert Center (EAC) located somewhere in California. Presumably the EAC would be funded by the State of California, as it would not be part of the IPAWS architecture. This alternative may not be easily extensible to a national EEW system. It is recommended instead that industry focus on extending the WEA service in LTE networks so it can support EEW timeliness requirements. This alternative also has the advantage that it would make use of the millions of WEA capable handsets already in circulation in western states. The current capabilities of the Japanese EEW system demonstrate this is an achievable goal for 4G networks.

WEA and Tsunami Warning

This analysis shows that WEA has the geo-targeting capabilities to provide effective tsunami warning. The timeliness of tsunami warning is also an issue, just as it is with EEW, although the timeliness requirements are not as severe. A tsunami generated from an earthquake far in the western Pacific Ocean would take hours to reach the California coastline. In this case, the current WEA service would provide sufficient tsunami warning time. A tsunami generated from an undersea fault located hundreds of miles off shore would reach coast within 10 to 15 minutes, however. It could take someone located in a threatened area 10 minutes or more to reach higher ground. Reducing time delays in the WEA service will make it a more useful system for tsunami warning, regardless of the source location of the tsunami.

Emergency managers will also need to have WEA tsunami warning messages pre-loaded and ready to go to meet desired warning times. The National Oceanic and Atmospheric Administration, USGS, and the California Office of Emergency Services (CAL-OES) have developed tsunami emergency response playbooks to speed up the tsunami warning process.⁷ These playbooks should be revised to include pre-defined WEA tsunami warning messages. DHS and FCC should work to reduce WEA message transmission time delays to maximize the value of WEAs for tsunami warning.

⁷ Rick I. Wilson and Kevin M. Miller, "Tsunami Emergency Response Playbooks and FASTER Tsunami Height Calculation: Background Information and Guidance for Use" (California Geological Survey, 2014), <http://nws.weather.gov/nthmp/2013mesmms/abstracts/Californiaevacplaybook.pdf>.

Conduct an Information Sharing Experiment with the Wireless Industry to Improve WEA Geo-Targeting Accuracy

Could further improvements be made to WEA when precision geo-targeting of WEA messages is required? This report shows how knowing the location of cell towers and coverage areas can inform public safety planning and responses. Further improvement in WEA GTP is possible if government emergency managers had access to the actual location of Tier 1 carrier cell antennas and coverage areas. We recommend the FCC approach the Tier 1 wireless carriers and ask them to consider a limited experiment in which the carriers provide precise data for a limited number of small controlled test areas to calibrate the accuracy of the methods developed in this study.

Sharing Information on Wireless Network Damage

Several of the scenarios considered included the broadcast of WEA messages after significant damage has probably occurred in the affected area. In these cases it is likely that the cell phone network will have suffered significant damage and may not be operational in some areas. Carrier operators will know whether parts of their network are damaged, but AOs may not. Because of the possibility of damage, AOs may hesitate to issue WEA messages to affected areas. If the network operators informed AOs of the status of their networks after events such as an earthquake or terrorist attack, it would facilitate AO planning on how and whether to use WEA messages after these destructive events. Therefore, it is recommended that the Tier 1 carriers inform local emergency managers and AOs if their networks suffer significant damage, and where coverage gaps result from such damage.

1. Introduction

The Wireless Emergency Alert (WEA) system provides a powerful tool for alert originators (AOs) as it sends emergency messages to anyone with a WEA-capable mobile device.⁸ It is a nationwide system that is integrated with the Federal Emergency Management Agency (FEMA) Integrated Public Alert and Warning System (IPAWS). The IPAWS aggregator authenticates all WEA messages transmitted by AOs and forwards them to the wireless carriers providing WEA coverage in the affected area. The wireless networks of the four Tier 1 carriers in the U.S. are all WEA-capable, and the wireless networks of many other smaller wireless carriers are also capable.⁹ National Weather Service (NWS) Weather Forecast Offices (WFOs) and emergency managers at the local, state and federal levels today send thousands of WEA imminent threat alerts to people in affected areas throughout the U.S.

The WEA system has been operational since 2012, but many aspects of its performance have not been systematically tested in live carrier networks. Questions remain regarding the timeliness of WEA messages. For example, how much delay is incurred from the time a message is transmitted by the AO to the time when it is received on cell phones? Questions also exist about the level of geo-targeting accuracy WEA can achieve. For example, when a WEA message is sent to only people who are located within 5 miles of a tornado track, how many people in the affected area will receive the message? And will people outside of the area also receive the message?

AOs have expressed a desire to better understand WEA geo-targeting capabilities and limitations. Uncertainty persists because the major wireless carriers consider the radio frequency (RF) coverage details and performance of their networks to be proprietary. Although the wireless carriers publish low-resolution nationwide wireless network coverage maps, they closely guard the detailed coverage provided by small subsets of their networks that would be needed to assess geo-targeting accuracy of WEA messages sent to small threat areas. They consider the detailed coverage of their networks and the location of key components such as cellular antennas to be proprietary, leaving AOs to guess how they should define warning polygons that are used to geo-target WEA messages.

1.1 Research Objectives

Improving the geo-targeting capabilities of WEA messages was one of the top research priorities of the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) in 2012, the other being public response. DHS S&T awarded RAND Corporation a contract in 2013 to answer the following questions: What is the optimal WEA RF geo-targeted area (GTA) for specific types of imminent threat

⁸ A range of federal, state, local and tribal government officials can be AOs, including emergency managers and NWS weather forecasters.

⁹“Wireless Emergency Alerts Mobile Penetration Strategy” (Department of Homeland Security, 2013), <http://www.firstresponder.gov/TechnologyDocuments/Wireless%20Emergency%20Alerts%20Mobile%20Penetration%20Strategy.pdf>.

scenarios and can the wireless or cellular communications networks provide the level of geo-targeting desired in these different scenarios and environments?

Consistent with these questions the objectives of this study are to evaluate the public benefit and operational performance trade-offs of precisely geo-targeted WEA messages and to identify the optimal WEA RF GTA sizes for the following four imminent threat scenarios:

- Tornado warnings in Alabama;
- Earthquake in southern California;
- Tsunami warning and coastal evacuation orders in southern California; and
- Nuclear radiation and hazardous airborne plume warnings in the U.S. National Capital Region.

This study is divided into two volumes because of the size and complexity of the analysis related to different imminent threat scenarios. The results of the tornado scenario are described in Volume 1 of the report. This second volume is focused on the quantitative geo-targeting analysis of the earthquake, tsunami and nuclear radiation scenarios.

This research can assist AOs in constructing accurate WEA warning areas, and senior decision makers in the federal government (i.e., DHS S&T, FEMA and the Federal Communications Commission (FCC)) that are concerned with the operation and modernization of the WEA system and the revision of WEA regulations and standards that will improve WEA geo-targeting accuracy.

1.2 Organization of this Report

This report is organized as follows: Section 2 provides a brief overview of the analytical approach and methods used in this study. Section 3 describes the events and timeline for the earthquake early warning scenario. Section 4 examines the RF coverage provided by the Tier 1 wireless carriers in the southern California area where the earthquake occurs. Section 5 examines geo-targeting performance (GTP) of the WEA service in the earthquake early warning (EEW) scenario. Section 6 describes the tsunami warning scenario and Section 7 presents the results of the WEA geo-targeting analysis for this scenario. Section 8 describes the events and timeline for the nuclear terrorism scenario. The WEA service could play a key role if such an attack were to occur, especially to warn people of radiation hazards and evacuation routes. Section 9 summarizes the geo-targeting analysis of WEA messages for radiation and evacuation warnings for this nuclear incident scenario. This report ends with Section 10, which includes the conclusions of the study.

2. Analytical Approach

In an ideal situation, AOs would have perfect knowledge of the hazard or threat and the area affected, along with the capabilities and limitations of the commercial mobile service provider (CMSP) radio access network (RAN). If this were the case, AOs could send a WEA message precisely to the area and people threatened. Of course, such an assumption is unrealistic and AOs have to estimate not only the size of the area under threat, but also the dimensions of RF coverage area to which the geo-targeted WEA message will actually go. Today they do this as best they can with the limited information available to them on the configuration and coverage of the wireless carrier networks in their area.

This analysis estimates the size of the RAN coverage area given the dimensions of a warning polygon specified by the AO for four specific imminent threat scenarios. It also examines whether it is possible to identify the best method for selecting cellular network antennas for a given warning polygon. The optimal size can potentially be determined by balancing trade-offs between WEA cell broadcast coverage provided by the CMSP RAN, uncertainty regarding the size of the cell broadcast coverage area, the lifesaving potential of alerting the public in the affected area, and the potential for inducing alert fatigue (if alerts are sent too often, or the public is over-alerted, when they are not under threat). This analysis incorporates the uncertainties associated with the specific circumstances of an emergency incident, and uses study results for potential future imminent threat scenarios to estimate the size of the area impacted by a specific type of hazard or imminent threat. The approach is summarized briefly below. A more detailed description of the approach can be found in Volume 1 of this report.

An overview of the WEA GTP methodology is illustrated in Figure 2.1. The data inputs essential for the method are shown on the left hand side of the figure. The outputs are shown in the right. Inputs include a variety of public and commercial data sources that were used to estimate the coverage of CMSP wireless networks.

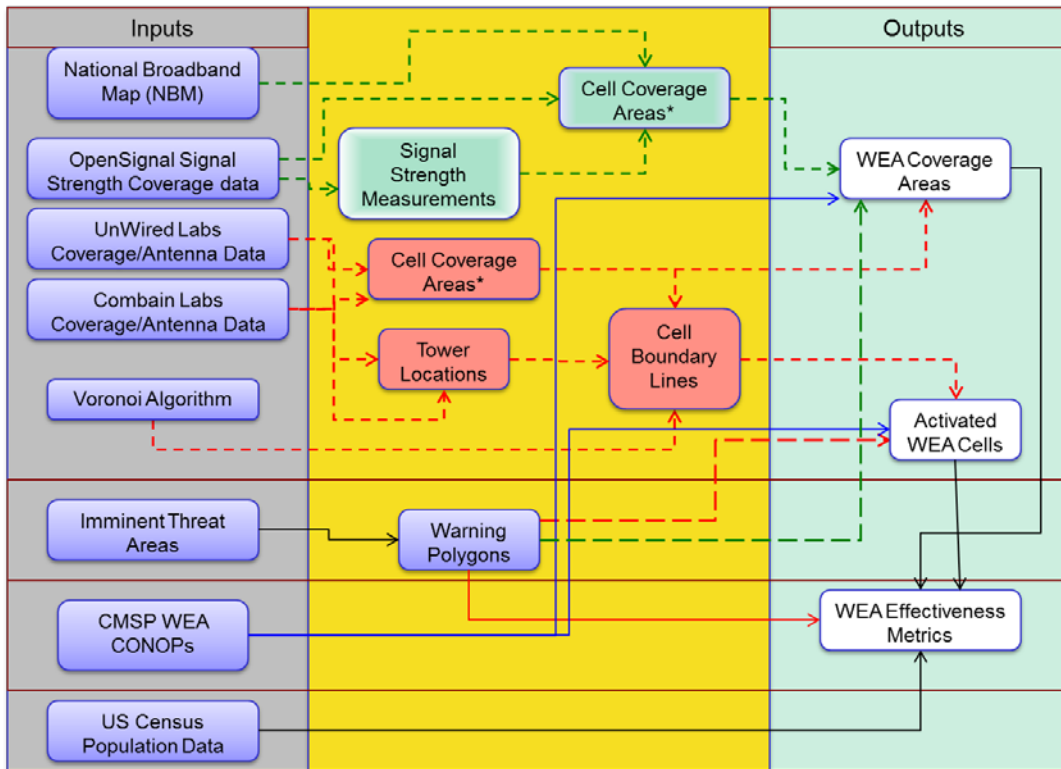
2.1 Cellular Network Radio Frequency Coverage Analysis

This study considers only the RF coverage provided by the four Tier 1 CMSPs: AT&T, T-Mobile, Sprint and Verizon. Two methods were developed and used to estimate the geospatial coverage of the CMSP RAN, depending upon the type of data available for each carrier. CMSP RAN antenna locations were used to estimate the geospatial dimensions of individual cells in the RAN using the Voronoi method. The key steps in this method are shown in Figure 2.1 using red dashed lines, with intermediate products highlighted in a light red background color. Because CMSPs do not readily reveal the location of their towers and antennas, the commercial data sources shown in the figure (Unwired Labs¹⁰ and Combain¹¹) were used to estimate tower locations and coverage.

¹⁰ “Unwired Labs Location API - Geolocation API and Mobile Triangulation API, Cell Tower Database,” *Unwired Labs Location API - Geolocation & Mobile Triangulation API*, accessed December 12, 2015, <http://unwiredlabs.com>.

¹¹ Lund Combain AB Sweden, “Wifi Positioning | Wifi Location | Cell ID - Combain,” *Combain Positioning Systems*, accessed November 3, 2015, <https://combain.com/>.

Figure 2-1: Analysis Methodology



- Two methods used – depending on type of data available for carrier network
- Methods indicated in green and red

In some parts of the U.S. Unwired Labs and Combain did not provide enough data to employ the Voronoi method. If this were the case, a second method was used to compute WEA coverage areas. The key steps in the second method are shown in Figure 2.1 using green dashed lines, with intermediate products highlighted in a light green background color.

In the second method, CMSP RAN coverage patterns were estimated using a combination of the FCC National Broadband Map (NBM) and data from another non-proprietary commercial source data provider — OpenSignal.com.¹² For further information on the methods used to estimate WEA coverage and on the commercial data sources used the reader is referred to Volume 1 of this report.

Imminent Threat Warning Areas

As mentioned above, authoritative studies of relevant imminent threat scenarios were used to define the warning polygons used in this analysis. The imminent threat scenarios considered are hypothetical in each case, because such events or incidents have not occurred, but they are considered possible and in some cases probable events for which emergency managers should plan.

¹² "OpenSignal.com," accessed November 3, 2015, <http://opensignal.com/about/>.

Today the AO defines the warning area as a warning polygon that can be used in a WEA message. This is done manually or automatically using software tools with little or no information on the CMSP RAN. In addition, WEA warning polygons are currently limited to 100 vertices and so it may only approximate the dimensions of the actual warning area and to polygons without crossing lines.

Yet another essential input to the analysis are the WEA antenna selection methods assumed to be used by CMSPs when transmitting WEA messages to their subscribers. These methods are described in the following section, “WEA Antenna Selection Methods.”

The results of the analysis are shown on the right hand side of Figure 2.1. Key results include the specific CMSP RAN cells activated in each imminent threat scenario. In some cases it is possible to determine these cells, depending upon the data available from commercial data sources. Another key result are areas covered by the WEA message. This type of result does not include the cells activated by the WEA transmission (because of data limitations), but it does include the area covered and the populations that receive the WEA message. These results are used to estimate WEA GTP in each imminent threat scenario. For more detail on the methods and algorithms used in the analysis, see Section 2 of Volume 1 of this report.

2.2 WEA Antenna Selection Methods

When an AO designs and sends an emergency alert, there are a variety of options for designating the geographic area that should be notified. The easiest and most primitive approach is to send the alert to an entire county, which is how WEA was originally envisioned. Some smaller AOs and disseminators do not have the capability to do otherwise.¹³ The largest AO (the NWS) and the largest alert disseminators (the Tier 1 carriers) are able to more accurately geo-target the geographic boundaries of around the population at risk, however. The mechanism used for geo-targeting is a geographic “polygon” which is comprised of a set of points and lines that delineate the boundary of the area under threat. There are significant limitations associated with accurately drawing the line. The WEA standard limits the number of points (vertices) to 100 per polygon.¹⁴ In contrast the NWS’s warning systems are not capable of producing warning polygons that use more than 20 vertices.¹⁵ This may narrow the geographic area that receives the alert and thus reduces the amount of over-alerting.

When an AO produces and sends a polygon to the alert disseminators, the disseminator can choose which cells will receive the broadcast alert. In method 1 (see Figure 2.2), only cell towers that are in the

¹³ “Wireless Emergency Alerts Mobile Penetration Strategy.”

¹⁴ “Joint ATIS/TIA CMAS Federal Alert Gateway To CMSP Gateway Interface Specification.”

¹⁵ “Storm Based Warnings: A Review of the First Year: October 1, 2007 through June 30, 2008” (National Weather Service, Office of Climate, Water, and Weather Services, February 18, 2016), http://www.wral.com/asset/weather/2008/10/15/3741623/SBW_report_6.pdf.

alert polygon broadcast the alert.¹⁶ In method 2 (see Figure 2.3), cells that are inside of and those that intersect with the alert polygon broadcast the alert.¹⁷ Sections 3, 4 and 5 show the impact of WEA alerting methods on over-alerting and alert failure rates.

Figure 2-2: WEA Method 1



Figure 2-3: WEA Method 2



There are other methods that can be used to determine which antennas in a cellular network should be illuminated to send a WEA alert to maximize RF coverage of the warning polygon. Some wireless carriers may use a centroid method to select antennas for WEA messaging in Long Term Evolution (LTE) networks that can make use of cell sector antenna systems.¹⁸ In addition, TeleCommunication Systems, Inc., an industry firm, has proposed a similar algorithm for selecting antennas for WEA messaging. In this study we only examine WEA methods 1 and 2 and not these other methods because they require knowledge of sector antennas, information which is not typically available from commercial information sources.

2.3 U.S. Population Data

U.S. census population data is another essential input to the analysis. It is used to determine the population under threat and to estimate the WEA GTP metrics described below.

Several population data sources were considered. The most detailed and comprehensive is the decennial census conducted by the U.S. Census Bureau. From that, the most geographically precise area that the bureau publishes is a census block, which represents the residential locations of individuals. This is typically most accurate in the evenings and at night while most people are at home. These are,

¹⁶ *Geotargeted Alerts and Warnings: Report of a Workshop on Current Knowledge and Research Gaps* (Washington, D.C.: National Academies Press, 2013), <http://www.nap.edu/catalog/18414>.

¹⁷ *Ibid.*

¹⁸ "Feasibility Study For Wea Cell Broadcast Geo-Targeting" (Alliance for Telecommunications Industry Solutions, 2015), https://access.atIS.org/apps/group_public/download.php/25924/ATIS-0700027-FeasibilityStudy.pdf.

however, the smallest geographic areas that the census publicly reports data for. For this analysis, the 2010 decennial census was selected, which is the most recent dataset on the residential location of individuals.¹⁹

2.4 Cellular Mobile Device and CMSP Subscriber Data

Once an estimate of the location of the population has been developed, an estimate of the proportion of the population that has a WEA compatible mobile device connected to a participating CMSP is made. The Pew Research Center Estimates that 90 percent of the U.S. adults have a mobile phone (64 percent of U.S. adults have smartphones).²⁰ Further, based on RAND's analysis of comScore data, it is estimated that 59 percent of the mobile phone population was WEA compatible as of December 2014.²¹ This represents significant growth in the number of WEA compatible phones (three years ago, the number was essentially zero). Using these data it is estimated that by December 2016, 90 percent of all mobile devices will be WEA compatible.²²

The mobile network that a device is connected to also has an effect on whether the device will receive a WEA message. Although there are more than 80 mobile network operators in the U.S.,²³ the four largest Tier 1 carriers represent 98 percent of the market.²⁴ Figure 2.4 represents the market share of each of Tier 1 carrier as of the third quarter of 2015.²⁵ To simplify our analysis, a proportion of each census block's population was assigned to one of the top four carriers to estimate whether they would receive a WEA message.

¹⁹ U.S. Census Bureau Administration and Customer Services Division, "US Census Bureau Publications - Census of Population and Housing," accessed February 18, 2016, <http://www.census.gov/prod/www/decennial.html>.

²⁰ <http://www.pewinternet.org/data-trend/mobile/cell-phone-and-smartphone-ownership-demographics/>.

²¹ To estimate this, we used the WEA compatible phone models from the Tier 1 carrier websites and purchased mobile phone market survey data from comScore to count how many of each model is currently in use.

²² Department of Homeland Security, Wireless Emergency Alerts – Mobile Penetration Strategy, July 2013. <http://www.firstresponder.gov/TechnologyDocuments/Wireless%20Emergency%20Alerts%20Mobile%20Penetration%20Strategy.pdf>.

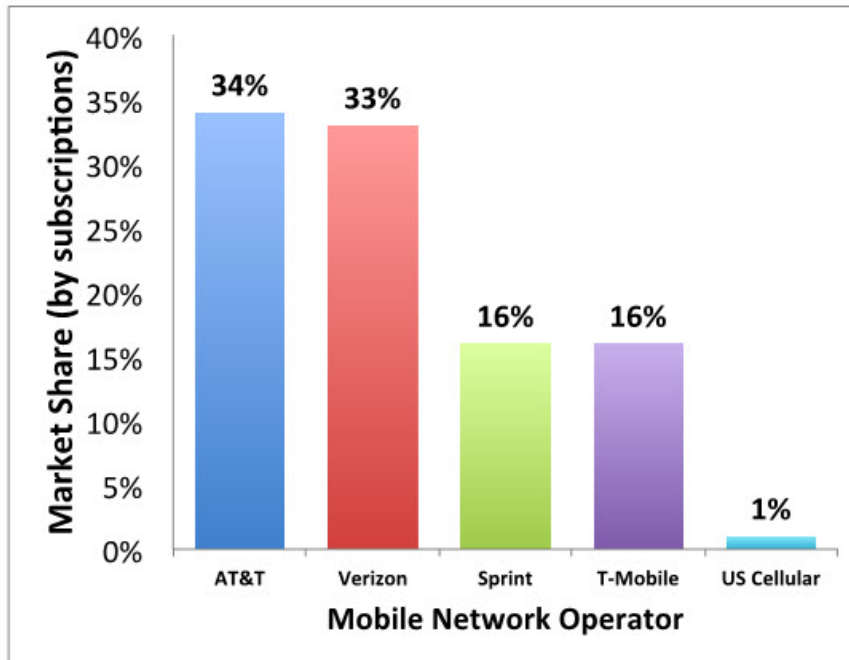
²³ https://en.wikipedia.org/wiki/List_of_United_States_wireless_communications_service_providers.

²⁴ This includes Mobile Virtual Network Operators such as Tracfone, Boost, Virgin, Cricket, etc., who purchase network bandwidth directly from the larger carriers and re-sell it to subscribers.

²⁵ Chetan Sharma Consulting via Statistia.com

<http://www.statista.com/statistics/199359/market-share-of-wireless-carriers-in-the-us-by-subscriptions/>.

Figure 2-4: Tier 1 Carrier Market Share by Subscribers



Source: Chetan Sharma Consulting via Statistia.com

2.5 WEA GTP Metrics

For each warning polygon defined in each scenario, the RF coverage methods described above and U.S. census data are used to estimate the alert failure rate (AFR) and an over-alert rate (OAR) for selected WEA messages. This is done by overlaying the alert polygons on the Voronoi-derived cell network, or by overlaying the alert polygons on a composite estimate of the CMSP coverage area (the composite is based on a coverage superset that includes coverage data from the NBM and OpenSignal.com). Depending on the WEA broadcast method, we select the cells that will be broadcasted the alert. The population in the census block's centroids that are within an alerted cell are then tabulated only if that population has cellular network coverage (according to our combined NBM and OpenSignal estimates). If that population has coverage, then the population is added to the "alerted" category. If that population lies within the geo-targeted polygon, then they are assigned to the true positive category. If the population lies outside the alert polygon, they are assigned to the false positive category (over-alerting). If the population lies within the warning polygon, but does not receive the alert due to lack of coverage or because their "cell" was not selected to broadcast the alert, then this population is added to the false negative category (warning failure):

- Warning rate (true positive): Percent receiving alert that should receive it;
- OAR (false positive): Percent receiving alert that should not receive it; and
- AFR (false negative): Percent not receiving alert that should receive it.

Figure 2-5: WEA GTP Metrics

| | Population that received the alert | Population that did not receive the alert |
|---|---|---|
| Population that should receive the alert | Percent receiving alert that should receive it | Percent not receiving alert that should receive it |
| Population that should not receive the alert | Percent receiving alert that should not receive it | |

If the Voronoi method is used, all the alerting rates shown in Figure 2-5 are estimated. The alerting rate is shown green in Figure 2-5, AFR is shown in red and OAR is shown in yellow. If this second CMSP RAN coverage estimation method is used, it is possible to obtain alerting and alert failure rate estimates, but not an over-alerting rate.

2.6 RF Coverage Errors

Volume 1 describes the two methods used to estimate the RF coverage of cellular networks: (1) the high resolution Voronoi method; and (2) the flat coverage method, where cell geometry data is not available. Volume 1 also describes the errors associated with the two methods. In Volume 1 it was shown that errors in the RF coverage estimates affect the accuracy of alert failure and over-alerting rate estimates. These errors are situation dependent, as they depend upon the size of the warning polygon, population density and other factors. We use the same RF coverage error estimating techniques and apply them to CMSP RAN coverage of the warning polygons considered in Volume 2.

The AFR and OAR errors associated with the two RF coverage estimation methods are shown in Table 2-1. For densely populated urban areas these errors are relatively small, and can be smaller still if the warning polygon is large and has an area much larger than its perimeter. For sparsely populated rural areas and for small warning polygons, the AFR error and the OAR error is relatively large, as shown in Table 2-1. For alert warning polygons that cover areas with urban and rural populations densities, and which are moderate in size, the error rates will typically be somewhere in between the rural and urban cases. The derivation of these error rates is given in Volume 1.

Table 2-1: Geo-Targeting Metric Error Estimates

| | AFR Error (%) | OAR Error (%) |
|--|---------------|---------------|
| Rural, sparsely populated, small area (AL) | 5 | 15 |
| Urban, densely populated, small area (Naples, CA) | 0 | 5 |
| Urban, densely populated, moderately sized area (AL) | 0.5 | 3.6 |

For small densely populated areas where cellular network coverage is very good (such as along the coast of southern California) it is found that AFR error is very small, but because of potential RF signal spillover effects the OAR error can still be large, or about 5 percent, as indicated in Table 2-1.

The error rates for very large warning polygons (i.e., those that have many more interior Voronoi cells than perimeter cells), can be lower than those shown in the table above. This is examined in the EEW scenario. In Section 4 it is shown that in this case the AFR can be zero, and the OAR can be very low — on the order of 1 percent or less, even though significant parts of the warning polygon are not covered by any wireless carrier.

Finally, note that both the AFR and OAR errors are biased, but in opposite directions. The AFR error is biased downward. As explained in Volume 1, RF spillover effects mean that cell broadcast RF signals can spill over into areas where no RF coverage was initially estimated. The spillover effects reduce the AFR, according to the maximum possible error shown in Table 2-1. The AFR error rate cannot add to the baseline AFR estimate (as there is no such thing as a negative RF spillover effect), however.

On the other hand, OAR behaves in the opposite way. If significant RF spillover occurs into neighboring cells, the OAR can increase up to the maximum error rate given in Table 2-1. Similarly, the OAR cannot subtract from the baseline OAR estimate.

3. Earthquake Early Warning Scenario

One of the most devastating natural disasters that could strike California is a major earthquake. Even just a partial release of the energy stored in the San Andreas Fault could lead to widespread destruction in one of the United States' most densely populated areas. Although long-term prediction of an earthquake is still not possible, earthquake warnings can be issued — and potentially acted upon — during the short time that it takes for shock waves to travel from the epicenter of an earthquake to an affected area. This requires a warning system working on a timeline of seconds.

Due to the large size of the area affected by an earthquake, geo-targeting granularity may not be as critical as for smaller-scale disasters; however, it still would be important since not all areas of a county will be affected equally, as shown below in one particular earthquake scenario considered probable by the U.S. Geological Survey (USGS).

3.1 EEW

An EEW system is composed of a set of distributed seismic sensors that are networked to an Earthquake Alert Center (EAC). The EAC would employ automated decision-making algorithms to quickly generate and transmit a warning message to the public.

An earthquake generates two types of waves — S- and P-waves. P-, or compressional, waves move quickly from the epicenter of the quake, but do not cause much damage. S-waves on the other hand move the Earth physically like an ocean wave moves through water. The S-wave contains much of the kinetic energy of earthquake and is more damaging.

EEW systems rely upon the detection of the P-wave first. P-waves are detected by the network of seismic sensors. These detections are sent to the EAC. The EAC triangulates on these detection events and estimates the epicenter of the earthquake and its strength or magnitude. Once this information is available, an automated decision algorithm issues an EEW message to the area that will experience the greatest destructive effects of the quake or the most shaking.

As of 2015, EEW systems are operational in Japan, Mexico, Taiwan, Turkey and Romania. The systems in Japan and Mexico can also send EEW messages directly to cell phones. These systems can provide advanced warning of a large earthquake with an epicenter 20 or more miles away.

Such a system is not yet operational in the United States although several are under development along the West Coast. The USGS, in partnership with the State of California and several California universities, is developing the California Integrated Seismic Network (CISN), which is designed to provide early warning of an earthquake. CISN is not yet integrated with any U.S. wireless cellular carrier network.

EEW could provide significant public safety and economic benefits if timely early warning messages were transmitted to industrial facilities, transportation systems, airports, hospitals, buildings (including

elevators) and to the public. People could seek cover in safe parts of buildings. Hazardous manufacturing processes and oil and gas pipelines could be shut down to reduce the risks of explosion and fire. Elevators could be stopped and opened at the closest floor reducing the number of people trapped. Delicate surgical operations could be suspended before major shaking begins. These and other steps enabled by EEW could reduce economic damage and fatalities and injuries caused by an earthquake. To reach the general public, however, EEW messages would have to be sent to cell phones, especially if the earthquake were to occur during the day when people are outside of their homes. Later, this section examines the technical issues involved with sending EEW messages to cell phones by means of the WEA service. In the scenario description below it is assumed the CISON has become operational and that WEA EEW is technically feasible and operational (perhaps only on 5G networks, as described below).

3.2 Scenario Description

This analysis is based on the USGS “ShakeOut Scenario” published in 2008 and which has since found widespread adoption for earthquake-related disaster planning and preparedness exercises.²⁶ The scenario assumes a release of the San Andreas Fault that will generate an earthquake of magnitude 7.8. Such an earthquake would have devastating effects on Los Angeles and surrounding areas (Figure 3-1).

Based on a simulation of shock wave propagation conducted by the USGS,²⁷ approximately 45 seconds will pass between when the earthquake can be first detected at its epicenter and when the first shock waves reach the Los Angeles basin. Strong ground shake will occur in Los Angeles at about 75 to 200 seconds (Figure 3-2), with the worst ground shake between about 100 and 120 seconds.

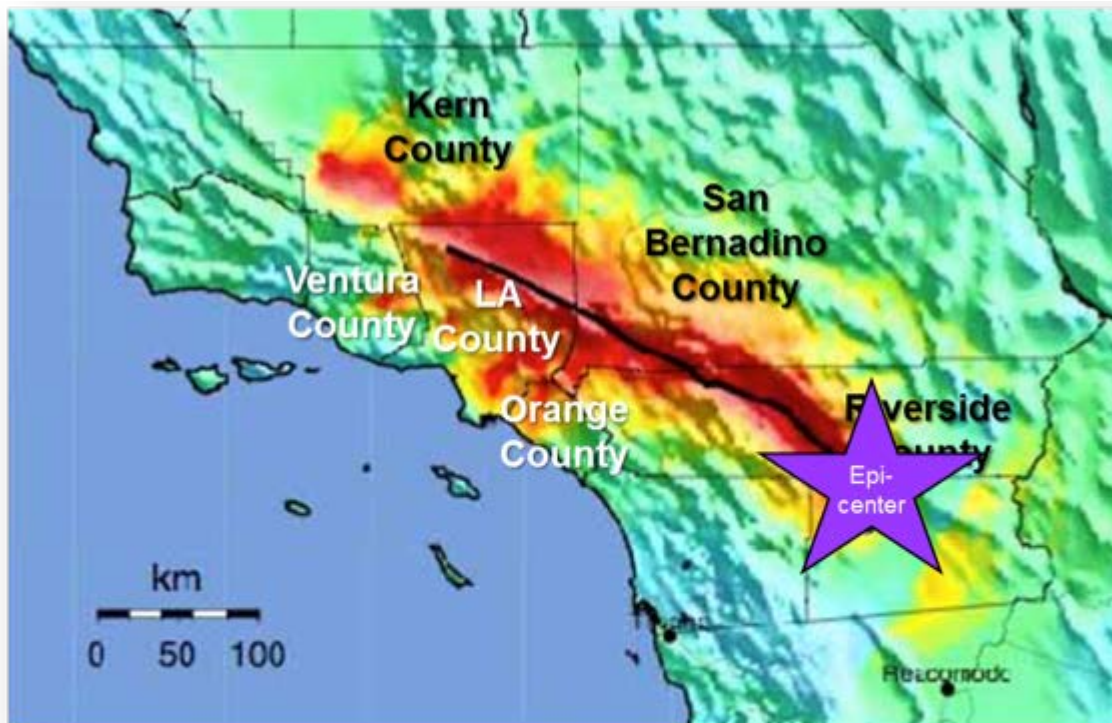
Is this scenario realistic? The southern San Andreas Fault has been identified as one of the most likely locations for a very large earthquake in California. Geologists that have studied the region conclude the southern San Andreas Fault has generated earthquakes of magnitude 7.8 or greater on average every 150 years. The last earthquake in this region occurred more than 300 years ago, so one can conclude that the southern San Andreas Fault is overdue for a large earthquake. Furthermore, geologists have concluded the most likely initial rupture point for this type of quake is one of the endpoints of the fault.

Although the details of this scenario are specific to the assumptions laid out in the ShakeOut Scenario report, the underlying considerations are applicable to most if not all parts of the U.S. that are threatened by earthquakes.

²⁶ U.S. Geological Survey, “The Great California ShakeOut - Southern San Andreas ShakeOut Scenario,” accessed March 16, 2016, <http://www.shakeout.org/california/scenario/>.

²⁷ http://earthquake.usgs.gov/regional/nca/simulations/animation.php?mov=ShakeOut_mapview&set=shakeout.

Figure 3-1: Earthquake Scenario Overview Map Showing Expected Intensity and Damage



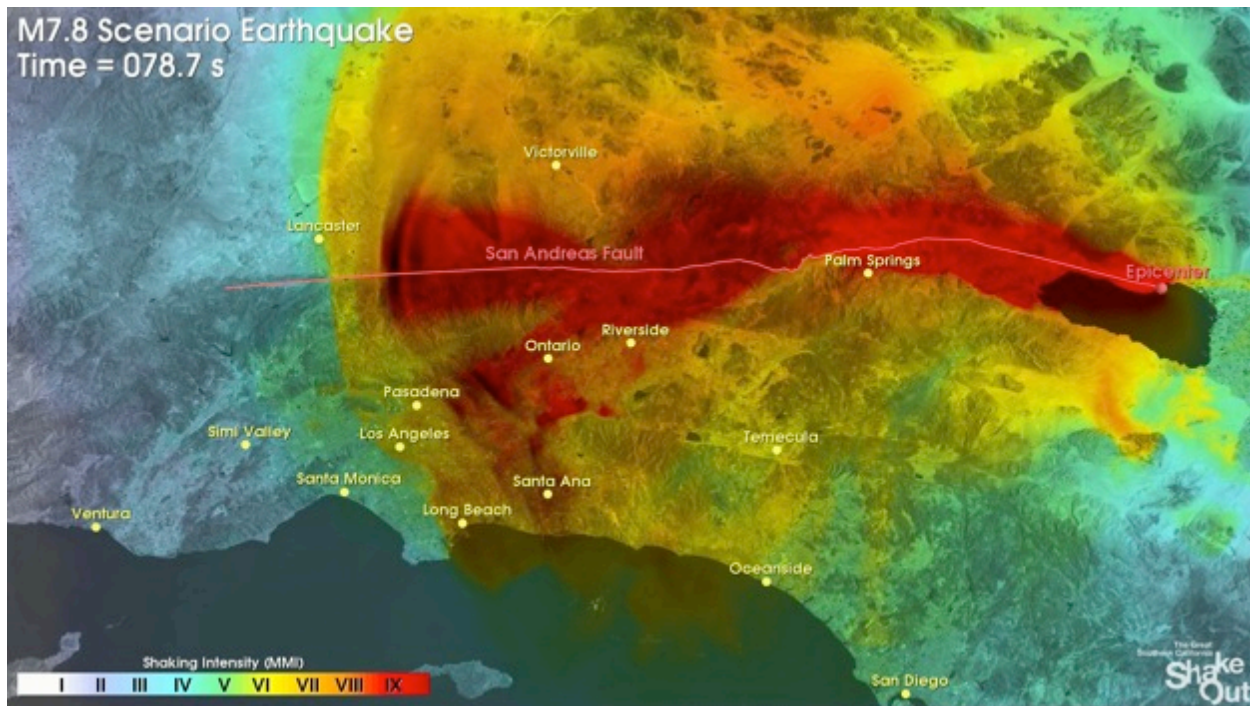
Modified Mercalli Intensity Scale

| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|------------------------|----------|---------|---------|------------|--------|-------------|----------------|---------|------------|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
| PEAK ACC. (%g) | <17 | .17-1.4 | 1.4-3.9 | 3.9-9.2 | 9.2-18 | 18-34 | 34-65 | 65-124 | >124 |
| PEAK VEL. (cm/s) | <0.1 | 0.1-1.1 | 1.1-3.4 | 3.4-8.1 | 8.1-16 | 16-31 | 31-60 | 60-116 | >116 |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

Source: USGS²⁸

²⁸ Lucile Jones et al., "The ShakeOut Scenario" (U.S. Geological Survey, 2008), <http://pubs.usgs.gov/of/2008/1150/of2008-1150.pdf>.

Figure 3-2: Earthquake Simulation Shows Delay in Ground Shake Arrival



Source: USGS²⁹

3.3 Earthquake Scenario Warning Polygons

The earthquake impact map shown in Figure 3-1 was imported into Google Earth and geo-referenced. A detailed *impact polygon* was manually drawn around the area where destructive effects are predicted to occur in the ShakeOut Scenario analysis. Note the yellow, orange and red areas in Figures 3-1 and 3-2. The areas indicated in orange and red will experience moderate to severe shaking. These are the areas where the earthquake would cause the most destruction and damage.

To approximate the less-detailed warning zone that would have to be generated in real time in the seconds following the earthquake onset, a more coarse *warning polygon* was created that included the impact polygon plus a buffer zone (to take into account uncertainty regarding the size of the earthquake impact area). The coarser warning polygon is indicated by the thick purple line in Figure 3-3. Given the short amount of time available to estimate the dimensions of the warning polygon prior to sending the EEW messages, the thick purple line is more likely to resemble the warning polygon that would be used to geo-target EEW messages.

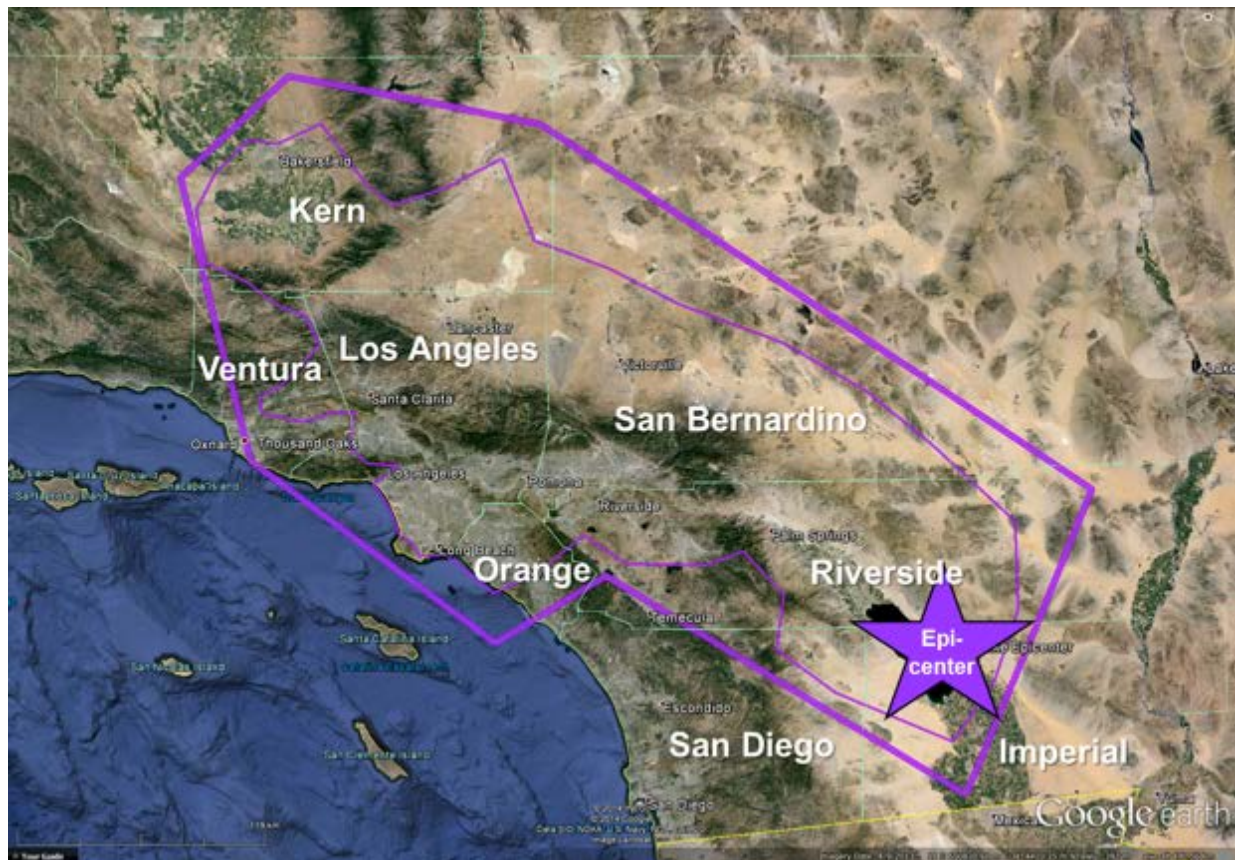
An important feature of the prototype CISON is that it can provide an estimate of the epicenter location, the magnitude of the earthquake and its intensity within seconds of the start of shaking. These estimates can be delivered within 10 seconds of earthquake start, as was demonstrated in the recent

²⁹ http://earthquake.usgs.gov/regional/nca/simulations/animation.php?mov=ShakeOut_mapview&set=shakeout.

6.0 earthquake in Napa Valley, California. In this quake CISON provided about 10 seconds of warning to test volunteers located in the San Francisco bay area.³⁰

Figure 3-3 shows that the warning zone fully includes some counties, but only intersects several other counties. For the latter counties it is clear that geo-targeting at the sub-county level will avoid over-alerting. Conversely, if EEW messages were geo-targeted to the county level, a large number of residents in some counties would receive the EEW message but would not experience a major earthquake. If EEW messages were to be sent for moderate sized earthquakes (as well as large infrequent quakes) this level of over-alerting could eventually lead to alert fatigue by the public, and could possibly lead residents to opt out of WEA imminent threat alerts or simply ignore the EEW alerts when they receive them.

