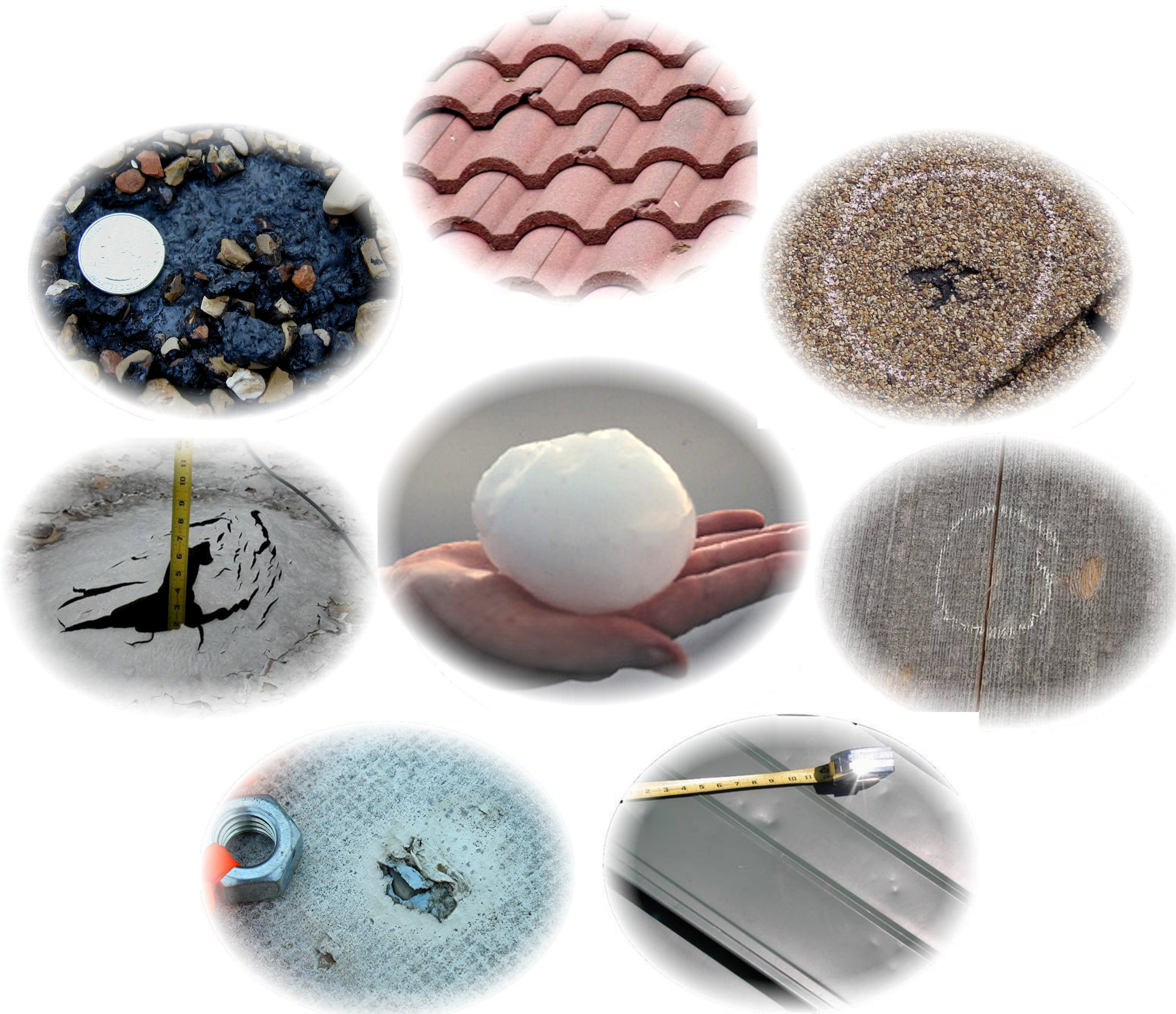
HAILSTORM INVESTIGATION

OKLAHOMA CITY, OK
APRIL 21, 2004



RICOWI, Inc.

Roofing Industry Committee on Weather Issues, Inc.

HAILSTORM INVESTIGATION REPORT
Oklahoma City, OK – April 21, 2004

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Preface

This document was prepared and published by the Roofing Industry Committee on Weather Issues, Inc. (RICOWI). The following organizations are Sponsor Members of RICOWI:

This document will be posted on RICOWI's website (www.ricowi.com) and available for free download. Copies on CD can be ordered by email: paws01@charter.net. A shipping and handling fee will be charged.

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RICOWI, Inc.
Roofing Industry Committee on Weather Issues, Inc.

The Roofing Industry Committee on Weather Issues, Inc.

Mission
RICOWI is committed to:

- Encourage and coordinate research to provide a more knowledgeable information base of roof issues including wind, hail, energy efficiency and durability effects;
- Accelerate the establishment of new or improved industry consensus standard practices for weather design and testing where they are recognized as needed;
- Improve the understanding of roof weather concepts and issues within the building community in general.

Background
The Roofing Industry Committee on Weather Issues, Inc. (RICOWI) was established in 1990 as a non-profit organization to identify and address important technical issues related to the cause of wind damage which include:

- Dynamic testing of roof systems;
- Importance of sample size for tests;
- Role of wind tunnels and air retarders;
- Need for acceptable procedures for ballasted systems;
- Field data and response team reports;
- General lack of communication within the roofing industry as to what the problems are, what is being done and should be done to alleviate them, and how effectively information is transferred within the roofing industry and to others in the building community.

In 1996, RICOWI was incorporated as a non-profit corporation devoted to research and education on wind issues. After a review of the need for similar education and research in the areas of hail, energy efficiency and durability effects, the organization's objectives were broadened in 1999 to include other weather topics, and "Wind" in RICOWI's name was changed to "Weather" to reflect the expanded scope. RICOWI is assisted by Oak Ridge National Laboratory, the banner organization.

Meetings
RICOWI meetings are held twice a year, in the spring and fall. The spring meeting is usually in conjunction with the spring seminar, which is scheduled to coincide with the Roof Consultants Institute's Annual Convention. RICOWI meetings are attended by people that are concerned about roofing and weather issues.

The meetings include a technical forum and a business session where the direction and business of RICOWI is discussed. During the technical segment, the Sponsor and Affiliate Members have an opportunity to report on the latest developments in their organizations and technical subjects of common interest. Any concerned or interested individual can bring their knowledge or concern to another group of experts that can peer review their ideas, suggest tests or procedures, or confirm that they are headed in the right direction.

Seminars
RICOWI Seminars on the proper design, installation and testing procedures for specific roofing materials are held once or twice a year. Fall seminars are usually held at research testing or educational facilities and include a tour. They are of interest to roofing professionals, architects,

contractors, engineers, facility managers and those in the insurance industry.

Hurricane and Hail Investigation Programs

RICOWI has implemented two strategic investigation programs:

- Wind Investigation Program (WIP)
- Hail Investigation Program (HIP)

The purpose of the programs is to investigate the field performance of roofing assemblies after major hurricane and hailstorm events and:

- To factually describe roof assembly performance and modes of damage;
- To formally report the results for substantiated hurricane/hail events.

The data collected will provide unbiased detailed information on the wind and hail resistance of low-slope and steep-slope roofing systems from credible investigative teams. We can expect a greater industry understanding of what causes roofs to perform or fail in severe wind and hail events, leading to overall improvements in roof system durability, the reduction of waste generation from re-roofing activities, and a reduction in insurance losses that will lead to lower overall costs for the public. The reports and multimedia presentation will document roofing systems that fail or survive major weather events and will provide educational materials for roofing professionals to design wind and hail resistant roofing systems. All data will be used to improve building codes, roof systems design, and educate the industry and the public.

ROOFING INDUSTRY COMMITTEE ON WEATHER ISSUES, INC.
HAILSTORM INVESTIGATION REPORT
April 21, 2004 Hailstorm, Oklahoma City, OK

ABSTRACT:

The Roofing Industry Committee on Weather Issues, Inc. (RICOWI) has completed an inaugural Hailstorm Investigation Program (HIP). Four inspection teams examined over one hundred roofing systems during a four-day period to evaluate the effects of a significant hailstorm that passed through portions of Oklahoma City on April 21, 2004. The purpose of the project was to document the effects of hail impact on a variety of roofing products, and to describe roof assembly performance and modes of damage for substantiated hailstone sizes.

1. INTRODUCTION

A field investigation program has been completed by RICOWI regarding hail effects to roofing from a storm that occurred in the Oklahoma City area on April 21, 2004.

RICOWI was established in 1990 as a non-profit international organization comprised of major roofing associations, members of academia, educational and test facilities, the insurance industry, and others involved in the science of roofing.

The mission of the HIP is:

- To investigate the field performance of roofing assemblies after major hailstorm events;
- To factually describe roof assembly performance and modes of damage;
- To formally report the results for substantiated hail events.

The RICOWI HIP project was the first industry-wide research program ever conducted to assess field damage from a major hailstorm in the United States. The storm was selected by the RICOWI criteria of having been declared an insurance catastrophe by Property Claim Service (an insurance services company) and having hailstones larger than 1.5 inches in diameter in a region of five square miles or greater in a previously defined area (the Dallas/Fort Worth or Oklahoma City metropolitan areas had been targeted).