Figure 3-3: Earthquake Impact Polygon, Warning Polygon and Affected Counties



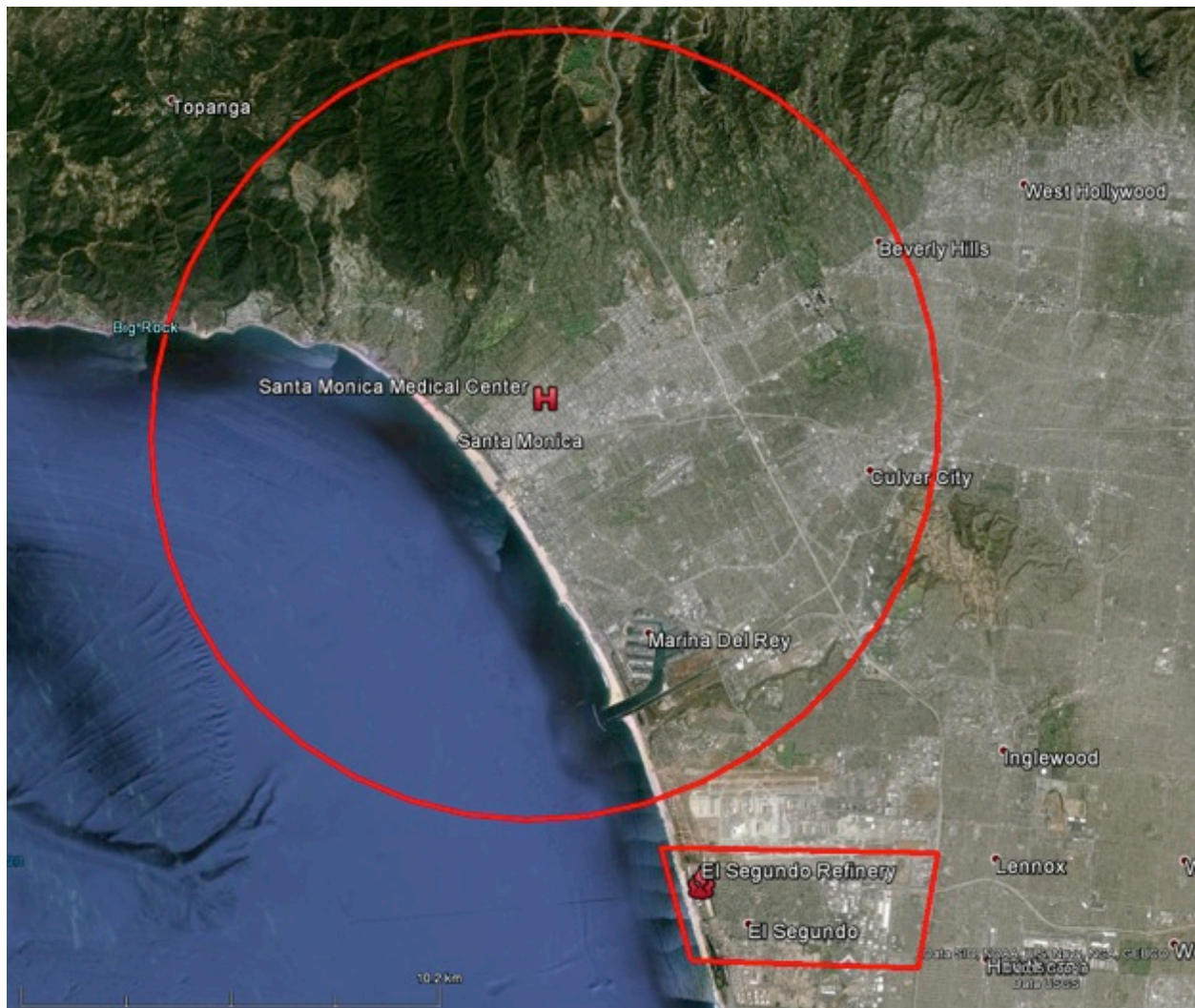
Source for Base Imagery: Google Earth

Local authorities will likely generate follow-on emergency messages, in sub-county warning zones as well, to warn the public of local threats or emergencies created in the aftermath of the earthquake, such

³⁰ Jim Carlton, "Earthquake Early Warning Systems Taking Too Long to Roll Out, Scientists Say," *Wall Street Journal*, May 17, 2016, sec. US, <http://www.wsj.com/articles/scientists-renew-push-for-earthquake-warning-system-on-west-coast-1463477410>.

as hazardous fires and emissions at oil and gas refineries. For this scenario, hypothetical city-wide and neighborhood-wide warning zones were created (see Figure 3-4).

Figure 3-4: Hypothetical Post-Earthquake Message Warning Polygons



Source for Base Imagery: Google Earth

3.4 WEA Warning and Evacuation Messages

To model meaningful message traffic across the WEA infrastructure for this scenario, it is assumed that the “ShakeAlert” EEW System that is currently under development is operational, and that WEA latency times have been reduced from the current minute-plus baseline to mere seconds.³¹ The ShakeAlert system would automatically send out the immediate warnings, while local and state authorities would manually issue subsequent emergency messages. These post-event emergency messages were modeled

³¹ Doug Given, “ShakeAlert-Earthquake Early Warning Progress and Status” (CISN Steering Committee Meeting, 2014), <http://www.shakealert.org/>.

based on the ShakeOut Scenario public information and communication timelines, and damage estimates contained in the ShakeOut documentation.³²

Table 3-1 shows the timeline and details for these messages. The first EEW message is shown in the second row of the table. The next three messages are examples of warning messages that could be sent by local and regional authorities after the earthquake and after some damage appraisal.

Table 3-1: Timeline and Details of WEA Warning Messages

| Time | Event Code | Geo-target Rough Order of Magnitude Size | Warning Polygon | Message Number | WEA Freetext Message (90 Character Limit) |
|-------|------------|--|---|-------------------|---|
| T+10s | EQW | Multiple Counties (500km x 200km) | Earthquake Warning Zone (Wide Purple Line) | 1 | “Strong earthquake coming. Drop, cover and hold on now! –USGS” |
| T+1h | CDW | Multiple Counties (500km x 200km) | Earthquake Warning Zone (Wide Purple Line) | 2 | “Water supply contaminated. Boil tap water for 10 minutes before drinking. – Cal OES |
| T+2h | LAE | City (~20km dia.) | Hospital Warning Zone (Red Circle) | 3 | “UCLA Medical Center Santa Monica severely damaged. Go to St. John’s if injured. – LA EMA” |
| T+6h | EVI | Neighborhood (3km x 6km) | Refinery Warning Zone (Red Trapezoid) | 4 | “Fire rapidly spreading east from El Segundo refinery. Move north or south now! – LA EMA” |

*EQW: Earthquake Warning; CDW: Civil Danger Warning; LAE: Local Area Emergency; EVI: Evacuation Immediate

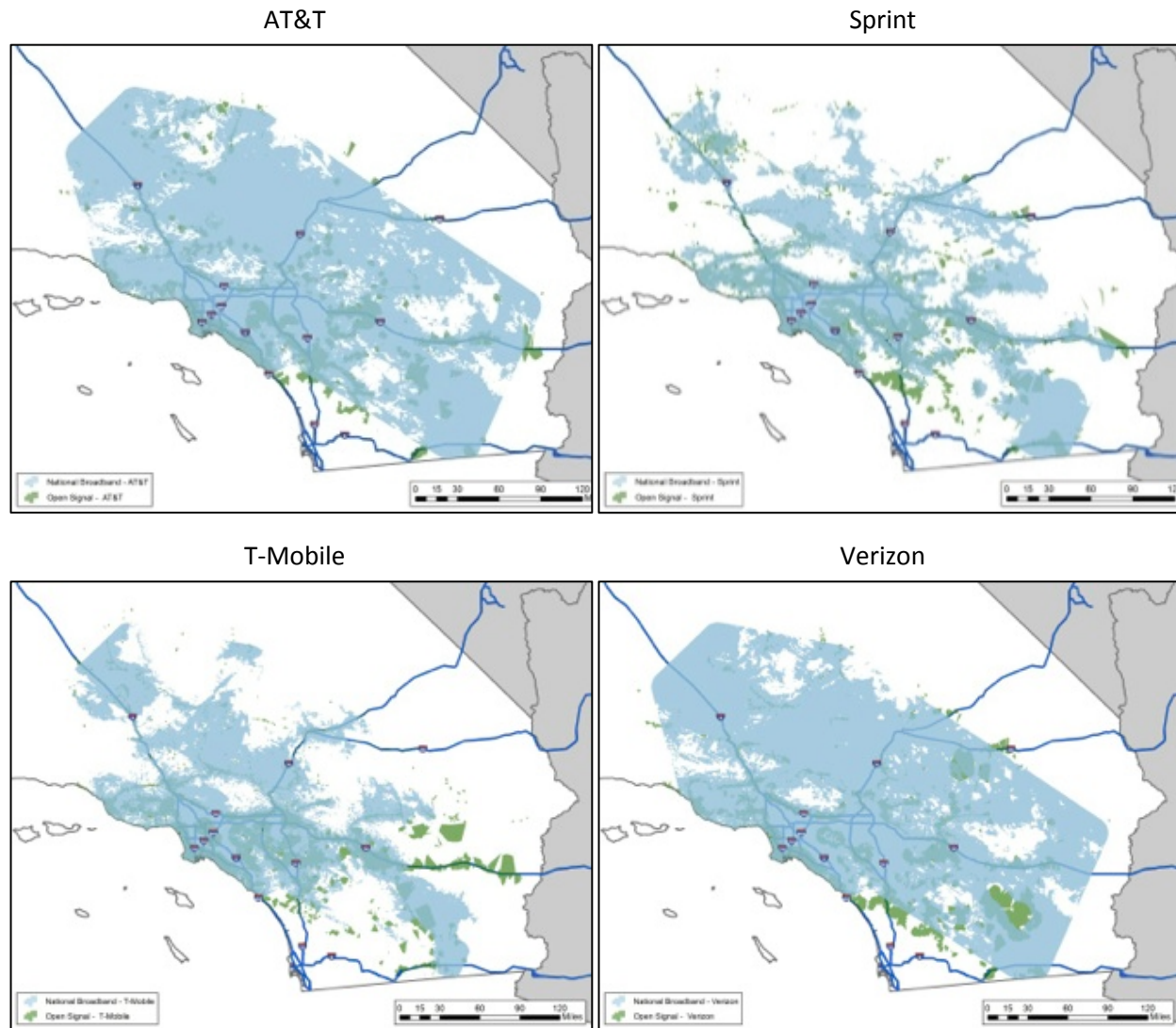
The first EEW message would be sent to the largest area as indicated in Figure 3-3. The hospital warning message would be sent to the large circular area shown in Figure 3-4, and the refinery fire evacuation-warning message would be sent to the smaller rectangular zone shown in the bottom of Figure 3-4.

³² Lucile Jones et al., “The ShakeOut Scenario.”

4. Tier 1 Carrier Coverage of Southern California

Figure 4-1 shows the RF coverage of the Tier 1 wireless carriers in southern California using data from the NBM and OpenSignal.com. The NBM coverage is shown in light blue. OpenSignal coverage is shown in green.

Figure 4-1: Tier 1 Carrier Coverage of Southern California (NBM and OpenSignal Data)



Sources: FCC and OpenSignal.com

Figure 4-1 shows that OpenSignal data provides additional areas of coverage not included in the NBM coverage areas for all four carriers. Even with the OpenSignal data, however, Sprint and T-Mobile still have significant coverage gaps in wide areas of southern California. AT&T and Verizon appear to have the best coverage in southern California. Figure 4-1 shows cellular network RF coverage is good in

densely populated areas along the coast and along major highways. Coverage tends to drop off in less densely populated areas to the northeast and east of Los Angeles.

4.1 Tier 1 Carrier Coverage in the Earthquake Area

Earthquake Warning Polygon

Figure 4-2: Earthquake Warning Polygon for the ShakeOut Scenario

This section estimates the coverage provided by the four Tier 1 wireless carriers in the region affected by the earthquake. This large area includes eight separate counties in southern California. Parts of this

region are sparsely populated and not covered by even the Tier 1 carriers. Because the area is so large, a new coverage estimation method is used that can be efficiently applied to large areas. For the interior of the warning polygon a combination of NBM and OpenSignal data is used.

Along the boundary of the warning polygon additional data from Unwired Labs and Combain is used to estimate antenna locations and cell sizes. The latter data sources are used to estimate antenna locations that exist just inside and outside of the warning polygon. In this way, Voronoi tessellation of a stripe of RF coverage area extending 15 km on either side of warning polygon boundary is created.

This approach allows one to estimate the size and density of individual CMSP RAN cells along the boundary of the warning polygon. This in turn enables estimation of OARs and AFRs for the two alternative WEA antenna selection methods defined in Section 2. For example, in WEA method 1, only antennas inside the boundary area are used to compute WEA GTP metrics.

WEA method 2 includes antennas inside the warning area and antennas outside of the warning area that also define cells that intersect the warning area, as determined by applying the Voronoi method to the antenna populations inside and outside the warning areas. Because correct application of the Voronoi method requires neighboring antennas to be included, antennas on both sides of the warning polygon boundary are used to obtain an accurate estimate of cell sizes along the boundary.

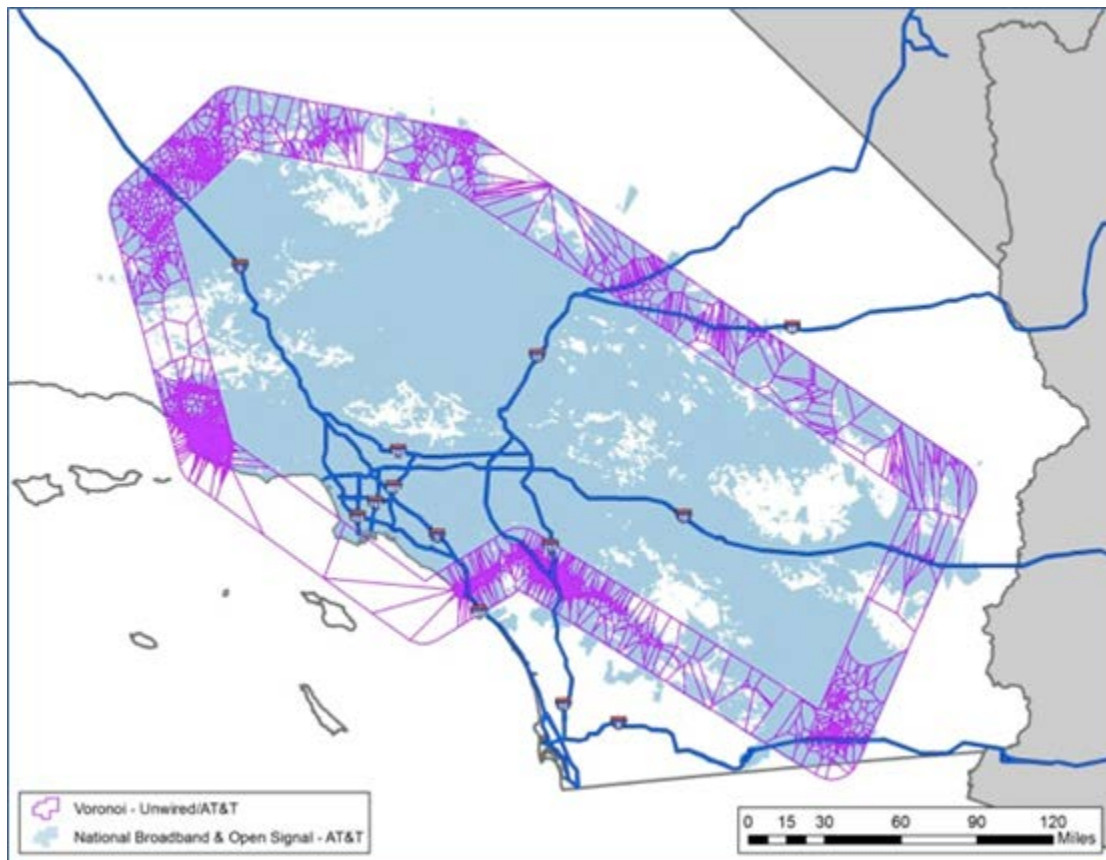
The coast of southern California is densely populated. All Tier 1 wireless carriers provide good coverage along the coast. For this reason the new coverage estimation method is not used to estimate the number of antennas near the coast. It is unnecessary to do so because the NBM and OpenSignal data sets provide sufficient coverage data along the coastal boundary areas of the warning polygon. The new method described above is only used along the boundaries of the earthquake warning polygon that extend inland. This restriction in the application of the new method saves considerable computing time and costs for purchasing commercial data along the entire coastline where the EEW polygon is situated.

AT&T Coverage

Figure 4-3 shows a hybrid estimate of AT&T network coverage in southern California in and nearby the EEW polygon. The blue interior areas illustrate where the AT&T network provides coverage based on data from the NBM and OpenSignal. The purple lines in the corridor that runs the boundary of the warning polygon show the locations of the individual cells in the AT&T network based on Unwired Labs

data. In heavily populated areas the cell density in the AT&T network is very high, whereas in sparsely populated areas the number of AT&T cells per square kilometer is much lower.

Figure 4-3: Voronoi Boundary Cells and Coverage of AT&T Network

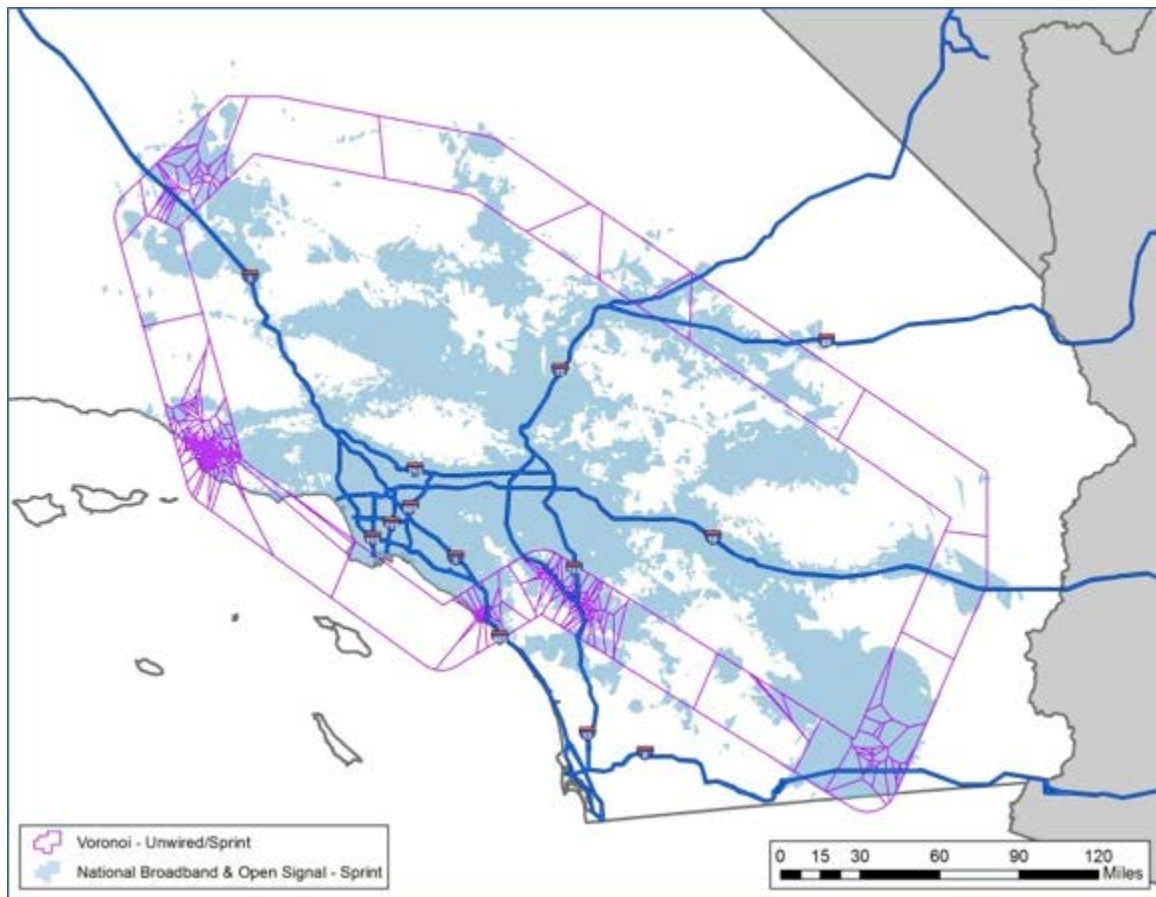


Sprint Coverage

Figure 4-4 shows our hybrid estimate for the coverage provided by the Sprint network in and nearby the EEW polygon area. The same color scheme is used to illustrate network coverage. Also, the same data sources are used to construct Figure 4-4. From the figure it is apparent the Sprint network does not provide as much coverage for the southern California region, especially the more sparsely populated areas away from the coast and major highways. The limited coverage of the Sprint network in sparsely

populated areas far inland is also illustrated by the very low Voronoi cell density along the far eastern boundary of the warning polygon.

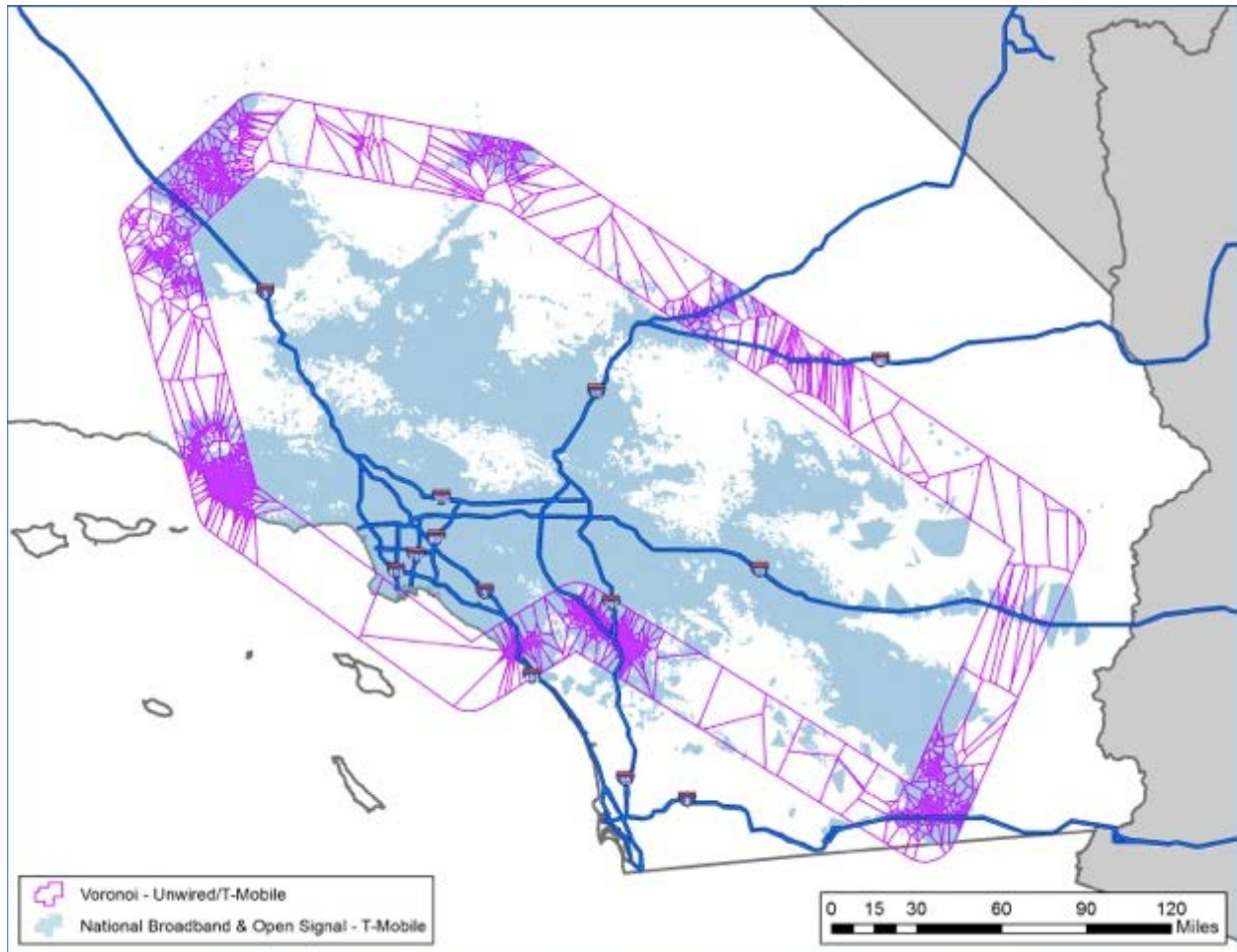
Figure 4-4: Voronoi Boundary Cells and Coverage of Sprint Network



T-Mobile Coverage

The coverage of the T-Mobile network in and nearby the EEW polygon area is shown in Figure 4-5. From the figure it is apparent the coverage of the T-Mobile network is marginally better than that of the Sprint network, but is not as good as AT&T, (according to the data sources used in this analysis). The Voronoi method is again used to estimate cell locations and boundaries along the perimeter of the warning polygon. These are highlighted in purple in the figure.

Figure 4-5: Voronoi Boundary Cells and Coverage of T-Mobile Network

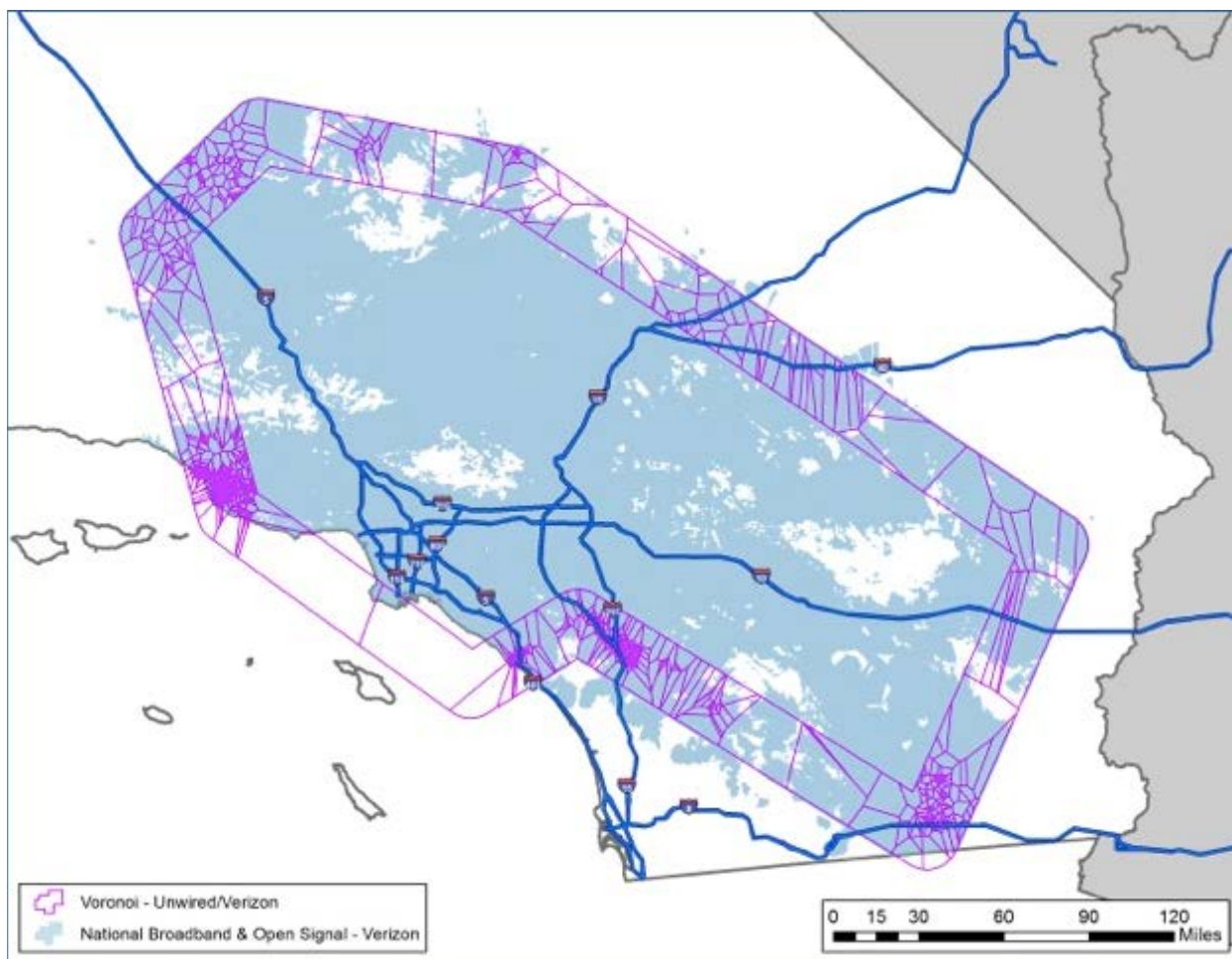


Verizon Coverage

The coverage of the Verizon network in and nearby the EEW polygon area is shown in Figure 4-6. It shows the coverage of the Verizon network is better than that provided by Sprint and T-Mobile, and as good, if not better than that provided by AT&T. These coverage estimates are based on the data sources used in this analysis, and do not depend on coverage data from the carriers.

The Voronoi estimate for the location and boundaries of individual cells in the Verizon network is also based on data from Unwired Labs. This estimate reveals that the Verizon network has a lower cell density than that found in the other cellular networks, even in the densely populated areas near the coast and along major highways. Verizon in many areas of the country has been allocated RF below those of the other carriers, and which have better propagation characteristics. Because of this, Verizon cells can be made larger in many areas of the country. This is the explanation for the cell density differences shown in this section.

Figure 4-6: Voronoi Boundary Cells and Coverage of Verizon Network



Cellular Infrastructure Damage

Since the initial WEA warning messages will be issued in the seconds before the arrival of the most damaging ground shocks, it is assumed that the cellular network will not be damaged during this critical time. Once the shock wave arrives, however, the cellular network will be degraded, both from individual towers being destroyed, from widespread power outages in the affected area and from damage to other components of the wireless carrier networks. This will affect the ability of emergency managers to use WEA (and other methods of communication) to send post-event emergency messages to the public.

After Hurricane Katrina, a mandatory rule was issued that required Tier 1 wireless carriers and other CMSPs with more than half a million subscribers to equip their cell sites with backup power systems that can sustain network operation for at least eight hours after a power grid failure.³³ Thus, it is possible that substantial parts of the cell phone network will still be operational hours after a major quake, even if the power grid is knocked offline.

It should be noted that network congestion due to high call volume will most likely reduce the quality of service for regular cell phone communications in the aftermath of the event. In contrast, if the cell phone network is still working in parts of the affected area, WEA messages will still get through even if the network is congested because WEA uses the network control channel and does not compete for resources of the core network.

³³ "Recommendations of the Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks," FCC Rule (Washington, D.C.: Federal Communications Commission, October 4, 2007), <http://www.njslom.org/FCC-07-177A1.pdf>.

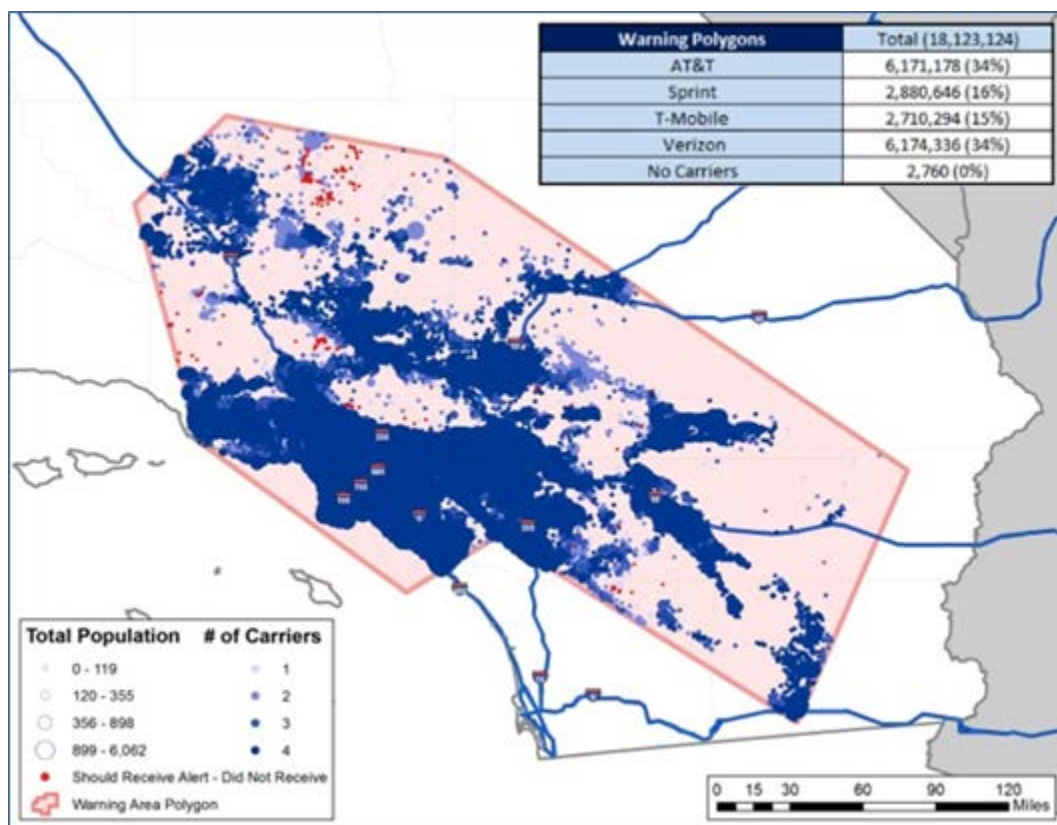
5. WEA Earthquake Early Warning Geo-Targeting Performance

This section examines the GTP of the WEA service for EEW. The primary focus of this assessment is on WEA GTP and not on the responsiveness needed to provide timely EEW. It should be noted, however, that a Japanese EEW system has been operational for several years which uses the same cell broadcast technology used by WEA. The Japanese system has provided up to 80 seconds of advance warning of an earthquake to Tokyo residents.³⁴ This section examines WEA message delays and implications for EEW.

5.1 Warning Populations

Figure 5-1 shows the population of the southern California region that would be affected by the earthquake, according to U.S. census data. This population would be at risk during the earthquake.

Figure 5-1: Population Distribution in the Warning Polygon (Census Tracts)

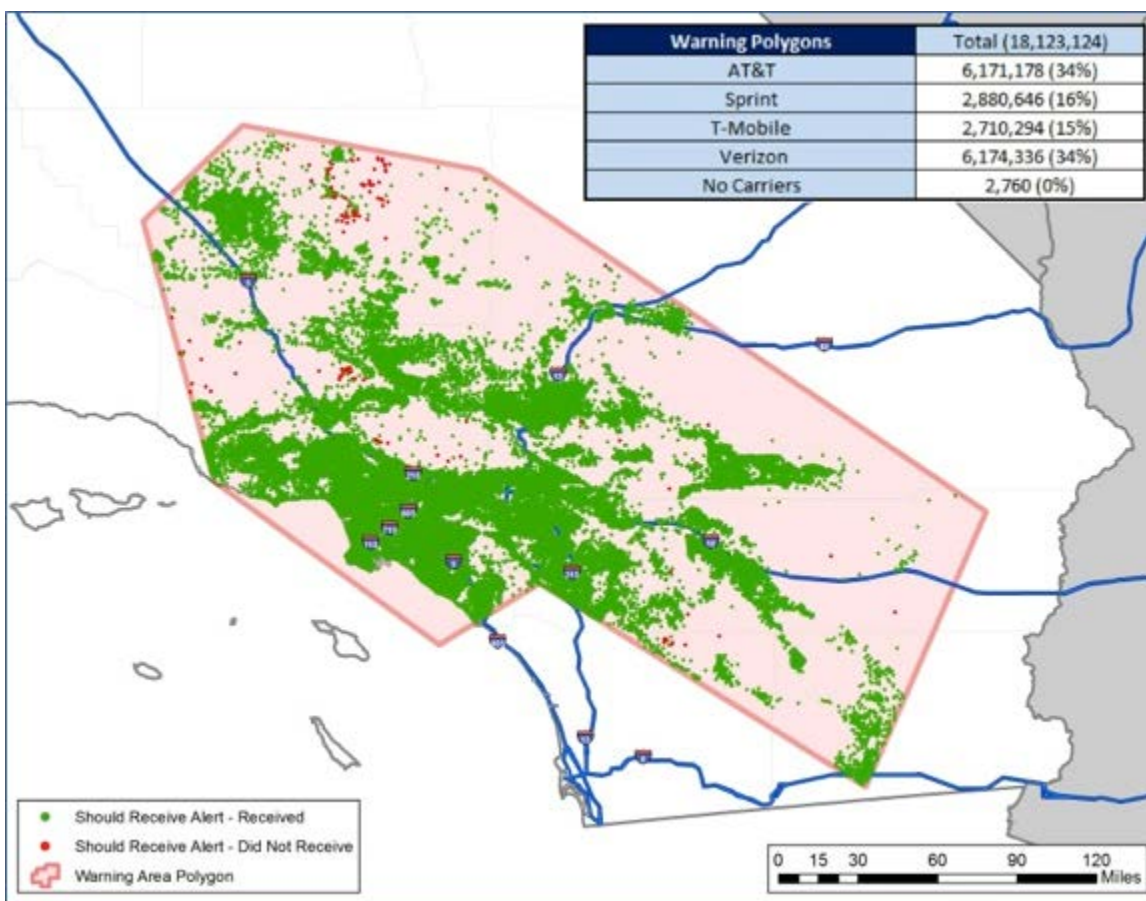


³⁴ Christopher Mims, "Cellular Technology That Told Japan an Earthquake Was Coming," *MIT Technology Review*, 2011, <https://www.technologyreview.com/s/423288/cellular-technology-that-told-japan-an-earthquake-was-coming/>.

The figure shows that more than 18 million people live in the affected area. Of those, over 6 million are AT&T subscribers. Another 6 million are subscribers to the Verizon network. The Sprint network has almost 2.9 million subscribers in the affected area, and T-Mobile more than 2.7 million.

The above subscriber estimates are based on the national market share numbers described in Section 2. The network coverage estimates shown here in Section 5 are used to estimate who lives within cell phone coverage and who does not in the affected area. The networks are designed by the Tier 1 carriers to cover almost everyone in southern California. Only a few thousand people live in locations without cell phone coverage, as shown in Figure 5-2 by the red points. Green points illustrate individuals that reside in areas with cell phone coverage.

Figure 5-2: Tier 1 RF Coverage of the Population in the Warning Polygon



5.2 AT&T WEA GTP

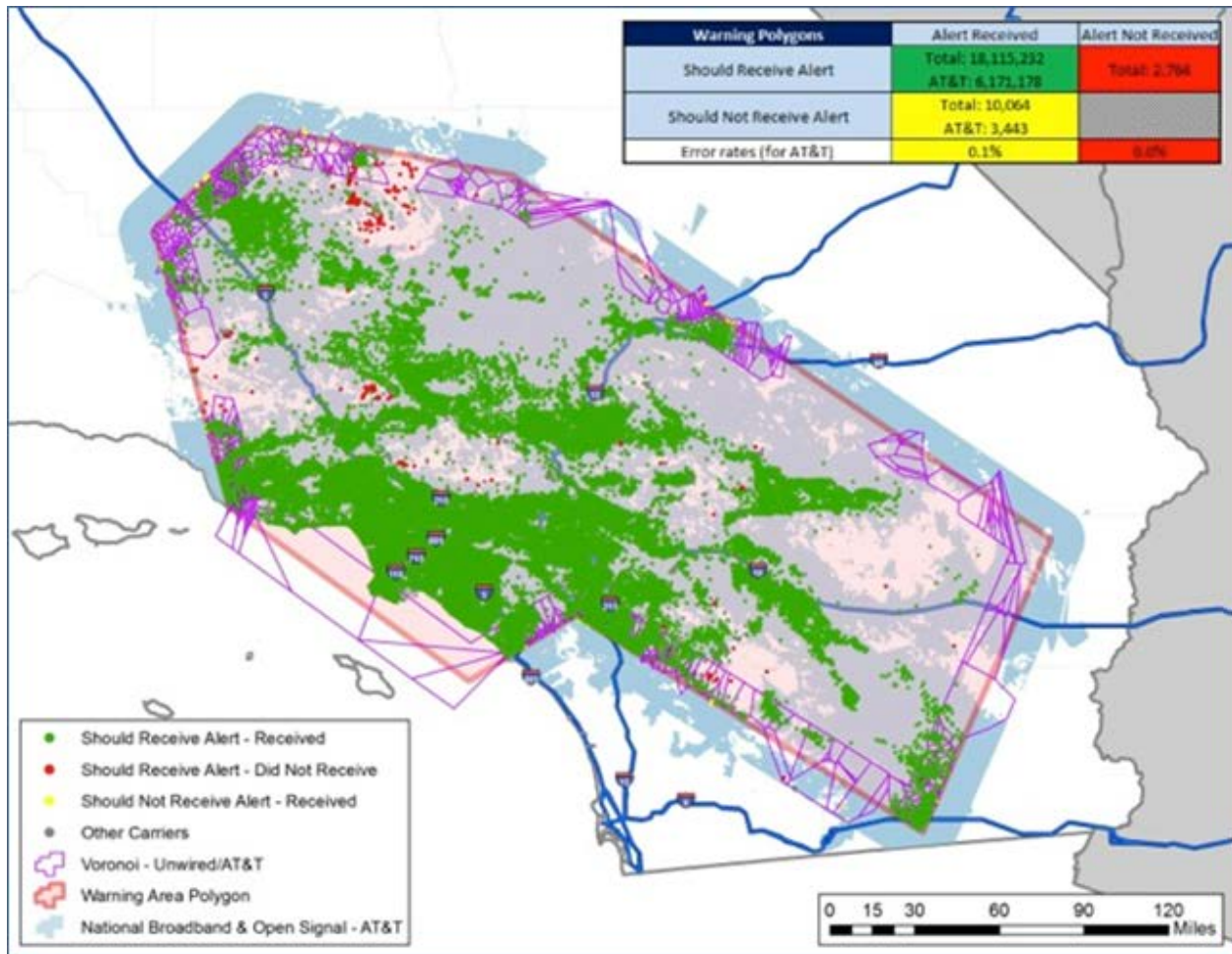
This section examines the GTP of the AT&T wireless carrier network when alternative WEA methods are employed. In method 1 only cell towers within the warning area are directed to broadcast WEA messages. In method 2 cell towers that are adjacent to the warning area as well as cell towers within the warning area are directed to broadcast WEA messages. As explained in Section 2, the cell towers

adjacent to the warning area that transmit must have a cell coverage area that overlaps with the warning area when method 2 is used.

AT&T Network WEA GTP - Method 1

Figure 5-3 shows the WEA GTP of the AT&T network when method 1 is used (i.e., when only cell tower antennas that lie entirely within the warning polygon are used to broadcast the WEA message). The results show that more than 99 percent of the population in the warning area receive the alert as indicated by the green points in the figure. Less than 3,000 people do not receive the alert but should because they do not lie in an area where cell phone coverage is available. The locations of these individuals are shown by red points. There are also a small number of people just outside the boundary of the warning area that receive the warning message but should not.

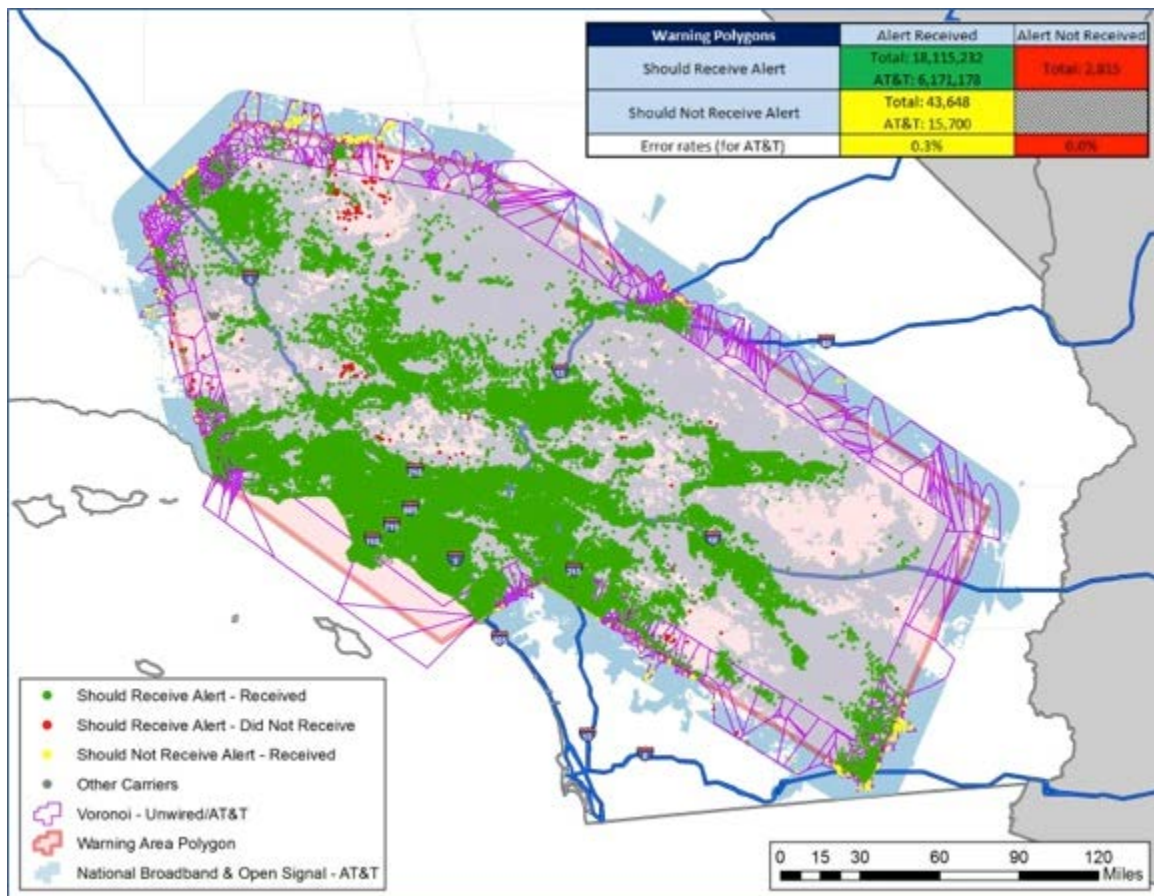
Figure 5-3: AT&T WEA GTP for Method 1



AT&T Network WEA GTP - Method 2

Figure 5-4 shows the WEA GTP of the AT&T network when method 2 is used. As with method 1, more than 99 percent of the population the alert in the warning area receive, as indicated by the green points in the figure. Less than 3,000 people do not receive the alert but should because they do not lie in an area where cell phone coverage is available, as shown by red points. There are people just outside the warning area that receive the warning message but should not, as shown by the yellow points in the figure. This over-alerted population increases by a factor of three but is still very small.