2. METEOROLOGICAL INFORMATION

On April 21, 2004 a super cell thunderstorm containing large hail passed through portions of Oklahoma County, including the cities of Yukon, Oklahoma City, The Village, and Nichols Hills. Hail size reports from the media and storm spotters indicated hailstones of up to 3.0 inches in Yukon and northwest Oklahoma City. In addition to the large hail sizes in some of the storm track, the hailstorm was noteworthy in duration and quantity of hail produced. The hailstorm passed over the Wiley Post Airport in northwest Oklahoma City, and the hail lasted for twenty-two minutes (average hailstorm duration is five to ten minutes). Media reports stated the Broadway Extension (US 77) Freeway in northern Oklahoma City was shut down by the accumulation of

Figure 1. A) Buckled vent cap; B) Awning punctured by hailstones; C) Hail impact spatter marks; D) Large dent in vent hood.

several inches of hail on the roadway, and media photographs confirmed this. Several carports in northern Oklahoma City, along with one commercial building roof, were reported to have collapsed from the weight of hail and rain. The Oklahoma Insurance Commissioner, Carroll Fisher, estimated the insured loss at $75 to $100 million shortly after the storm[1].

Refer to Appendix A for meteorological information from the National Climatic Data Center publication *Storm Data and Unusual Weather Phenomena.*

Prior to arriving for the field investigation, a HailTrax map from Weather Decision Technologies that estimated maximum hailstone diameters from the radar imagery was obtained. This was used to make a preliminary judgment on what areas to focus the inspections. The inspection sites were plotted onto the HailTrax map. It was possible to locate virtually all sites in the area where greater than 2.0 inch diameter hail was indicated (Figure 2).

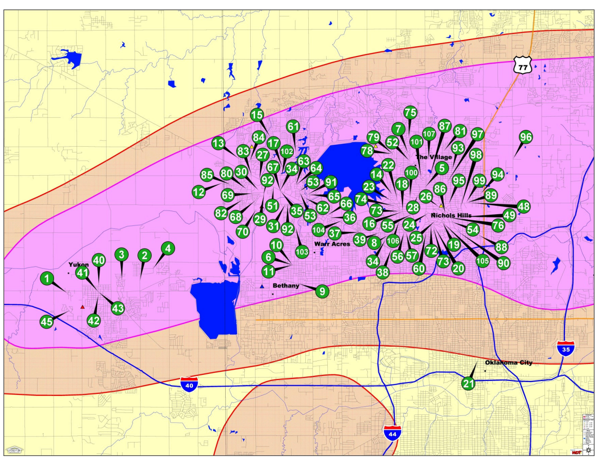

Figure 2. HailTrax map with inspection locations marked. Pink shaded areas had possibility of 2.0 inch diameter or larger hailstones. See Appendix B for full size.

3. INVESTIGATION PROTOCOL

Most members of the inspection teams were trained in hail damage identification and HIP procedures during a one day training program (or were provided remote training by way of video courses). An inspection form was developed and provided for each inspection site to gather background information, details about the roof system and substrates, the type and severity of damage to the roof, and determining the quantity, direction, and size(s) of hailstones that fell during the storm. Hail information was gathered on the sites by examining a variety of materials and surfaces that would contain impact marks or dents from hail impact, in addition to any damage found to the roof materials[2,3]. Property owners also offered some eyewitness accounts of hailstone size and quantity, photographs, and frozen hailstones. (With the exception of photographs or frozen hailstones observed, it should be understood the hailstone sizes listed are best estimates from the information gathered on-site and data offered in the referenced articles by Crenshaw and Morrison.) The (estimated) maximum hailstone sizes for the inspection locations were plotted on a map (Figure 3) and listed in the summary tables (Appendix C). The site inspection and ground survey information provided more detailed hail size information than was possible with the HailTrax map[4]. While the HailTrax map provided a general path of the storm, the actual swath of very large hail (2.0 inch diameter or greater) was much narrower (one to two miles across, instead of five to seven miles across), and the hail size varied considerably in short distances, particularly perpendicular (north/south) to the storm movement.

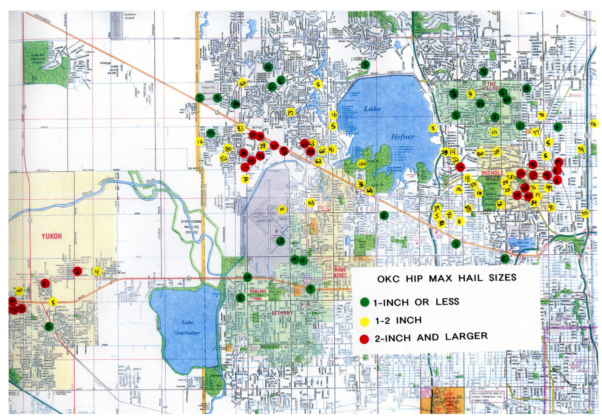

Figure 3. Plot of inspection and storm survey locations with maximum hailstone sizes. See Appendix D for full size.

Inspection teams were designed to consist of three members with a balance of manufacturer representatives, trade group representatives, engineers, roof consultants and insurance interests. One team member would record the site data on the form, one would photograph and log captions for the photographs, and one would inspect the property and mark items of interest. At times, the inspection teams contained only two members, and a few inspections were made by a single team member or the HIP site coordinator. The single member inspection forms and photographs were reviewed by other HIP team members and the coordinator for credibility, but are coded separately in the overall list. Some inspection teams were accompanied by roofing contractors or other interested parties who aided in arranging the inspection or in providing access.

The selection of inspection sites was targeted towards areas with moderate to large hail sizes and included a variety of roof system types. Sites primarily were obtained through contacts of HIP or RICOWI members, through local roofing contractors, or through appeals presented via print and television media for the public to volunteer their property for inspection. No money was offered or given for inspections, and the people offering their property were told in advance that roof replacement bids would not be given, nor would advice be given regarding their insurance claims.

The inspections were designed to get useful data about the following: hail size, frequency of hail hits, surface damage, significant product damage, and roof system response.

Typical inspections consisted of a complete visual survey of the roof surface. This was followed by randomly selecting sites where the hail hits were counted and the hail size was estimated. On each roof several random sites were selected for counting the hail hits. Other building or surrounding elements were also used to establish the size of the hail at the specific site being investigated. The results of the hail hits were observed, photographed and catalogued. Roofing material was removed and examined whenever the opportunity occurred, such as when re-roofing was in progress.

The inspections were largely non-destructive, but samples were taken from a few locations when circumstances allowed and property owners gave approval. Following the field investigation, the information from the inspection form was input into a central database, and digital photographs from each site were consolidated. Appendix C contains a summary table of the inspection locations with their roof type(s), maximum hailstone size, and hail effects observed.

4. FIELD RESULTS

A. LOW SLOPE SYSTEMS

A.1. BUILT-UP ROOFING (BUR)

Teams inspected thirteen built-up roofs in the study; ten with asphalt and four with coal tar pitch (one location had sections of each). Ages ranged from a few years old to at least three that were known or appeared to be older than twenty years old. One roof had an aluminum roof coating while the rest had pea-graveled aggregate surfaces. The conditions varied, with some roofs in good condition and some in poor condition. Blisters or wrinkles were commonly observed on roofs in poor condition. Maximum hailstone sizes ranged from about 1.0 inch to 2.5 inches in diameter. Damage was found in the field (and flashings) of five roofs with damage to curb flashings only noted on one building.

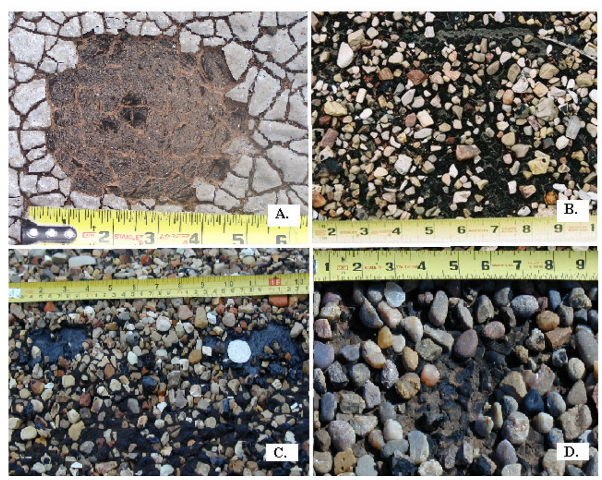

Figure 4. A) Location 33-Aluminum-coated BUR fractured in field; B) Location 76-Gravel aggregate surfaced BUR sustained 2.0 inch diameter hailstone impacts with no visible damage or reported leaks; C) Location 95-Wrinkle in coal tar BUR punctured in two locations; D) Location 94-Large hailstone displaced gravel, but BUR membrane did not appear to be damaged.