Figure 5-4: AT&T WEA GTP for Method 2



5.3 Sprint WEA GTP

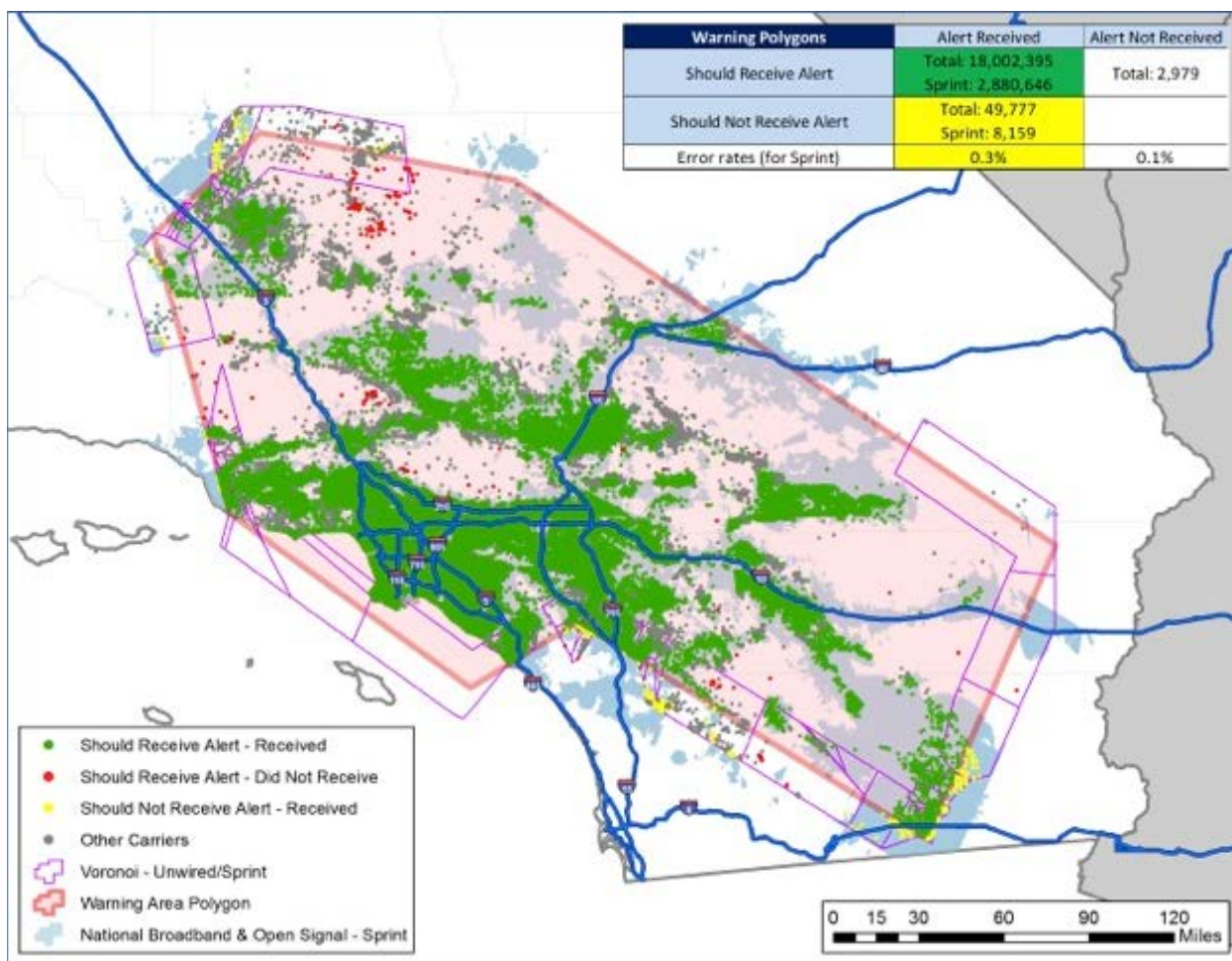
The previous section focused on the WEA GTP of the AT&T wireless network. The next few sections focus on the GTP of the other Tier 1 carriers. This section estimates the GTP of the Sprint network when WEA method 1 is used to select antennas for WEA message broadcast.

Figure 5-5 shows the Sprint coverage and WEA GTP in the EEW area. The gray points indicate population tracts that are not in the Sprint coverage area, but which are covered by one of the other Tier 1 carriers. The red points show population tracts not covered by any Tier 1 carrier, including Sprint. Adjusting for

market share using the data shown in Section 2, the Sprint WEA AFR is determined to be approximately 0.1 percent of the estimated subscriber base in the area shown in figure.

The same approach used for the AT&T network is used to calculate OAR and AFR for Sprint. Unwired Labs antenna data is used to identify the Sprint antennas located near the warning polygon boundary (within 10 miles) and that are inside or outside the warning polygon. These antennas are used to generate a Voronoi coverage map along the perimeter of the warning area. If no antennas are within this boundary area, then we do not include a Voronoi cell in the area, as shown in in the figure. The AFR and OAR for the Sprint network are shown in the figure. They both are relatively low because of the sparse populations located on the warning polygon boundary. Most of the 18 million people in the warning area are located well inside of the warning polygon.

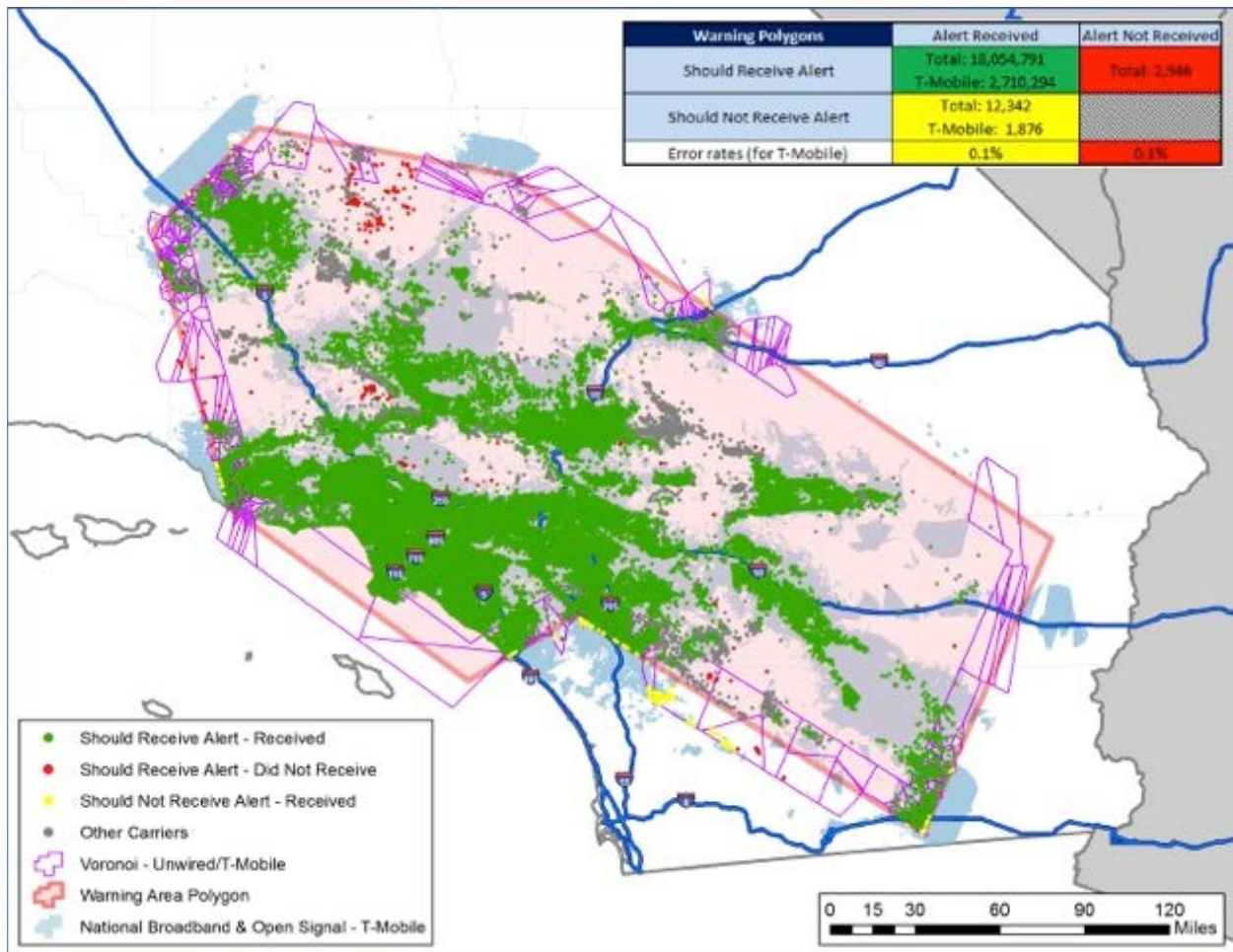
Figure 5-5: Sprint WEA GTP



5.4 T-Mobile WEA GTP

Figure 5-6 shows the T-Mobile coverage and WEA GTP in the EEW area. The same technique is used to estimate WEA GTP of the T-Mobile network. T-Mobile WEA AFR and OAR are also very low, about 0.1 percent and 0.1 percent, respectively, of the estimated subscriber base in the area considered.

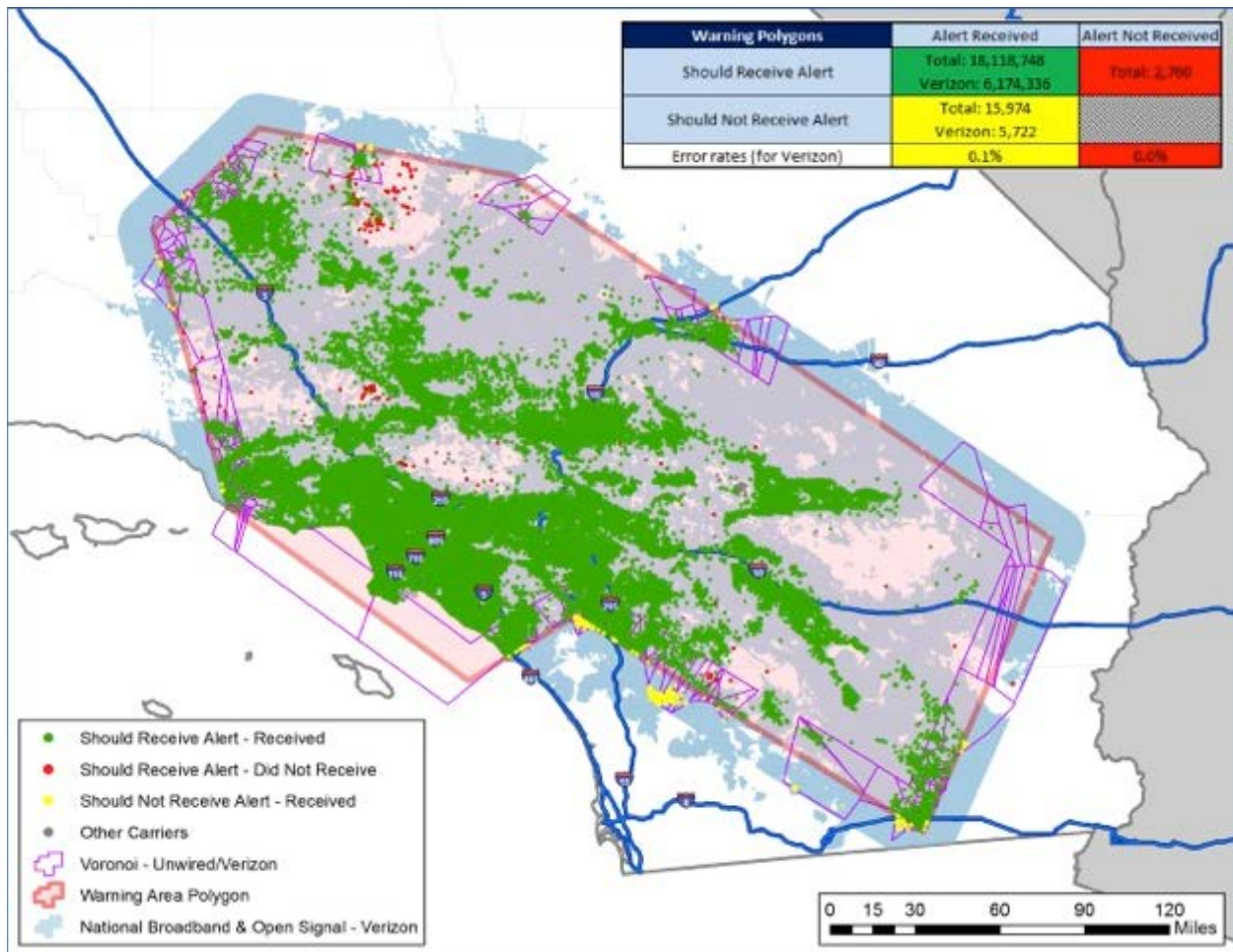
Figure 5-6: T-Mobile WEA GTP



5.5 Verizon WEA GTP

Figure 5-7 shows the Verizon coverage and WEA GTP in the EEW area. The Verizon WEA AFR is zero, which is as good as the AT&T AFR. This remarkably low AFR is undoubtedly due to the extensive cellular network coverage Verizon provides in southern California. The OAR is also very low at 0.1 percent.

Figure 5-7: Verizon WEA GTP



5.6 Timeliness of WEA EEW

A critical question is whether the WEA service will provide the timeliness needed to provide EEW before significant shaking starts in the entire warning area. For a large earthquake such as the one considered in the ShakeOut Scenario, it is technically feasible to provide early warning of the earthquake in areas far from the epicenter. Closer to the epicenter, however, it is more difficult to provide warning of the earthquake in advance of shaking using current seismic sensors and processing algorithms. A so-called blind zone exists near the epicenter where currently EEW is not feasible.³⁵ This is an area of approximately 20 miles in radius around the epicenter. As one proceeds to greater distance from the epicenter of an earthquake, early warning messages can provide more advance warning of the earthquake. It takes approximately 10 seconds to detect the earthquake and to determine its strength.³⁶

³⁵ "Feasibility Study for Earthquake Early Warning System," (Alliance for Telecommunications Industry Solutions (ATIS), 2015), <http://www.atis.org/newsroom/EarthquakeFeasibilityStudy.pdf>.

³⁶ Talbot, "80 Seconds of Warning for Tokyo."

This time delay includes the time required to process the seismic sensor data and determine the epicenter.

U.S. cell phone industry technical experts have studied whether it is feasible for the current version of the WEA service to provide EEW messages to the public. The results of the study found it was not feasible to use the current WEA service for EEW.³⁷ The report implies the current WEA service transmits WEA messages with substantial time delays that may be as high as 12 minutes.

It is important to note, however, the current WEA service has never been tested on live carrier networks and that government regulators do not have a good understanding of the time delays incurred when using the current WEA service. In addition, cell phone EEW capabilities are currently operational in a number of other countries that use 3G and 4G networks, including Turkey, Mexico, Japan, Romania and Taiwan.³⁸ Furthermore, the EEW system in Japan uses the same underlying technology as the U.S. WEA service, so in principal it should be possible to modify the current implementation of the U.S. WEA service so it could provide timely EEW messages.³⁹

The cell phone industry is studying how to improve the next version of the WEA service, which will be implemented on advanced 4G LTE networks. In a recent wireless industry study it was assumed that WEA would not be used for transmitting EEW messages to cell phones (i.e., that EEW messages would not be sent to the IPAWS aggregator, which is located near Washington, D.C.) and instead would be sent to the Tier 1 wireless carriers from a new special purpose EAC located somewhere in California. Presumably the EAC would be funded by the State of California. Another option for this is to use a new IPAWS aggregator backup node that could be located on the West Coast. This IPAWS aggregator backup node would be designated as the primary node for issuing WEA EEW messages. This would reduce delays in the WEA EEW message transmission process, relieving the primary IPAWS aggregator of the very short EEW message timeliness requirements, and would enable existing WEA-capable handsets used by Californians to receive WEA messages. Further study may be required to see what sort of modifications would be required in Tier 1 carrier wireless networks to reduce WEA time delays in carrier networks for EEW.

5.7 WEA Evacuation and Hospital Warning Messages

In the earthquake scenario, local emergency managers may decide to send a number of other warning messages after earthquake. One such message is a hospital closure and redirection message. Such a message could be sent to people near the UCLA Santa Monica medical center if it had to close due to earthquake damage (near the affected hospital). There are 538,000 people that reside in this area that

³⁷ "Joint ATIS/TIA CMAS Federal Alert Gateway To CMSP Gateway Interface Specification."

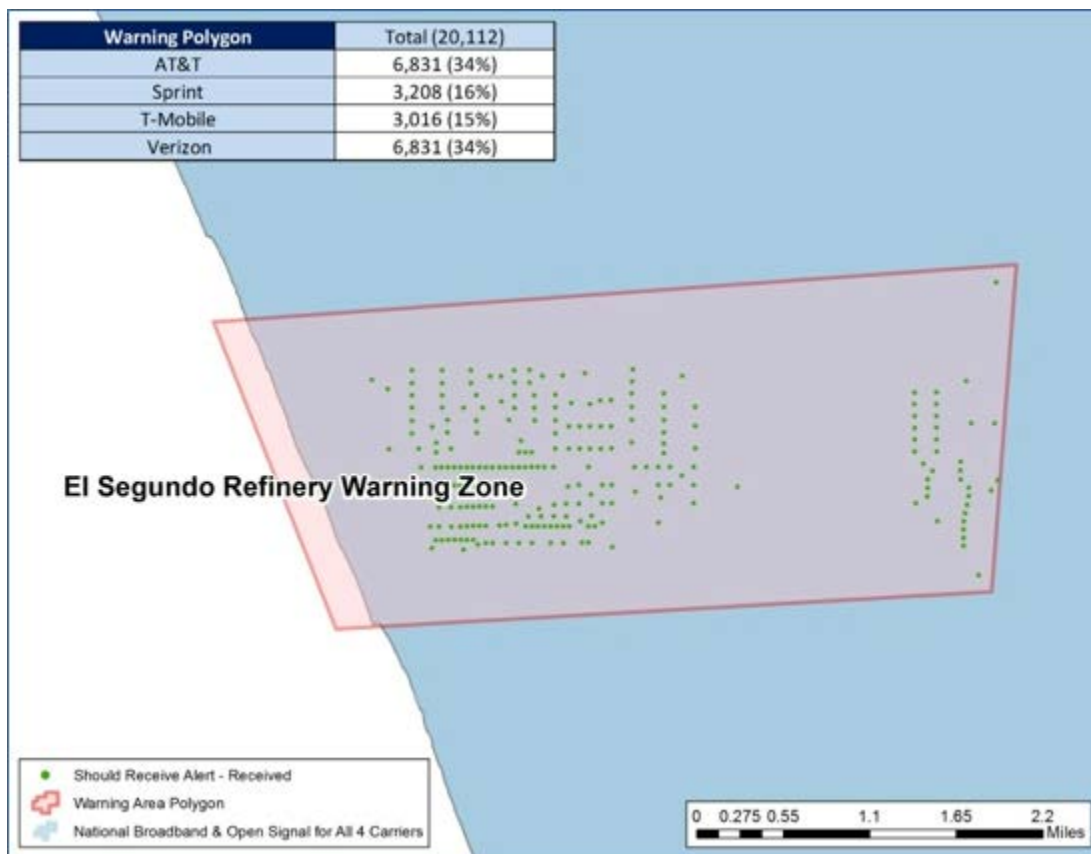
³⁸ Mark Johnson, "California Earthquake Early Warning System," 2015, <http://www.atis.org/newsandevents/webinar-pptslides/EEWSSlides-8252015.pdf>.

³⁹ Mims, "Cellular Technology That Told Japan an Earthquake Was Coming."

are normally well covered by the wireless networks of the Tier 1 carriers. It is possible that the cell network or cell towers would be damaged during an earthquake. If electricity is available to power portions of the network, however, it is likely that most people in this area would still have cell phone coverage because of redundant coverage each Tier 1 carrier provides in this densely populated region.⁴⁰ Therefore, while we cannot be certain, it is likely that nearly all people in the affected area would receive this WEA message.

The last possible WEA message we examine for the EEW scenario is an evacuation message to people surrounding the Chevron El Segundo refinery. A fire could break out at the refinery after the earthquake. Local emergency managers would then call for the area immediately surrounding the refinery to be evacuated. This area is shown in Figure 5-8 below, along with the population tracts in the area.

Figure 5-8: WEA El Segundo Refinery Warning Geo-Targeting Results



⁴⁰ The WEA system relies on an Internet connection to transmit the alert from the originator to the aggregator and on to the disseminator. If the link between the aggregator and disseminator is affected, a backup satellite link can be used.

From the figure one can see that a total of 20,112 people would be affected by the evacuation order. If we assume the electrical grid or backup power is still available to power the cell phone network infrastructure in the area, and if not too many cell towers are damaged, then it is reasonable to assume that the wireless networks of the Tier 1 carriers will still provide complete coverage of this relatively small area. In this case all people in the warning polygon would be alerted. The number of people warned to evacuate by each carrier are shown in the table in Figure 5-8.

5.8 Summary

The results of this section show all four Tier 1 carriers provide excellent coverage of the greater Los Angeles area, especially inside the warning polygon where most of the population is located.

- The AFRs for all four Tier 1 carriers are less than 0.1 percent.
- The OARs for all four Tier 1 carriers were estimated to be between 0.1 percent and 0.3 percent.

The OARs are small because the EEW warning polygon is very large and the vast majority of the population is located well inside the warning polygon; the perimeter effects that introduce AFR errors are reduced to very low levels. It can be shown that these perimeter effects are very small by comparing the population on the perimeter to that of the interior of the polygon. Below we show this ratio can be used to compute a maximum possible OAR due to RF spillover effects.

Use of WEA in Moderately Sized Earthquakes

In the EEW scenario OARs are small and may appear unimportant because large earthquakes are rare events. Consequently, there appears to be little risk of alert fatigue, even if OARs were larger.

It should be noted that earthquakes are not rare events in California, however. To estimate earthquake frequency we refer to the California earthquake statistics derived in the seminal paper by Gutenberg and Richter. They found the annual probability of a magnitude 6.5 earthquake in southern California to be approximately $P_{6.5} \approx 0.2$.

Similarly, using the same notation, Gutenberg and Richter estimate the annual probabilities of smaller quakes to be:

$$P_6 \approx 0.5, P_{5.5} \approx 1.4, P_5 \approx 3.4, P_{4.5} \approx 11.5.$$

These estimates indicate that WEA EEW messages will be rare events only if the EEW system is used to warn of large earthquakes of magnitude 6 or higher. If WEA EEW messages are sent for mid-sized or moderately sized earthquakes, a significant number of WEA EEW messages will be transmitted each year in southern California. Consequently, the use of WEA in moderate or mid-sized earthquakes could render OARs important.

A related issue is how large the warning polygons will be for smaller earthquakes. For moderately sized earthquakes the warning polygons should be much smaller because the damage zone will be much smaller. If the warning polygons used are larger than necessary this could lead to higher OARs than those estimated in this report for a large, magnitude 7.5 quake. It is beyond the scope of the current study to recommend thresholds for the two parameters that will be crucial in determining EEW OARs: (1) minimum size earthquake for which a WEA message would be sent; and (2) the size of warning polygons for moderately sized earthquakes. Further study is needed to determine an optimal EEW warning strategy that limit OARs using WEA.

Geo-Targeting Error Estimates

The AFR error estimation method described in Section 2 cannot be used for the EEW scenario because the population in the warning area is not uniformly distributed. The warning polygon includes large densely populated urban areas and large desert areas that contain very few people.

Consider the EEW polygon perimeter buffer zone first introduced in Figure 4-3. The population density is high along the coast in this buffer zone. The wireless network cell sizes are small in these densely populated areas. Therefore, for this error analysis we reduce the width of the buffer zone in densely populated areas to 1 km, which is assumed to be the average size of a cell in these areas. In the sparsely populated desert areas we maintain the width of the buffer zone at 15 km (beyond the edge of the warning polygon); it is assumed that cells will be larger in the sparsely populated areas. Using these adjusted buffer zone dimensions it is possible to calculate the maximum possible OAR, assuming cell antennas used to broadcast the WEA message from within the warning polygon spill over into the entire neighboring cells in the buffer zone defined above. Using U.S. census data we can calculate the number of people who would be warned in the buffer zone but should not be. The results of this analysis reveal the maximum possible OAR of approximately 1 percent.

The WEA GTP of the AT&T network was estimated for the cases when WEA method 1 or method 2 were used. In both cases the AFR was estimated to be zero. In method 1 the OAR was estimated to be 0.1 percent, and in method 2 it was estimated to be 0.3 percent. Because this difference is so small and is less than the possible maximum OAR error computed above (1 percent), it cannot be concluded that one WEA alerting method is superior to the other in this case. Both results are within the margin of OAR error for this scenario.

6. Tsunami Warning Scenario

Tsunamis are a serious threat to populations on the California coastline. Timely tsunami warning times may be measured in minutes in some cases, if the earthquake that generates the tsunami is relatively close to the coast of California. In other cases it may be in hours, if the earthquake generating event is far across the Pacific Ocean. In either case, WEA can play a significant role in saving lives in case of a tsunami.

Granular geo-targeting is important as well, since even the most severe tsunamis that emergency managers expect will only affect a rather narrow strip of the California coast — less than 1 km from the coastline on average. This section analyzes the use of the WEA service for issuing a tsunami warning to communities on the California coast.

6.1 Scenario Description

The scenario used for this analysis assumes that a large tsunami is triggered by an undersea earthquake near the Crespi Knoll, a sea mound at the north end of the San Diego Trough fault. This earthquake could, in turn, be triggered by a major San Andreas Fault release (cf. the earthquake scenario discussed in this report). Such a tsunami would affect the California coastline from Point Conception to the Mexican border, with the highest number of people at risk in Los Angeles County, specifically near Venice, Marina del Rey (MDR), Naples Island and Long Beach (see Figure 6-1).

Inundation data was taken from tsunami inundation maps developed by the California Department of Conservation,⁴¹ which in turn are based on research conducted at the Tsunami Research Center at the University of Southern California⁴² and are the basis for California's tsunami emergency planning. These maps show the Maximum Tsunami Inundation Line (MTIL) for each section of the California coast based on a worst-case tsunami and on digital elevation data for the coastline. The California Department of Conservation also provides this maximum inundation line in electronic format,⁴³ which was used to visualize the extent of the inundation and help generate the associated warning zones.

⁴¹ "Inundation Maps CGS Tsunami Web Site," accessed March 16, 2016, http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/Index.aspx.

⁴² Rick I. Wilson et al., "New Maximum Tsunami Inundation Maps for Use by Local Emergency Planners in the State of California, USA," *EOS, Transactions of the American Geophysical Union* 89, no. 53 (2008), http://www.conserve.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Documents/AGU08_tsunami_poster.pdf.

⁴³ "State Inundation Zones2.kmz," www.conservation.ca.gov/cgs/geologic_hazards/Tsunami, accessed March 16, 2016, about:blank.

Based on a tsunami travel time map provided by the National Oceanic and Atmospheric Administration (NOAA),⁴⁴ it was estimated that the tsunami in this scenario would reach Long Beach approximately 10 minutes after the initiating earthquake, and the Venice and MDR areas after approximately 15 minutes. Consequently, if the WEA service could provide a tsunami warning message less than one minute after NOAA and the USGS detect and geo-locate the underwater earthquake, it could provide more than 10 minutes of warning to residents in the tsunami warning zone. This could give them enough time to evacuate the area before the tsunami hits.

Figure 6-1: Tsunami Scenario with Affected Areas Highlighted in Red

Source for Base Imagery: Google Earth

6.2 Tsunami Warning Areas and Polygons for Los Angeles County

Even for the worst-case tsunami depicted in the California inundation maps, inundation would be mostly limited to the oceanfront and immediately adjacent areas. The MTIL does include several areas with significant populations at risk, however. In these areas, starting within minutes of the triggering earthquake and resulting tsunami formation, flood waters would rapidly (within less than one minute) rise above street level, carrying with them large amounts of debris, before receding after several more minutes. In those areas, anyone caught in the open or inside lightly-constructed buildings, such as most single-family homes, is at a high risk of being killed, either by drowning or by blunt trauma from debris. Depending on the severity of the earthquake, additional tsunamis can impact the affected area over the course of the next several hours. In the aftermath, residual flooding and roads blocked by debris will impede travel, destroyed gas lines will fuel fires, and toxic materials set free by the flooding will create additional hazards. All of these factors will delay emergency responders, especially if the earthquake that triggered the tsunami has created additional damage inland. Thus, the most effective way of protecting populations at imminent risk from a tsunami is to warn them of the approaching threat and instruct them to self-evacuate rapidly to higher ground — either a few hundred meters further inland, or to the upper stories of solidly-constructed buildings. Figure 6-2 shows a close-up of one of the few areas of the California coastline in which the inundation zone extends a significant distance from the beach.

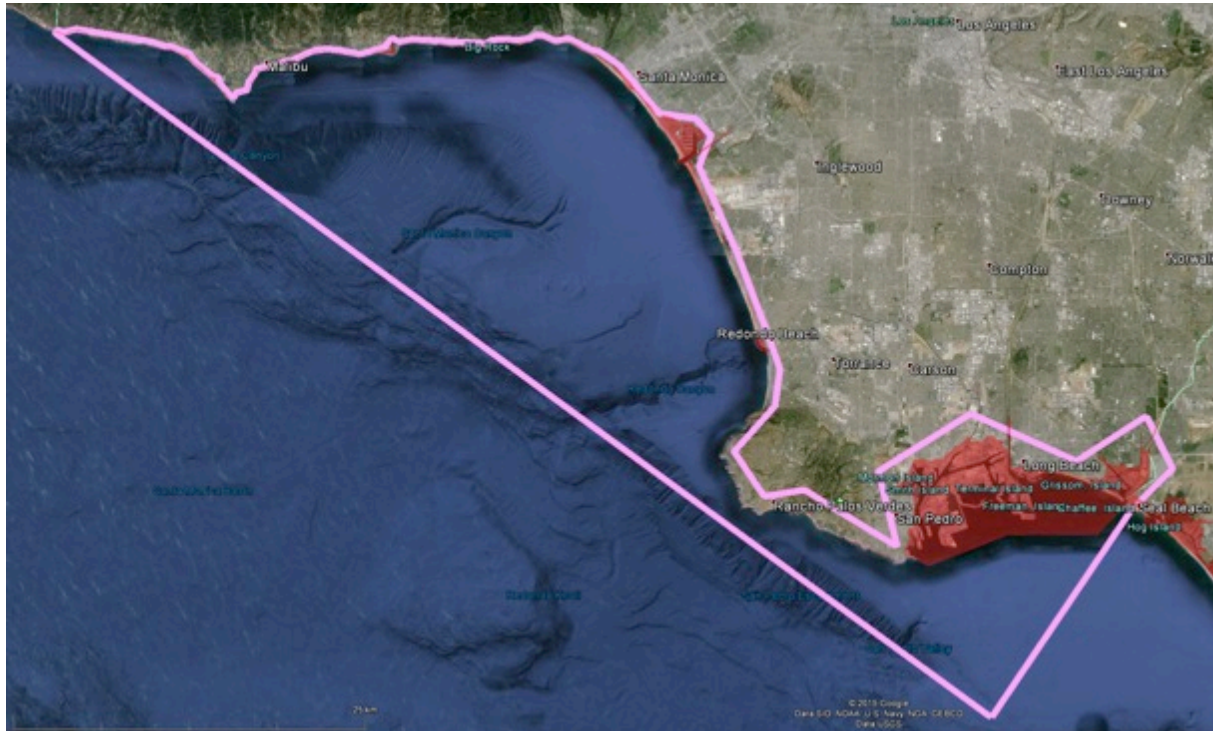
Figure 6-2: Inundation and Warning Zones for Venice and MDR



Source for Base Imagery: Google Earth

Figure 6-2 shows that large parts of Venice and MDR could be inundated in a tsunami (shown in red). Everyone inside this affected area should receive a tsunami warning. The warning polygon (shown in light purple) was generated by manually drawing a polygon in Google Earth that includes the relevant inundation zones as defined by the MTIL, plus a buffer zone based on settlement patterns and topography. Figure 6-3 shows the resulting overall warning zone polygon (shown in light purple) for all of Los Angeles County.

Figure 6-3: Overall Tsunami Warning Zone Polygon (Purple) for Los Angeles County



Source for Base Imagery: Google Earth

Figure 6-3 shows three areas that would be most affected by a tsunami in Los Angeles County:

- Venice-MDR area;
- Long Beach Harbor and nearby areas; and
- Naples Island and nearby areas.

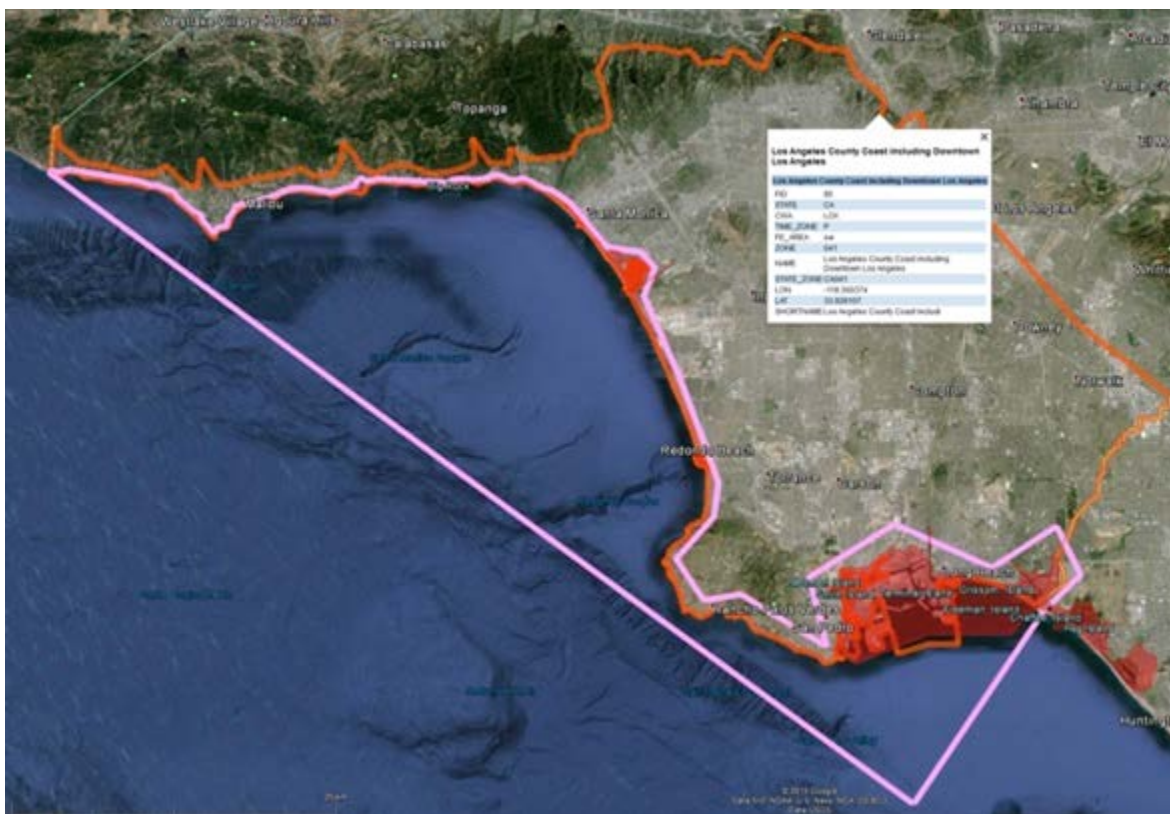
WEA performance in these three areas is examined below.

Small or Large WEA Tsunami Warning Polygons

It is not clear which federal or state agency would issue a WEA tsunami warning in southern California. This could be done by the NWS, which is already an authorized WEA AO. Or such a warning message could be issued by the NOAA Pacific Tsunami Warning Center.⁴⁵

If the NWS were to issue a tsunami warning based on NWS Warning Zones, the Tsunami Warning Polygon (TWP) could have a size that is of the same order of magnitude in size as counties. For the scenario considered in this report, Figure 6-4 shows the NWS Warning Zone for Los Angeles coastal areas covers mostly areas that do not need to receive a tsunami warning and which are far inland.

Figure 6-4: NWS Warning Zone CA041, Tsunami Inundation Zone and Smaller TWPs



Source for Base imagery: Google Earth

The NWS has the ability to send WEA severe weather alert messages to far smaller areas, and does so on a regular basis. It could certainly be possible for the NWS to send a tsunami warning to the smaller areas indicated in red in Figures 6-3 and 6-4. The geography of the southern California coast shows a tsunami warning message should ideally be limited to a narrow stretch of land adjacent to the coastline, and that message geo-targeting could play a particularly important role in this type of disaster.

⁴⁵ National Weather Service, "Pacific Tsunami Warning Center," *Pacific Tsunami Warning Center - Warnings*, accessed March 16, 2016, <http://ptwc.weather.gov/?region=1>.

6.3 Tsunami Evacuation Routes

Evacuating people at risk in a tsunami warning will likely be an important emergency activity that could save lives. Additionally, more detailed warning zones for a part of Los Angeles County where the topography and road network would make evacuation more difficult were examined. One such area is Naples Island, located in an inland lagoon and connected to the mainland only by three bridges. Limited egress routes mean that careful geo-targeting of evacuation instructions would be needed to reduce congestion and maximize the number of people who can successfully self-evacuate ahead of the tsunami.

Figure 6-5 shows the three geo-targeting evacuation zones for Naples Island, which were established by manually creating polygons in Google Earth based on the road network in this area. The three different warning polygons that were generated are color coded as indicated in the figure. Each evacuation zone is paired with a road and bridge that leads off the island.

Figure 6-5: Geo-targeted Evacuation Warning Polygons for Naples Island



Source for Base imagery: Google Earth

6.4 WEA Tsunami Warning and Evacuation Messages

To realistically model the message traffic across the WEA infrastructure for this scenario, WEA warning and evacuation messages were based on documentation from the NWS Pacific Tsunami Warning Center

website.⁴⁶ The WEA tsunami warning message is identical to that issued by the NWS for the only actual tsunami warning transmitted to date using the WEA service.⁴⁷ In accordance with the Tsunami Warning Center’s current procedures, the tsunami warning message would be prepared automatically, but would be reviewed by a Warning Center watch officer before being sent, resulting in minimal delays; for this scenario, it is assumed the warning would be sent approximately one minute after the undersea earthquake.

Detailed evacuation instructions based on local topography — such as those envisioned for Naples Island in our scenario — would have to either be prepared by local authorities ahead of time, together with a similarly automated process for their origination, or local AOs would have to prepare and issue such instructions within at most a few minutes of receiving a tsunami warning. Table 6-1 shows the timeline and content of WEA messages that could be issued in the tsunami scenario.

Table 6-1: Timeline and Details of WEA Warning Messages

| Time | Event Code | Geo-target ROM Size | Warning Polygon (LA County Only) | Message Number | WEA Free Text Message (90 Character Limit) |
|--------|------------|------------------------------------|----------------------------------|----------------|---|
| T+60s | TSW | Coastline (~400km x 1km) | Overall Tsunami Warning Zone | 1 | “Tsunami danger on the coast. Go to high ground or move inland. Listen to local news. –NWS” |
| | | Coastal Hinterland (~400km x 10km) | NWS CA041 (or LA County) | 2 | “Tsunami danger on the coast. Do not go near the water. Listen to local news. –NWS” |
| T+180s | TSW | Neighborhood (500m x 500m) | Naples Zone A | 3 | “Tsunami coming. Leave Naples immediately. Head NORTH via Appian Way bridge. –LA EMA” |
| | | | Naples Zone B | 4 | “Tsunami coming. Leave Naples immediately. Head WEST via 2nd Street bridge. –LA EMA” |
| | | | Naples Zone C | 5 | “Tsunami coming. Leave Naples immediately. Head EAST via 2nd Street bridge. –LA EMA” |

*TSW: Tsunami Warning

⁴⁶ Ibid.

⁴⁷ WEA tsunami warning, message ID 7881663 from IPAWS log file “FEMA IPAWS MSGXML 2011-10-20 to 2014-09-29.xlsx”, FEMA, 2014.

6.5 Potential for Cellular Infrastructure Damage

Since WEA warning messages and evacuation instructions will be issued in the minutes before the tsunami's arrival, we can assume that the cellular network will not be damaged during this critical time. If the earthquake that triggered the tsunami also caused destruction on land, however, there is a chance of degradations to cellular network performance, both from individual towers being destroyed, and over time from widespread power outages in the affected area. According to the FCC requirements mentioned earlier, cell sites that are not damaged should still function for up to eight hours after a loss of electricity from the power grid.⁴⁸

Furthermore, network congestion due to high call volume will most likely reduce the quality of service for ordinary voice and data traffic on cellular networks immediately prior to the arrival of the tsunami and in its aftermath. As explained earlier, WEA message reception would not be affected by this congestion.

⁴⁸ "Recommendations of the Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks."

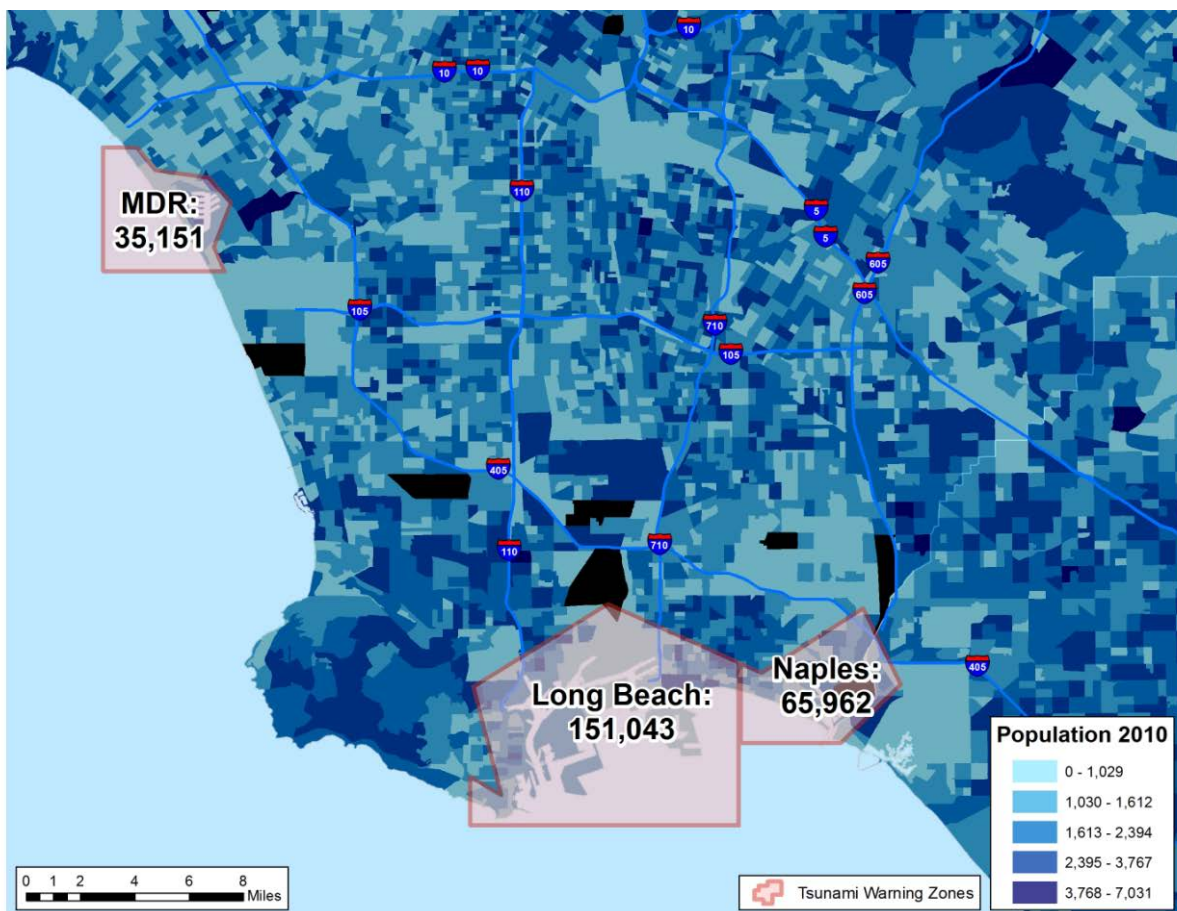
7. WEA Tsunami Warning Geo-Targeting Performance

This section examines WEA GTP in the southern California tsunami warning scenario described above. The geographic areas where the tsunami warning would be issued are densely populated and also are covered well by the Tier 1 wireless carriers. RAND has verified this observation by analyzing RF coverage data from the NBM, OpenSignal, Unwired Labs and Combain. There are very few coverage gaps in the larger NWS Warning Zone CA041, or in the three smaller areas considered — the Venice-MDR area, Long Beach and Naples Island. At least two of the Tier 1 carriers (AT&T and T-Mobile) employ a large number of cellular antennas in these areas, so the sizes of these cells are very small, in principle making precise geo-targeting of WEA messages possible.

7.1 Warning Populations

If a tsunami warning were sent to the larger NWS CA041 warning zone, the population to be warned would be 4,826,645. As discussed below, the majority of the population in this area would be not threatened by the tsunami.

Figure 7-1: Populations in Three Tsunami Inundation Areas



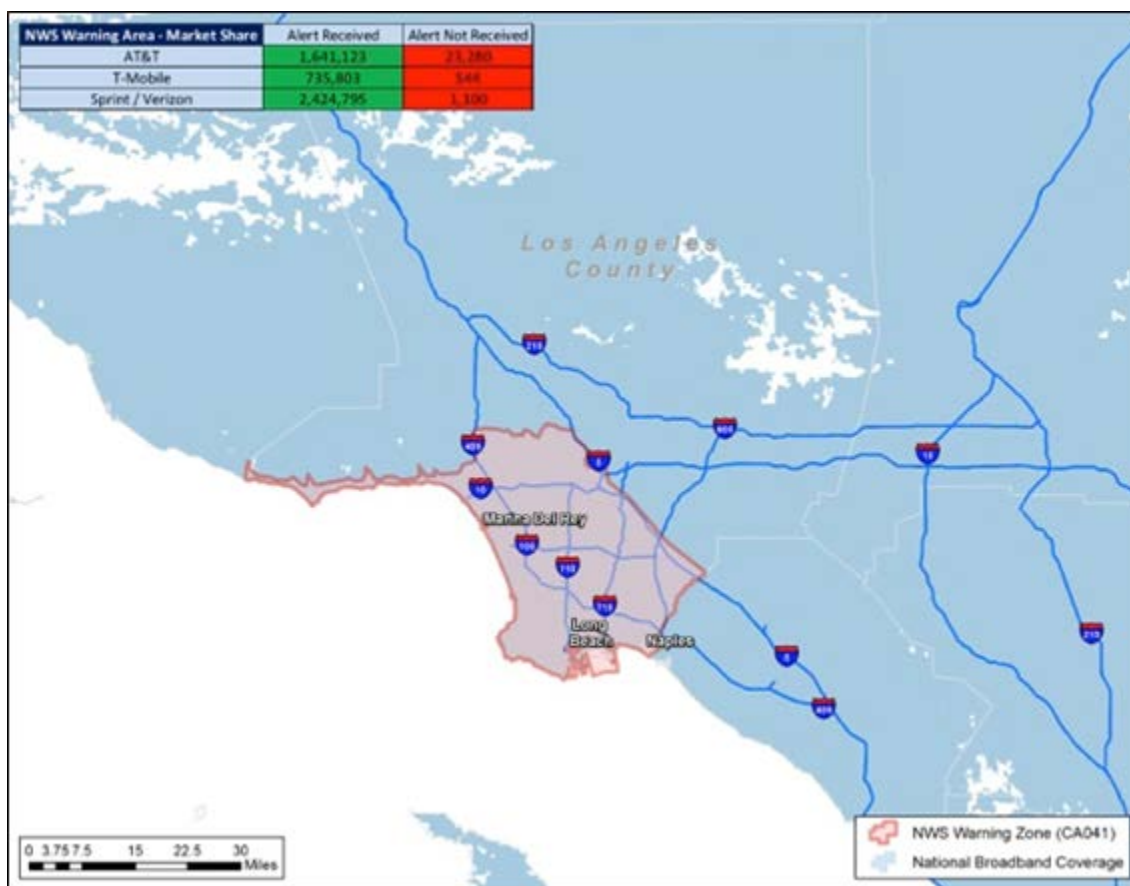
The populations of the three smaller areas threatened by the tsunami are shown in Figure 7-1. The total population in these three inundation zones is 252,156, or almost nine times less than the population in NWS CA041. So the amount of over-alerting and economic disruption that would result from sending tsunami warnings to the three smaller areas would be significantly less.⁴⁹

The following sections examine WEA GTP for the warning areas previously described. In all tsunami warning cases considered it is assumed all Tier 1 carriers use cell antenna selection method 1 when broadcasting the WEA message.

7.2 WEA Tsunami Warning GTP for NWS CA041

First consider the case when the tsunami warning is sent to all cell towers in the NWS CA041 warning area, as shown in Figure 7-2.

Figure 7-2: Tier 1 Carrier WEA Tsunami Warning Geo-Targeting for NWS Warning Zone CA041



⁴⁹ Other areas of the coastline in Los Angeles County should also receive a tsunami warning. According to Figure 6-4, however, these areas are much narrower and confined to the immediate coastline. These areas have much smaller populations than the three coastal areas highlighted in this analysis (Venice-MDR, Long Beach and Naples).

The table in the upper left hand corner of Figure 7-2 shows the WEA geo-targeting metrics for this case. Given the excellent coverage provided by the Tier 1 carriers in this area, the WEA alerting rate is very high and the AFR very low. More than 99.5 percent of the population in the warning area receives the alert. Only 0.005 percent of that same population fail to receive it. The bigger issue to consider in this case is that the majority of the population in the warning area are not under threat and are not in the tsunami inundation zone. Because the warning polygon is so large, the actual OAR is very large. Approximately 4.5 million people would receive the alert, but should not.⁵⁰

7.3 WEA Tsunami Warning GTP for Venice-MDR

If the tsunami warning is not sent to one large warning area such as NWS CA041, it will be sent in separate WEA messages to smaller warning polygons situated along the coastline. The three largest such areas are Venice-MDR, Long Beach and Naples Island. First the WEA tsunami warning performance of each Tier 1 wireless carrier in the Venice-MDR area is considered.

Estimated AT&T Network GTP

Figure 7-3 shows the estimated locations of cells and antennas in the AT&T network in the Venice-MDR warning polygon. The background blue color is AT&T coverage derived from the NBM. Ocean and the MDR harbor waters are shown in white. The coastline is indicated by a grey line. AT&T cell towers are depicted as purple points and cell boundaries by purple lines. As before, all cell boundaries are computed using the Voronoi algorithm applied to all cell tower locations.

Cell tower locations are based on Unwired Labs data. As this crowd sourced data is partly derived from location data for individual cell phones it does not provide an entirely accurate estimate of antenna locations. The initial set of AT&T cells tower locations included some towers that were estimated to be in the water (the Pacific Ocean). Obviously this is not correct. To correct these location errors in the original data set we developed an algorithm to reposition cellular antennas that, according to the Unwired Labs raw data, appeared to be in the water. This algorithm repositions these cell antennas to the nearest point on land. These antennas all now appear on the grey line indicating the Pacific coastline in Figure 7-3.

Note that some areas of the coastline shown in the figure appear white; the NBM appears to show parts of the coastal land area where the AT&T network appears to provide no coverage. In this case the NBM is not accurate, perhaps due to limited resolution of this nationwide dataset. This view is confirmed by the fact that Unwired Labs data show AT&T cell antennas in these “white no coverage” areas. Narrow man-made structures such as jetties or harbor piers are shown as thin grey lines in the figure. Some

⁵⁰ We arrive at this number by subtracting the populations of the Venice-MDR, Long Beach and Naples Island warning polygons from that of NWS CA041. Although there are people in tsunami inundation zones outside of the Venice-MDR, Long Beach and Naples Island warning polygons. This population is very small and probably on the order of several thousand people in Los Angeles County due to the narrowness of the inundation zones.

antennas are located on these piers and not located in the water. Finally, we note that the same raw data errors were found in Unwired Labs data for the antenna locations of the other Tier 1 carriers. The same antenna location correction algorithm is applied to the antenna locations of all four Tier 1 carriers.

Figure 7-3: Activated AT&T Cells for Venice-MDR

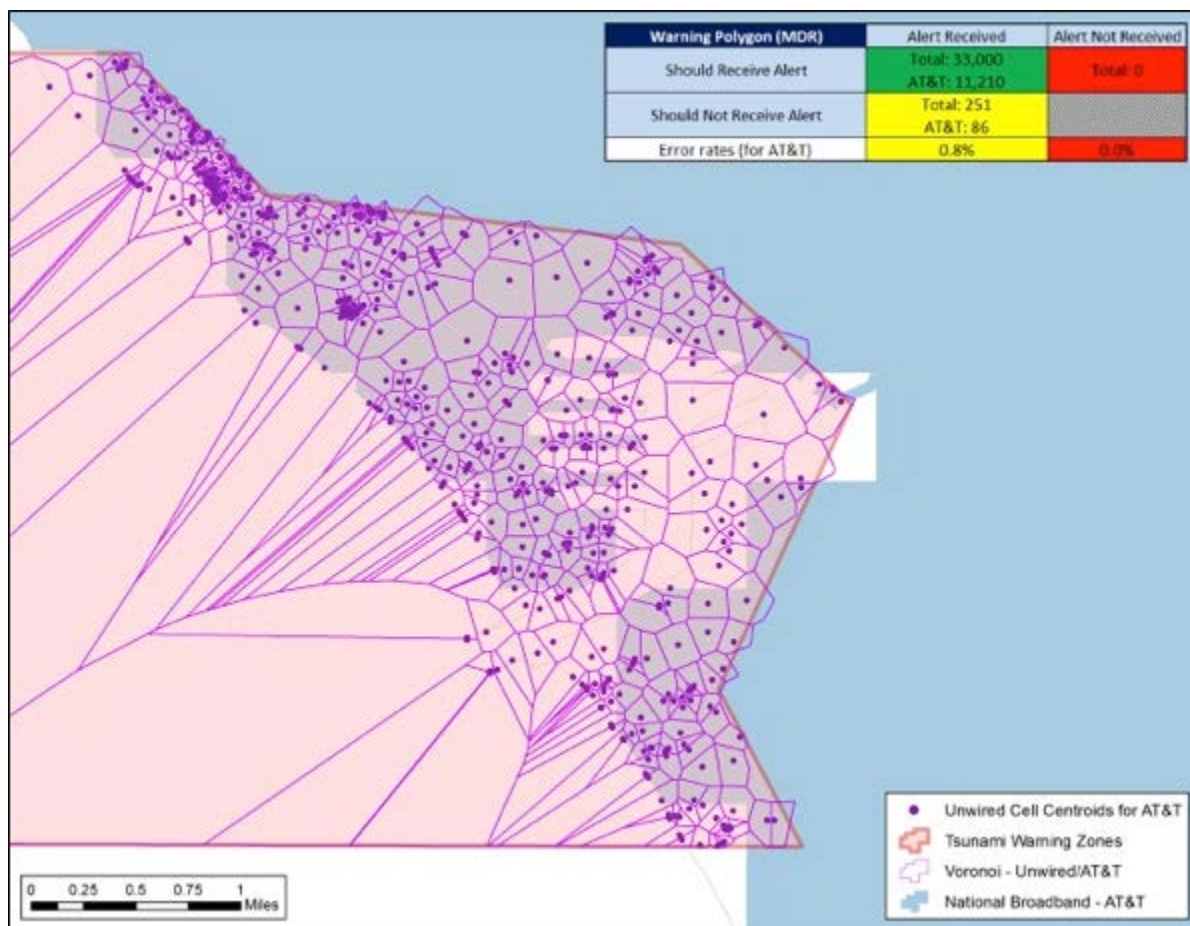
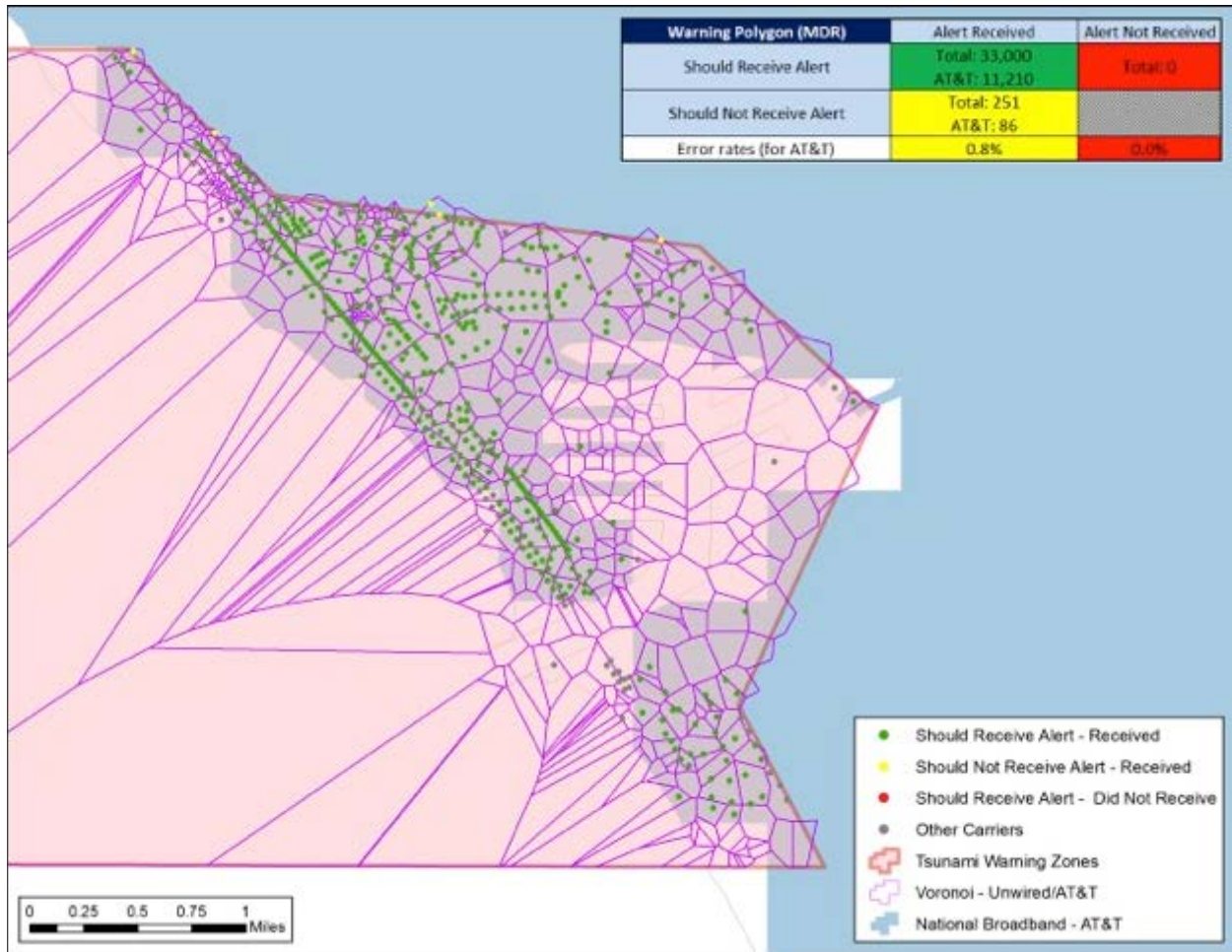


Figure 7-4 shows WEA GTP estimates for the AT&T network in the Venice-MDR area. The green points represent census tracts or people that are in the warning polygon and receive the alert (and should receive it). Yellow points represent people who received the alert and reside outside of the warning polygon and should not receive it. Because of the small size of the cells in this area, the OAR is relatively small — only 0.8 percent of the population in the Venice-MDR tsunami warning area.

Red points indicate those who should receive the tsunami warning but do not. There are no red points in the figure, indicating that there are no alert failures in this case. AT&T network coverage in this area is very good and all members of the population are covered.

Figure 7-4: AT&T WEA GTP for Venice-MDR



Estimate of the T-Mobile Network GTP

Figure 7-5 shows the cells that are activated in the T-Mobile network for the hypothetical tsunami warning message that would be sent to the Venice-MDR area. The same data source (Unwired Labs) is used to estimate the location of T-Mobile cell antennas, and the same antenna location correction algorithm was used to place cell antennas on land near the coastline.

Figure 7-5: Activated T-Mobile Cells in Venice-MDR

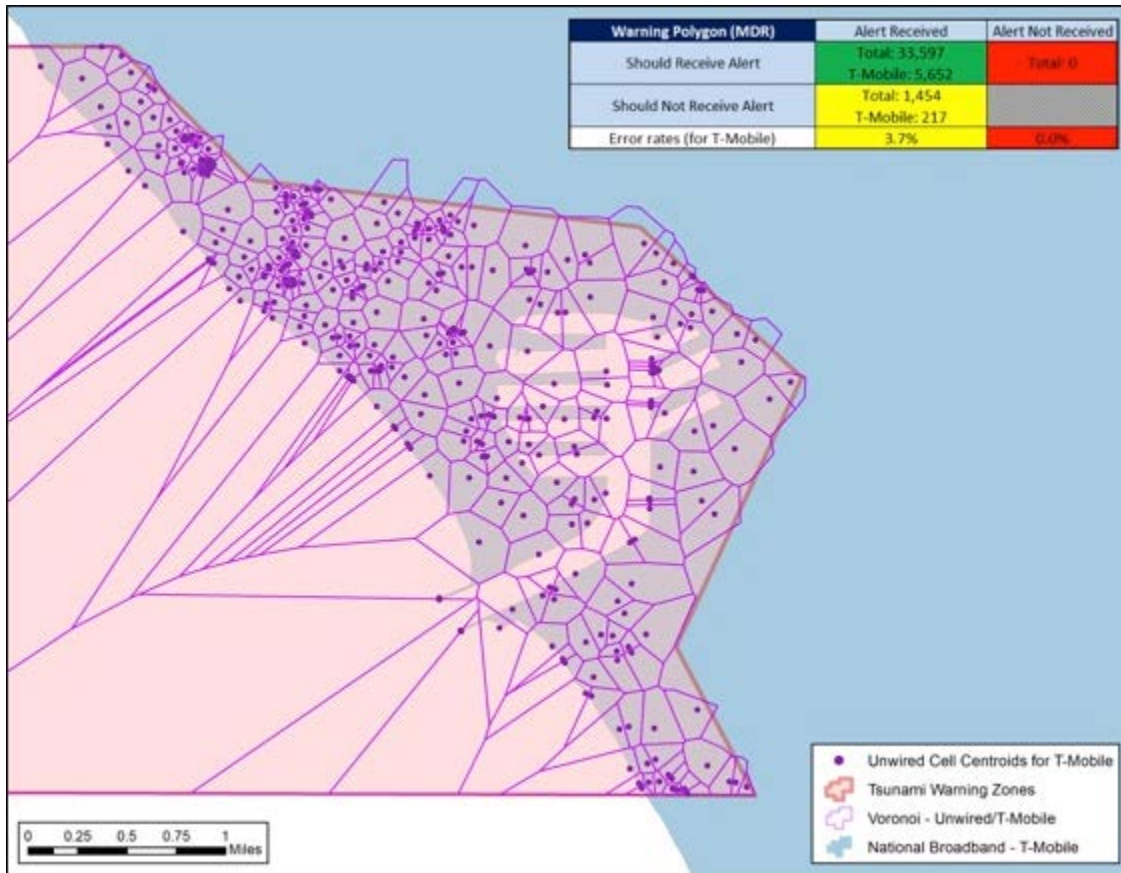
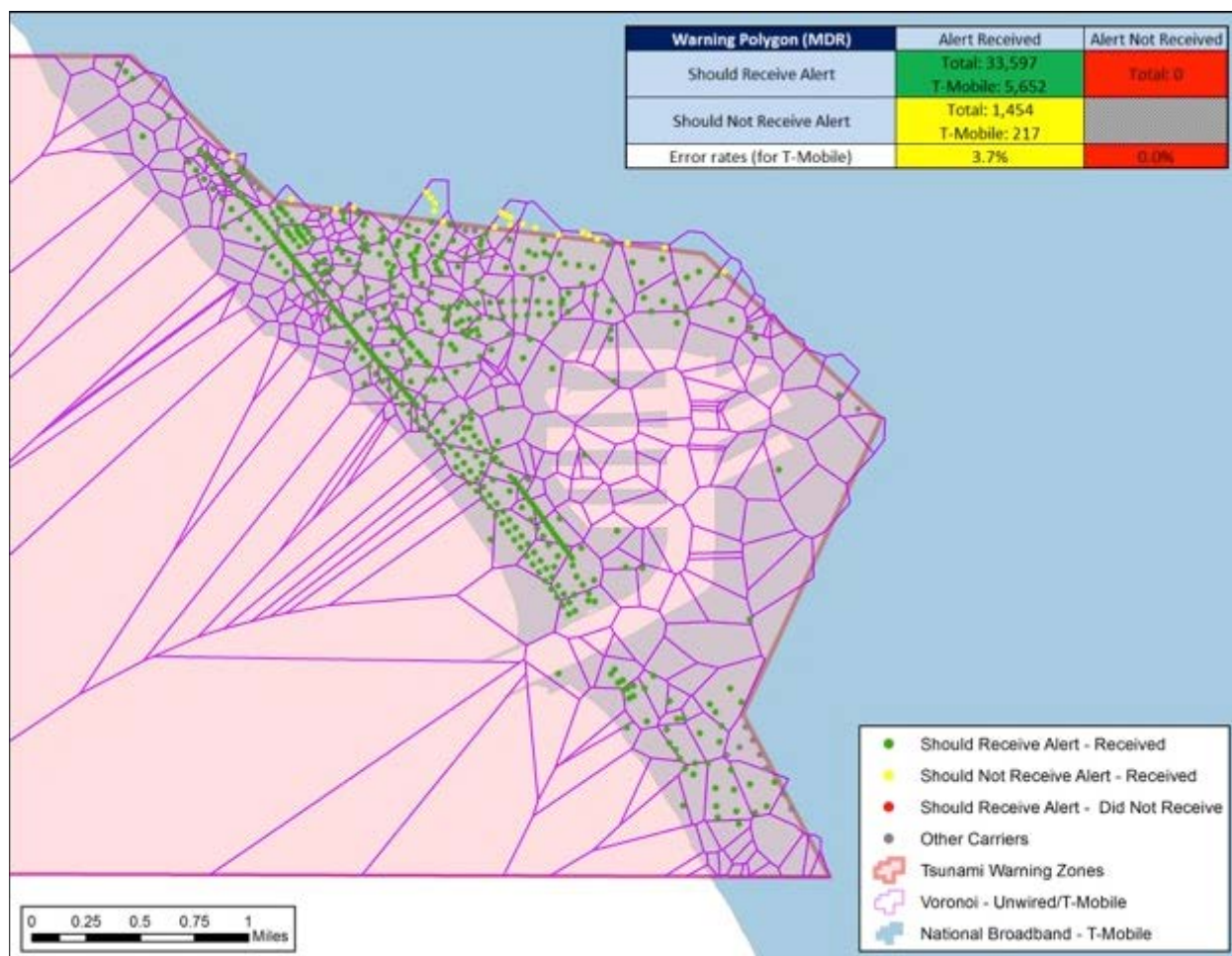


Figure 7-6 shows WEA GTP results estimates for the T-Mobile network in the Venice-MDR area. Just as before, the green points represent census tracts or people that receive the alert in the warning polygon. Yellow points represent people who received the alert and reside outside of the warning polygon and should not receive it. Some of the T-Mobile cells are larger than those in the AT&T network which leads to some bleed over in the northern regions of the warning polygon, as shown in Figure 7-6. This increases the OAR to approximately 3.7 percent of the population in the warning area.

Red points indicate those who should receive the tsunami warning but do not. There are no red points in the figure, indicating there are no alert failures. T-Mobile network coverage in this area is very good and all members of the population are covered.

Figure 7-6: T-Mobile WEA GTP for Venice-MDR



Estimated GTP of the Sprint and Verizon Networks

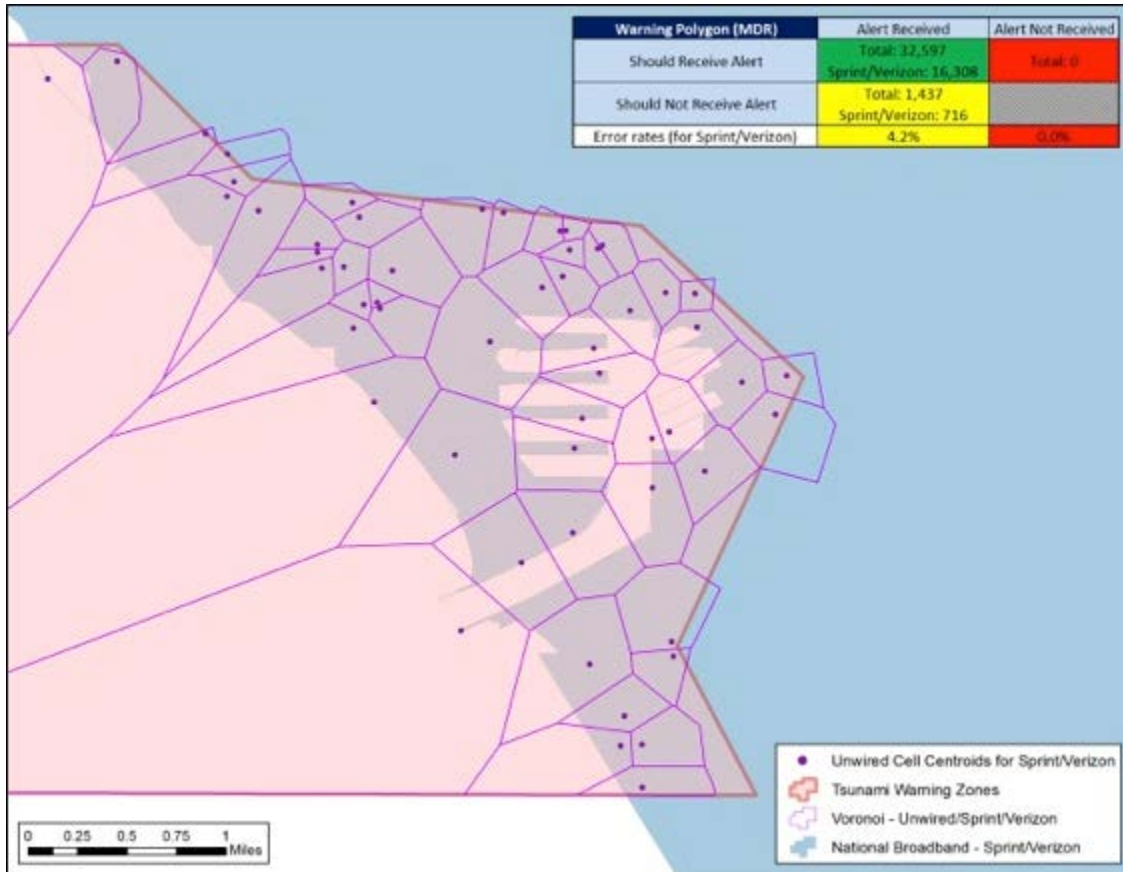
Figure 7-7 shows the cells in the Sprint and Verizon networks that are used to transmit the tsunami warning message that would be sent to the Venice-MDR area, using method 1 for the WEA cell broadcast. The same data source (Unwired Labs) was used to estimate the location of Sprint and Verizon cell antennas, and the same antenna location correction algorithm was used to place cell antennas on land near the coastline.

There was a much lower number of cell antennas in the Venice-MDR area in the Sprint and Verizon networks in the Unwired Labs data set. There could be errors in the Unwired Labs data or data may be missing for some of the carriers in the data set. On the other hand, as mentioned before in this report, in many areas of the country Verizon⁵¹ is allocated more frequencies at lower radio bands than the

⁵¹ Neal Gomba on January 25 and 2013 at 1:25 Pm, "Verizon Wireless Sells Lower 700MHz Spectrum to AT&T for \$1.9 Billion," *ExtremeTech*, accessed February 28, 2016, <http://www.extremetech.com/electronics/146841-verizon-wireless-sells-lower-700mhz-spectrum-to-att-for-1-9-billion>.

other Tier 1 wireless carriers.⁵² Lower frequency radio signals have better propagation characteristics in urban environments. For example path attenuation can increase by three to 10 dB between 1.3 GHz and 800 Mhz.⁵³ This would enable Verizon to use larger cells and may explain the differences in the Unwired Labs data for the different carriers. Also, it is known that in parts of the country Sprint leases, or is planning to lease, cellular network resources from other carriers or tower companies.⁵⁴ For the reasons mentioned above, it was decided to combine the cell tower data for Verizon and Sprint in this analysis.

Figure 7-7: Activated Sprint and Verizon Cells in Venice-MDR



⁵² "Cellular Frequencies," *Wikipedia, the Free Encyclopedia*, February 14, 2016, https://en.wikipedia.org/w/index.php?title=Cellular_frequencies&oldid=704983645.

⁵³ Kazimierz Siwiak and Bahreini, *Radiowave Propagation and Antennas for Personal Communications*, Third (Artech House, 2007), <http://www.artechhouse.com/Main/Books/Radiowave-Propagation-and-Antennas-for-Personal-Co-1193.aspx>.

⁵⁴ "Sprint Spending, Verizon Towers Top Infrastructure News," *RCR Wireless News*, September 18, 2014, <http://www.rcrwireless.com/20140918/wireless/sprint-spending-verizon-towers-top-infrastructure-news-week-tag4>.

Figure 7-8: Sprint and Verizon WEA GTP in Venice-MDR

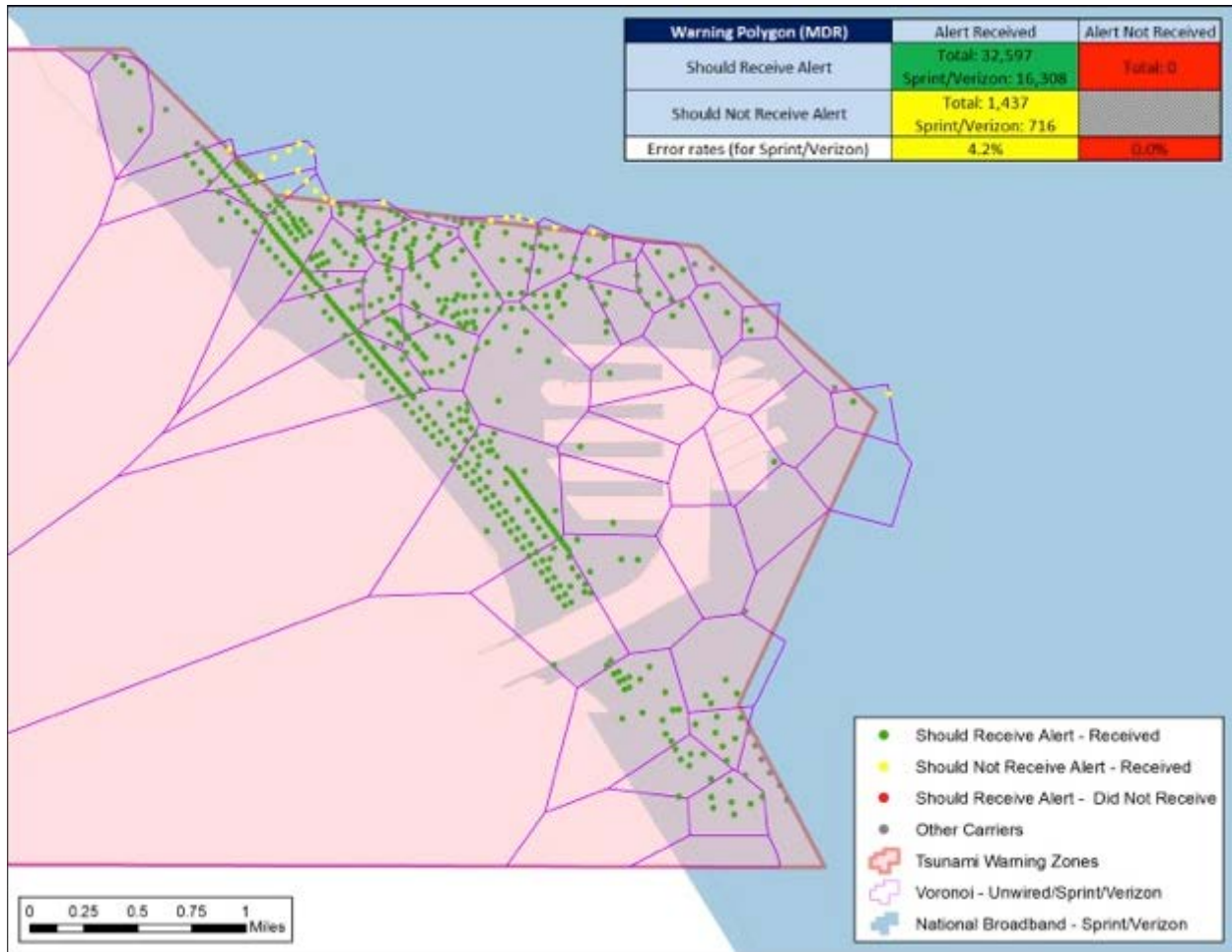


Figure 7-8 shows WEA GTP results estimates for the Sprint and Verizon networks in the Venice-MDR area. The Sprint and Verizon cells are larger than those in the AT&T network which leads to bleed over in the northern regions of the warning polygon. This increases the OAR to 4.2 percent of the population in the warning area. For the Sprint and Verizon networks there are no alert failures in this case. The network coverage of these two Tier 1 carriers in this area is very good and all members of the population are covered.

7.4 WEA Tsunami Warning GTP for Long Beach

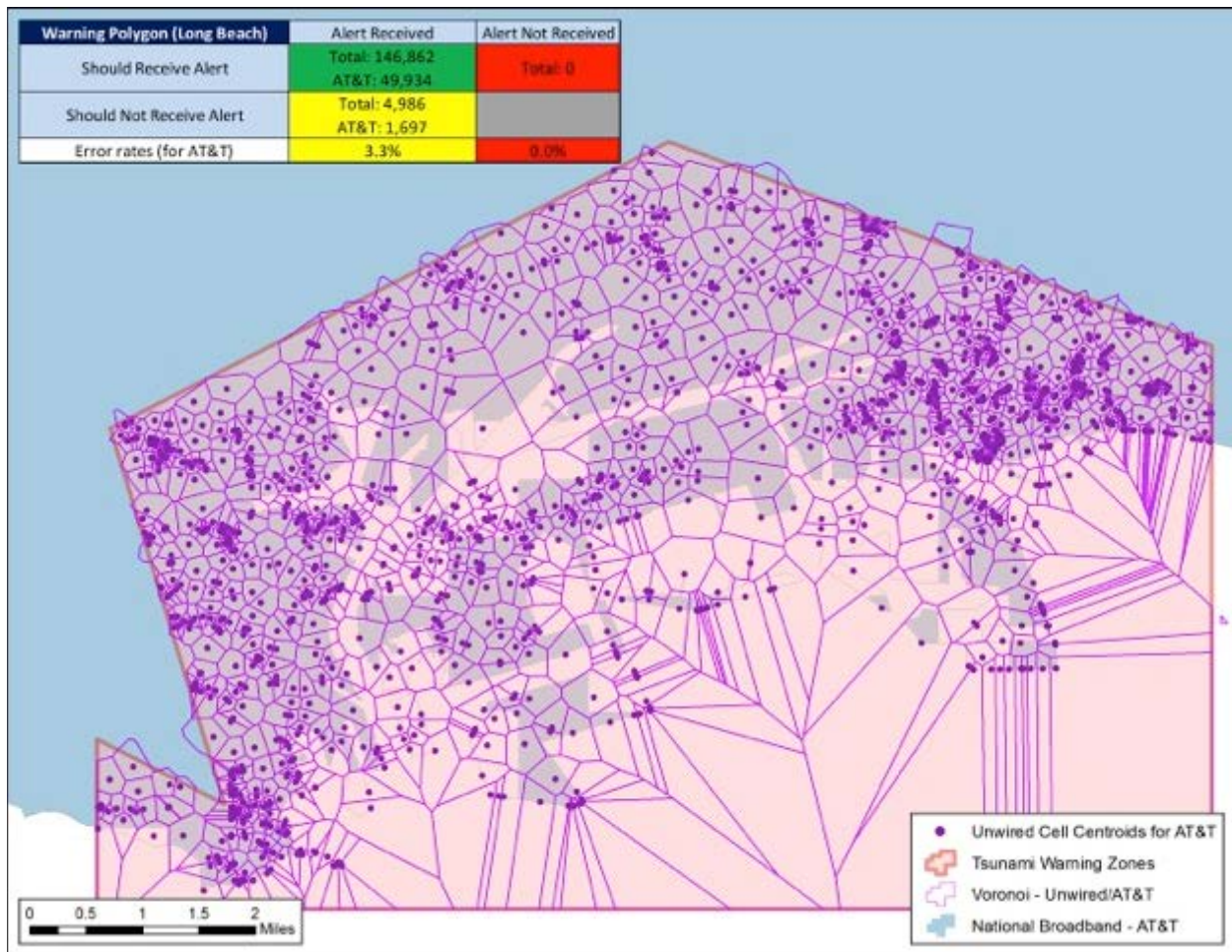
This section considers WEA GTP in the case where a tsunami warning is issued for Long Beach Harbor and surrounding areas that would be in the inundation zone.

AT&T WEA GTP

Figure 7-9 shows the estimated location of AT&T antennas in the Long Beach Harbor area that would be activated to issue the tsunami warning using method 1. Consistent with the definition of method 1 only

antennas inside the warning polygon would be activated. The cell boundary surrounding these antennas are drawn as before using the Voronoi method.

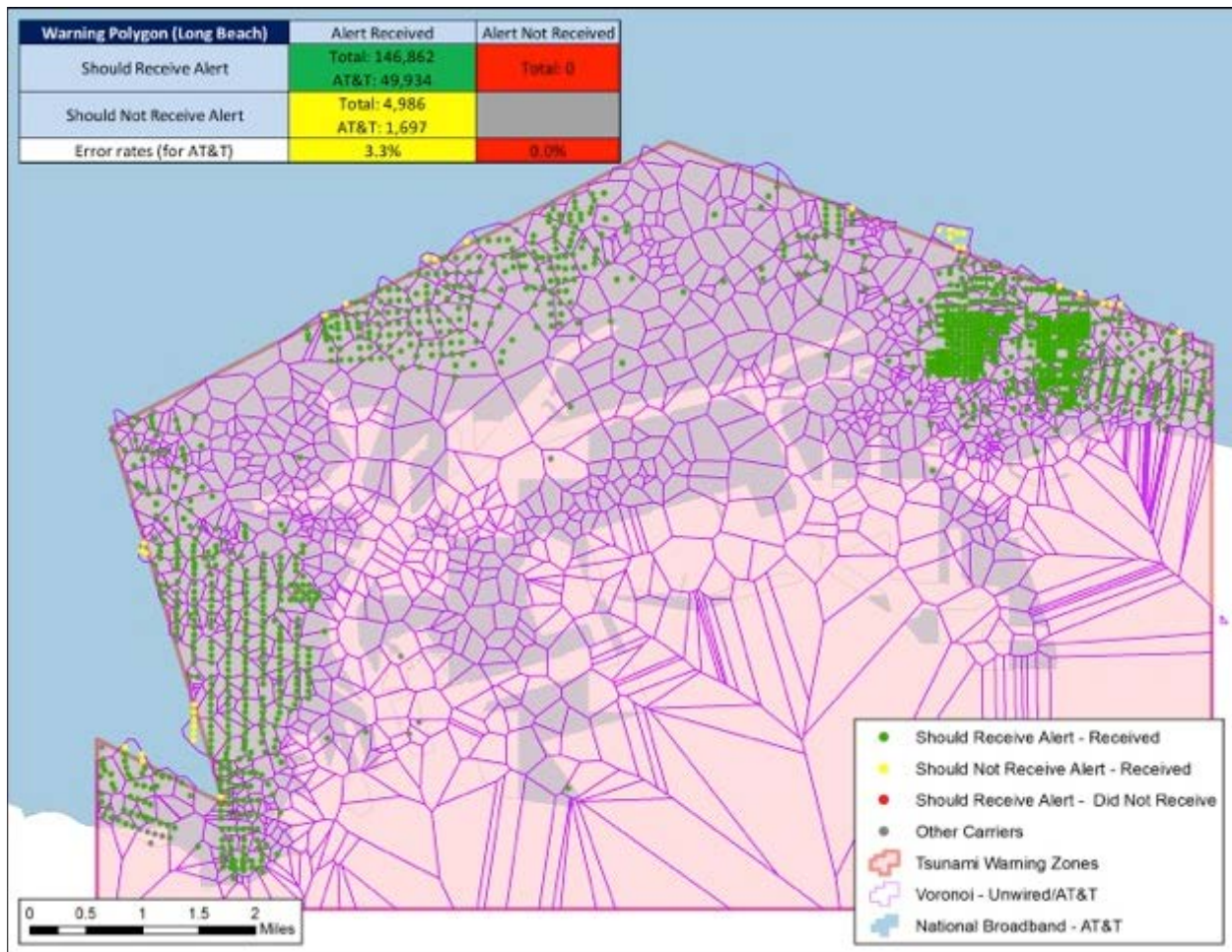
Figure 7-9: Activated AT&T Cells in Long Beach Harbor



Shown in Figure 7-10 are WEA GTP estimates for the AT&T network in the Long Beach Harbor area. From the absence of red points in the figure one can see there are no alert failures. There are a relatively small number of over-alerted individuals on the boundaries of the warning polygon. The OAR

is approximately 3.3 percent which translates to about 1,697 people who receive the alert but should not.

Figure 7-10: AT&T WEA GTP for Tsunami Warning of Long Beach Harbor

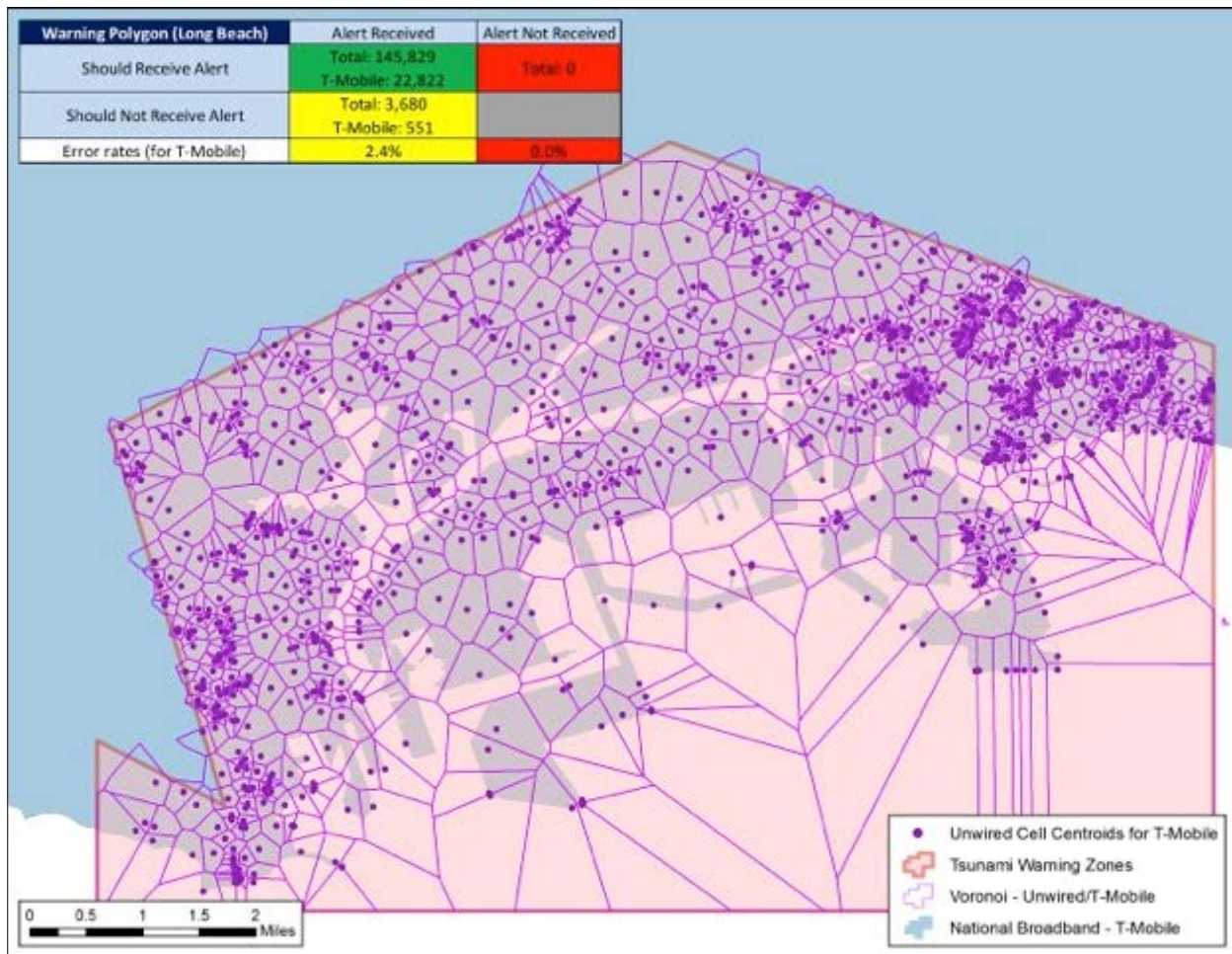


Estimated T-Mobile Network GTP

Figure 7-11 shows the cells that would be activated in the T-Mobile network for the hypothetical tsunami warning message for the Long Beach Harbor area. The same data source (Unwired Labs) is used

to estimate the location of T-Mobile cell antennas, and the same antenna location correction algorithm was used to place cell antennas on land in the harbor area.