Common damage modes were fracturing or puncturing of unsupported regions including blisters, wrinkles, and curb flashings. In one case of a wrinkled and brittle membrane, isolated damage was found to unsupported regions with hail as small as 1.0 inch in diameter. Damage to the flood coat was found in supported areas (non-blistered) in the field of the roof with hailstones 2.0 inches in diameter on a pea-gravel aggregate surfaced roof. Fracturing of the built-up membrane was observed. Hail size of about 2.5 inches in diameter caused hairline fracturing through all plies of an aluminum-coated built-up membrane and a gravel aggregate surfaced built-up membrane. This damage was visually determined by probing the impact site from the external surface; there were no test cuts. Some gravel aggregate surfaced roofs sustained hail impacts of 1.5 to 2.0 inches in diameter without apparent damage in the field of the roof. On the gravel aggregate surfaced roofs that sustained damage, the gravel was propelled out of the impact areas and the flood coat was fractured, with no instances observed of gravel being driven into the roof membrane. Roofs of advanced age suffered greater damage, although the difference often related to the amount of blistering rather than strictly age.

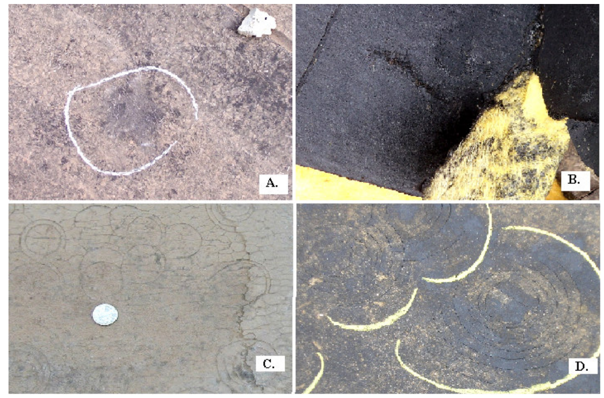

Figure 5. A) Location 34-Hail impact-caused bruise in APP membrane at seam overlap; B) Location 34-Fracture observed in underside of photo A after test cut; C) Location 88-Multiple circular fractures in surface of APP membrane in ponding region of roof; D) Location 74-Multiple concentric circular fractures in surface.

A.2. MODIFIED BITUMEN

A total of eleven modified bitumen membrane roofs were inspected in the study; six with SBS (styrene butadiene styrene) modifier and five with APP (atatic polypropylene) modifier. The modified bitumen membrane roofs where test cuts were taken were installed as single application installations. Some membranes had granule surfacing and some had smooth-surfacing or aluminum-coating. Ages ranged from about three years old to some that appeared to be about fifteen years old. The conditions varied, with some roofs in good condition and some in fair condition. Maximum hailstone sizes ranged from about 1.25 inches to 2.5 inches in diameter. Damage was found in the field portion of five roofs.

Common damage modes were fracturing or bruising of the membrane or displacement of granules from granule-surfaced membranes that had been recently exposed. (Bruising / fracturing is indicated by circles where granule loss was visible, and an indentation that is either visible or can be felt with finger pressure.) Fracturing of the membrane was observed on all roofs where the hail size was 2.0 inches or larger in diameter and was not found when the hail size was less than 1.5 inches in diameter. However, the undersides of the membranes were not examined on all roofs, so it is not known which of these were surface

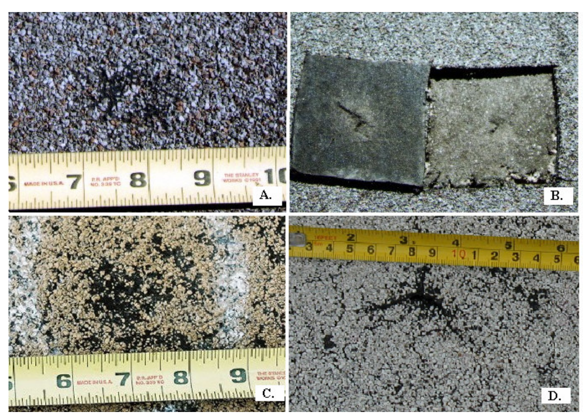

Figure 6. A) Location 26-Impact-caused bruise observed on surface of SBS membrane; B) Location 26-Fracture in underside of membrane at Photo A; C) Location 76-Impact-caused bruise with recent granule loss on surface of SBS membrane; D) Location 95-Impact-caused fracture observed on surface in blistered location.

fractures and which resulted in immediate leaks. On roofs with maximum hail sizes in the range of 1.5 to 2.0 inches in diameter, the extent of damage varied from no damage observed to significant damage. Bruising or fracturing of the membrane often occurred in this size range when the underlying substrate was a compressible substrate, such as polyisocyanurate board insulations or wood fiberboard.

There were two levels of damage identified on the membranes from hail impact; loss of granule surfacing or fracturing / bruising. Granule loss was not found to cause water infiltration. The bruising that was found was related to the fracturing of the membrane and could allow water infiltration. Destructive analysis of two single application modified bitumen roofs confirmed that impact areas that had some visible granule loss and also felt “bruised,” or soft under finger pressure, had been fractured on the underside of the membrane, although the fractures were not visible on the surface.

A.3. SPRAYED POLYURETHANE FOAM (SPF)

Five roofs were inspected with SPF roofing, with hail-caused damage found on three roofs. All the roofing systems involved polyurethane foam with an elastomeric coating. It appeared that all of the roofs had been applied over built-up roofing, and four of the roofs were considered in poor condition. Maximum hailstone sizes impacting the roofs ranged from 0.5 to 1.75 inches in diameter. Three roofs had hail-caused indentations with fractures in the coating, and these roofs had been struck with hailstone sizes of 1.0 inch or larger. The fractures were either concentric circular or radiating fractures, with fractures as small as 0.5 inch diameter. The foam was a bright color where it had been recently exposed.

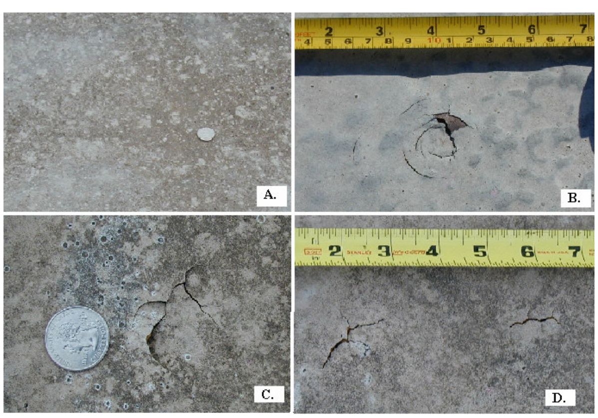

Figure 7. A) Location 100-Hailstone impacts had removed surface grime, but not fractured SPF coating; B) Location 94-Impact-caused concentric circular fractures; C) Location 97-Hail impact spatter mark at starburst fracture on indentation in SPF; D) Location 97-Two adjacent hail-caused fractures in SPF coating.

Immediate leaks into the buildings would not be expected from the hail-caused fractures in the coating as the foam is closed-cell and would not allow liquid water to pass through. In addition, the underlying built-up membranes may have offered additional protection from leaks. The two roofs without hail-caused fractures in the coating had been struck with hailstone sizes of 0.5 to 1.0 inch in diameter. Although moderate to severe (foam) blistering was found on some roofs, the blistering did not appear to have a material affect on the amount of hail-caused fracturing of the surface coating.

A.4. METAL

Six low sloped metal roofs were inspected, involving painted or alloy-plated metal panels. Maximum hailstone sizes impacting the roofs ranged from 1.0 to 2.5 inches in diameter. Surface spatter marks were visible where hailstones had removed some of the surface grime or oxidation. Dents occurred from hail impact on the roofs that had been struck with 1.5 inch or larger diameter hail. On these roofs, the hail-caused dents were found to be a cosmetic issue, with no functional damage to the paint or the metal plating. On exposed fastener systems, there were no instances found of fasteners loosened by hailstone impact.

Four steep slope metal roofs were inspected: three metal shingle panels and one standing seam copper roof. Maximum hailstone sizes impacting the roofs ranged from 0.75 to 1.75 inches in diameter. Surface spatter marks were visible where hailstones had removed some of the surface patina of the metal or surface grime and oxidation

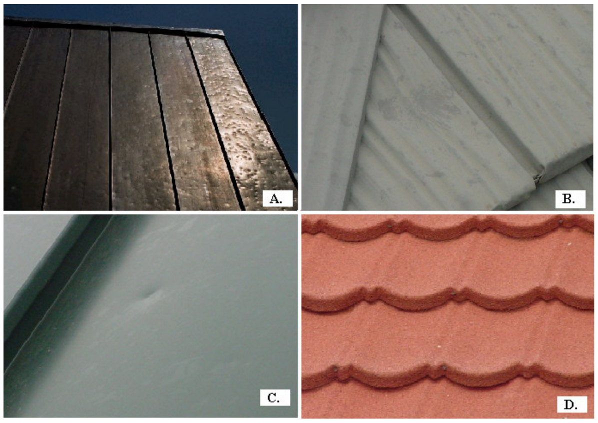

Figure 8. A) Multiple dents in copper standing seam from survey; B) Location 17-Hail-caused spatter mark at dent in aluminum shake panel; C) Location 59-Hail-caused spatter mark with dent in painted standing-seam metal; D) Location 66-No impact-caused dents visible in stone-coated steel panels.

from the painted surfaces. Dents occurred from hail impact on three of the four roofs, with one metal shingle panel having no dents with 1.25 inch diameter hail. On the other roofs, the hail-caused dents were found to be a cosmetic issue, with no functional damage. Panel joints had not been distorted sufficiently to affect the water shedding ability of the panels.