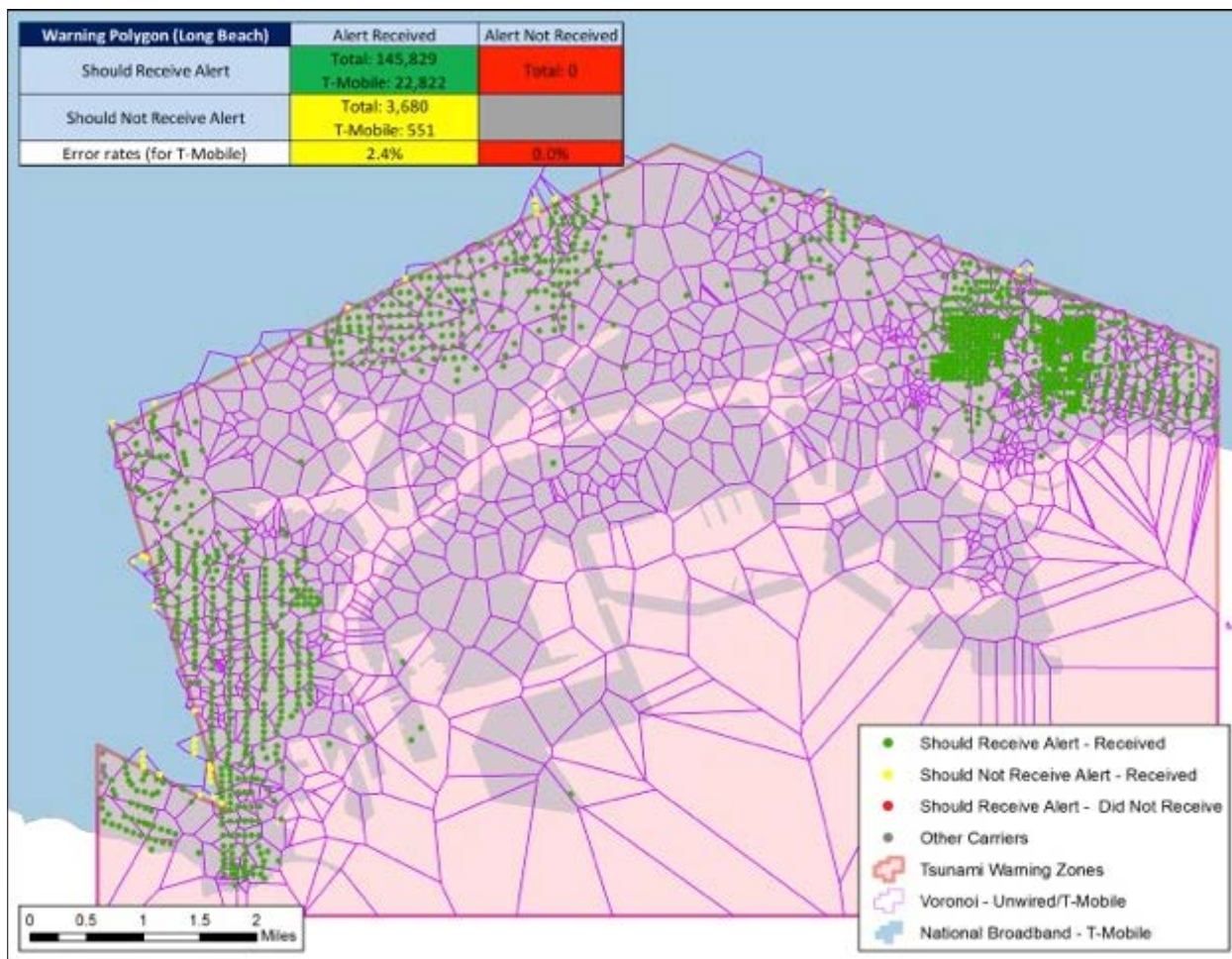
Figure 7-11: Activated T-Mobile Cells in the Long Beach Harbor Area



Shown in figure 7-12 are WEA GTP estimates for the T-Mobile network in the Long Beach Harbor area. There are also no red points in the figure and no alert failures. There are a small number of over-alerts

on the boundaries of the warning polygon. The OAR is 2.4 percent which translates to about 551 people who receive the alert but should not.

Figure 7-12: T-Mobile WEA GTP for Tsunami Warning of Long Beach Harbor

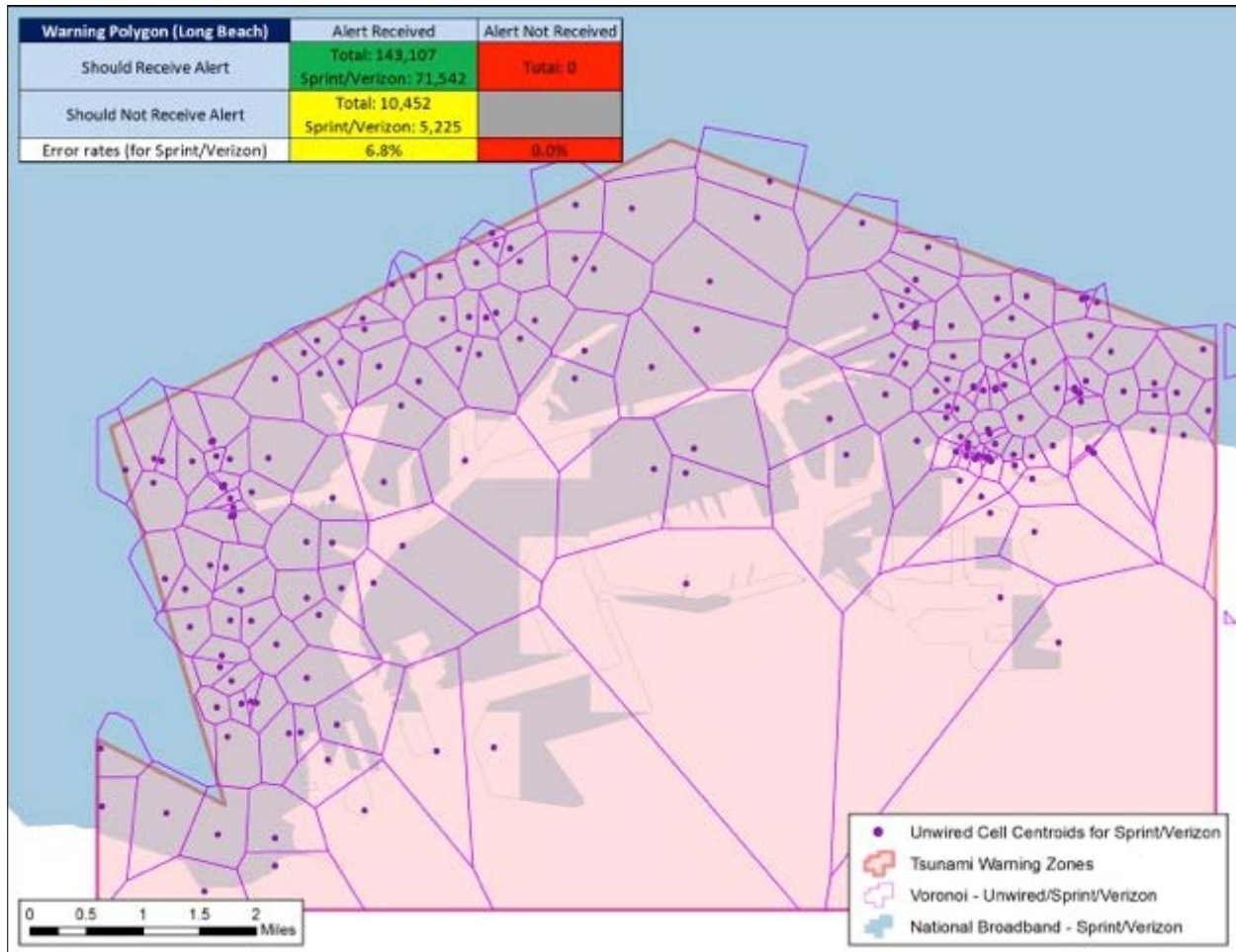


Estimated Sprint and Verizon Network GTP

Figure 7-13 shows the cells in the Sprint and Verizon networks that would be used to transmit the tsunami warning message for the Long Beach Harbor area. The same data source (Unwired Labs) was used to estimate the location of Sprint and Verizon cell antennas, for the Long Beach area, and the same antenna location correction algorithm was used to place cell antennas on land near the coastline.

It is apparent from the figure that the Unwired Labs data indicates that there is a lower number of Sprint and Verizon antennas in this area when compared to the AT&T and T-Mobile networks. Just as before, it is assumed this difference is due to the lower frequencies used in the Verizon and Sprint networks in this area, and to possible antenna and bandwidth leasing by Verizon to Sprint.

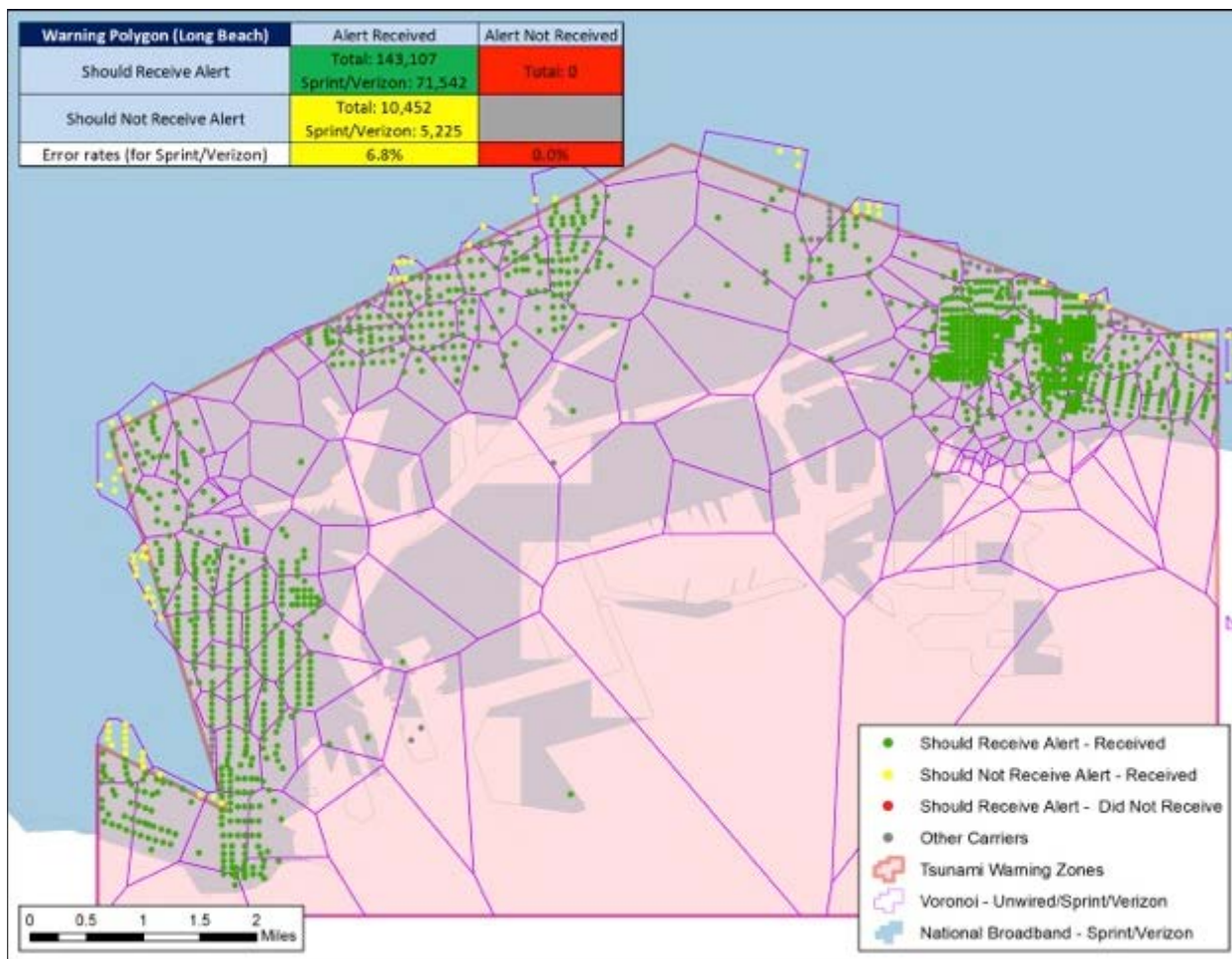
Figure 7-13: Activated Sprint and Verizon Cells in Long Beach Harbor



Shown in figure 7.14 are WEA GTP estimates for the Sprint and Verizon networks in the Long Beach Harbor area. Just as with the other carriers, there are also no red points in the figure and no alert failures. The area is relatively small (less than 10 miles across) and of course it is relatively flat, ideal for the propagation of radio waves. There are a small number of over-alerts on the boundaries of the

warning polygon. The OAR is 2.4 percent which translates to about 5,225 people who receive the alert but should not.

Figure 7-14: Sprint and Verizon GTP for Tsunami Warning of Long Beach Harbor



7.5 WEA Tsunami Warning GTP for Naples Island

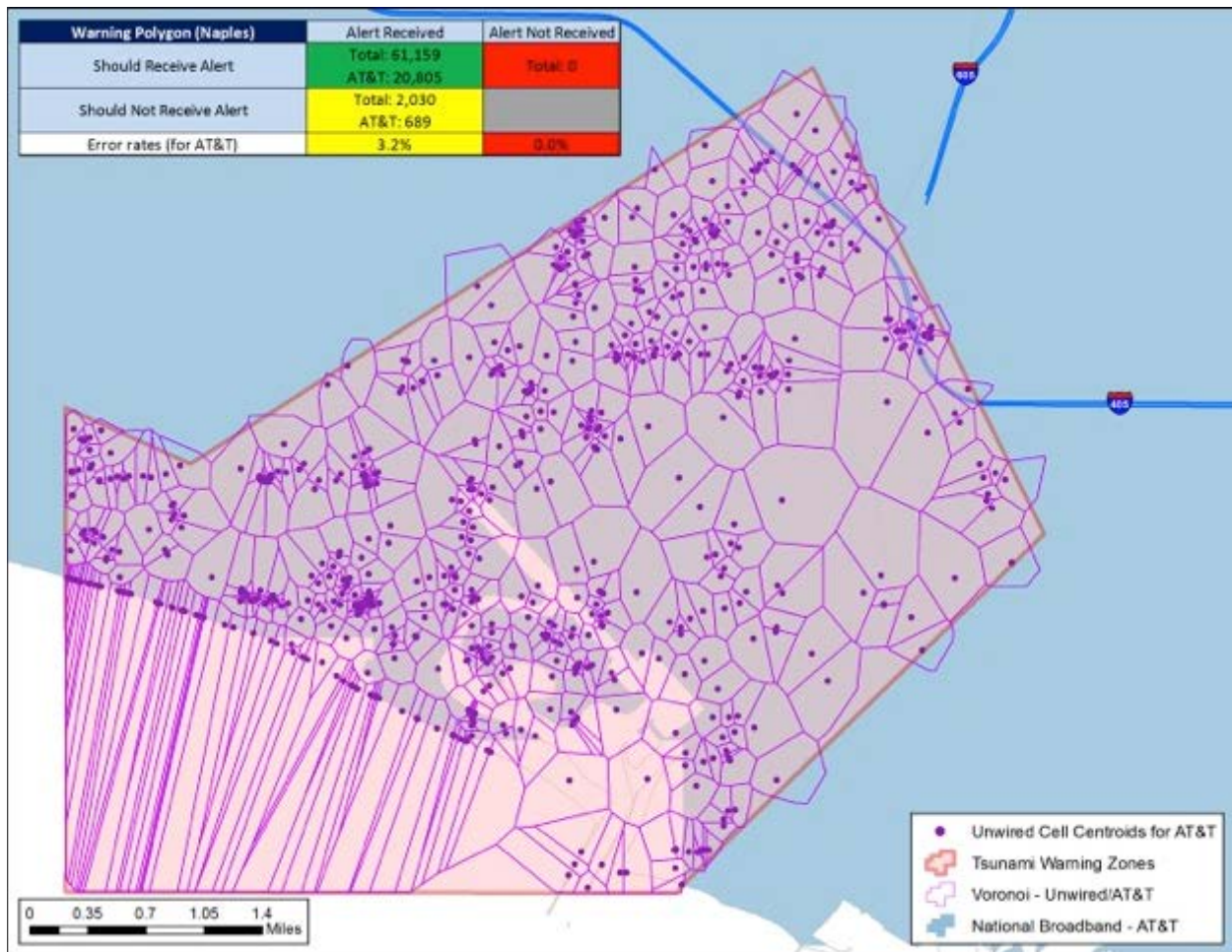
Next consider WEA GTP when a tsunami warning is issued for Naples Island. Naples Island is immediately to the southeast of Long Beach Harbor and is relatively unique in southern California. It includes an inland waterway and behind a barrier peninsula in the waterway is a small island that is densely populated. Also important to consider in this warning scenario is the fact that the island is connected to the mainland by only three relatively small and narrow bridges. All people on the island would be asked to seek higher ground in such a scenario and would have to evacuate the island over one of these three bridges.

Estimated AT&T Network GTP

Figure 7-15 shows the location of AT&T antennas in this area that would be activated to issue the tsunami warning using method 1. Consistent with the definition of method 1, only antennas inside the

warning polygon would be activated. The cell boundary surrounding these antennas are drawn as before using the Voronoi method.

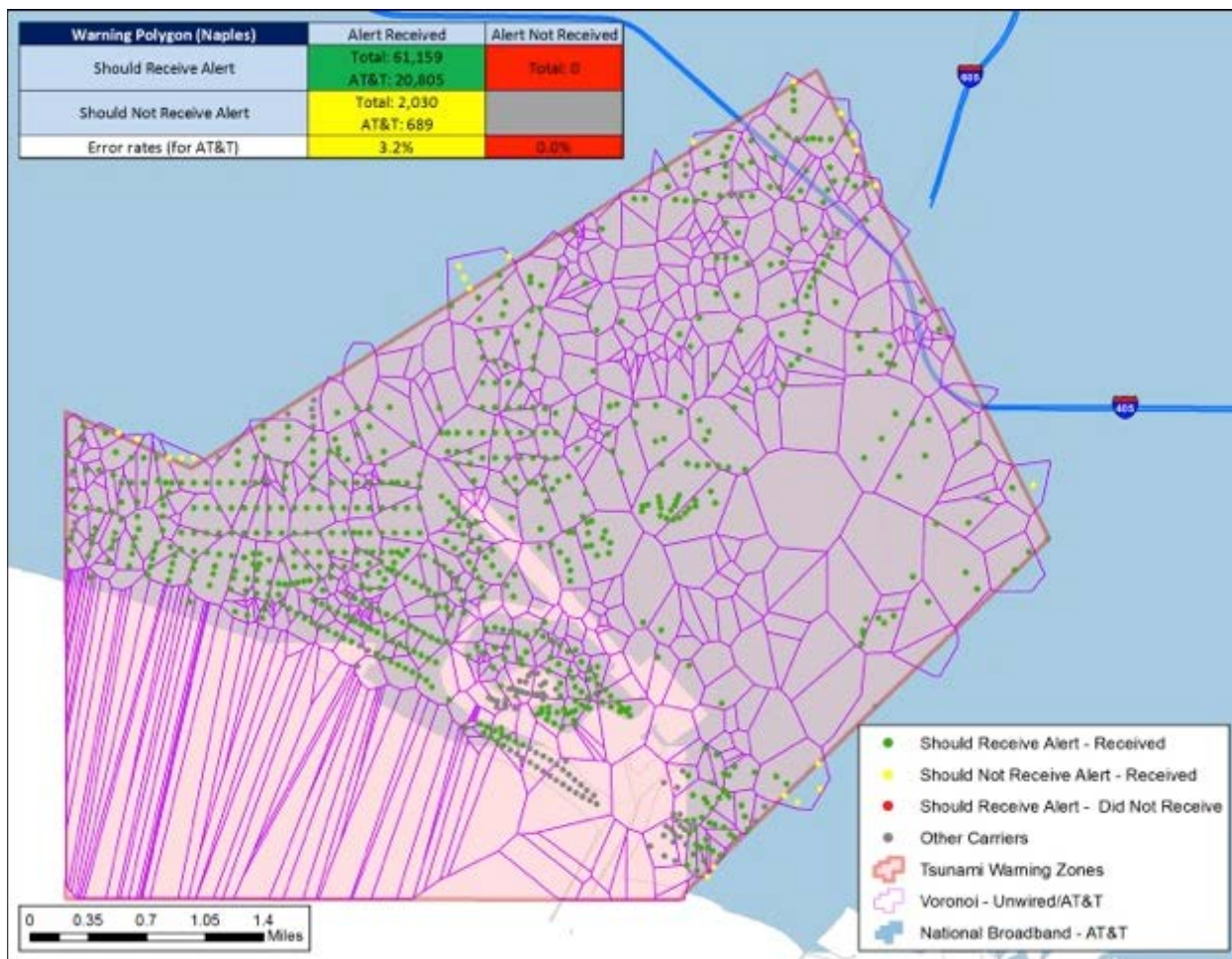
Figure 7-15: Activated AT&T Cells in Naples



Shown in Figure 7-16 are WEA GTP estimates for the AT&T network in the Naples Island area. From the absence of red points in the figure one can see there are no alert failures. There are a relatively small

number of over-alerted individuals on the boundaries of the warning polygon. The OAR is approximately 3.2 percent which translates to approximately 689 people who receive the alert but should not.

Figure 7.16: AT&T WEA GTP in Naples

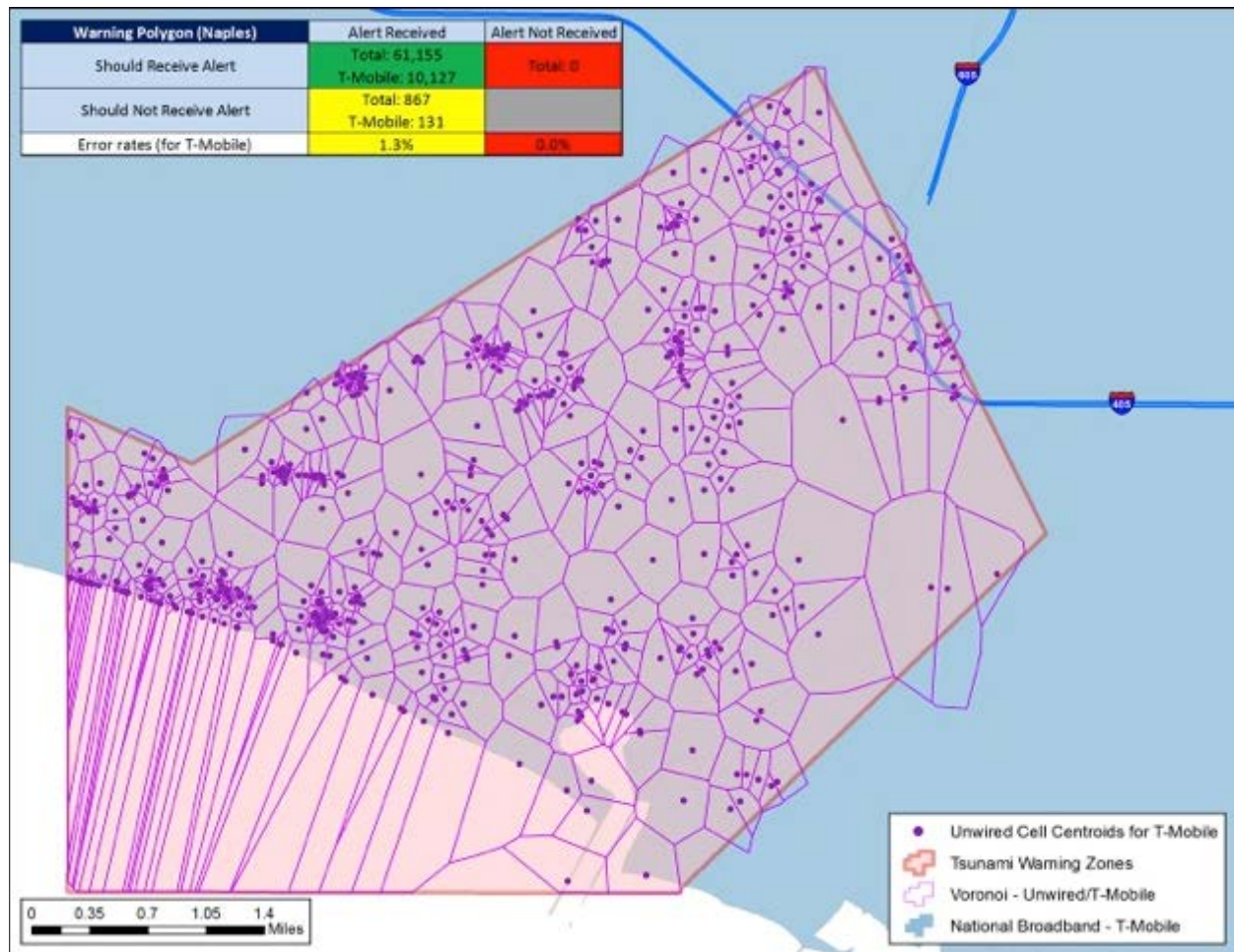


Estimated T-Mobile Network GTP

Figure 7-17 shows the cells that would be activated in the T-Mobile network for the hypothetical tsunami warning message for the Naples Island area. The same data source (Unwired Labs) is used to

estimate the location of T-Mobile cell antennas, and the same antenna location correction algorithm was used to place cell antennas on land in the harbor area.

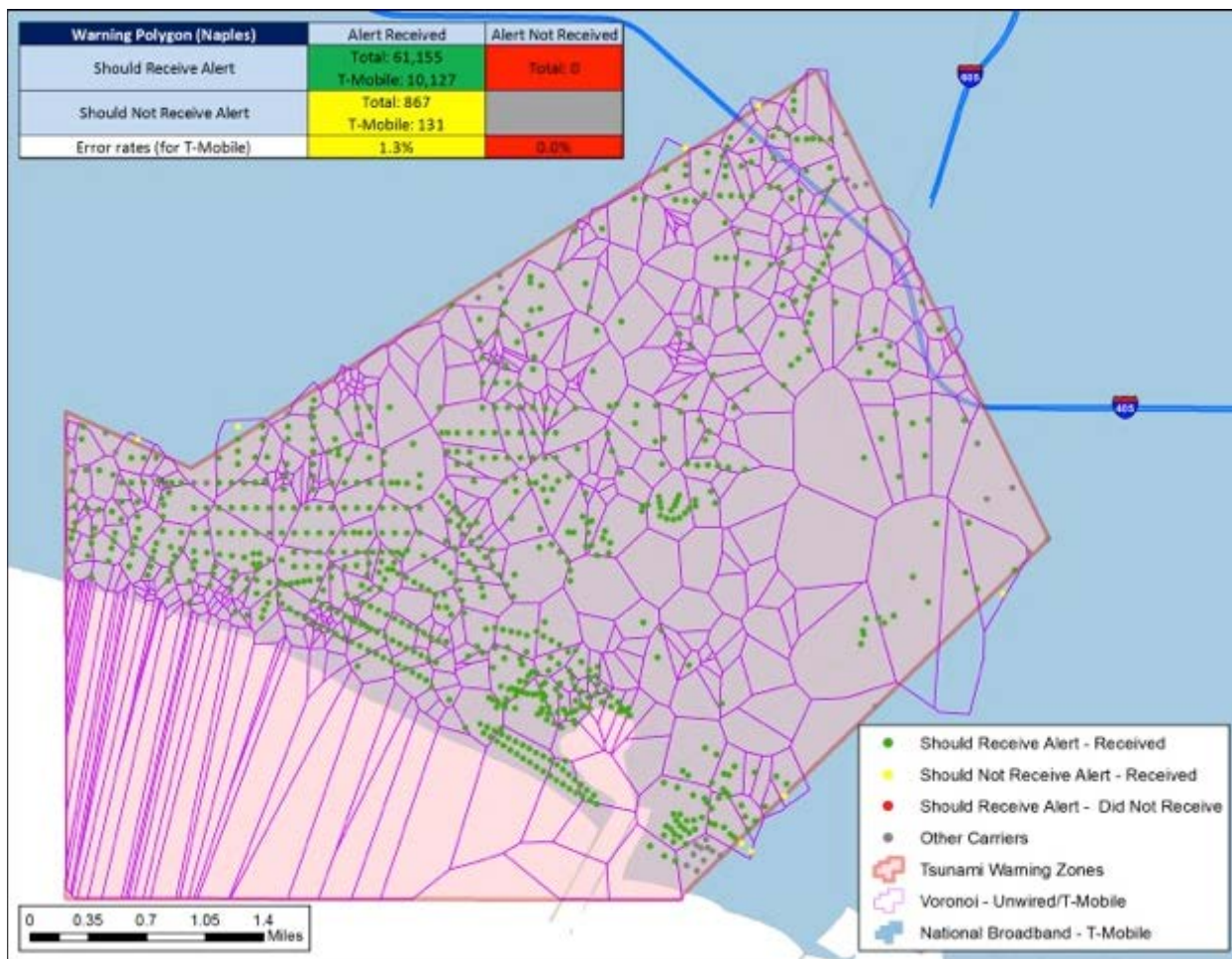
Figure 7-17: Activated T-Mobile Cells in Naples



Shown in Figure 7-18 are WEA GTP estimates for the T-Mobile network for the Naples Island area. There are also no red points in the figure and no alert failures. There are a very small number of over-alerted

people on the boundaries of the warning polygon. The OAR is 1.3 percent which translates to about 131 people who receive the alert but should not.

Figure 7-18: T-Mobile WEA GTP in Naples



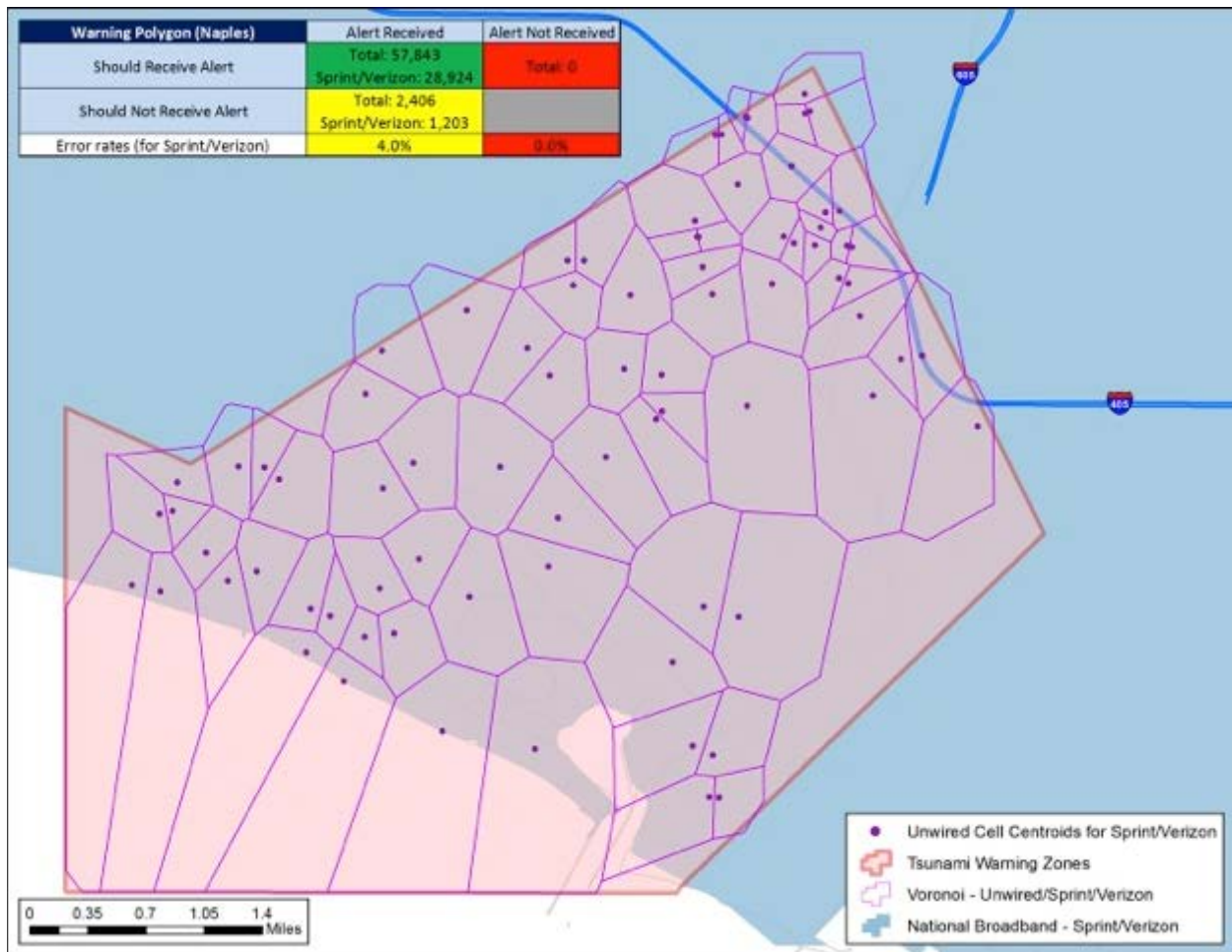
Estimated Sprint and Verizon Network GTP

Figure 7-19 shows the cells in the Sprint and Verizon networks that would be used to transmit the tsunami warning message for the Naples Island area. The same data source (Unwired Labs) was used to estimate the location of Sprint and Verizon cell antennas, and the same antenna location correction algorithm was used to place cell antennas on land near the coastline.

The figure shows there is a relatively small number of Sprint and Verizon antennas in this area in comparison to the AT&T and T-Mobile networks. Just as before we assume this difference is due to the

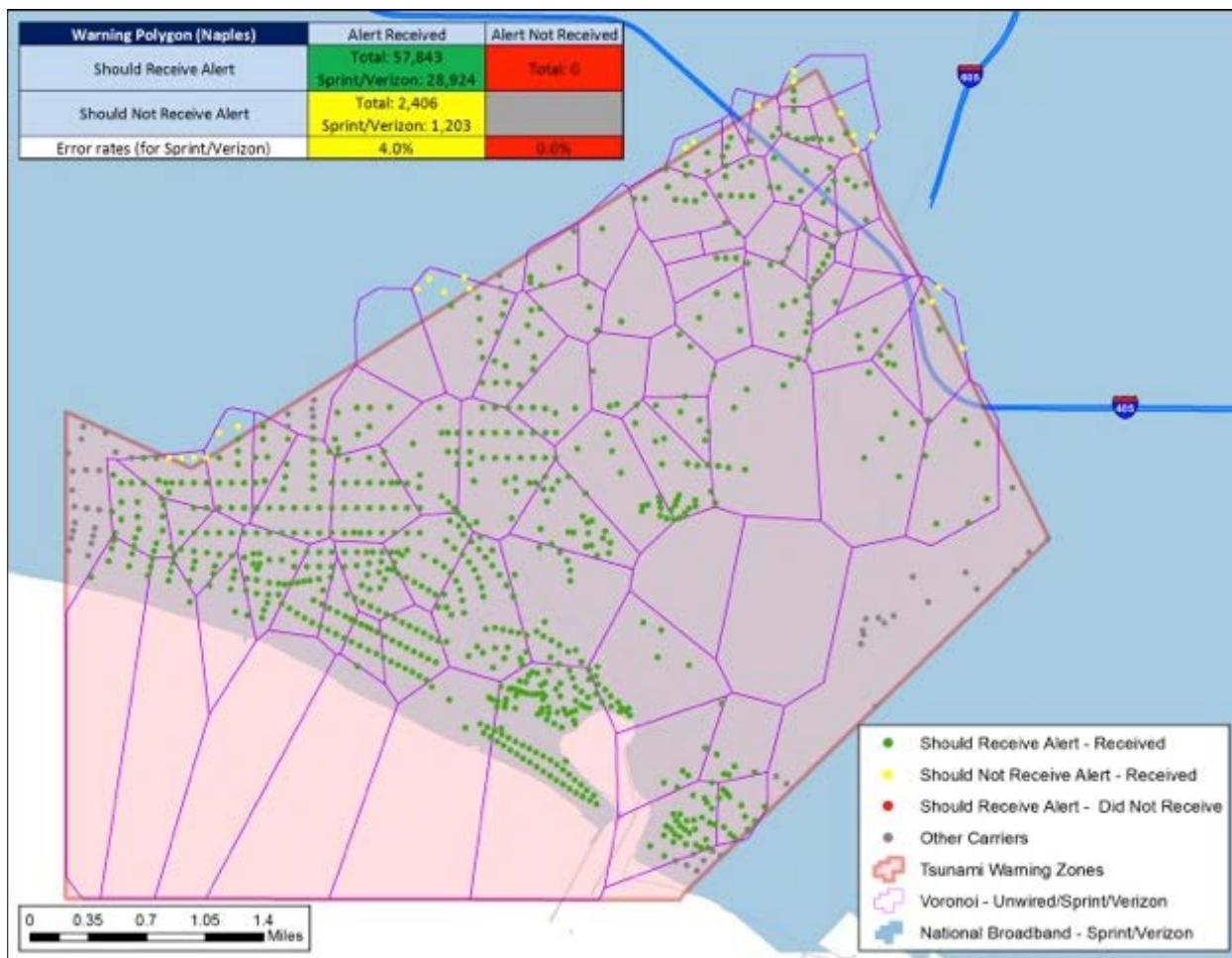
lower frequencies used in the Verizon and Sprint networks in this area, and to possible antenna leases by Verizon to Sprint.

Figure 7-19: Activated Sprint and Verizon Cells in Naples



Shown in figure 7-20 are WEA GTP estimates for the Sprint and Verizon networks in the Naples Island area. Just as with the other carriers, there are no red points in the figure and no alert failures. Just as in Long Beach Harbor, the Naples Island area is relatively small (less than 10 miles across) and it is relatively flat, ideal for the propagation of radio waves. There are a small number of over-alerts on the boundaries of the warning polygon. The OAR is estimated to be 4 percent, which translates to approximately 1,203 people who receive the alert but should not.

Figure 7-20: Sprint and Verizon WEA GTP in Naples



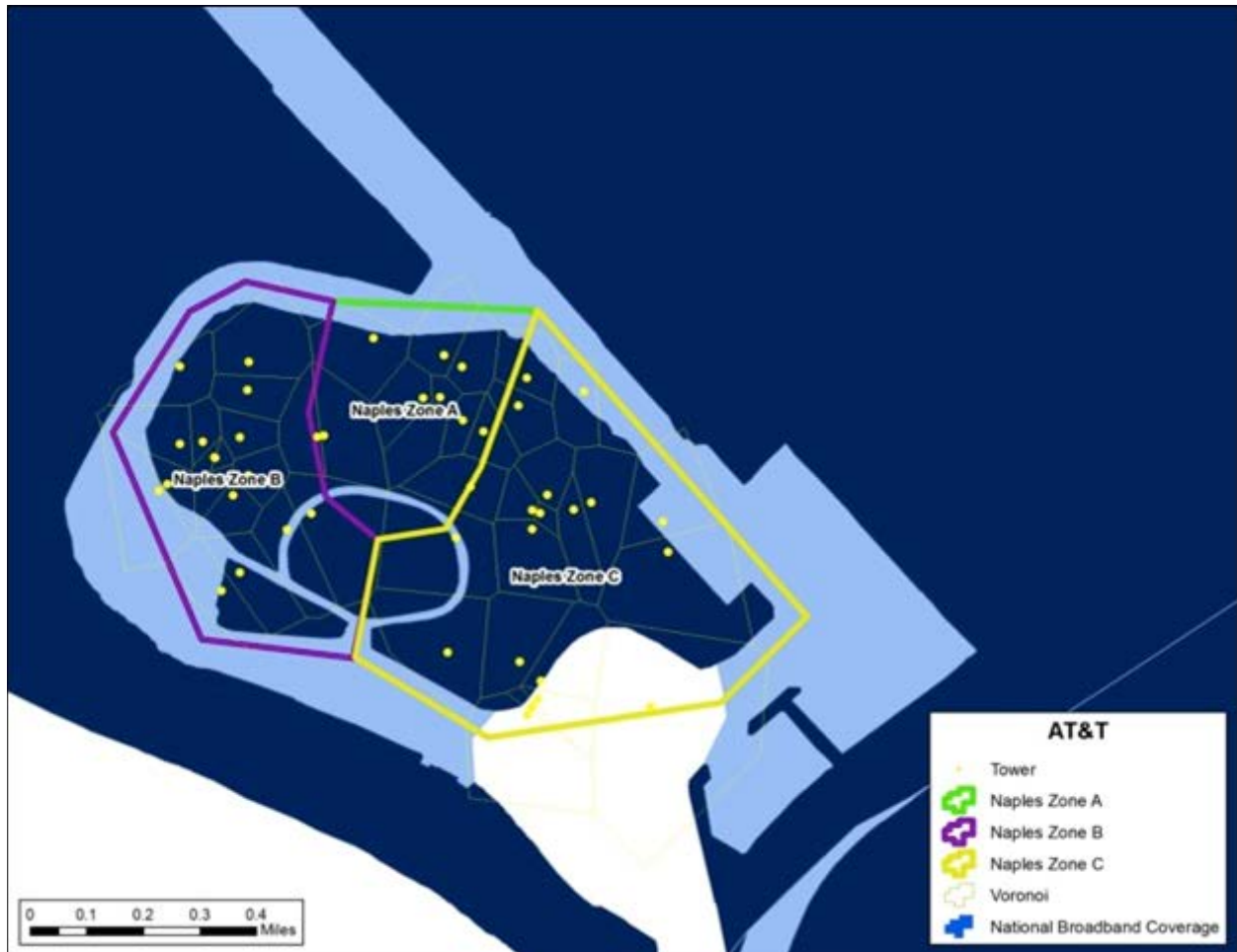
7.6 WEA Geo-Targeted Evacuation of Naples

Can WEA be used to support the evacuation of Naples Island before a tsunami strikes? We divide the island into three separate evacuation zones: Zone A in the center of the island, Zone B for the western part of the island and Zone C for the eastern part. Figure 6-4 shows the location of these three bridges. Below we examine WEA GTP of the AT&T and T-Mobile networks when they are used to issue evacuation orders for Naples Island. We do not include the Sprint or Verizon networks in this analysis because commercial data sources for Sprint and Verizon cell towers did not have the required accuracy to carry out this analysis.

AT&T Network Performance

Shown in figure 7-21 are the estimated locations of the AT&T antennas on the island. As before, cell boundaries were derived using the Voronoi method. Consistent with the discussion of this scenario in Section 6, it is assumed that three separate WEA evacuation messages would be sent to the island. Ideally the evacuation message intended for the residents of Zone B would only go to people in Zone B. And similarly for the WEA evacuation messages people in Zone A and Zone C.

Figure 7-21: AT&T Cells on Naples Island



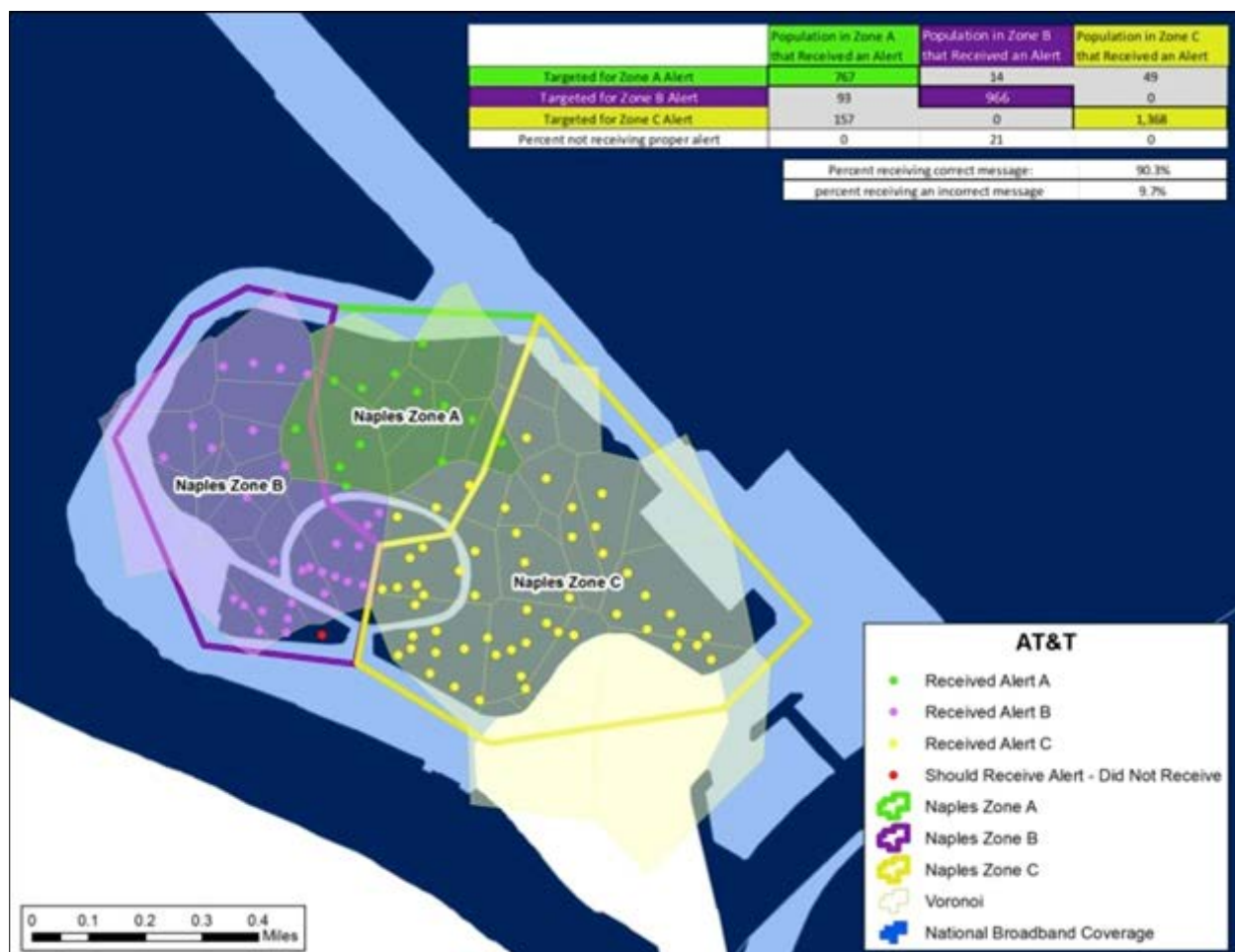
The geo-targeting results for this scenario are shown in Figure 7-22 assuming AT&T uses WEA method 1. In the upper right-hand corner of the figure is a table that shows how well the AT&T WEA service is estimated to send geo-targeted evacuation messages to three separate but adjacent zones on Naples Island. The points in the figure show the U.S. census population tracts that receive the alert (purple, green and yellow points), and those that do not (red points).

The table in the figure shows the number of people alerted in each of the three evacuation zones who receive the message intended for people in each zone. The number of people who are properly alerted

in Zone A, 767, is highlighted in green in the table. The number of people who are alerted correctly in Zone B, 966, is highlighted in purple, and the number of people who are properly alerted in Zone C, 1,368, is highlighted in yellow. These are the diagonal elements of the table or matrix. The off-diagonal elements are highlighted in grey and show the number of people who receive an incorrect evacuation message from a neighboring zone. For example, 14 people in Zone B are over-alerted when they receive a Zone A evacuation message, and 49 people in Zone C are over-alerted when they receive a Zone A evacuation message. In total, 313 people receive a second incorrect evacuation message on the island, which translates to 9.7 percent OAR for these three evacuation messages. Just over 90 percent of the population of the island receive only the correct evacuation message.

The alert failures in each zone are the following: 767 out of 1,017 people in Zone A receive the alert that is intended for Zone A, for a 25 percent failure rate; 966 out of 1,001 people in Zone B receive the alert that is intended for Zone B, for a 4 percent failure rate; and 1,368 out of 1,417 people in Zone C receive the alert that is intended for Zone C, for a 3 percent AFR. The overall AFR for the AT&T network is estimated to be 10 percent, mainly because there is one population tract on the island that is not covered by any AT&T antenna on the island (assuming WEA method 1 was used to select antennas).

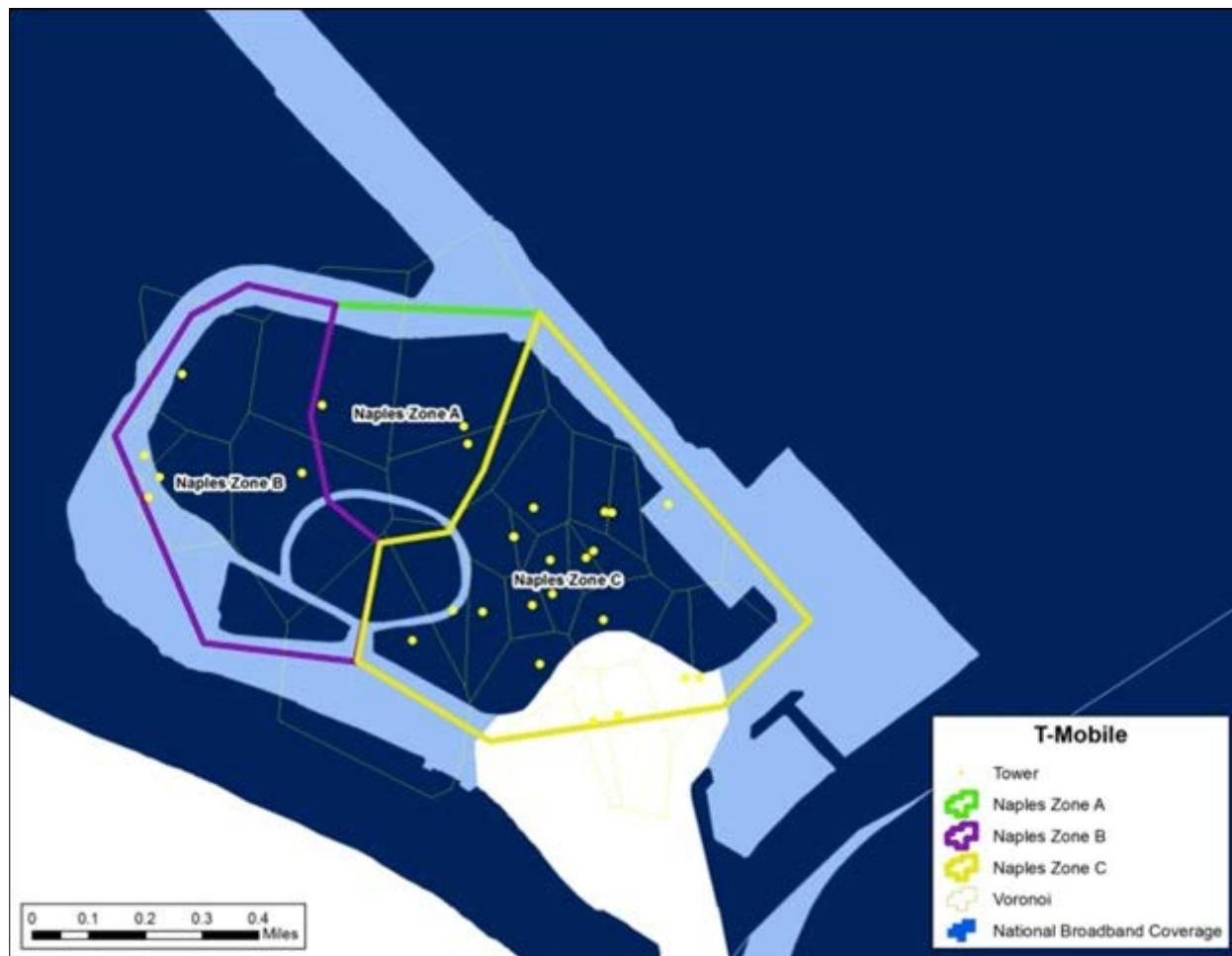
Figure 7-22: AT&T WEA GTP for Evacuation of Naples Island



T-Mobile Network Performance

Shown in Figure 7-23 are the estimated locations of the T-Mobile antennas on the island. The GTP of the T-Mobile network when three separate WEA evacuation messages are sent to the three evacuation zones defined above for Naples Island using WEA method 1 is examined in this section.

Figure 7-23: T-Mobile Antennas and Cells on Naples Island

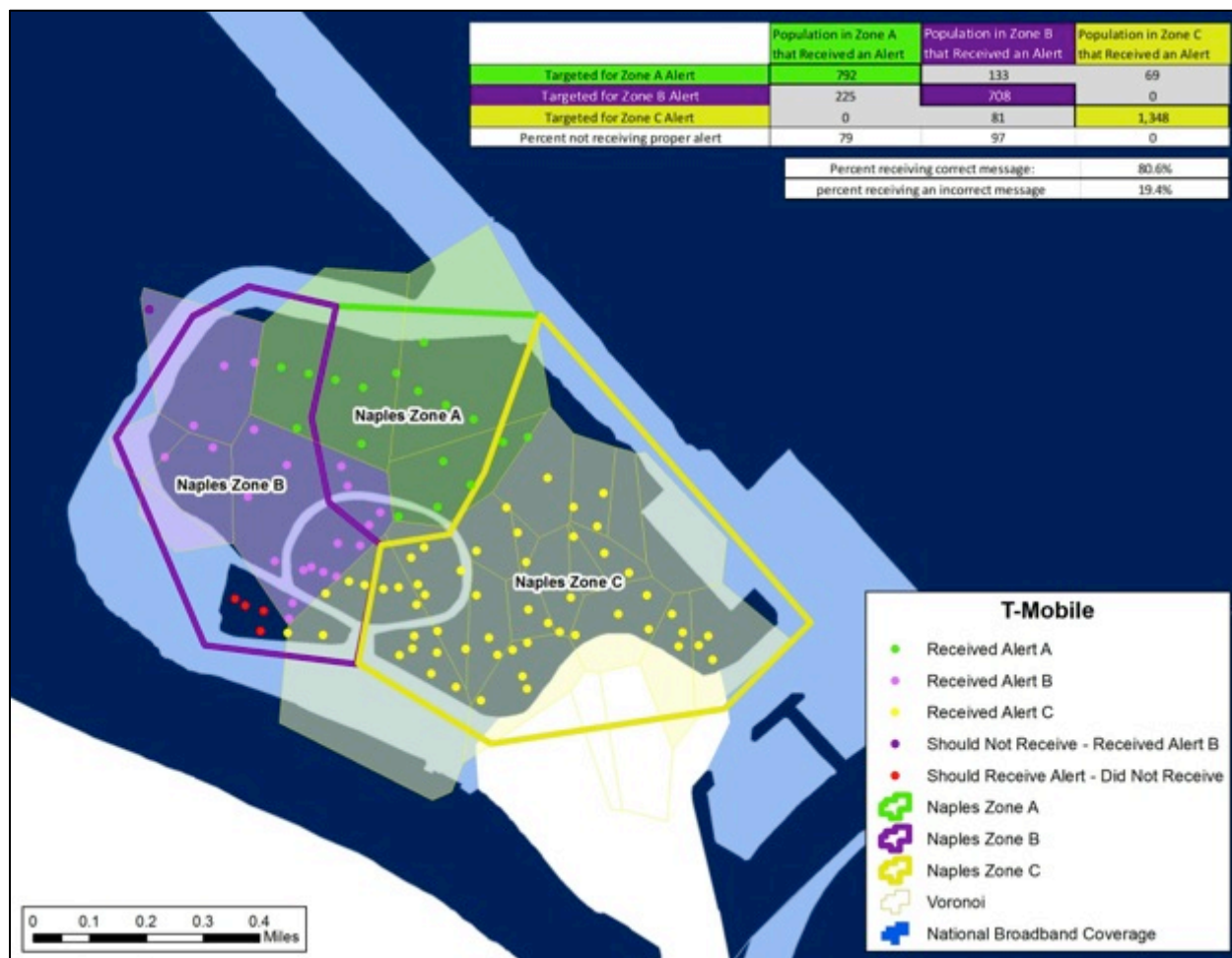


WEA GTP results for the T-Mobile network are shown in figure 7-24. The table in the upper right-hand corner of the figure shows how precisely the T-Mobile WEA service is estimated to send geo-targeted evacuation messages to the three zones on Naples Island.

First OARs are examined. The table in the figure shows the number of people alerted in each of the three evacuation zones by the T-Mobile network; 792 people are properly alerted in Zone A, as highlighted in green in the table. The number of people who are alerted correctly in Zone B, 708, are highlighted in purple, and the number of people who are properly alerted in Zone C, 1,348, is highlighted in yellow. The off-diagonal elements highlighted in grey show the number of people who receive an incorrect evacuation message from a neighboring zone. In total, 508 people receive an incorrect evacuation message on the island, which translates to 19.4 percent OAR. Of the island's population, 80.6

percent receive the correct evacuation message and do not receive a second incorrect evacuation message.

Figure 7-24: T-Mobile WEA GTP for Evacuation of Naples Island



Now we consider AFRs for this scenario for the T-Mobile network. There are alert failures in each evacuation zone. The AFRs are 22 percent in Zone A, 29 percent in Zone B and 5 percent in Zone C. The highest AFR is in Zone B, as indicated by the red points in Figure 7-24. The red points symbolize the population tracts on the island that are not covered by cell antennas on the island. The overall AFR is 17 percent.

7.7 Summary

Tsunami Warning

The analysis above shows WEA can provide effective geo-targeting of tsunami messages to small coastal communities in southern California. All four Tier 1 carrier networks provide excellent coverage of the

TWP, so all Tier 1 carrier AFRs are estimated to be zero, as is the average taken over all inundation zones and all Tier 1 carriers:

$$AFR_{ave}(TWP) = 0$$

There is some spillover of the WEA cell broadcast signal into surrounding areas not threatened by the tsunami. OARs were estimated to be between 0.8 and 6.8 percent in the three different tsunami inundation zones considered. The average OAR taken over the four carriers and three inundation zones is 3.3 percent.

The OAR error rate for the TWP is approximately 5 percent (see Table 2-1) because the TWP is relatively small. The probable OAR errors are larger than OAR estimates themselves. So the differences in computed OARs are not statistically significant. The average OAR value lies somewhere between the range indicated below:

$$OAR_{ave}(TWP) \sim (3.3\% \text{ to } 8.3\%)$$

Nevertheless, even with potential RF signal spillover, the number of people that could suffer over-alerting in this case (about 21,500 in the worst case) is far less than would be the case if the tsunami alert were sent to the entire NWS CA041 warning area. If the tsunami warning were sent to the larger warning area, more than 3.8 million people would be over-alerted (i.e., they would receive the tsunami warning but should not get it).

Tsunami Evacuation Warning

The utility of WEA for the evacuation of a small island in advance of the tsunami was also examined. The scenario is particularly challenging because Naples Island is only a few miles across. Three zones also defined the Naples Island tsunami evacuation zone (TEZ). The average AFRs for the three zones were found to be 23 percent, 16 percent and 4 percent.⁵⁵ The average AFR over the entire Island or TEZ is 13 percent.

The error in this estimate due to spillover of the cell broadcast signal for the TEZ is very small, so the average AFR estimate is:

$$AFR_{ave}(TEZ) = 13\%$$

The average OARs for the three evacuation zones were found to be 13 percent, 16 percent and 8.5 percent.⁵⁶ The average OAR over the entire Island or TEZ is 14.5 percent.

$$OAR_{ave}(TEZ) \sim (14.5\% - 19.5\%)$$

⁵⁵ These are averages over the AFRs for the two Tier 1 carriers considered.

⁵⁶ These are averages over the AFRs for the two Tier 1 carriers considered.

In this case the individual evacuation warning polygons are small and perimeter RF spillover effects are significant. Despite these errors these results suggest the WEA service could play a positive role in the evacuation of Naples Island and could help the majority of the island's population evacuate efficiently.

8. Washington D.C. Nuclear Terrorism Scenario

One of the most serious disasters emergency planners prepare for is the detonation of a nuclear weapon in a metropolitan area by terrorists. Due to the great destructive power of these devices, and the complexity of nuclear weapons effects, strategic emphasis has generally been placed on preventing such weapons from falling into the hands of terrorists, and in interdicting such weapons before they can be smuggled into a U.S. city. Should the unthinkable occur, however, the WEA service could provide an important channel for disseminating time-critical information to the population in much of the affected area, and thus prevent further loss of life — if planned for and implemented correctly by the responding authorities. This section examines how the WEA service could be used in the aftermath of a nuclear detonation, and discusses related insights of relevance to both emergency managers and WEA developers.

8.1 Scenario Description

This analysis is based on a detailed scenario that was developed for a recent comprehensive study that examined emergency response planning in the aftermath of nuclear terrorism.⁵⁷ This research was funded by FEMA and DHS S&T, with contributions from several national laboratories. It is based on a detailed, physics-based, location-specific simulation of the effects of a nuclear weapon detonating in the heart of Washington, D.C., and develops and assesses a range of recommended responses by individuals in the affected area, as well as by responding authorities. Additional modeling work was performed by RAND, based on publicly available literature.⁵⁸

The scenario covers a broad geographic area in the Mid-Atlantic region surrounding Washington D.C., also known as the National Capital Region (NCR). Prompt weapons effects, such as flash, blast, heat and prompt radiation, would affect a radius of several miles around Ground Zero, while fallout would affect a multi-state area. Similarly, the scenario involves a broad range of time scales: from milliseconds for the prompt effects, to minutes for the onset of fallout, to days/weeks (and likely months and years) for the long-term aftereffects.

Although the details of this scenario are specific to Washington, D.C., the underlying considerations — which are of the most relevance in the context of our study — are applicable to any urban area; thus the insights, conclusions and recommendations gleaned from this analysis are applicable as well.

⁵⁷ Mr. Steve Chase et al., “National Capital Region - Key Response Planning Factors for the Aftermath of Nuclear Terrorism” (Department of Homeland Security, 2011), <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.361.5058&rep=rep1&type=pdf>.

⁵⁸ Samuel Glasstone, Philip J. Dolan, and others, *The Effects of Nuclear Weapons: Compiled and Edited by Samuel Glasstone and Philip J. Dolan* (US Dept. of Defense, 1977).

8.2 Nuclear Weapons Effects in an Urban Area

Nuclear weapons work by setting free a vast quantity of energy in a very short time, which then causes the intended destructive effects. Nuclear weapons effects include:

1. A burst of initial (prompt) nuclear radiation, which causes health effects in humans and animals;
2. A burst of electromagnetic energy (electromagnetic pulse or EMP) which can destroy electric and electronic equipment;
3. A fireball that radiates energy in the thermal and visible parts of the electromagnetic spectrum, which can cause (temporary or permanent) “flash blindness,” burns in humans and animals, and start fires;
4. A blast wave that causes damage to structures and lung damage, as well as missile injuries in humans and animals; and
5. Radioactive contamination attached to particles that rise into the air with the rising fireball and are subsequently deposited as fallout downwind from Ground Zero, which again can cause health effects in humans and animals.

Although all nuclear weapons follow the same principles and create the same types of effects, the magnitude and relative impact of those effects, including the associated timelines, depends on the yield (i.e., the explosive power) of a nuclear weapon. This yield is generally stated by comparing it to the mass of conventional TNT explosive that would be required to set free a comparable amount of energy. For the purposes of this study, a relatively low weapons yield of 10 kilotons (kt) was assumed, which is comparable to the yields of the nuclear weapons used in Japan at the end of World War II. Nuclear weapons of this type are considered easier to manufacture than the megaton-class thermonuclear weapons that are part of the arsenal of the major nuclear powers, and thus most nuclear detonation scenarios involving terrorist perpetrators assume a device in the 10-20 kt range.

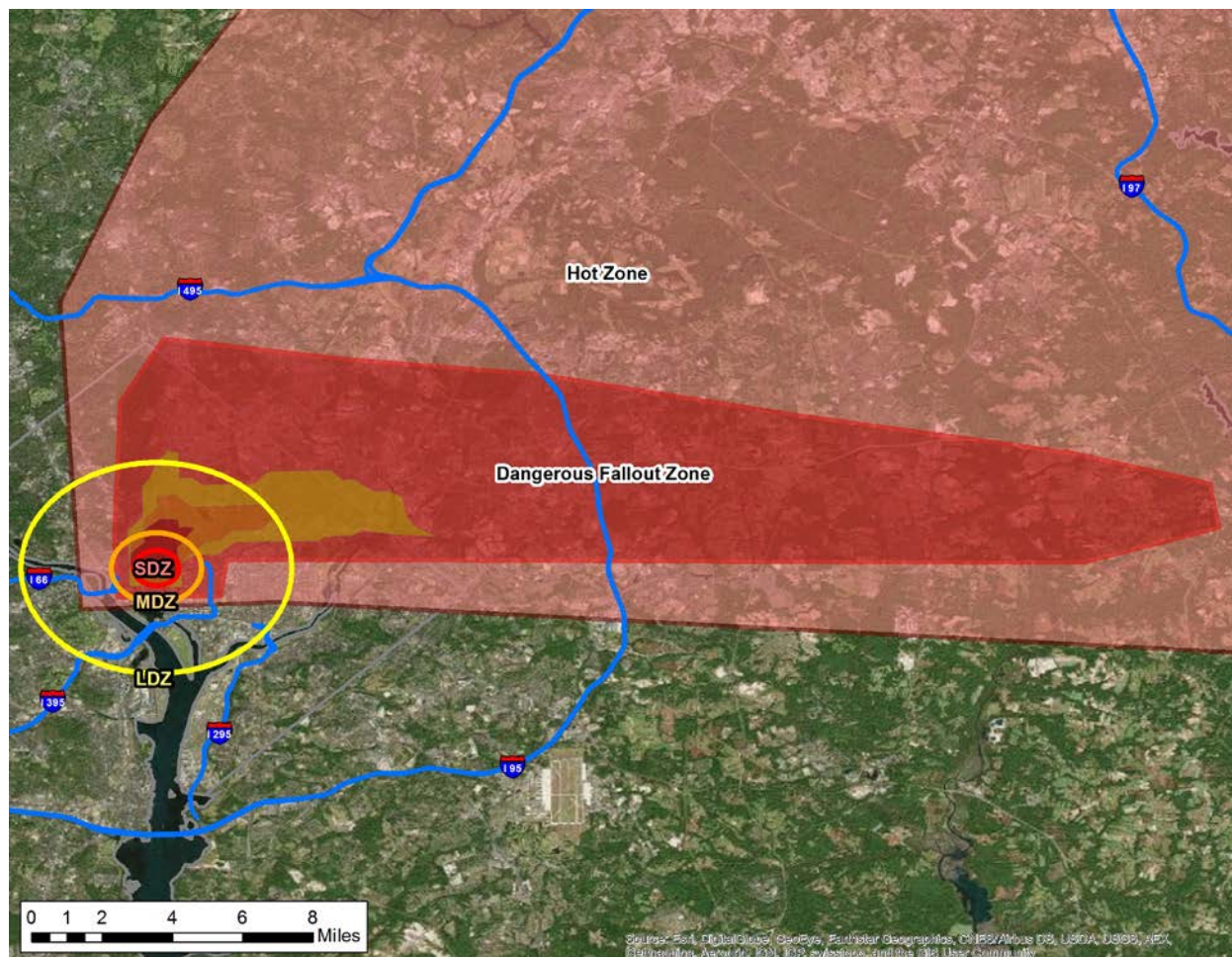
For our scenario, the detailed analysis provided by the DHS study showed dangerous effects at the following distances from Ground Zero:

1. Prompt radiation: 0.6 miles
2. EMP effects: up to 5 miles
3. Thermal effects: up to 0.5 miles depending on lines-of-sight between buildings, and flash blindness up to 8 miles depending on time of day and weather conditions
4. Blast damage:
 - severe damage zone (SDZ, most buildings destroyed) 0.5 miles
 - moderate damage zone (MDZ, significant building damage and rubble) up to 1 mile
 - light damage zone (LDZ, windows broken) up to 3 miles
5. Fallout: depending on weather conditions
 - dangerous levels (acute radiation injury possible) up to 20 miles downwind
 - increased levels (exposure control required) up to several hundred miles downwind

Figure 8-1 shows the relevant effect zones for our scenario, overlaid on a satellite image of Washington, D.C., and the surrounding region. Note that the distribution of fallout depends on wind speed and direction in the troposphere over the affected area, and thus, for a real-world incident, the shape and orientation of the dangerous fallout zone and hot zone may vary considerably from what is shown here.

Figure 8-1 shows what the Dangerous Fallout and hot zones could look like if this attack occurred in winter, when winds are blowing in an eastward direction.

Figure 8-1: Effects of a 10 kt Nuclear Burst in Washington, D.C.



Source for Base Imagery: Google Earth

Regarding the timeline, for a 10 kt device, effects 1, 2 and 3 take place within fractions of a second after detonation, and thus happen too fast for any response. The blast wave, on the other hand, takes approximately 15 seconds to reach the outer limit of the LDZ. Thus, since the main threat in the LDZ is missile injury (e.g., from broken glass), an immediate “duck and cover” response by those in the affected area has the potential to avoid a significant amount of injuries. This must be self-initiated, however, since no existing warning system is agile enough to issue a meaningful warning within this time frame.

On the other hand, fallout takes several minutes to several hours to spread across the area. Radiation levels from fallout then decrease again within hours to days. Thus WEA (and other warning systems) can play a critical role in warning the affected population of fallout-related dangers and providing them with timely updates and instructions. Our analysis will therefore focus on fallout-related warnings.

8.3 AO Issues

Nuclear weapons effects would affect multiple jurisdictions (as shown in Figure 8-1), and thus the emergency planning for such a scenario should clearly delineate responsibilities among affected agencies for issuing related alerts, so that those in the affected area are not confused by potentially conflicting messages. Due to the rapidly developing effects, this de-confliction must occur well prior to such an event.

Since the focus of our analysis was on the technical capabilities and limitations of WEA, a simplifying assumption was made that all messages across the affected area would be issued by a single agency. In the following discussion, “DCEMA” (Washington, D.C., Homeland Security and Emergency Management Agency) serves as a placeholder for the acronym of whatever authority would be issuing the warnings in an actual attack.

8.4 WEA Warning and Evacuation Messages

To realistically model the message traffic across the WEA infrastructure for a nuclear scenario, radiation warnings and evacuation instructions developed for this study are based on the DHS report “Key Planning Factors: Response to an IND in the NC.”⁵⁹

Initial Warnings

The federal government has issued guidance to local officials about immediate action messaging after a nuclear detonation (Figure 8-2). The amount of text in this guidance far exceeded the 90-character limit of WEA free text messages, and thus the most important elements of it were extracted and turned into a series of three messages for distribution by AOs in the first minutes after the detonation.⁶⁰ Additional messages with updates on the radiation risk would follow once authorities were able to initially characterize the path of the fallout cloud (see Table 8-1).

These immediate warnings would be issued to the population within a 50 mile radius of Ground Zero (the “initial shelter-in-place” zone as per federal guidelines), while subsequent messages would be geo-targeted based on initial assumptions about the fallout distribution (see Figure 8-3).

⁵⁹ Chase et al., “Key Planning Factors: Response to an IND in the NC.”

⁶⁰ Note the proposed increase of the character limit for WEA free text messages to 280 characters would allow AOs to transmit much more detailed emergency response instructions to the affected population.

Figure 8-2: Messaging Guidance for Local Emergency Managers in Case of Nuclear Detonation

Sample Key Message from Federal Government IND Messaging Effort

Impacted Community: Immediate Action Message
Suggested for local or state spokesperson: Fire Chief, Mayor, Governor

- We believe a nuclear explosion has occurred at [Location] here in [City].
- If you live anywhere in the metropolitan area, get inside a stable building immediately.
- You can greatly increase your chance of survival if you take the following steps.
 - **Go deep inside:**
 - Find the nearest and strongest building you can and go inside to avoid radioactive dust outside.
 - If better shelter, such as a multi-story building or basement can be reached within a few minutes, go there immediately.
 - If you are in a car, find a building for shelter immediately. Cars do not provide adequate protection from radioactive material.
 - Go to the basement or the center of the middle floor of a multi-story building (for example the center floors (e.g., 3 – 8) of a 10-story building).
 - These instructions may feel like they go against your natural instinct to evacuate from a dangerous area; however, health risks from radiation exposure can be greatly reduced by:
 - Putting building walls, brick, concrete or soil between you and the radioactive material outside, and
 - Increasing the distance between you and the exterior walls, roofs, and ground, where radioactive material is settling.
 - **Stay inside:**
 - Do not come out until you are instructed to do so by authorities or emergency responders.
 - All schools and daycare facilities are now in lockdown. Adults and children in those facilities are taking the same protective actions you are taking and they will not be released to go outside for any reason until they are instructed to do so by emergency responders.
 - **Stay tuned to television and radio broadcasts for important updates**
 - If your facility has a National Oceanic and Atmospheric Administration (NOAA) Weather Radio, this is a good source of information.
 - If you have been instructed to stay inside, stay tuned because these instructions will change.
 - Radiation levels are extremely dangerous after a nuclear detonation, but the levels reduce rapidly in just hours to a few days.
 - During the time when radiation levels are the highest, it is safest to stay inside, sheltered away from the material outside.
 - When evacuating is in your best interest, you will be instructed to do so.
 - People in the path of the radioactive plume – downwind from the detonation - may also be asked to take protective measures.

Source: FEMA, "[Planning Guidance for Response to a Nuclear Detonation](#)," Second Edition, June 2010, page 123.

Table 8-1: Timeline and Details of WEA Warning Messages

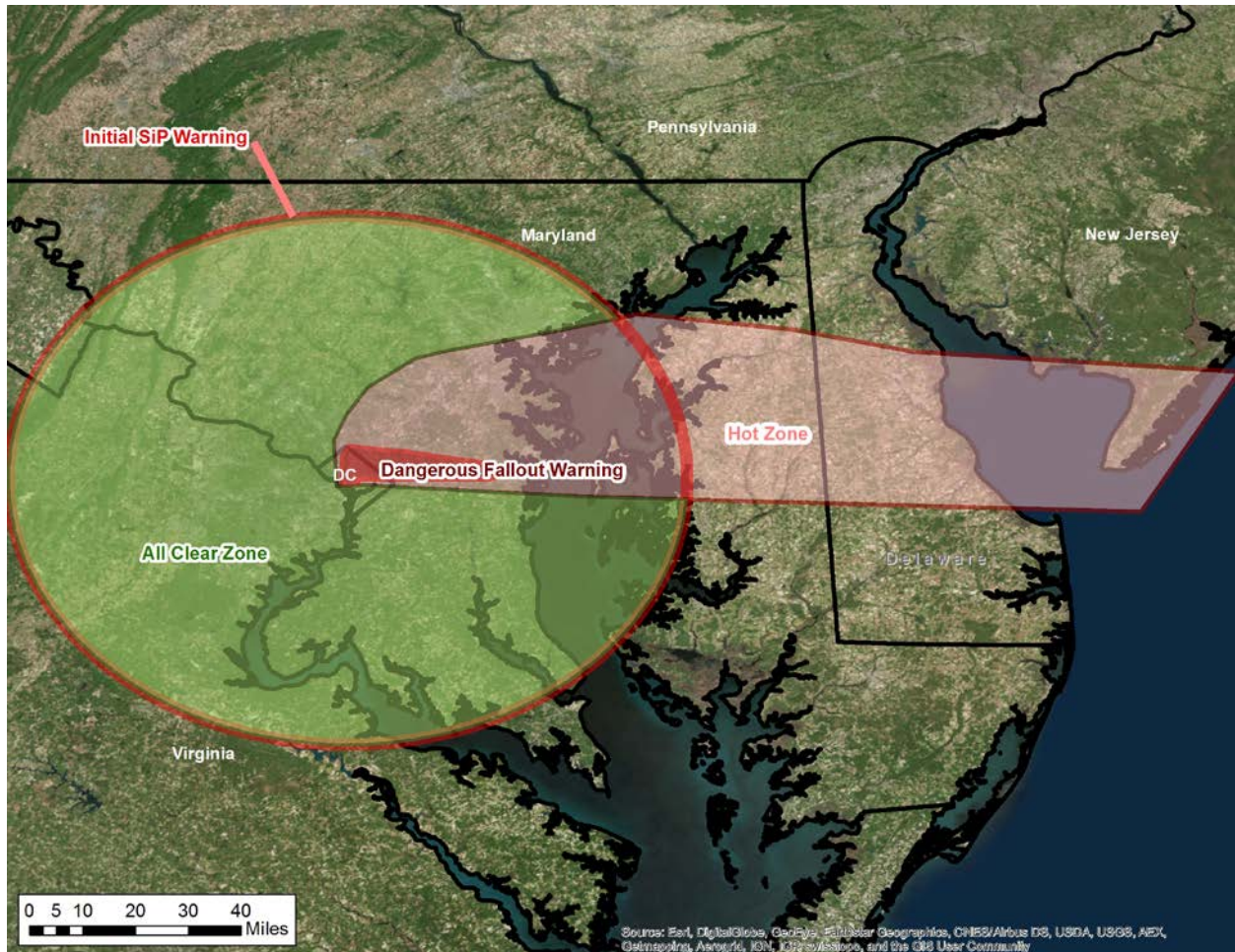
| Time | Event Code | Geotarget ROM Size | Warning Polygon (Figure X.2) | Message Number | WEA Freetext Message (90 Character Limit) |
|--------|------------|------------------------------------|------------------------------|----------------|--|
| T+5s** | RHW | Multiple Counties (100mi dia.) | Initial SiP | | "Radiological Hazard in this area until 11:00 PM EST Take Shelter Now -U.S. Government" |
| T+60s | RHW | Multiple Counties (100mi dia.) | Initial SiP | 1 | "Nuclear explosion in DC. Take shelter deep inside building now. Listen to radio - DCEMA" |
| T+120s | RHW | Multiple Counties (100mi dia.) | Initial SiP | 2 | "Best shelter: nearest and strongest building, basement or center of middle floor - DCEMA" |
| T+180s | SPW | Multiple Counties (100mi dia.) | Initial SiP | 3 | "Stay inside until authorities order evacuation. Expect to stay for hours-days -DCEMA" |
| T+600s | CDW | Multiple Counties (100mi dia.) | Initial SiP | 4 | "Nuclear explosion in DC. Significant damage. Do not approach DC area -DCEMA" |
| T+0.5h | RHW | Multiple Counties (~ 40mi x 140mi) | Hot Zone | 5 | "High radiation levels outside. Stay in shelter until authorities instruct otherwise -DCEMA" |
| | | A Few Counties (~ 10mi x 30mi) | Dangerous Fallout Zone | 6 | "Lethal radiation levels outside. Shelter deep inside building now -DCEMA" |
| T+1h | RHW | Multiple Counties (~100mi dia.) | All Clear Zone*** | 7 | "No further radiation risk in this area. Stay away from DC metro area -DCEMA" |

* RHW: Radiological Hazard Warning; SPW: Shelter in Place Warning; CDW: Civil Danger Warning

** This near-immediate warning message illustrates a potential future capability. Due to the physics of nuclear weapons, a nuclear detonation presents a characteristic double-flash signature (Barasch, G.E.: "Light Flash Produced by an Atmospheric Nuclear Explosion", LASL-79-84, November 1970), which will be detected by the space-based U.S. Nuclear Detection System (USNDS; cf. the 1999 National Security Space Road Map). Timing of the double flash is correlated to the yield of the weapon, and thus to the magnitude and geographic extent of weapons effects. USNDS sensors can also determine the location of Ground Zero. Thus, the USNDS could automatically send WEA messages to the affected area within a few seconds of a nuclear detonation, in an approach comparable to the systems that are currently under development for generating automated EEW messages. The following Common Alerting Protocol (CAP) message elements could be used: category "CBRNE" – event code "RHW" – urgency "Immediate" – severity "Extreme" – certainty "Observed" – response "Shelter" – expiration [+11h].

*** Initial Shelter in place (SiP) zone minus hot zone

Figure 8-3: Warning Zone Polygons and Associated WEA Message Numbers



Source for Base Imagery: Google Earth

Evacuation Instructions

Once more detailed measurements and predictive modeling results of the fallout distribution become available, authorities would issue evacuation instructions to the population in the most affected areas, based on a variety of factors such as weather, building types, road conditions and radiation levels.⁶¹ The associated messages (Table 8-2) and geo-targeted areas specific to this scenario (Figure 8-4) were generated based on the details provided in the DHS study.⁶² The shapes of the evacuation zones, as well as the timing of evacuation instructions, are based on the analysis provided in the DHS report, which takes into consideration projected radiation levels in the area and their changes over time, as well as staging concerns to optimize traffic flow.

⁶¹ Chase et al., “Key Planning Factors: Response to a Nuclear Detonation in the NCR, 2011.”

⁶² Ibid.

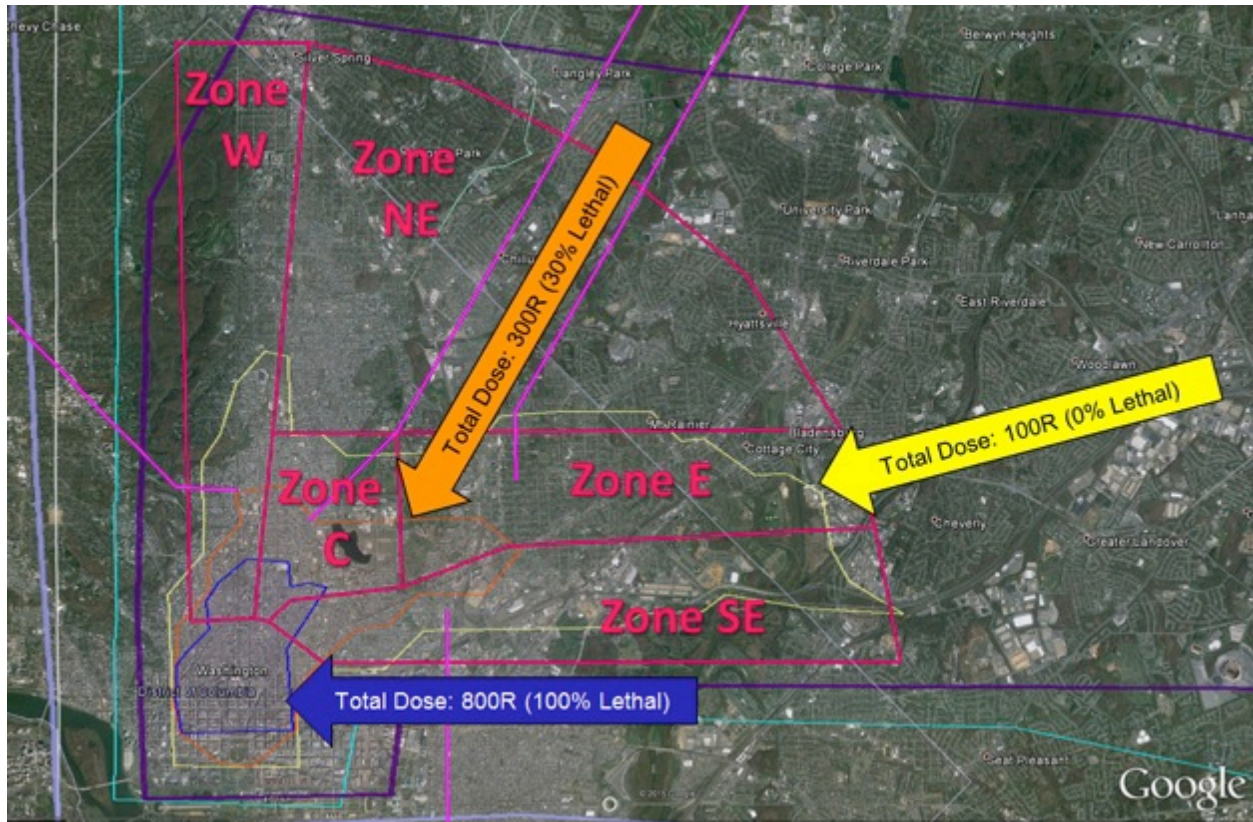
As with the initial warning messages, the 90-character limit of WEA free text messages only allows for generalized instructions, and requires sending multiple messages to convey even the basics. Emergency messaging channels with more bandwidth should be used for more detailed instructions.

Table 8-2: Timeline and Details of WEA Evacuation Messages

| Time | Event Code | Geotarget ROM Size | Warning Polygon | Message Number | WEA Freertext Message (90 Character Limit) |
|------|------------|--------------------|-------------------------|----------------|---|
| T+1h | SPW | City (10km x 10km) | Evac Zones W, NE, E, SE | 8 | "If you are in a basement or other good shelter, stay there for next 12 hours –DCEMA" |
| T+1h | EVI | Ward(s) (1-10km) | Evac Zone W | 9 | "If you are in a poor shelter evacuate now. Head WEST to avoid radiation -DCEMA" |
| T+1h | EVI | Ward(s) (1-10km) | Evac Zone NE | 10 | "If you are in a poor shelter evacuate now. Head NORTHEAST to avoid radiation -DCEMA" |
| T+1h | EVI | Ward(s) (1-10km) | Evac Zone E | 11 | "If you are in a poor shelter evacuate now. Head NORTHEAST to avoid radiation -DCEMA" |
| T+1h | EVI | Ward(s) (1-10km) | Evac Zone SE | 12 | "If you are in a poor shelter evacuate now. Head SOUTH to avoid radiation -DCEMA" |
| T+3h | EVI | Ward(s) (1-10km) | Evac Zone C | 13 | "If you are in a basement or other good shelter, stay there for next 12 hours –DCEMA" |
| T+3h | EVI | Ward(s) (1-10km) | Evac Zone C | 14 | "If you are in a poor shelter evacuate now. Head NORTHEAST to avoid radiation -DCEMA" |

* SPW: Shelter in Place Warning; EVI: Evacuation Immediate

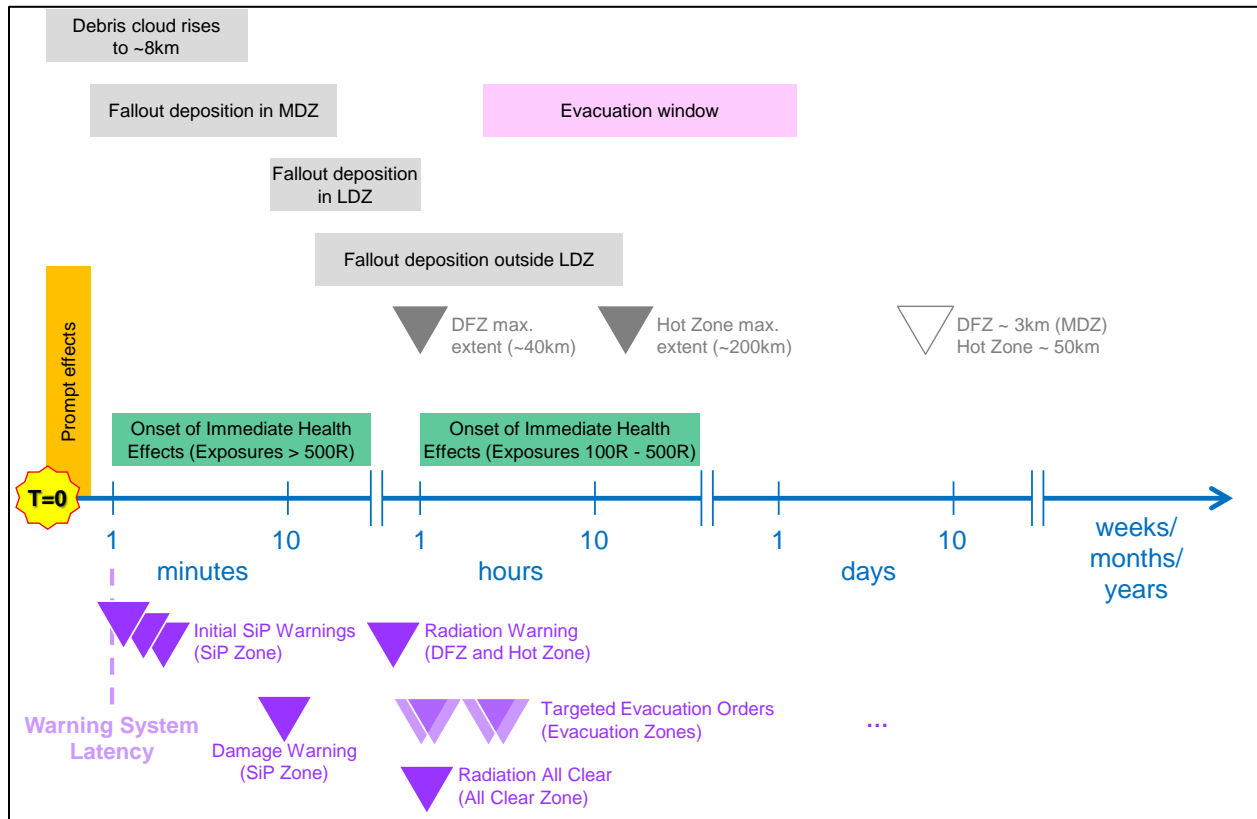
Figure 8-4: Evacuation Zone Polygons (Red Lines) and Directions (Purple Lines) Based on Radiation Levels (Blue/Orange/Yellow Lines)



Source for Base Imagery: Google Earth

Figure 8-5 shows how the initial warning and evacuation messages could be timed with respect to the weapons effects. The timing of these warnings and evacuation messages is intended to minimize radiation exposure and other risks to the population near the blast zone and surrounding areas. The differing geometries of the warning polygons shown in Figure 8-4 indicate the potential importance of precise WEA geo-targeting in minimizing risks to the population.