A.5. SINGLE-PLY SHEET MEMBRANES

Six single-ply roofs were inspected during the investigation: three EPDM, two PVC, and one TPO. One of the stone ballasted EPDM roofs with typical ASTM D 448 ballast of more than ten pounds per square foot was located in the area of high intensity large hail, sustaining hundreds of impacts by 2.0 inch diameter and larger hail with no observed or reported damage. A fully-adhered EPDM membrane in the same area also had no visible or reported damage to the membrane; however, the underlying insulation was dented at large impact sites. The area of dented insulation board was small enough that any change in uplift resistance would be negligible. While performance was generally good on examined roofs with single-ply sheet membranes, there were not sufficient sample sizes to identify conclusions regarding hail impact resistance.

Figure 9. A) Location 35-Large hail impact on PVC-covered parapet with no apparent damage; B) Location 88-Hail impact marks visible on TPO membrane surface, but no fractures visible; C) Location 27-Insulation dented, but no fracture in EPDM membrane at 2.0 inch diameter impact; D) Location 31-No fracture visible in EPDM membrane where stone ballast had been displaced by large hailstone impact.

B. STEEP SLOPE SYSTEMS

B.1. ASPHALT SHINGLES

A total of forty-five asphalt shingle roofs were inspected during the survey, with thirty-six showing some form of damage. (Nine had damage to the edges and unsupported area and twenty-four had damage to the edges, unsupported areas and the field of the shingle.) Maximum hail sizes on the asphalt shingle roofs inspected ranged from about 0.5 inch to over 2.0 inches in diameter. Most of the asphalt shingles inspected were of standard, fiberglass mat three-tab or laminated asphalt shingles, with the exception of five roofs with organic mat asphalt shingles and two roofs with laminated asphalt UL2218 Class 4 impact-resistant modified bitumen shingles. Substrates included solid decking, as well as overlays on wood and asphalt shingles.

Damage modes were primarily fracturing or rupturing of the shingle mats or broken shingle edges. Areas with fractured mats generally displayed loss of granules sufficient to expose asphalt, and the recently exposed asphalt was dark in color with limited oxidation. The nine shingle roofs without damage had been struck with hail sizes from 0.5 to 1.25 inches in diameter, while

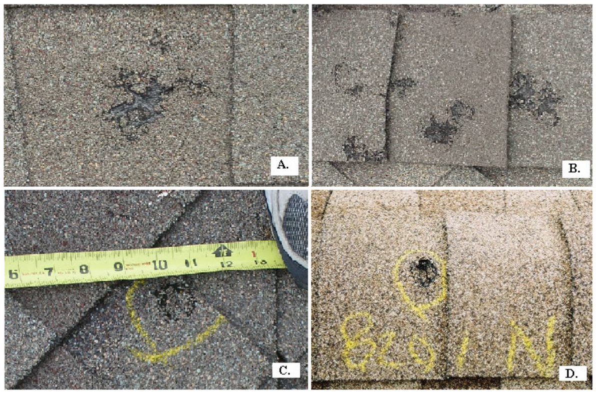

Figure 10. A) Location 21-Hail impact puncture in laminated shingle that overlaid wood shingles; B) Location 25-Multiple hail impact-caused bruises in hip shingles; C) Location 72-Hail-caused bruise in unsupported valley shingle; D) Location 82-Hail-caused puncture of unsupported region of high-profile ridge shingle.

the remaining roofs had been struck with 1.0 to 2.0+ inch diameter hail. Shingles on solid decking generally had damage when the hail sizes were greater than 1.5 inches in diameter, while asphalt shingle overlays on wooden or asphalt shingles generally had damage with hailstones approximately 1.0 inch or greater. Damage in the form of fractures or punctures commonly occurred to asphalt shingles that overlaid either wooden or asphalt shingles due to the top layer of shingles being less supported. In general, hip and ridge shingles sustained greater damage than field shingles, especially in the case of high-profile ridge shingles. These shingles had more extensive and severe damage than field shingles due to the unsupported areas of the ridge shingle profile. Hail impact damage was most concentrated on the windward roof slopes having the most direct hail impacts. In areas where hail sizes were less than 1.0 inch in diameter, there were no identifiable areas of spalled granules from impact or significant or severe general granule loss, even in areas with thirty to one hundred hail impacts per square foot.

Figure 11. A) Location 76-Multiple fractures in old organic shingles; B) Location 16-Hail impact puncture in shingle that overlaid wood shingles; C) Location 5-No hail impact damage to modified bitumen shingle; D) Location 81-No hail impact damage to shingle in area with a large quantity of small hailstones.

Known or estimated ages of the roofs ranged from less than one year to approximately twenty years. Asphalt shingles that appeared (or were known to be) older than ten years and showed signs of embrittlement or deterioration were somewhat more susceptible to damage, and often the damage was more severe. The two modified bitumen shingles examined had no hail-caused damage and were in very good condition, with both roofs less than two years old. The maximum hail size at one site was about 1.25 inches in diameter, and less than 1.0 inch in diameter at the other site. Because of the limited data, the age of these roofs and the size of the hail, no conclusions could be reached concerning the performance of modified shingles.

B.2. TILE

A total of four clay and four concrete tile roofs were inspected during the survey, with five having some tile fractures from hail impact. Maximum hail sizes on the tile roofs inspected ranged from about 1.25 inches to nearly 3.0 inches in diameter. The profiles included flat, mission, and roll style. Substrates were solid decking with battens or lath boards.

Damage mode was fracturing of the tile field or edge when struck with relatively large hailstones. Fracture surfaces from the recent hail displayed unweathered (clean) surfaces, while older fractures (from foot traffic or other previous damage) observed on the roofs often had grime or mildew darkening the surface. A common pre-existing crack pattern was a single fracture near the lower right corner of interlocking tiles. In contrast, hail-caused cracking typically resulted in multiple fractures. Tiles generally had damage when the hail sizes were greater than 1.75 inches in diameter, and even in these cases, only a small percentage of tiles had been fractured. Hail impacts that did not cause damage could be observed where surface oxidation or grime had been removed by impact, but the tile had not fractured. Hail-caused damage was most concentrated on the windward roof slopes having the most direct hail impacts. One roof that did not have damage had a 15:12 pitch, resulting in less direct impacts. Thicker tiles were somewhat more resistant to damage. Tile ages ranged from less than ten years old to more than twenty years old; age of tiles did not appear to have an appreciable effect on hail impact resistance. Large amounts of small hail had no adverse effect on the tiles.

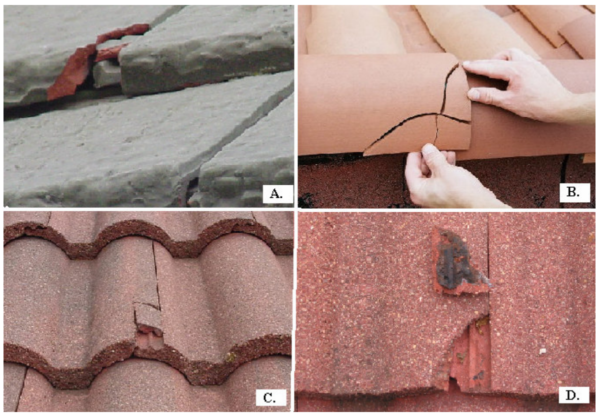

Figure 12. A) Location 58-Multiple fracture at corner of clay tile; B) Location 76-Starburst fracture in barrel ridge tile (clay); C) Location 62-Multiple fracture in right overlap of concrete tile from hail impact; D) Location 19-Right corner fracture in concrete tile that had been repaired previously (prior to hailstorm).

B.3. CEDAR SHAKES & SHINGLES

A total of nine cedar shake roofs were inspected during the survey, with eight showing some form of damage. All roofs had surface marks from impacting hailstones, but impact-caused splits or punctures were considered as functional damage, while surface marks would be a temporary cosmetic condition. Maximum hail sizes on the cedar roofs inspected ranged from about 0.75 inch to about 2.0 inches in diameter. The majority of roofs were medium-thickness (nominal 0.5 inch measurement at the butt) 24 inch cedar shakes. Substrates included solid decking and spaced lath boards.

Damage modes were primarily fracturing (splitting) or puncturing of the wood when struck with relatively large hail. The hail-caused splits were coincident with, or closely associated with, bright-colored indentations in the wood from hail impact, and the wood fracture surfaces were bright-colored. Bright hail-caused splits could be contrasted with gray-colored interior surfaces of splits due to natural weathering. Often, surface marks from hail impact and indentations in the wood did not result in splitting of the wood. Punctures occurred in areas of the wood that were eroded or thinner than average, and fresh color in the underlying wood and broken wood pieces confirmed the impact damage. Hail-caused splitting or puncturing of the wood generally was found when hailstones exceeded 1.0 inch diameter on thinner wood and 1.5 inches in diameter on standard dimension wood (0.5 inch or thicker).