Figure 8-5: Extent and Timing of Nuclear Effects and Related WEA Warning Messages



8.5 Cellular Carrier Coverage Estimates for Affected Region

Cellular Infrastructure Damage

Blast damage will fully disable cellular infrastructure inside the SDZ and most of the MDZ. It will partially disable cellular infrastructure inside the LDZ, depending on distance from Ground Zero and cell site type (freestanding mast, mounted on building, antenna height above ground, etc.). EMP will likely affect cellular infrastructure and may also affect handsets in the LDZ and beyond, up to approximately 5 miles from Ground Zero in this scenario. Blast damage to infrastructure, as well as EMP, may also interrupt the power supply beyond the MDZ, further affecting cellular infrastructure (and also making it more difficult for those in the affected area to keep their handsets charged). As mentioned earlier, the FCC now requires large CMSPs to provide backup power to their cell sites. Consequently, cell sites of the Tier 1 wireless carriers that are not damaged should still function for up to eight hours after a loss of electricity from the power grid.⁶³

⁶³ "Recommendations of the Independent Panel Reviewing the Impact of Hurricane Katrina on Communications Networks."

Due to the complexities involved, detailed modeling of these effects was beyond the scope of this study. Based on information available in the open literature,⁶⁴ it was instead estimated that 100 percent of the cellular infrastructure would be nonoperational inside the SDZ, 75 percent inside the MDZ and 25 percent inside the LDZ. Thus, it can be assumed that cellular service will likely remain available for the vast majority of the population outside the zone of destruction.

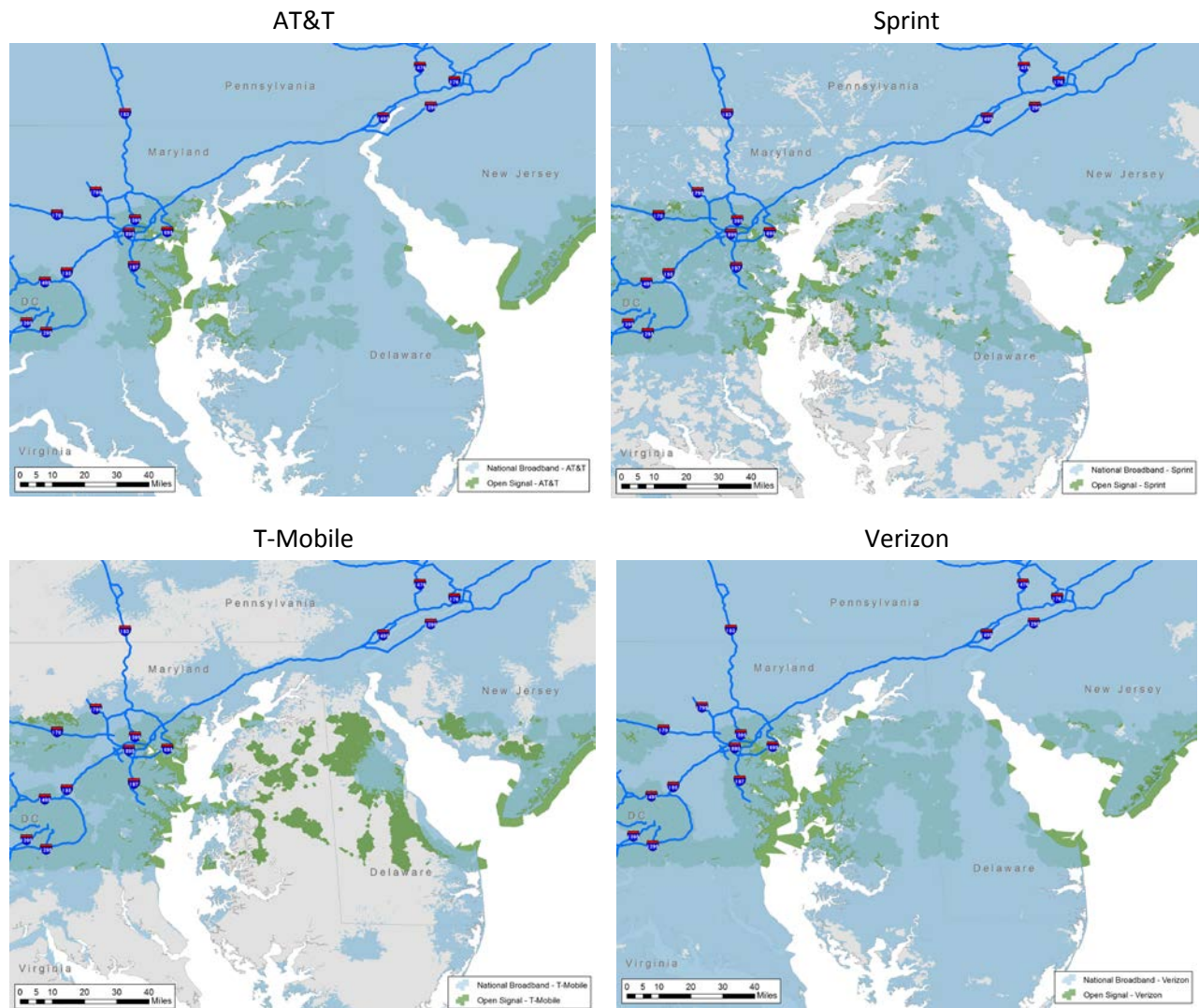
⁶⁴ Glasstone, Dolan, and others, *The Effects of Nuclear Weapons*.

9. WEA Geo-Targeting Performance in a Major Nuclear Incident

9.1 Tier 1 Carrier RF Coverage in the Mid-Atlantic Region

Figure 9-1 shows the RF coverage of the four Tier 1 wireless carriers in the Mid-Atlantic region, using both the NBM and data from OpenSignal.com. NBM coverage is shown in light blue. OpenSignal coverage is shown in green.

Figure 9-1: Tier 1 Coverage from the NBM Dataset (2014)



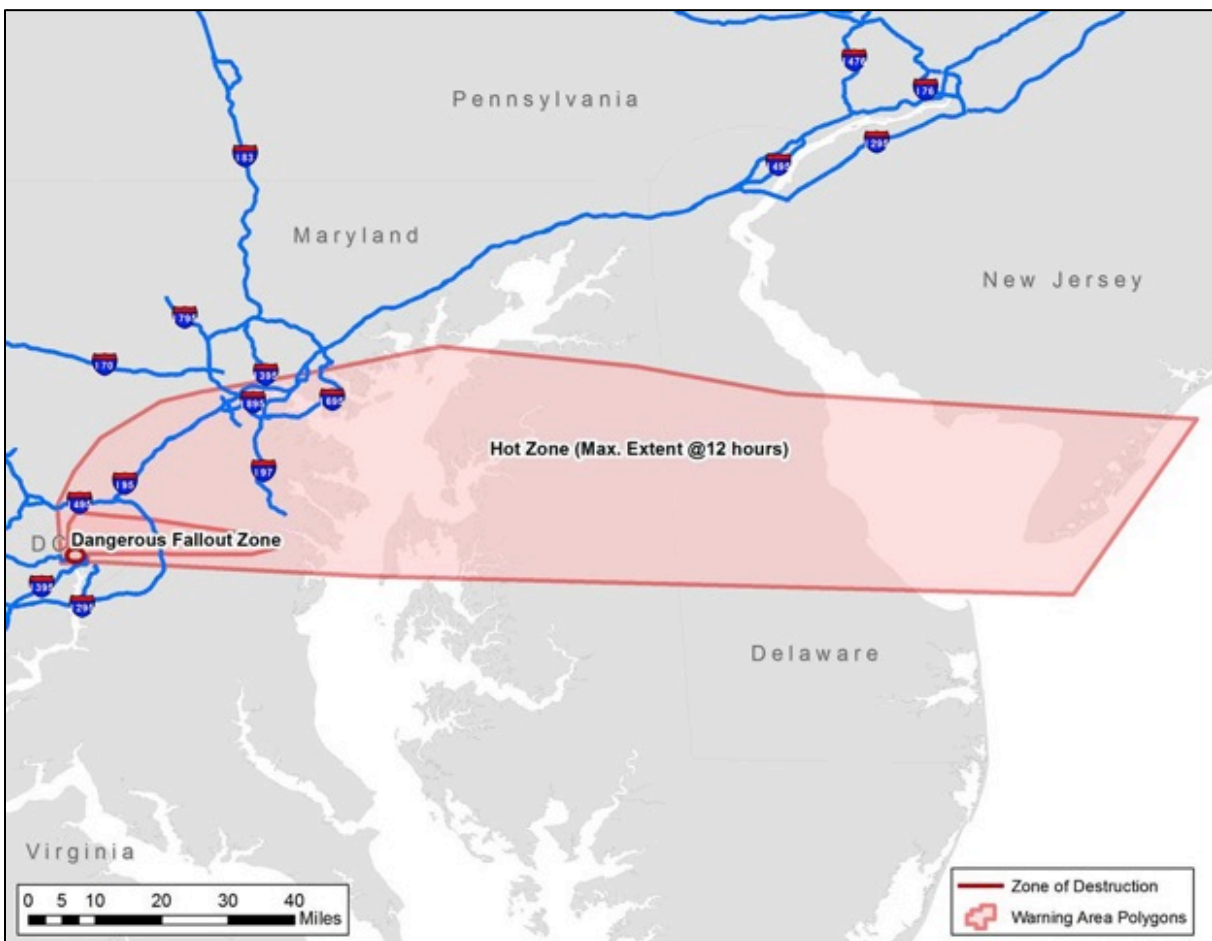
AT&T and Verizon coverage is good in the densely populated areas near Washington, D.C., and also in less densely populated areas on the Delmarva Peninsula. Sprint and T-Mobile coverage tends to drop off in less densely populated areas to the east of Washington, D.C. The coverage maps shown in Figure 9-1

will be used to examine WEA GTP for the nuclear incident and radiation-warning scenario. Additional data from Unwired Labs and Combain is used to estimate CMSP RAN antenna locations in specific parts of the radiation warning areas.

9.2 Radiation Warning Polygons

Shown in Figure 9-2 are two of the first warning polygons issued in the nuclear terrorism scenario. The smaller polygon, which extends only a short distance outside of the beltway region of Washington, D.C., shows the location where dangerous fallout will be present after the blast. The larger warning polygon indicates the location of a Hot Zone where a radiation hazard will exist for up to 12 hours after the blast.

Figure 9-2: Hot Zone and Dangerous Fallout Warning Areas



9.3 Warning Populations

Shown on Figure 9-3 are the population totals for these two warning polygons. The variation in population density throughout the region is indicated by the blue color code and also by the size of the census block groups. Note that in densely populated urban areas census blocks are much smaller and thus, have smaller populations (lighter colors). One can see there are densely populated areas in Maryland, Delaware and New Jersey that are far from the blast site in Washington, D.C. A significant number of people in these distant areas would be affected in this scenario.

Figure 9-3: Populations in Two Nuclear Incident Warning Areas

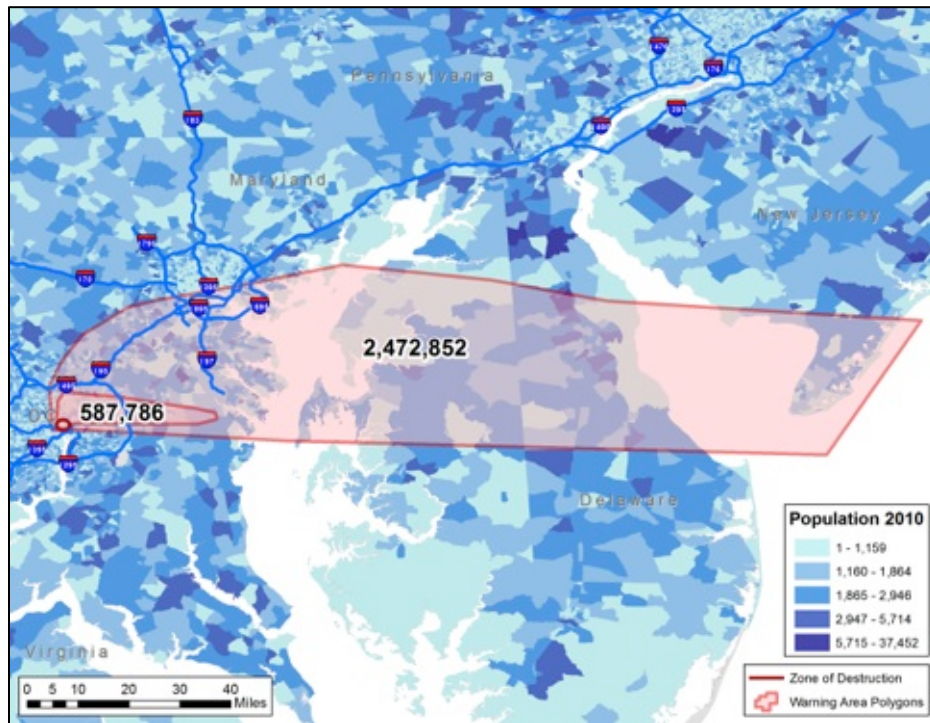


Figure 9-4 zooms in on the smaller of the two warning polygons. It shows a large swath of the NCR would be subject to a radiation hazard for up to 12 hours after the blast. The WEA message that would be issued in this area would warn residents to stay indoors.

Figure 9-4: Population in the Dangerous Fallout Warning Area

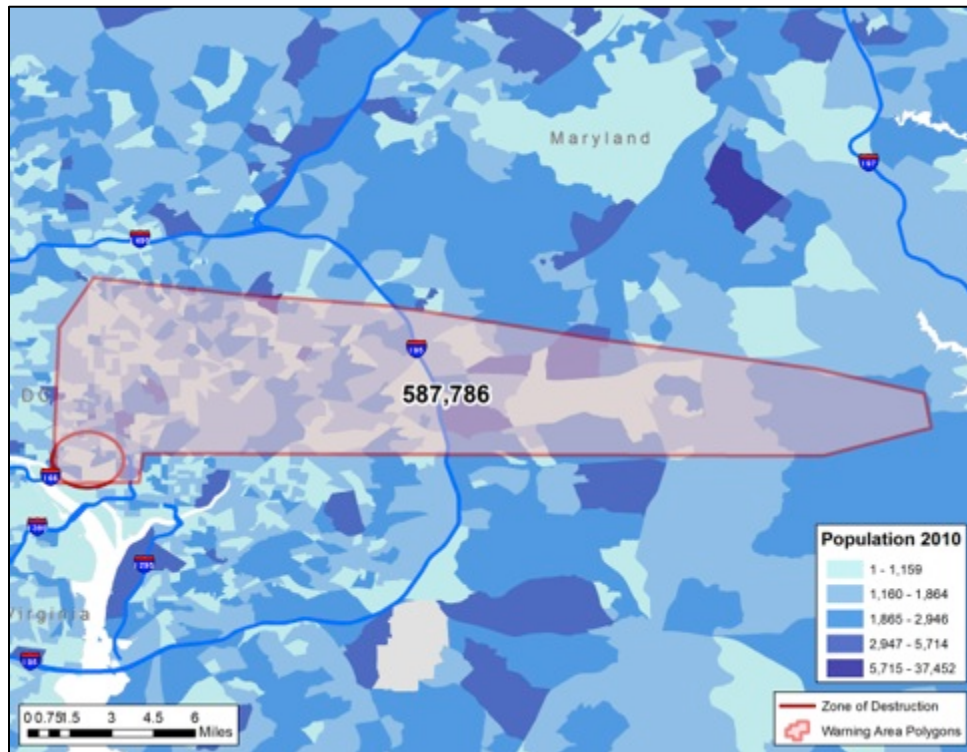


Figure 9-5 shows the distribution of Tier 1 carrier subscribers in the larger Hot Zone warning area. There are more than 2.4 million people in this warning polygon. The combined coverage of all four carriers completely blankets this region, so all parts of the population are covered by one or more carriers. The same is true for the population of the smaller Dangerous Fallout Zone warning polygon shown in Figure 9-6 below.

Figure 9-5: Tier 1 Carrier Subscribers in the Hot Zone Warning Area

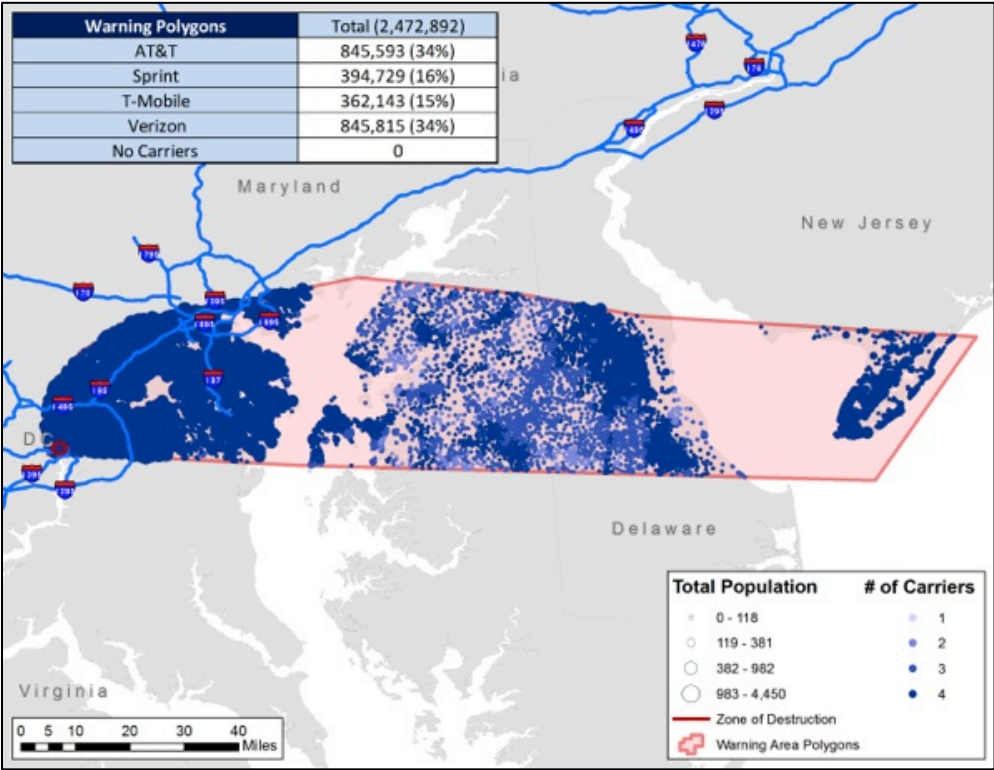
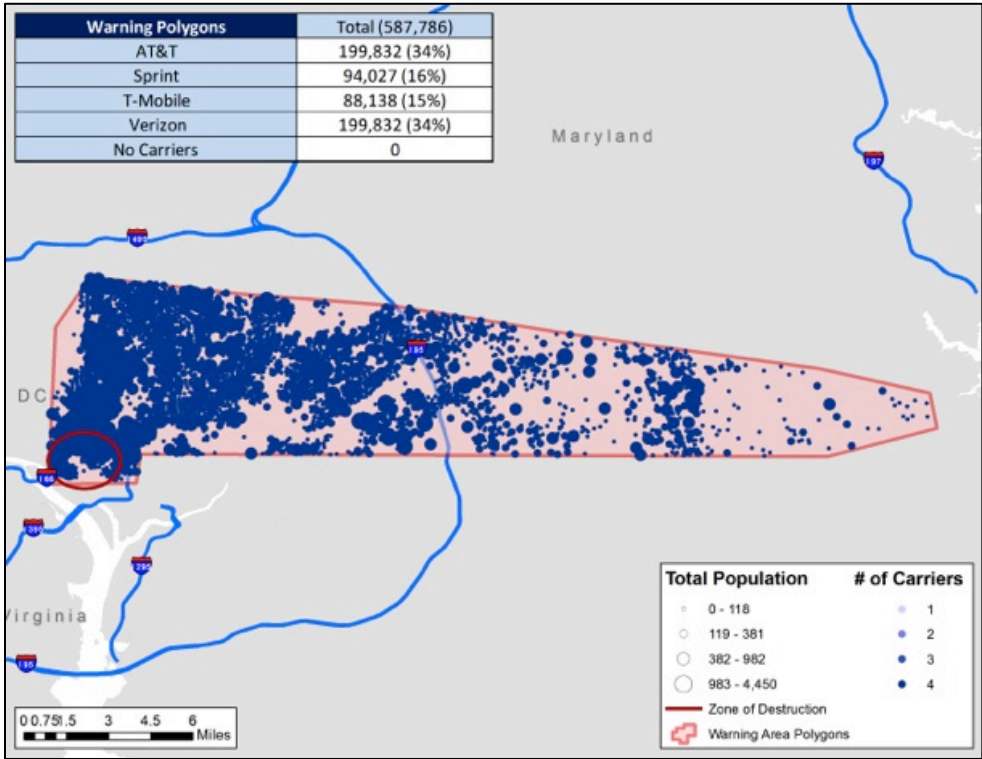


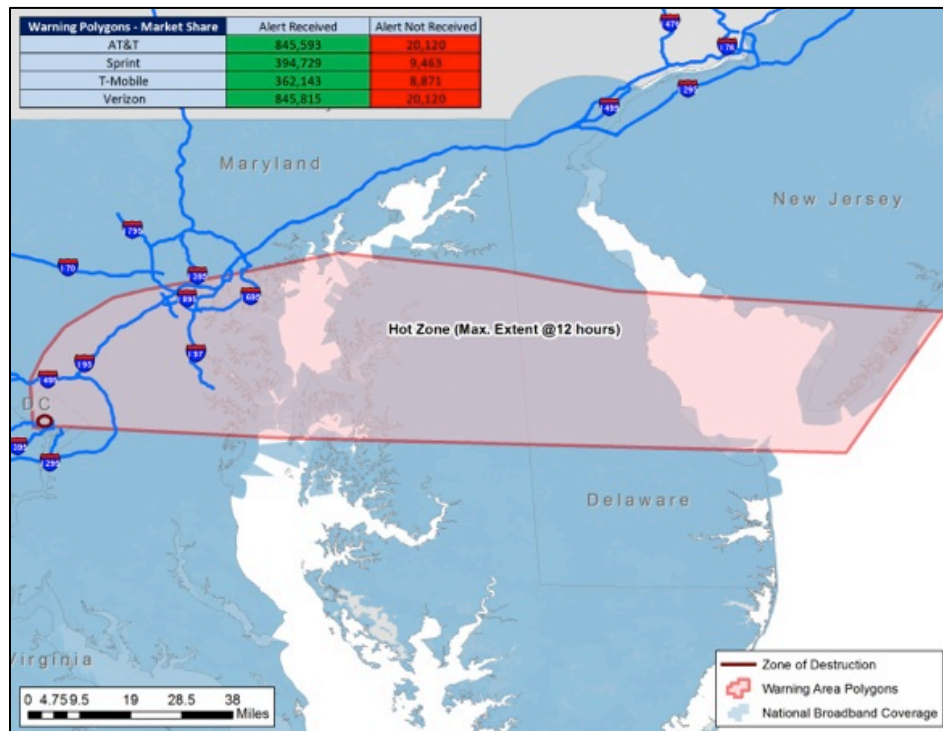
Figure 9-6: Tier 1 Subscribers in the Dangerous Fallout Warning Area



9.4 WEA GTP for the Hot Zone Warning Area

Figure 9-7 shows WEA GTP results for the hot zone warning polygon. The coverage of the Tier 1 wireless carriers is very good in this larger area and there are no alert failures for this message caused by pre-event gaps in carrier coverage. On the other hand, the discussion in the previous section shows the carrier wireless networks would suffer significant damage in the vicinity of the nuclear blast, the SDZ and out to the edge of the MDZ. The radius of the MDZ is about 1 mile and that of the SDZ is one-half mile. Within the SDZ, the cell phone infrastructure would be destroyed. Within the MDZ, a significant fraction of the wireless network infrastructure and many cell phone handsets would be damaged by the physical blast or by EMP. Outside of the MDZ more of the network and a greater fraction of the cell phone handsets would survive. For simplicity it is assumed that all wireless network infrastructure and cell phones outside of the MDZ survive. It is also assumed that the Tier 1 wireless carriers have emergency power systems that maintain power to the wireless infrastructure outside the MDZ. Given these assumptions, the population of the MDZ that lies within the hot zone warning polygon is subtracted out when we estimate the number of people in the warning the polygon who receive the alert. Consequently, everyone who should receive the alert does receive it if they lie outside the MDZ and if they are located in the warning polygon.

Figure 9-7: WEA GTP for the Hot Zone Warning Area

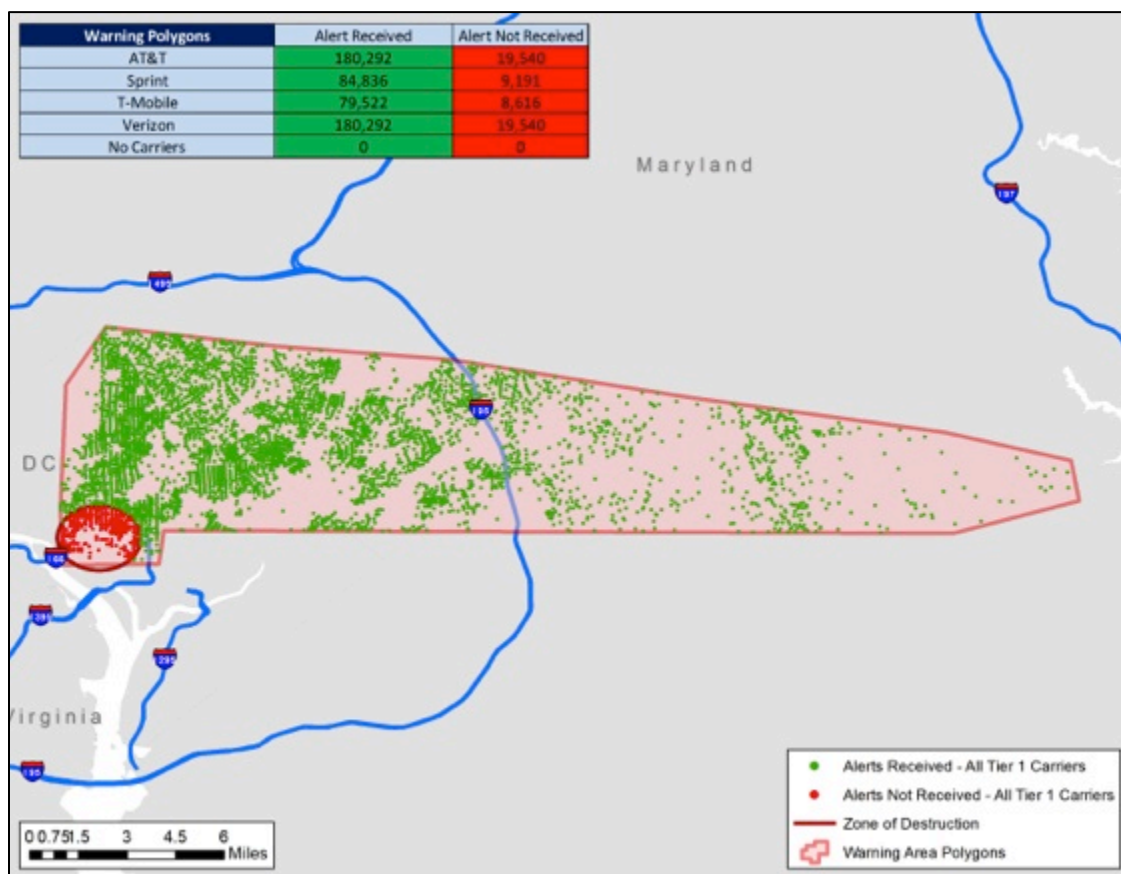


As shown in Figure 9-7, however, there are a significant number of alert failures because of the damage suffered by the network and because of the number of cell phones damaged in the blast in the MDZ. Even so, because the MDZ is relatively small, the overall AFR in this case is only about 2 percent.

9.5 WEA GTP for the Dangerous Fallout Warning Area

Figure 9.8 shows the WEA GTP results for the dangerous fallout warning area. The dangerous fallout warning polygon overlaps with the SDZ and MDZ. The same assumptions used above are also used to estimate the number of people who would receive the dangerous fallout message — that all wireless carrier infrastructure is destroyed within the MDZ and all cell phones in the MDZ are destroyed or disabled by the blast or EMP. Again, for simplicity it is assumed that the wireless infrastructure of the Tier 1 carriers remains largely intact outside of the MDZ and that emergency power systems are used to keep it operational. Given these assumptions everyone who should receive the alert does receive it if they lie outside the MDZ and if they are located in the warning polygon.

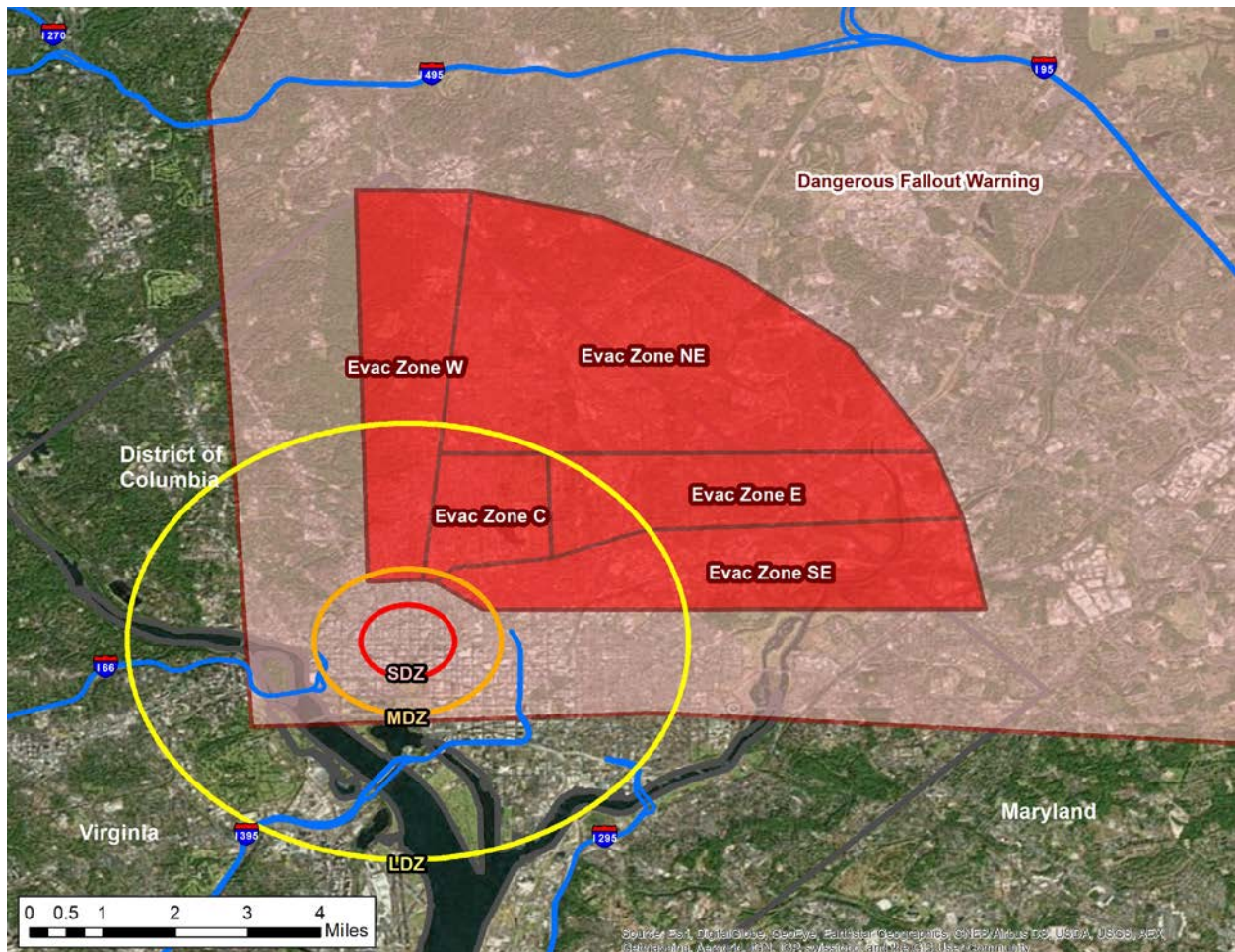
Figure 9-8: WEA GTP for the Dangerous Fallout Warning Area



A significant number of alert failures occur because of the damage suffered by the network and the number of cell phones disabled or destroyed in the MDZ. The dangerous fallout warning polygon is significantly smaller than the hot zone polygon. Because of this, the overall AFR in this case is only about 10 percent.

Once authorities have determined that the radiation fallout risk has fallen to acceptable levels, parts of the city of Washington, D.C., and surrounding suburbs may be evacuated, especially where it may not be possible to provide electric power, water or other essential services. Figure 9-9 shows damage evacuation zones that could be established by authorities several hours or even days after the blast. People in different sectors of the evacuation zone would be directed to leave the area using different routes to ease congestion and to minimize risk of radiation exposure during evacuation.

Figure 9-9: Hypothetical NCR Damage Area Evacuation Zones



The geo-targeting capabilities of the WEA service could enable a large scale complex evacuation operation to proceed effectively in the NCR. The next few sections explore how well the WEA service could support such an operation. Also, note that almost all of the evacuation area lies outside of the MDZ. Therefore, it is assumed the wireless infrastructure of the Tier 1 carriers survives largely intact in the evacuation zone, cell phones in this same area still work, and the wireless infrastructure remains operational because of the use of emergency power generators at individual cell sites.

Tier 1 Wireless Carrier Coverage of the Damage Zone

The next four figures show the coverage of the AT&T, T-Mobile, Sprint and Verizon networks in the vicinity of the evacuation zones. It is evident from the figures that the density of the cell networks is much higher in the lower left-hand corner of the figures, or in the city of Washington, D.C. cell antenna locations in the figures are based on data from Unwired Labs. The background colors in the figures show aggregate carrier coverage as determined by the NBM. The Voronoi method was used to create cell boundaries in these figures as described in Section 2. The figures show that each of the Tier 1 wireless carriers provides good coverage of the damage evacuation zones. This of course assumes that the cellular networks of the wireless carriers do not sustain significant damage in the nuclear blast.

Figure 9-10: AT&T Cells in the Evacuation Zones

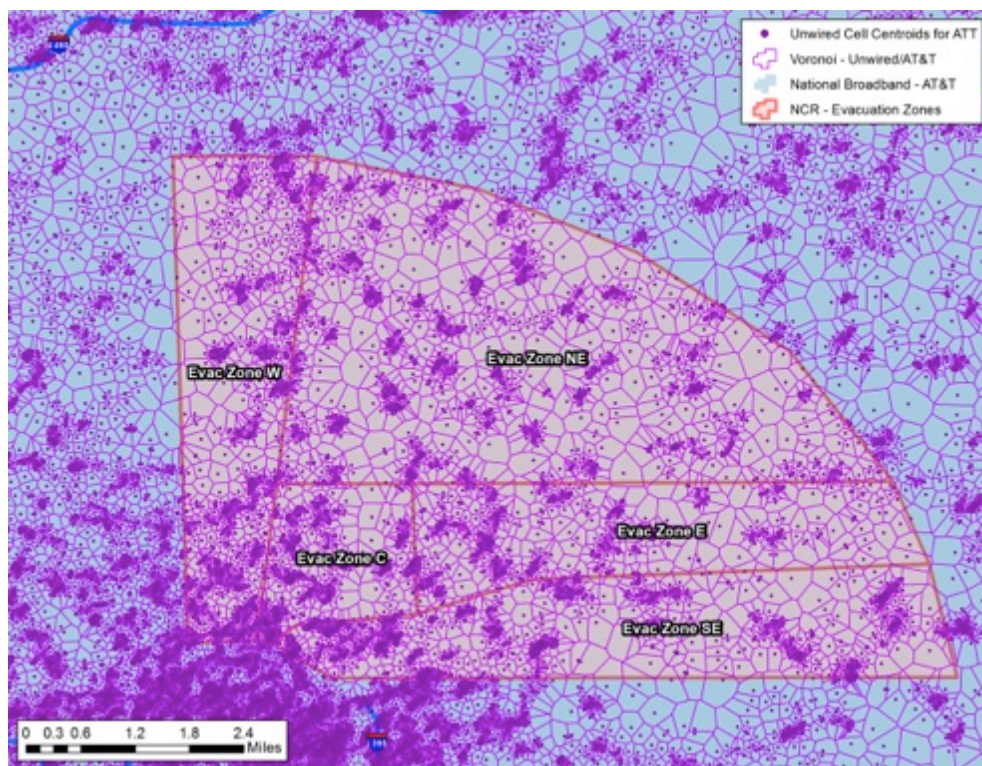


Figure 9-11: T-Mobile Cells in the Evacuation Zones

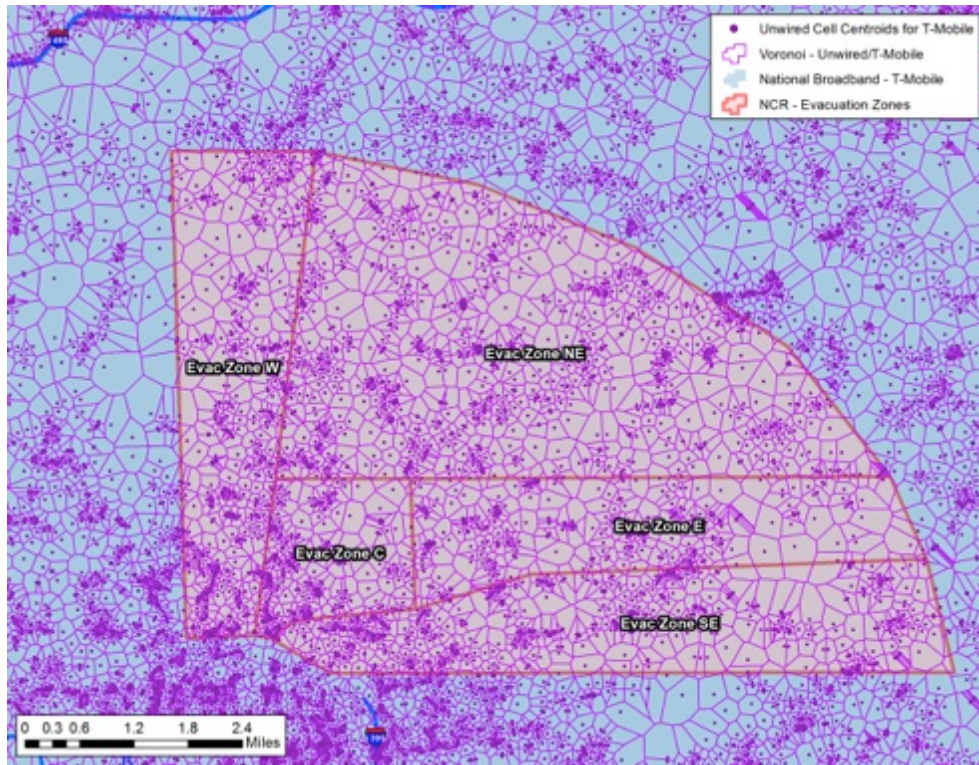


Figure 9-12: Sprint Cells in the Evacuation Zones

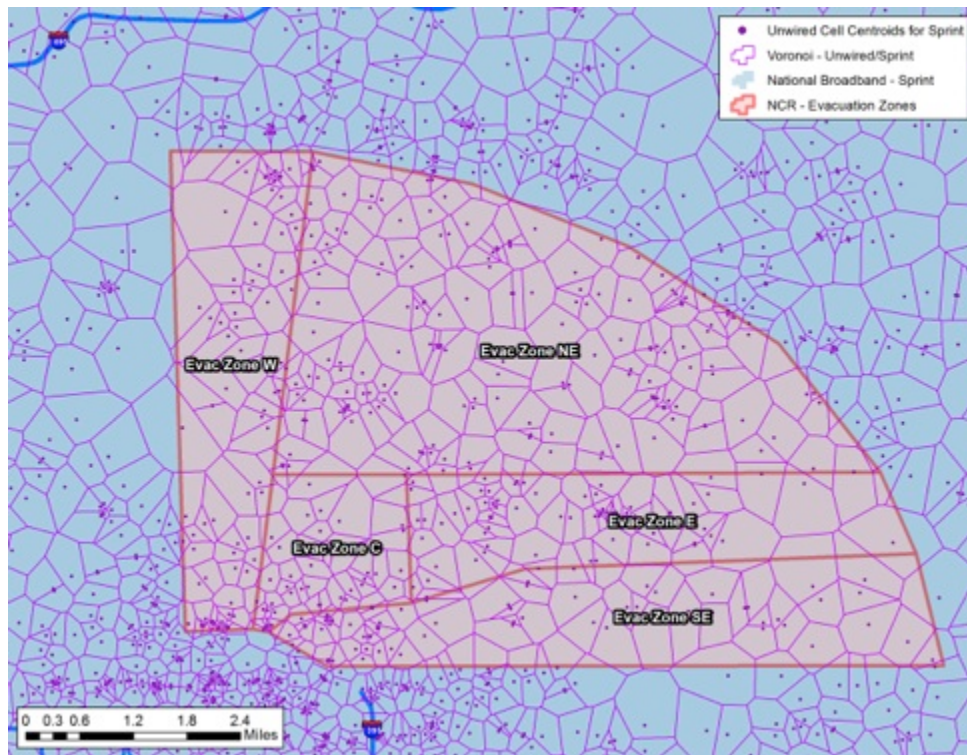
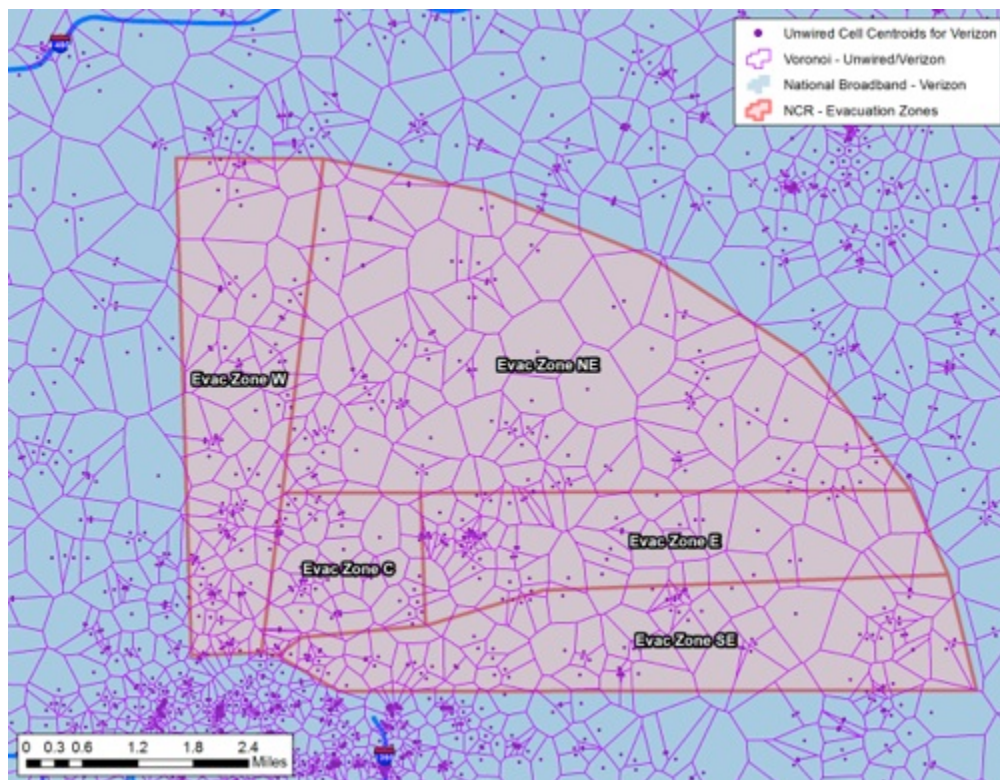


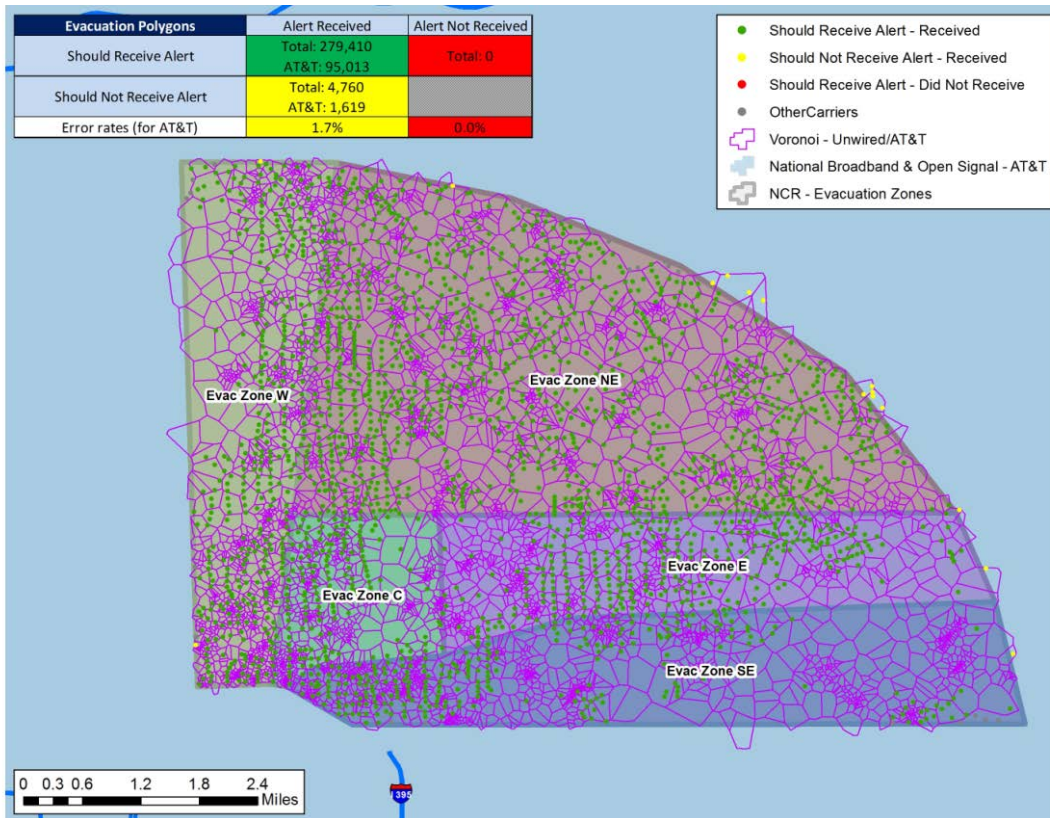
Figure 9-13: Verizon Cells in the Evacuation Zones



9.7 WEA Geo-Targeting Results for Damage Zone Evacuation Warning - Method 1

Figure 9-14 shows WEA GTP results for the damage zone evacuation area for the four Tier 1 wireless carriers, assuming WEA method 1 is used to select WEA broadcast antennas. In the results shown below it is assumed the Tier 1 wireless networks do not sustain significant damage in the evacuation area, and are still operating at the time the evacuation message is issued. Figure 9-14 shows WEA GTP of the AT&T network for WEA method 1.