Figure 13. A) Location 105-Gray split from weathering (left) and fresh split from hail impact (right); B) Location 86-Shake pieces broken off by hail impact; C) Location 105-Large hail impact without a split; D) Location 15-Small impact marks on shake surface (no hail impact damage).

Known or estimated ages of the wood roofs were from five to greater than fifteen years. Roofs older than ten years with surface erosion from weathering displayed reduced hail resistance. Large quantities of smaller hail (0.75 inch diameter or less) had no affect other than surface marks that will fade with further weathering[5].

5. RESULTS

The RICOWI hail investigations obtained a considerable amount of beneficial data for all parties interested in the effects of hail impact on roofing products. It was the first large-scale hailstorm investigation by balanced teams representing roof manufacturers, roofing industry trade groups, roof consultants, researchers and engineers, and the insurance industry. The HIP investigations provided field data related to scientifically estimated hailstone sizes that supported previous laboratory testing and field experience reported in several referenced documents. The joint inspections by the balanced teams resulted in consensus data gathered from the inspection sites.

The inspection teams were able to investigate a number of roofs that had been impacted by a recent significant hailstorm, factually describe roof performance and modes of damage, and correlate the damage with hailstone size(s) and quantities. Data was gathered that can be used in improving evaluation of hail-impacted roofing and improving design of roofing systems to resist hail impact damage. In reviewing the overall results, the following findings emerged:

- Hail-caused damage, if it occurred, was readily apparent to the trained eye in most cases. Circumstances where further sampling could be appropriate included low slope roofing material that incorporated laminated plies of materials, such as modified bitumen membranes, built-up roofing, and some thermoplastic membranes.
- The effects of hail impact were distinguishable from normal weathering. Impact-caused fractures in materials had appearances that were distinct from cracking or other indications of long-term weathering. Impact generally resulted in circular and starburst-shaped fractures, and the fracture surfaces had limited oxidation, shrinkage, or grime accumulation, and there was often direct surface evidence of the hail impact. Examples included asphaltic materials that appeared dark black-colored with coincident indentation or fracturing, fresh splits in cedar appeared bright orange-colored with associated impact dent, recently exposed SPF was bright-colored with a coincident fracture in the coating, clean fracture surfaces with multiple fractures on concrete and clay tiles, and concentric circular fractures in the flood coat of built-up roofing.
- Hailstone size (and resultant impact energy) was more critical than hailstone quantity in determining if the roofing was damaged. Areas with the large quantities of hail did not sustain roofing damage if the maximum hailstone size at that site did not exceed that necessary threshold of damage for that material. Almost no damage was found in areas where the maximum hailstone size was less than 1.0 inch in diameter, with the exception of badly deteriorated and unsupported material. When maximum hailstone size was between 1.0 and 2.0 inches in diameter, the level of damage ranged from none to considerable depending on material, age/condition, roof slope, and support conditions. When maximum hailstone size was greater than 2.0 inches in diameter, most roofing material sustained damage. Exceptions were EPDM membranes, a fairly new thermoplastic, some concrete tiles, and an aggregate surfaced BUR without blisters, however, there were only one or two of each of these types of roofs inspected and therefore the conclusions only relate to the specific roofs inspected.
- The teams observed that the threshold for roof damage from hailstone impact to most materials was between 1.25 and 2.0 inches, which correlates with the size ranges used in most standard impact resistance tests used to simulate the effects of hail impact, including UL 2218, FM 4473, and FM 4470. This field investigation suggests this is an appropriate range as roofing material performance varied with hailstone impacts of this size range. No attempts were made to compare various test methods or to correlate test method results to field-observed hail effects.
- Materials that were unsupported or over easily compressible substrates had greater damage than those over more solid substrate. This was demonstrated in asphalt shingles that overlaid uneven substrates (previous asphalt or wood shingle roofs), certain high profile asphalt shingle ridge units that had

unsupported regions, blisters in built-up roofing, curb or parapet flashings of low slope roofing that had unsupported regions, areas adjacent to seams in modified bitumen or single-ply membranes, and low slope roofing that was installed over compressible insulation boards.

- Some materials displayed reduced hail impact resistance with respect to age and deterioration. Categories included asphaltic products (including modified bitumens), elastomeric coatings, and cedar shakes.
- Hail effects on metal roof systems were seen as cosmetic, rather than functional. Indentations occurred with larger hailstones, but painted coatings or stone-coatings had not been compromised by the denting. It should be noted, however, that all of the steep metal roofs inspected were impacted by hailstones of 1.75 inch diameter or less (one low-sloped system was impacted by up to 2.5 inch diameter hailstones.)
- A qualitative finding, which could be studied better in future investigations, was that the reported scope of insurance claim repairs often exceeded what was deemed necessary by our investigation teams. In several cases, the inspected roofing systems that had been slated for replacement by the insurance claim, were found to have little to no functional damage. However, due to stated policy of not requesting insurance claim information, the data was not quantifiable.

6. FUTURE RESEARCH

Although many hail-impacted roofs were inspected and significant data was gathered, there remains need for additional HIP investigations. Other useful information or different methodologies could include:

- Quicker mobilization would allow for inspection of some of the most severely damaged roofs.
- Greater collection of samples would allow additional verification of failure modes. Taking undamaged samples from damaged roofs would permit laboratory testing using standard impact tests to attempt to duplicate observed field damage. This could allow correlation of laboratory results to field performance.
- Investigating a greater variety and number of roofs would provide additional verification of performance.
- Cooperation with the insurance industry would permit an analysis of claim payments vs. observed damage, and provide a basis for recommendations to reduce insurance losses.
- A procedure of monitoring service life and future repairs by owners of inspected roofs would provide data on the long-term effects of hail impact on roofing. Inspected roofs that were not replaced could be revisited after a period of time to evaluate any additional damage or degradation related to hail impact.
- The size and scope of future HIP investigations will be related to additional funding sources or research grants. The Oklahoma City HIP was funded largely by RICOWI and its sponsor and member organizations, with a supplementary research grant provided by the Roof Consultants Institute and its Foundation.

7. ACKNOWLEDGEMENTS

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Thank you to the people of central Oklahoma for your kindness, hospitality, and willingness to share your experiences with us.

8. REFERENCES

1. *Central Oklahoma Hailstorm Caused 75-100 Million Dollars Damage*, Kevin King, www.ktul.com, April 27, 2004.

2. Morrison, Scott J., *Dents in Metal Roof Appurtenances Caused by Ice Ball Impacts*, Proceedings of the 12th International Roofing and Waterproofing Conference, 2002, Orlando, Florida.

3. Crenshaw, Vickie; Koontz, Jim. *Hail: Sizing It Up!,* Western Roofing, May/June 2002.

4. Marshall, Timothy P., Herzog, R. et al. *The Dallas-Fort Worth, TX Hailstorm: 5 April 2003*, AMS 22nd Conference on Severe Local Storms, 2004, Hyannis, MA.

5. Herzog, R. F., Marshall, T. P., *Protocol For Assessment of Hail-Damaged Roofing*, Proceedings of the North American Conference on Roofing Technology, 1999, Toronto, Canada.

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Oklahoma City, OK – April 21, 2004

List of Appendices

APPENDIX A: Storm Data and Unusual Weather Phenomena

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Canadian County									
Yukon	21	1504CST			0	0			Hail (1.75)
	Hail was reported covering the ground.								
Canadian County									
Yukon	21	1509CST			0	0			Hail (3.00)
	Hail was observed at the intersection of 7th and Oak Streets.								
Oklahoma County									
Bethany	21	1509CST			0	0			Hail (0.88)
	Hail was observed at 39th Street and Council Road.								
Oklahoma County									
Bethany	21	1514CST			0	0			Hail (1.75)
	Hail was observed at the intersection of 39th Street and Council Road.								
Grady County									
9 E Chickasha	21	1519CST			0	0			Hail (0.88)
Grady County									
1 W Tabler	21	1524CST			0	0			Hail (0.88)
Oklahoma County									
Bethany	21	1524CST			0	0			Hail (0.88)
	Hail was observed at the Wiley Post Airport (KPWA).								
Oklahoma County									
Oklahoma City	21	1526CST			0	0			Hail (1.75)
	Hail was reported at the intersection of Hefner and Council Roads.								
Grady County									
9 E Chickasha	21	1528CST			0	0			Hail (1.00)
Oklahoma County									
Oklahoma City	21	1530CST			0	0			Hail (3.00)
	Hail was observed at the intersection of Wilshire Boulevard and Council Road.								
Oklahoma County									
Nichols Hills to 2 NE Nichols Hills	21	1541CST 1551CST			0	0	3M		Hail (1.00)
	Quarter size hail was observed at the corner of Grand Boulevard and Nichols Road. As the storm continued northeastward to Britton Road hail up to the size of quarters were observed with hail on the ground ranging from 3 inches to as much as 2 feet deep. Several cars got stuck in hail and had to be towed or dug out on the Broadway Extension. Hail damaged numerous structures and vehicles. The weight of the hail caused a carport to fall on one vehicle.								
Mcclain County									
9 S Blanchard	21	1546CST			0	0			Hail (1.00)
Oklahoma County									
2 W The Vlg	21	1550CST			0	0			Hail (1.75)
	Hail was covering the ground up to two inches deep.								
Oklahoma County									
Oklahoma City	21	1555CST			0	0			Hail (1.00)
	Hail was reported at Britton Road and Kelley Avenue.								
Payne County									
Stillwater	21	1555CST			0	0			Hail (1.00)
Payne County									
7 E Stillwater	21	1555CST			0	0			Hail (1.00)
	Hail was observed covering the ground three inches deep.								
Cleveland County									
3 NW Moore	21	1610CST			0	0			Hail (0.75)
	Hail was observed at 119th Street and Western Avenue.								
Garvin County									
5 E Elmore City	21	1610CST			0	0			Hail (1.00)
Cleveland County									
Moore	21	1611CST			0	0			Hail (0.75)
	Hail was reported at 19th Street and Interstate 35.								
Cleveland County									
Moore	21	1615CST			0	0			Hail (0.75)
	Hail was observed at 4th Street and Eastern Avenue.								