Figure 9-14: AT&T WEA GTP for Evacuation Warning Using Method 1



The green points in Figure 9-14 indicate the census population tracts that receive the evacuation message. WEA evacuation messages are received by 95,013 AT&T subscribers in the evacuation area. In this case there are no alert failures, as the network provides full coverage of the area. There is a small amount of over-alerting of residents in nearby areas, equal to about 1.7 percent of the total population of the alert area, or about 1,619 AT&T subscribers (assuming the market share percentages given in Section 2), as shown in the figure in yellow.

Figures 9-15 through 9-17 show the corresponding results for T-Mobile, Sprint and Verizon, assuming WEA method 1 is used. These estimates show the T-Mobile and Verizon networks do not have any alert failures in the evacuation area, assuming these networks did not sustain significant damage from the blast and that these networks remain powered after the attack. Each of the carriers does experience some over-alerting, as indicated in yellow.

Figure 9-15: T-Mobile WEA GTP for Evacuation Warning Using Method 1

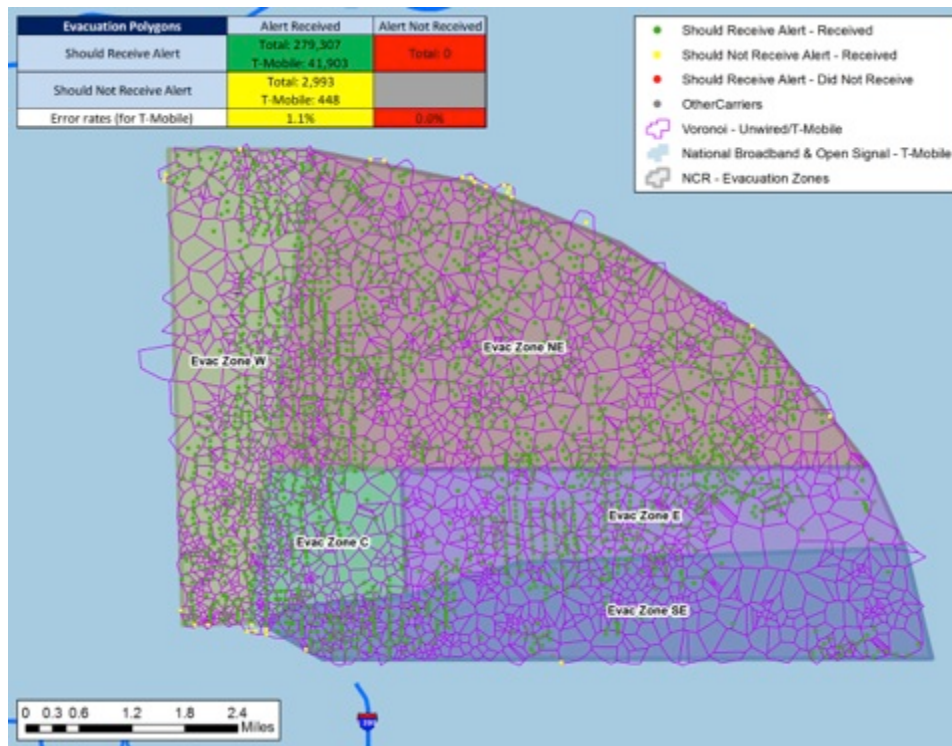


Figure 9-16: Sprint WEA GTP for Evacuation Warning Using Method 1

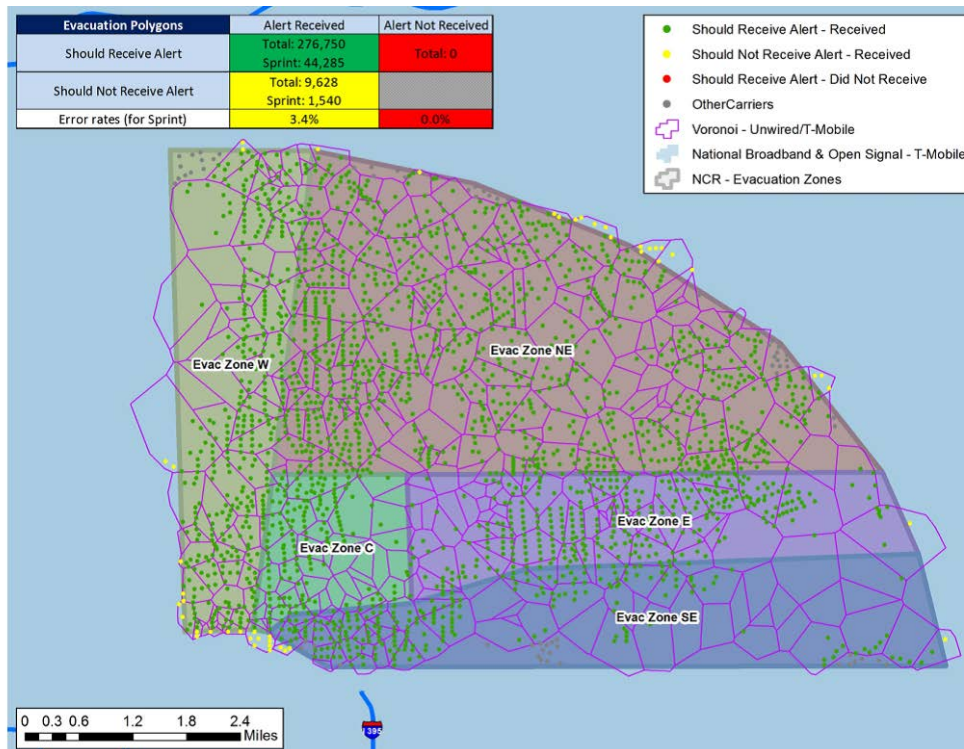
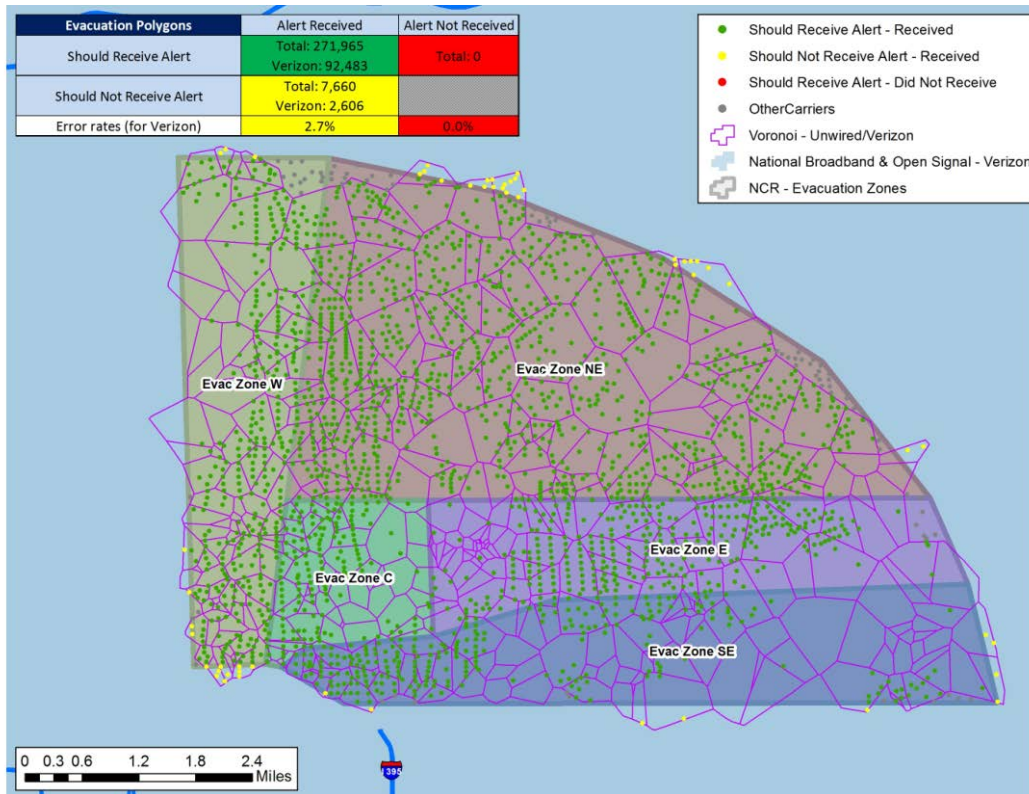


Figure 9-17: Verizon WEA GTP for Evacuation Warning Using Method 1



Results Summary for WEA Method 1

Table 9-1 below summarizes the WEA GTP of the four Tier 1 carrier networks for the damage zone evacuation message.

Table 9-1: WEA GTP for Damage Area Evacuation Warning - Method 1

| | OAR (%) | AFR (%) |
|----------|---------|---------|
| AT&T | 1.7 | 0 |
| Sprint | 3.4 | 0 |
| T-Mobile | 1.1 | 0 |
| Verizon | 2.7 | 0 |

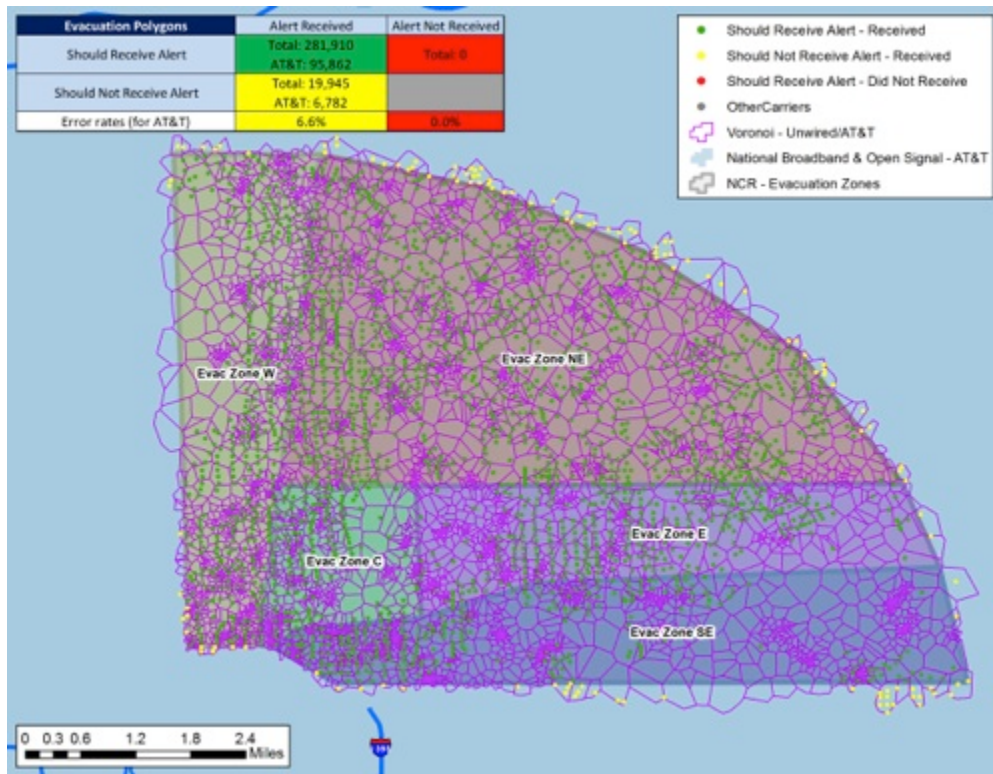
The AFRs are zero, assuming damage to the cell phone infrastructure is limited as described earlier in this section. When method 1 is used the OARs are all less than 4 percent.

One could surmise that OARs are not an important consideration in this scenario. It is important to note, however, that over-alerting caused by such evacuation messages in the nuclear scenario is important because the evacuation messages need to be accurately geo-targeted to avoid sending people into areas with heavy fallout. If people receive the message but are in a safe (low fallout) area they may be put at further risk if they evacuate through a high fallout area.

9.8 WEA Evacuation Warning Geo-Targeting Results - Method 2

This section shows the WEA GTP results for the damage zone evacuation area for the four Tier 1 wireless carriers, assuming WEA method 2 is used by each of the carriers. As before, the results assume the Tier 1 wireless networks do not sustain damage in the evacuation area, and are still operating at the time the evacuation message is issued. Figure 9-18 shows WEA GTP results for the evacuation area for the AT&T network.

Figure 9-18: AT&T WEA GTP for Evacuation Warning Using Method 2



As before, the green points indicate the approximate location of census tracts that receive the evacuation message. Yellow points that lie just beyond the boundary of the census tracts indicate the location of census tracts (people) that lie just outside the warning polygon that receive the evacuation warning message, but should not. These people are over-alerted. From the figure one can see that for the AT&T network the OAR increases significantly in this case.

Figures 9-17 through 9-19 below show the corresponding results for T-Mobile, Sprint and Verizon, assuming WEA method 2 is used. It is estimated that when WEA method 2 is used the Sprint, T-Mobile and Verizon networks do not have any alert failures in the evacuation area. The OARs do increase as indicated in the yellow portions of the tables in the figures below.

Figure 9-19: Sprint WEA GTP for Evacuation Warning Using Method 2

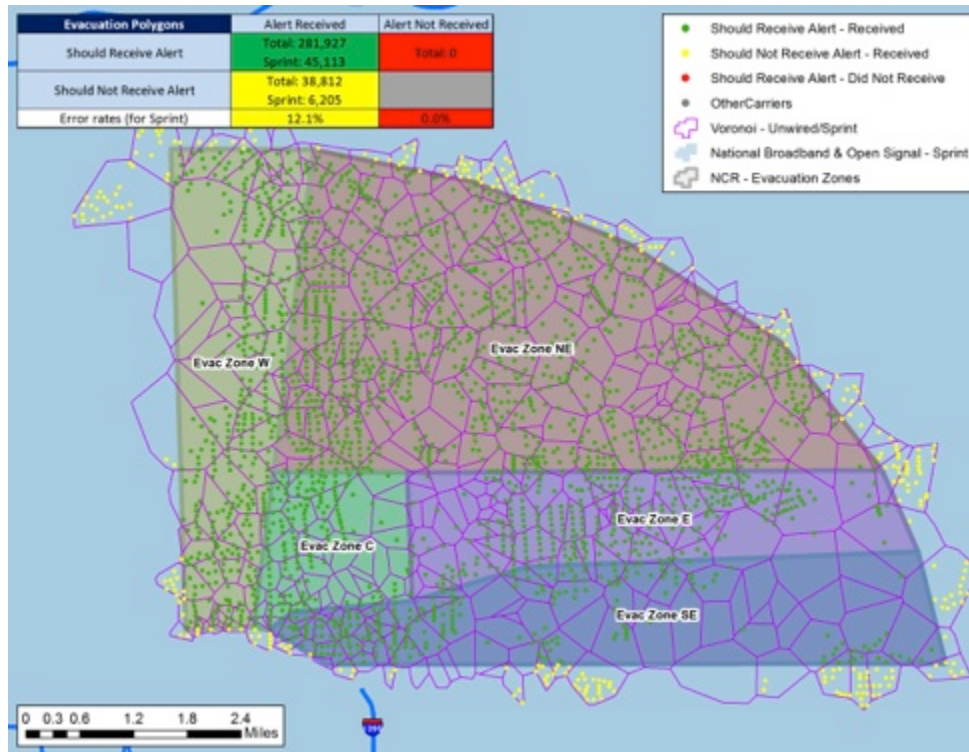


Figure 9-20: T-Mobile WEA GTP for Evacuation Warning Using Method 2

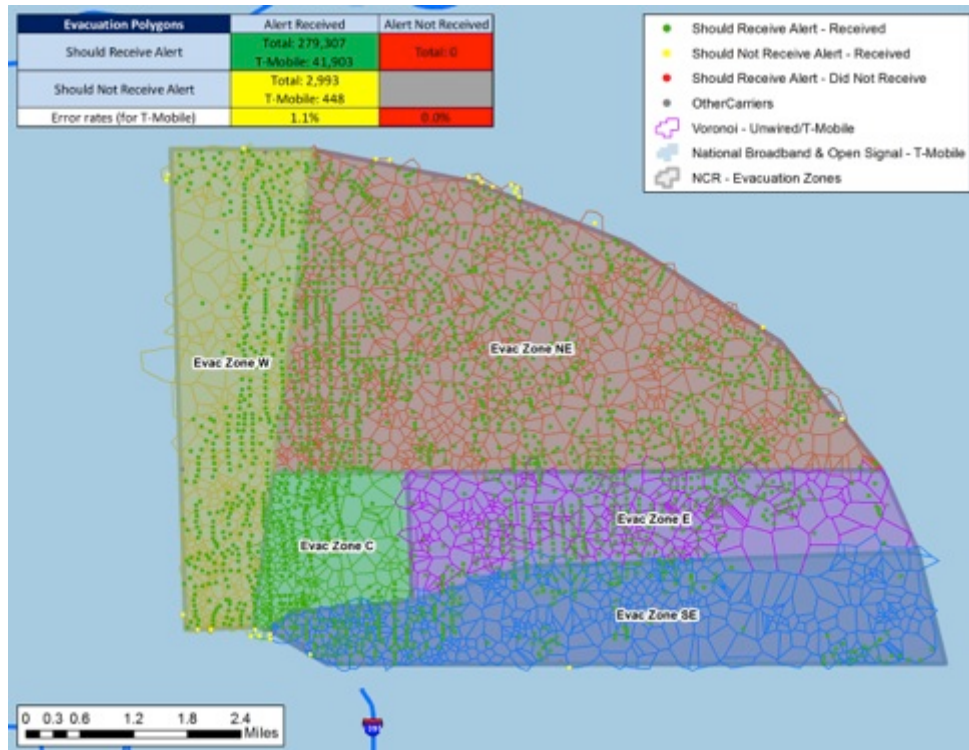
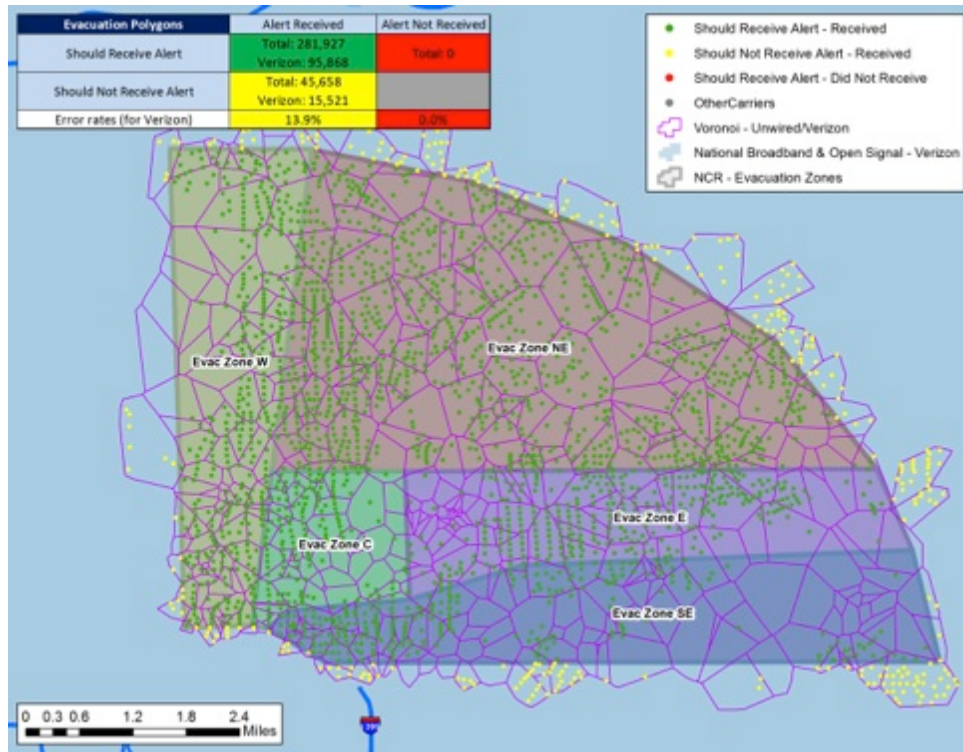


Figure 9-21: Verizon WEA GTP for Evacuation Warning Using Method 2



Results Summary for WEA Method 2

Table 9-2 below summarizes the WEA GTP of the four Tier 1 carrier networks for the damage zone evacuation message when WEA method 2 is used.

Table 9-2: WEA GTP for Damage Area Evacuation Warning - Method 2

| | OAR (%) | AFR (%) |
|----------|---------|---------|
| AT&T | 6.6 | 0 |
| Sprint | 12.1 | 0 |
| T-Mobile | 1.1 | 0 |
| Verizon | 13.9 | 0 |

The results in the table show that AFRs are zero when method 2 is used to select WEA antennas, assuming as before the damage to the cell phone infrastructure is limited as described earlier in this section. When method 2 is used, the OARs are larger than for method 1 for three of the four Tier 1 carriers.

9.9 Summary

For the Washington, D.C., nuclear terrorism scenario we examined WEA GTP for two types of warning messages that would be sent to large areas minutes to days after the attack. The first warning is a hot zone warning message that would be sent to specific residents in Washington, D.C., Maryland, Delaware and New Jersey that are in the path of the radiation plume generated by the explosion. Even though this

warning polygon includes some rural areas, the coverage offered by the Tier 1 carriers in this area is very good, except in the MDZ, where cell phone networks would likely suffer heavy damage. In this case the AFR was approximately 2 percent of the warning population because of the lack of cell network coverage and damaged handsets in the MDZ.

WEA GTP was examined for a second WEA message sent to a smaller, but still large area, the WEA hot zone warning polygon. In this case, the AFR is larger, about 10 percent of the warning population because the area is smaller relative to the size of the MDZ.

The last WEA message examined for this scenario was an evacuation warning message issued to a still smaller area which includes the MDZ. In this case, AFRs for all Tier 1 carriers were estimated to be zero, assuming only a small fraction of the cell towers outside the MDZ are damaged or without power. For this case the performance of antenna selection methods 1 and 2 were also evaluated. Both methods yield good AFR performance, with an AFR equal to zero in both cases.

It was found that WEA method 1 provides better OAR performance than method 2 for some Tier 1 carriers, and also when the average is taken over the performance of all Tier 1 carriers. The difference is statistically significant for the average case, even when RF spillover effects are taken into account. This suggests that WEA method 1 may provide somewhat better performance for evacuation warnings in densely populated urban areas.

10. Conclusions

This study examined how the WEA service could be used to alert the public of an imminent threat to their safety for three rare but potentially deadly scenarios:

- A large destructive earthquake;
- A tsunami warning; and
- A terrorist detonation of nuclear weapon in an urban area.

Each case examines how WEA could be used to safely and quickly evacuate the public from a threat area. The benefits of providing advanced warning of these events are evaluated. Any perceptible operational performance advantages of precisely geo-targeted WEA messages using different cell antenna selection methods was also examined in these three scenarios. For these scenarios we found no statistically significant advantage for using either WEA method 1 or 2.

10.1 WEA GTP for EEW

In the USGS ShakeOut Scenario a large earthquake strikes on the San Andreas Fault in southern California. This analysis shows the WEA EEW message reaches 99 percent of all people in the warning area (more than 18 million people). EEW message AFR and OAR estimates are shown in Table 10-1.

Table 10-1: WEA GTP for Earthquake Warning - Method 1

| | OAR (%) | AFR (%) |
|----------|---------|---------|
| AT&T | 0.1 | 0 |
| Sprint | 0.3 | 0.1 |
| T-Mobile | 0.1 | 0.1 |
| Verizon | 0.1 | 0 |
| Average | 0.15 | 0.05 |

A detailed error analysis described in the body of this report indicates that the differences between Tier 1 carrier OAR performance shown in Table 10-1 are not statistically significant, but that all carriers likely have an OAR that is less than 1 percent of the population to be warned. This is the case in the earthquake scenario, because the coverage of high population areas provided by the Tier 1 wireless carriers is very good and because the vast majority of the population to be warned lives well within the EEW warning polygon and not on the boundary of the warning polygon.

WEA EEW GTP in Moderately Sized Earthquakes

In the large earthquake EEW scenario estimated WEA OARs are small and may appear unimportant because large earthquakes are rare events. Consequently, there appears to be little risk of alert fatigue. As noted earlier, however, earthquakes are not rare events in California. Past studies of earthquake frequency in southern California reveal the area could experience almost a dozen large to moderate sized earthquakes each. These estimates indicate that WEA EEW messages will be rare only if the EEW system is used to warn of large earthquakes of magnitude 6 or higher. If WEA EEW messages are sent for mid-size or moderately sized earthquakes, a significant number of WEA EEW messages will be transmitted each year in southern California. Consequently, the use of WEA in moderate or mid-size earthquakes could render OARs important.

A related issue is how large the warning polygons will be for smaller earthquakes. For moderately sized earthquakes the warning polygons should be much smaller because the damage zone will be much smaller. If the warning polygons used are larger than necessary this could lead to higher OARs than those estimated in this report for a large, magnitude 7.8 quake. It is beyond the scope of the current study to recommend thresholds for the two parameters that will be crucial in determining EEW OARs: (1) the minimum size earthquake for which a WEA message would be sent; and (2) the size of warning polygons for moderately sized earthquakes. Further study is needed to determine an optimal EEW warning strategy that limit OARs using WEA.

Timeliness of WEA Warning Messages

It may be possible to provide more than 100 seconds of warning time to people in the metro Los Angeles area before significant shaking begins in the ShakeOut Scenario — but only if the EEW warning can be transmitted to the public with a transmit delay of 20 seconds or less.

A critical question for the WEA service is whether it can provide the timeliness needed to provide EEW before significant shaking starts in the entire warning area. For a large earthquake such as the one considered in the ShakeOut Scenario it is technically feasible to provide early warning of the earthquake to people in areas far from the epicenter. Seismic sensor networks require about 10 seconds to determine the location and strength of the earthquake and to generate the warning message.⁶⁵ If a communications system can deliver the EEW message in 20 seconds or less, it could provide a maximum of 100 seconds of warning time (for an earthquake similar to the one in the ShakeOut Scenario).

An EEW system is not yet operational in California, however such a system is under development. Cell phone industry technical experts have studied whether it is feasible for the current version of the WEA service to provide EEW messages to the public. This study found it was not feasible to use the current WEA service for EEW. The report implies the current WEA service transmits WEA messages with

⁶⁵ Talbot, “80 Seconds of Warning for Tokyo.”

substantial time delays that may be as high as 12 minutes.⁶⁶ It is important to note that the current WEA service has never been tested on live carrier networks and that government officials do not have a good understanding of the time delays incurred when using the current WEA service.

Cell phone-based EEW systems are operational in Turkey, Mexico, Japan, Romania and Taiwan.⁶⁷ Japanese and Mexican EEW systems have demonstrated they can provide EEW messages to cell phones with only seconds of delay. Furthermore, the Japanese EEW system uses the same underlying technology as the U.S. WEA service (cell broadcast), so in principle it should be possible to modify the current implementation of the U.S. WEA service so it can provide timely EEW messages.

10.2 WEA Tsunami Warning GTP

This study examined potential tsunami inundation zones in Los Angeles County, California. There are three areas in this county that could be subject to a tsunami: Venice-MDR, Long Beach Harbor and the Naples Island area just south of Long Beach Harbor. Elsewhere in Los Angeles County tsunami inundation zones are relatively narrow and only a small number of people would be affected. Therefore, the study focused on WEA GTP for a TWP that covers these three areas. The WEA geo-targeting analysis results for the tsunami warning scenario are presented in Table 10-2.

Table 10-2: Summary of WEA Tsunami Warning GTP Results

| | AFR (%) | OAR (%) |
|-------------------------------------|----------------|----------------|
| <i>Venice-MDR</i> | | |
| AT&T | 0 | 0.8 |
| T-Mobile | 0 | 3.7 |
| Sprint/Verizon | 0 | 4.2 |
| <i>Long Beach Harbor</i> | | |
| AT&T | 0 | 3.3 |
| T-Mobile | 0 | 2.4 |
| Sprint/Verizon | 0 | 6.8 |
| <i>Naples Island</i> | | |
| AT&T | 0 | 3.2 |
| T-Mobile | 0 | 1.3 |
| Sprint/Verizon | 0 | 4.0 |
| <i>Average (all regions)</i> | 0 | 3.3 |

These three areas are densely populated and highly developed. The Tier 1 wireless carrier networks provide excellent coverage in these areas, as long as their networks are not damaged. It is assumed this would be the case, up until the time the tsunami strikes. Therefore, the AFRs for the tsunami warning message are zero for all four Tier 1 carriers in each of the three warning zones that comprise the TWP. Consequently, the average AFR for the TWP is zero.

⁶⁶ "Joint ATIS/TIA CMAS Federal Alert Gateway To CMSP Gateway Interface Specification."

⁶⁷ Mark Johnson, "California Earthquake Early Warning System," 2015, <http://www.atis.org/newsandevents/webinar-pptslides/EEWslides-8252015.pdf>.

$$AFR_{ave}(TWP) = 0$$

The OARs are higher than those estimated for the EEW scenario. The average the OAR for all three areas and all carriers is 3.3 percent. The OAR error rate for the TWP is approximately 5 percent (see Table 2-1) because the TWP is relatively small. Therefore, the differences in computed OARs are not statistically significant. The average OAR value lies somewhere in the range indicated below:

$$OAR_{ave}(TWP) \sim (3.3\% \text{ to } 8.3\%)$$

Nevertheless, even with potential RF signal spillover, the number of people that could suffer over-alerting in this case (approximately 21,500 in the worst case) is far less than would be the case if the tsunami alert were sent to the entire NWS CA041 warning area.

The analysis shows that only 252,156 people would actually be in danger in Venice-MDR, Long Beach Harbor and Naples Island, which corresponds to the population of these three tsunami inundation zones. If geo-targeted WEA tsunami warning messages were only sent to these three zones, only people in these areas would receive the alert. In this case an additional 8,321 to 21,500 people outside of these zones would be over-alerted (they would receive the alert but should not have).

The number of people that would be over-alerted would be much smaller than the effective over-alerting rate that would result if a tsunami warning message was sent to the larger near countywide area known as NWS CA041 (see Figure 7-2). In the latter case more than 4.2 million people would be alerted of the tsunami, but the vast majority of these people would not be in danger. One can only imagine the economic disruption, traffic and dislocation that would result if over four million people were warned of a tsunami and if a significant fraction of these people left work or their home in search of higher ground. The geo-targeting capabilities of the WEA service would prevent this from happening.

10.3 WEA GTP in the Evacuation of Naples Island

This study also examined how the WEA service could be used to facilitate the evacuation of Naples Island, which is located on an inland waterway just south of Long Beach Harbor. It would be entirely inundated in the event of a large tsunami. This island is connected to the mainland by three bridges. more than 3,400 people live on the island. In the scenario considered, residents would only have 10 to 15 minutes to evacuate the island. Three zones were defined in the Naples Island TEZ and three geo-targeted WEA messages were sent that directed the population in each sector to evacuate the island using the bridge in each sector.

This is perhaps one of the most challenging scenarios for WEA, as it would require transmission of geo-targeted evacuation messages to very small areas, each less than one-half mile across. We examined the performance of two of the Tier 1 wireless carriers networks for this scenario.

The average AFRs for the three zones were found to be 23 percent, 16 percent and 4 percent.⁶⁸ The average AFR over the entire Island or TEZ was estimated to be 13 percent. The error in this estimate due to spillover of the cell broadcast signal for the TEZ is very small, thus the average AFR estimate is:

$$AFR_{ave}(TEZ) = 13\%$$

The average OARs for the three evacuation zones were found to be 13 percent, 16 percent and 8.5 percent.⁶⁹ The average OAR over the entire Island or TEZ was estimated to be 14.5 percent. Given the OAR error induced by RF spillover effects the average OAR could anywhere in the range below.

$$OAR_{ave}(TEZ) \sim (14.5\% \text{ to } 19.5\%)$$

In this case the individual evacuation warning polygons are small and perimeter RF spillover effects are significant. Despite these errors the results suggest the WEA service could play a positive role in the evacuation of Naples Island and could help the majority of the island's population evacuate efficiently.

Uncertainty Regarding WEA Message Latency Can Impact Emergency Management Planning

A separate concern in this scenario is the responsiveness of the WEA service. If it would take 10 minutes for the WEA message to be transmitted to the island population, there would not be enough time for and orderly evacuation. On the other hand, if the WEA message could be delivered within 10 to 20 seconds after the initial tsunami is detected then it may be possible to evacuate the island in an orderly fashion (this assumes the tsunami evacuation messages had already been planned by local emergency managers). This example highlights the need for emergency managers and AOs to better understand the responsiveness of the WEA service so that they can plan to use WEA in an effective way.

10.4 WEA GTP Radiation Hazard and Evacuation Warning

The third imminent threat scenario considered began with a nuclear terrorist attack in Washington, D.C. This analysis focused on the use of the WEA service after the attack to minimize the exposure of the surviving population to hazardous fallout and radiation. The specifics of the scenario considered were developed in a DHS sponsored study. The scenario specifies the existence of a dangerous fallout zone that would extend up to 40 miles away from the center of Washington, D.C. A larger "hot" or hazardous radiation zone would exist for up to 12 hours after the attack and would extend hundreds of miles away and cover several states, including a small part of New Jersey. We examined how the WEA service could be used to send shelter in place instructions to people in both warning areas.

More than 2.4 million people are located in the hot zone. Assuming the Tier 1 wireless networks remain largely intact outside of the blast damage area, the hot zone warning message would be received by 98 percent of the population in the warning area (the AFR would equal 2 percent). Only those people that

⁶⁸ These are averages over the AFRs for the two Tier 1 carriers considered.

⁶⁹ These are averages over the AFRs for the two Tier 1 carriers considered.

were located close to the blast would not receive message, either because their phones no longer worked or because of damage to the wireless network infrastructure.

More than 587,000 people are located in the dangerous fallout warning area. Approximately 90 percent of the population in the dangerous fallout zone would be warned. Approximately 10 percent of the population in this smaller warning area would not receive the message, either because their phones would not work or because of damage to the wireless networks.

10.5 WEA GTP for Evacuation Warning

This study also examined WEA GTP in the terrorist nuclear attack scenario. In this scenario it is assumed that emergency managers issue an evacuation warning to an area that suffers heavy damage and which lacks power and other essential services. It is also assumed the majority of the wireless network infrastructure would still be working in the evacuation zone when the evacuation order was given. Given this assumption AFRs for all Tier I carriers are estimated to be zero.

$$AFR_{ave}(\text{Evacuation Zone}) = 0$$

Because of the small size of the evacuation zone, and potential for spillover to close in areas where cell antennas may not be working, this estimate is likely to be correct, if the number of users with damaged phones is not included. This analysis did not attempt to estimate the number of phones that would be damaged by EMP and at what ranges these damage effects would prevent the reception of WEA messages. The OAR for the evacuation warning message varies depending upon the method used to select which cell antennas are used to issue the WEA evacuation warning (i.e., WEA method 1 or 2). These results are shown in Table 10-3.

Table 10-3: WEA OARs for Nuclear Blast Evacuation Area Warning

| | Method 1 | | Method 2 | |
|----------|----------|-----------|----------|-------------|
| | Estimate | Range | Estimate | Range |
| AT&T | 1.7 | 1.7- 6.7 | 6.6 | 6.6 -11.6 |
| Sprint | 3.4 | 3.4 – 8.4 | 12.1 | 12.1- 17.1 |
| T-Mobile | 1.1 | 1.1 – 6.1 | 1.1 | 1.1 – 6.1 |
| Verizon | 2.7 | 2.7 – 7.7 | 13.9 | 13.9 – 18.9 |
| Average | 2.2 | 2.2 – 7.2 | 8.4 | 8.4 – 13.4 |

The evacuation warning polygon is relatively small which introduces RF spillover effects which are a source of error to our estimate. Using the OAR error estimate for a small urban area in Table 2-1, the error in the OARs is estimated to be +5 percent.

WEA method 1 provides better performance than method 2 for most Tier 1 carriers. The difference is only statistically significant for Sprint and Verizon, however. This suggests that WEA method 1 may

provide somewhat better performance for evacuation warnings in urban areas. It should also be noted that GTP differences between carriers are not statistically significant if method 1 is used, but are marginally significant if method 2 is used by all carriers. The spread in performance is larger for method 2.

10.6 Relationship Between WEA GTP and Warning Area Size

Analysis of the three scenarios above shows there is a tradeoff between the size of the warning area or polygon and WEA GTP. WEA geo-targeting accuracy is higher for larger warning areas, as is the case in the EEW scenario. On the other hand, WEA geo-targeting accuracy is lower for smaller warning areas. We found OARs increased for smaller warning areas, such as those used in tsunami and damage zone evacuation orders.

WEA antenna selection method 1 provides better performance than method 2 for the case where evacuation warning messages are issued in a small densely populated urban areas. This assessment is based on OAR differences as both methods yield an AFR of zero in this case. The evacuation warning areas considered in this study are relatively small. For larger areas we did not find a statistically significant difference in performance between method 1 and 2.

10.7 Recommendations

WEA and EEW

This study demonstrates that the current WEA service can effectively geo-target EEW messages. Industry studies imply that EEW message time delay may be too large to provide effective warning using the current WEA service, however. In light of these findings it is recommended that DHS, the State of California, the State of Oregon and the USGS investigate whether there are relatively inexpensive ways to modify the current WEA service to improve its responsiveness.

Consistent with this objective it is recommended the WEA service be tested on the West Coast and in the NCR to measure the time latency of WEA messages in these two areas. If there is a significant time difference in message latency between East Coast and West Coast WEA messages, it may make sense to establish a second IPAWS aggregator on the West Coast to support WEA messaging and which would be dedicated to EEW.

An EEW specific WEA test should be conducted on the West Coast to determine if the current WEA service could be useful for EEW even without improvements. If testing determines it is necessary, DHS, the FCC and the Tier 1 wireless carriers should explore technical solutions that can reduce WEA message transmission time delays from minutes to seconds, thus making WEA EEW feasible in 4G networks. If instrumented properly, such a test could determine the source of the largest time delays in the system.

A new IPAWS aggregator backup node could be located on the West Coast and would provide resilience to the IPAWS architecture. This IPAWS aggregator backup node would be designated as the primary node for issuing WEA EEW messages. This would reduce delays in the WEA EEW message transmission process, relieving the primary IPAWS aggregator of the very short EEW message timeliness requirements, and most importantly would enable existing WEA capable handsets used today by millions of Californians to receive WEA messages. A separate study may be required (depending upon the WEA service test results) to determine whether modifications would be needed in Tier 1 wireless carrier networks to reduce WEA time delays in carrier networks for EEW.

Cell phone industry experts have examined improvements to the next version of the WEA service being designed for advanced 4G LTE networks. In a recent wireless industry study it was assumed WEA would not be used for transmitting EEW messages to cell phones (i.e., that EEW messages would not be sent to the IPAWS aggregator, which is located near Washington, D.C.) and instead would be sent to the Tier 1 wireless carriers from a new special purpose EAC located somewhere in California. Presumably the EAC would be funded by the State of California, as it would not be part of the IPAWS architecture. This alternative may not be easily extensible to a national EEW system. We recommend instead that industry focus on extending the WEA service in LTE networks so it can support EEW timeliness requirements. This alternative also has the advantage that it would make use of the millions of WEA capable handsets already in circulation in western states. The current capabilities of the Japanese EEW system indicate that this should be an achievable goal for 4G networks.

WEA and Tsunami Warning

This analysis shows that WEA has the geo-targeting capabilities to provide effective tsunami warning. The timeliness of tsunami warning is also an issue, just as it is with EEW, although the timeliness requirements are not as severe. A tsunami generated from an earthquake far in the western Pacific Ocean would take hours to reach the California coastline. In this case, the current version of the WEA service would provide sufficient tsunami warning time. A tsunami generated from an undersea fault located just hundreds of miles off shore would reach coast within 10 to 15 minutes, however. It could take someone located in the three threatened areas 10 minutes or more to reach higher ground. So reducing time delays in the WEA service will make it a useful warning dissemination path for tsunami warning, regardless of where the tsunami originates.

Emergency managers will also need WEA tsunami warning messages pre-loaded and ready to go to meet desired warning times. NOAA, USGS and CAL-OES have developed tsunami emergency response playbooks to speed up the tsunami warning process.⁷⁰ These playbooks should be revised to include pre-defined WEA tsunami warning messages. DHS and FCC should work to reduce WEA message transmission time delays to maximize the value of WEA for tsunami warning.

⁷⁰ Wilson and Miller, "Tsunami Emergency Response Playbooks and FASTER Tsunami Height Calculation: Background Information and Guidance for Use."

Conduct an Information Sharing Experiment with the Wireless Industry to Improve WEA Geo-Targeting Accuracy

Could further improvements be made to WEA when precision geo-targeting of WEA messages is required? This report shows how knowing the location of cell towers and coverage areas can inform public safety planning and responses. Further improvement in WEA GTP is possible if government emergency managers had access to the actual location of Tier 1 carrier cell antennas and coverage areas. We recommend the FCC approach the Tier 1 wireless carriers and ask them to consider a limited experiment in which the carriers provide precise data for a limited number of small controlled test areas to calibrate the accuracy of the methods developed in this study.

Sharing Information on Wireless Network Damage

Several of the scenarios considered included the broadcast of WEA messages after significant damage has probably occurred within the affected area. In these cases it is likely that the cell phone network will have suffered significant damage and may not be operational in some areas. Carrier operators will know whether parts of their network are damaged, but AOs may not. Because of the possibility of damage AOs may hesitate to issue WEA messages to affected areas. If the network operators informed AOs of the status of their networks after events such as an earthquake or terrorist attack, it would facilitate AO planning on how and whether to use WEAs after these destructive events. It is recommend that the Tier 1 carriers inform local emergency managers and AOs if their networks suffer significant damage.

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