APPENDIX A: Continued

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Oklahoma County									
2 SE Arcadia	**21**	**1616CST**			**0**	**0**			**Hail (0.88)**
	Hail was observed at Highway 66 and Post Road.								
Cleveland County									
3 S Slaughterville	**21**	**1620CST**			**0**	**0**			**Hail (1.25)**
Mcclain County									
2 NW Purcell	**21**	**1620CST**			**0**	**0**			**Hail (0.88)**
Mcclain County									
2 NW Purcell	**21**	**1626CST**			**0**	**0**			**Hail (1.00)**
Oklahoma County									
2 W Harrah	**21**	**1628CST**			**0**	**0**			**Hail (1.00)**
	Hail was observed at the intersection of 23rd Street and Luther Road.								
Mcclain County									
5 SW Purcell	**21**	**1630CST**			**0**	**0**			**Hail (2.00)**
Oklahoma County									
Choctaw	**21**	**1630CST**			**0**	**0**			**Hail (1.25)**
Garvin County									
Elmore City	**21**	**1632CST**			**0**	**0**			**Hail (0.75)**
Oklahoma County									
Harrah	**21**	**1632CST**			**0**	**0**			**Hail (1.00)**
Mcclain County									
Purcell	**21**	**1635CST**			**0**	**0**			**Hail (1.75)**
Garvin County									
5 N Hennepin	**21**	**1646CST**			**0**	**0**			**Hail (0.88)**
Garvin County									
5 E Elmore City	**21**	**1649CST**			**0**	**0**			**Hail (1.00)**
Pottawatomie County									
2 E Pink	**21**	**1657CST**			**0**	**0**			**Hail (1.00)**
Payne County									
Yale	**21**	**1658CST**			**0**	**0**			**Hail (0.88)**
Cleveland County									
2 S Noble	**21**	**1700CST**			**0**	**0**			**Hail (1.00)**
Pottawatomie County									
2 N Wanette	**21**	**1705CST**			**0**	**0**			**Hail (0.88)**
Harper County									
6 S Buffalo	**21**	**1707CST**			**0**	**0**			**Hail (0.88)**
Harper County									
6 S Buffalo	**21**	**1710CST**			**0**	**0**			**Hail (0.88)**
Lincoln County									
2 N Chandler	**21**	**1710CST**			**0**	**0**			**Hail (0.75)**
Harper County									
5 S Buffalo	**21**	**1719CST**			**0**	**0**			**Hail (1.00)**
Garvin County									
2 E Stratford	**21**	**1720CST**			**0**	**0**			**Hail (0.88)**
	Hail was reported on Highway 19.								
Pottawatomie County									
Shawnee	**21**	**1720CST**			**0**	**0**			**Hail (0.75)**
	Hail was observed a half a mile north of the intersection of Harrison and Highland Streets.								
Pontotoc County									
3 NW Vanoss	**21**	**1722CST**			**0**	**0**			**Hail (0.88)**
Carter County									
3 W Lone Grove	**21**	**1730CST**			**0**	**0**			**Hail (0.75)**
Garvin County									
Stratford	**21**	**1745CST**			**0**	**0**			**Hail (0.88)**
Murray County									
5 W Dougherty	**21**	**1748CST**			**0**	**0**			**Hail (1.75)**

APPENDIX A: Continued

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Carter County									
Ardmore	**21**	**1749CST**			**0**	**0**			**Hail (0.88)**
Pottawatomie County									
Pink	**21**	**1749CST**			**0**	**0**			**Hail (1.00)**
Carter County									
3 N Springer	**21**	**1758CST**			**0**	**0**			**Hail (1.00)**
Carter County									
Ardmore	**21**	**1800CST**			**0**	**0**			**Hail (0.75)**
Ellis County									
8 N Shattuck	**21**	**1800CST**			**0**	**0**			**Hail (1.00)**
Harper County									
15 SE Buffalo	**21**	**1800CST**			**0**	**0**			**Hail (0.88)**
Oklahoma County									
2 N Choctaw	**21**	**1803CST**			**0**	**0**			**Hail (0.88)**
	Hail was observed at 59th Street and Choctaw Road.								
Oklahoma County									
4 E Spencer	**21**	**1806CST**			**0**	**0**			**Hail (0.88)**
	Hail was observed at the intersection of 54th Street and Hiwassee Road.								
Harper County									
2 E May	**21**	**1809CST**			**0**	**0**			**Thunderstorm Wind (G52)**
Love County									
Overbrook	**21**	**1810CST**			**0**	**0**			**Hail (1.75)**
Ellis County									
20 N Gage	**21**	**1811CST**			**0**	**0**			**Hail (1.00)**
Carter County									
6 S Ardmore	**21**	**1815CST**			**0**	**0**			**Hail (1.00)**
	Hail was observed at Lake Murray Village.								
Love County									
6 NE Marietta	**21**	**1820CST**			**0**	**0**			**Hail (1.00)**
Love County									
5 NE Marietta	**21**	**1825CST**			**0**	**0**			**Hail (1.75)**
Love County									
5 N Marietta	**21**	**1825CST**			**0**	**0**			**Hail (1.75)**
Ellis County									
7 NNW Shattuck	**21**	**1826CST 1828CST**	**0.3**	**30**	**0**	**0**			**Tornado (F0)**
	A storm chaser and several fire department personnel observed this narrow tornado in open country.								
Ellis County									
7.5 NNW Shattuck to 7 N Shattuck	**21**	**1828CST 1831CST**	**1**	**200**	**0**	**0**			**Tornado (F0)**
	This large multi-vortex tornado was videotaped by a storm chaser. No damage was reported.								
Johnston County									
Mill Creek	**21**	**1830CST**			**0**	**0**			**Hail (0.75)**
Marshall County									
6 NNW Lebanon	**21**	**1830CST**			**0**	**0**			**Hail (2.75)**
Alfalfa County									
3 N Cherokee	**21**	**1833CST**			**0**	**0**			**Hail (1.75)**
Pottawatomie County									
5 NW Shawnee	**21**	**1839CST**			**0**	**0**			**Hail (0.75)**
	Hail was observed at Interstate 40 and Highway 177.								
Pottawatomie County									
5 NW Shawnee	**21**	**1841CST**			**0**	**0**			**Hail (1.00)**
Pottawatomie County									
Shawnee	**21**	**1845CST**			**0**	**0**			**Hail (1.50)**
	KWTV Channel 9 in Oklahoma City reported hail on west side of Shawnee.								

APPENDIX A: Continued

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Pottawatomie County									
Shawnee	**21**	**1847CST**			**0**	**0**			**Hail (1.25)**
	Hail was observed at intersection of Kickapoo and Federal Street.								
Pottawatomie County									
Shawnee	**21**	**1853CST**			**0**	**0**			**Hail (1.00)**
Woodward County									
Ft Supply	**21**	**1859CST**			**0**	**0**			**Hail (0.88)**
Marshall County									
Oakland	**21**	**1900CST**			**0**	**0**			**Hail (0.75)**
Pontotoc County									
4 E Ada	**21**	**1900CST**			**0**	**0**			**Hail (0.88)**
Woods County									
4 NNE Waynoka	**21**	**1900CST**			**0**	**0**			**Hail (1.75)**
Pottawatomie County									
5 NW Shawnee	**21**	**1904CST**			**0**	**0**			**Hail (1.00)**
	Hail was reported at Interstate 40 and Highway 177.								
Pottawatomie County									
4 N Shawnee	**21**	**1905CST**			**0**	**0**			**Hail (1.50)**
Johnston County									
Pontotoc	**21**	**1910CST**			**0**	**0**			**Hail (1.00)**
Woodward County									
Woodward Arpt	**21**	**1911CST**			**0**	**0**			**Thunderstorm Wind (G57)**
	Wind was measured by the AWOS at the Woodward Airport (KWWR).								
Marshall County									
5 E Kingston	**21**	**1915CST**			**0**	**0**			**Hail (1.00)**
Marshall County									
4 S Madill	**21**	**1915CST**			**0**	**0**			**Hail (1.75)**
	Hail was reported covering the ground.								
Marshall County									
3 ENE Kingston	**21**	**1920CST**			**0**	**0**			**Hail (1.75)**
Woodward County									
Mooreland	**21**	**1923CST**			**0**	**0**			**Hail (0.75)**
Bryan County									
9 W Durant	**21**	**1930CST**			**0**	**0**			**Hail (2.50)**
Hughes County									
1 SW Atwood	**21**	**1930CST**			**0**	**0**			**Hail (0.88)**
Woodward County									
4 E Curtis	**21**	**1930CST**			**0**	**0**			**Hail (1.00)**
Woodward County									
7 E Mooreland	**21**	**1930CST**			**0**	**0**			**Hail (1.00)**
Woodward County									
1 E Mooreland	**21**	**1936CST**			**0**	**0**			**Hail (1.75)**
Woodward County									
Mooreland	**21**	**1936CST 1946CST**			**0**	**0**			**Hail (1.00)**
Woods County									
13 E Waynoka	**21**	**1940CST**			**0**	**0**			**Hail (1.00)**
Seminole County									
5 WNW Little	**21**	**1946CST**			**0**	**0**			**Hail (0.75)**
	Hail was observed at mile marker 194 of Interstate 40.								
Dewey County									
1 E Vici	**21**	**1948CST**			**0**	**0**			**Hail (1.00)**
Dewey County									
Vici	**21**	**1948CST**			**0**	**0**			**Hail (1.00)**
Grant County									
Wakita	**21**	**2000CST**			**0**	**0**			**Hail (1.00)**

APPENDIX A: Continued

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Woodward County									
6 SSE Quinlan	21	2000CST			0	0			Hail (0.75)
Grant County									
Wakita	21	2015CST			0	0			Hail (1.00)
Major County									
19 N Chester	21	2015CST			0	0			Thunderstorm Wind (G52)
Seminole County									
Cromwell	21	2015CST			0	0			Hail (1.00)
Seminole County									
Cromwell	21	2015CST			0	0			Thunderstorm Wind (G52)
Woods County									
Dacoma	21	2015CST			0	0			Hail (1.75)
Bryan County									
Armstrong	21	2020CST			0	0			Hail (2.75)
Seminole County									
4 W Cromwell	21	2021CST			0	0			Hail (1.00)
Alfalfa County									
3 NE Carmen	21	2025CST			0	0			Hail (2.00)
Major County									
19 N Chester	21	2030CST			0	0			Hail (1.00)
Alfalfa County									
Lambert	21	2100CST			0	0			Hail (1.75)
Blaine County									
Canton	21	2108CST			0	0			Hail (0.88)
Grant County									
3 SW Renfrow	21	2115CST			0	0			Hail (0.88)
Grant County									
3 SW Renfrow	21	2115CST			0	0	0.10K		Thunderstorm Wind (G52)
	Several two to three inch diameter tree limbs were downed.								
Blaine County									
Okeene	21	2130CST			0	0			Hail (0.75)
Major County									
Ringwood	21	2135CST			0	0			Hail (0.75)
Garfield County									
Drummond	21	2145CST			0	0			Thunderstorm Wind (G61)
Garfield County									
Lahoma	21	2145CST			0	0			Thunderstorm Wind (G61)
Garfield County									
Enid	21	2154CST			0	0			Hail (0.88)
Garfield County									
Enid	21	2154CST			0	0			Thunderstorm Wind (G61)
Garfield County									
Waukomis	21	2157CST			0	0			Hail (1.00)
Garfield County									
Enid	21	2159CST			0	0			Hail (0.75)
Garfield County									
Enid	21	2159CST			0	0			Hail (0.75)
Garfield County									
Enid	21	2159CST			0	0			Thunderstorm Wind (G56)
Garfield County									
Vance Afb	21	2159CST			0	0			Hail (1.00)
Garfield County									
Vance Afb	21	2159CST			0	0			Thunderstorm Wind (G58)

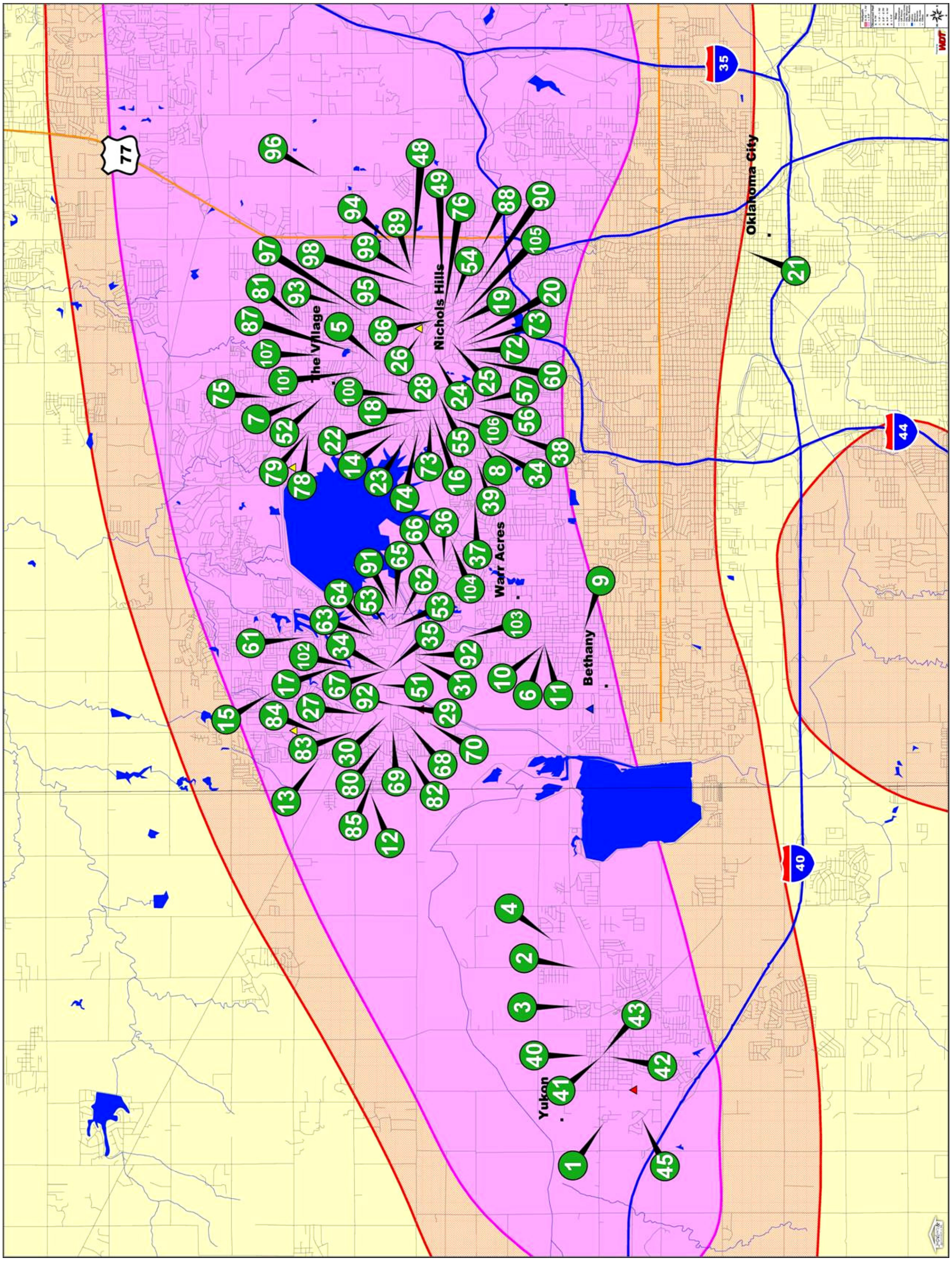
APPENDIX A: Continued

Storm Data and Unusual Weather Phenomena

April 2004

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Western, Central and Southeast									
Garfield County									
Enid	**21**	**2200CST**			**0**	**0**	**20K**		**Thunderstorm Wind (G61)**
	Strong straight-line winds caused a mile wide swath of damage in the western business district of Enid along Highway 412, west of Highway 81. The roof was damaged at the Homeland grocery store and at Stevens Ford Dealership. Large metal power poles were also downed.								
Kingfisher County									
Hennessey	**21**	**2214CST**			**0**	**0**			**Hail (0.75)**
Noble County									
6 S Billings	**21**	**2230CST**			**0**	**0**			**Thunderstorm Wind (G52)**
Logan County									
Marshall	**21**	**2245CST**			**0**	**0**			**Hail (0.75)**
Noble County									
7 SE Marland	**21**	**2300CST**			**0**	**0**			**Hail (0.75)**
Noble County									
8 ESE Marland	**21**	**2300CST**			**0**	**0**	**0.20K**		**Thunderstorm Wind (G61)**
	A two foot diameter tree was downed.								
Kay County									
Ponca City	**21**	**2310CST**			**0**	**0**			**Hail (1.00)**
Payne County									
Glencoe	**21**	**2321CST**			**0**	**0**			**Hail (1.00)**
	Hail was reported on the west side of town. Penny, nickle, and quarter size hail was also observed to be covering the ground.								
Payne County									
Ripley	**21**	**2330CST**			**0**	**0**			**Hail (0.75)**
Lincoln County									
4 NW Tryon	**21**	**2334CST**			**0**	**0**			**Hail (0.88)**
Lincoln County									
2 N Agra	**21**	**2345CST**			**0**	**0**			**Hail (0.88)**
	A major hail storm moved through the Oklahoma City metro on this day primarily affecting the western and northern sides of the city. Hail up to the size of baseballs was observed along with many areas reporting hail on the ground ranging from 3 inches deep to 2 feet deep. The hail damaged numerous structures and vehicles with several people also needing their vehicles towed or dug out of the hail on streets across the city. Damage estimates across the Oklahoma City metro were 100 million dollars. Storms also produced two tornadoes in Ellis county in northwest Oklahoma with no known damage reported.								
Seminole County									
5 SW Seminole	**22**	**1708CST**			**0**	**0**			**Hail (1.00)**
	Hail was observed on Highway 59, three miles west of Highway 99.								
Garvin County									
5 N Hennepin	**22**	**1715CST**			**0**	**0**			**Hail (0.88)**
Seminole County									
Seminole	**22**	**1715CST**			**0**	**0**			**Hail (0.88)**
	Hail was reported covering the ground.								
Seminole County									
3 NE Bowlegs	**22**	**1721CST**	**0.1**	**20**	**0**	**0**			**Tornado (F0)**
	This very brief tornado lasted for less than 30 seconds and was observed by a storm chaser. There is no known damage.								
Seminole County									
1 S Seminole	**22**	**1722CST**			**0**	**0**			**Hail (1.75)**
	Hail was observed at Highway 99.								
Seminole County									
Wewoka	**22**	**1800CST**			**0**	**0**			**Hail (0.75)**
Lincoln County									
5 W Prague	**22**	**1919CST**			**0**	**0**			**Hail (1.00)**
Lincoln County									
5 N Prague	**22**	**1919CST**			**0**	**0**			**Hail (1.00)**
Lincoln County									
10 NW Prague	**22**	**1920CST**			**0**	**0**			**Hail (1.00)**
Seminole County									
1 S Seminole	**22**	**2140CST**			**0**	**0**			**Hail (1.00)**

APPENDIX B: HailTrax Map



APPENDIX C: Inspection Summary Table by Roof Type

Inves. No.	Team No.	Building Type	Roof Type	Condition	Felt Type	Detail	Maximum Hail Size Inches	Hail Effects See Notes
1	1	Residence	Asphalt Shingle	Excellent	None	Laminated	1.5	2,3
47	S	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	3.0	2,3
44	S	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	2.5	2,3
73	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	2.5	1,2,3
72	1	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	2.25	2,3
72(a)	1	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	2.25	2,3
2	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	2.0	2,3
3	1	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	2.0	2,3
21	2	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	2.0	2,3
45	S	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	2.0	2,3
46	S	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated, Overlay	2.0	2,3
53	2	Residence	Asphalt Shingle	Fair	Organic	3-Tab Overlay	2.0	2,3
68	2	Residence	Asphalt Shingle	Fair	Organic	3-Tab	2.0	2,3
69	2	Residence	Asphalt Shingle	Good	Organic	3-Tab Overlay	2.0	4
14	2	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated, Overlay	1.75	2,3
25	2	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	1.75	2,3
1	1	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	1.5	2,3
4	1	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	1.5	0
8	1	Residence	Asphalt Shingle	Poor	Fiberglass	Laminated, Overlay	1.5	2
16	2	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	1.5	2,3
65	2	Residence	Asphalt Shingle	Fair	Fiberglass	3-Tab	1.5	2,3
82	1	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	1.5	0
90	4	Government	Asphalt Shingle	Fair	Fiberglass	Laminated	1.5	2,3
5	1	Residence	Asphalt Shingle	Excellent	Fiberglass	Modified Bitumen	1.25	0
7	1	Residence	Asphalt Shingle	Poor	Fiberglass	3-Tab	1.25	2,3
12	2	Residence	Asphalt Shingle	Good	Fiberglass	3-Tab	1.25	2
28	3	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	1.25	2
56	2	Residence	Asphalt Shingle	Fair	Fiberglass	3-Tab Overlay	1.25	2,3
57	2	Residence	Asphalt Shingle	Poor	Organic	3-Tab Overlay	1.25	2
63	2	Residence	Asphalt Shingle	Fair	Fiberglass	3-Tab Overlay	1.25	2,3
75	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	1.25	2
104	S	Commercial	Asphalt Shingle	Fair	Fiberglass	Laminated, Overlay	1.25	2
6	1	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	1.0	2
80	1	Residence	Asphalt Shingle	Excellent	Fiberglass	3-Tab	1.0	0
107	S	Residence	Asphalt Shingle	Fair	Fiberglass	3-Tab Overlay	1.0	2
10	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	0.75	2
11	1	Residence	Asphalt Shingle	Good	Fiberglass	Laminated	0.75	2
13	2	Residence	Asphalt Shingle	Excellent	Fiberglass	Modified Bitumen	0.75	0
61	2	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated, Overlay	0.75	0
78	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	0.75	0
79	1	Residence	Asphalt Shingle	Fair	Fiberglass	Laminated	0.75	0
84	1	Residence	Asphalt Shingle	Excellent	Fiberglass	Laminated	0.75	0
85	1	Residence	Asphalt Shingle	Excellent	Fiberglass	3-Tab Overlay	0.75	1,2,3
87	S	Residence	Asphalt Shingle	Poor	Fiberglass	3-Tab	0.75	0
81	1	Residence	Asphalt Shingle	Poor	Organic	3-Tab	0.5	2,3
50	3	School	Built-up Roofing	Excellent	Fiberglass	Granule Surfaced Cap Sheet	1.25	0
48	4	Commercial	Built-up Roofing	Fair	Fiberglass	Gravel Surfaced	2.0+	1,2,3
89	4	Commercial	Built-up Roofing	Good/Fair	Fiberglass	Lava Rock Surfaced	2.0+	2,3
32	3	Commercial	Built-up Roofing	Poor	Fiberglass	Aluminum-Coated	2.5	1,2,3
33	3	Commercial	Built-up Roofing	Fair	Organic	Gravel Surfaced	1.0	1,2,3

Notes:

Hail Effects:
(1) Surface marks (no fractures)
(2) Fractures in edges (unsupported regions)
(3) Fractures in field areas
(4) Denting
(5) Coating fractures

APPENDIX C: Continued

Inves. No.	Team No.	Building Type	Roof Type	Condition	Felt Type	Detail	Maximum Hail Size Inches	Hail Effects See Notes
98	4	Government	Built-up Roofing	Fair	Organic	Coal Tar Pitch, Ballasted	2.5	1,2,3
95	4	School	Built-up Roofing	Fair	Organic	Coal Tar Pitch	2.3	1,2,3
43	S	Commercial	Built-up Roofing	Poor	Organic	Asphalt	2.0	2,3
18a	2	Commercial	Built-up Roofing	Good	Fiberglass	Smooth Surface	1.8	0
94	4	School	Built-up Roofing	Good	Fiberglass	Gravel Surfaced	1.8	1
97(a)	4	School	Built-up Roofing	Fair	Organic	Gravel Surfaced	1.8	1
90(b)	4	Government	Built-up Roofing	Fair	Fiberglass	Gravel Surfaced	1.5	0
36	3	Commercial	Built-up Roofing	Good	Fiberglass	Gravel Surfaced	1.3	0
104(a)	S	Commercial	Built-up Roofing	Poor	Organic	Coal Tar Pitch, Ballasted	1.3	1,2,3
52	3	School	Built-up Roofing	Excellent	Organic	Coal Tar Pitch	1.0	2,3
100	4	School	Built-up Roofing	Good	Organic	Coal Tar Pitch, Gravel Surfaced	1.0	0
99	4	Church	Cedar Shake	Fair	NA	24-inch Medium	2.3	1,2,3
26	2	Residence	Cedar Shake	Fair	NA	24-inch Medium	2.0	1,2,3
86	S	Residence	Cedar Shake	Excellent	NA	24-inch Medium	2.0	2
105	S	Government	Cedar Shake	Good	NA	24-inch Medium	2.0	1,2
24	2	Residence	Cedar Shake	Good	NA	24-inch Medium	1.8	1,2,3
23	2	Residence	Cedar Shake	Poor	NA	24-inch Medium	1.5	1,2,3
55	2	Residence	Cedar Shake	Fair	NA	24-inch Medium	1.5	2,3
77	1	Residence	Cedar Shake	Poor	NA	24-inch Medium	1.0	0
15	2	Residence	Cedar Shake	Poor	NA	24-inch x 3/8-inch	0.8	1,2
54	2	Church	Clay Tile	Good	NA	Clay Tile	1.8	1,2,3
58	2	Church	Clay Tile	Excellent	NA	Clay Tile	1.5	2
41a	S	Government	Concrete	Good	NA	Elastomeric Coating	2.0	0
62	2	Residence	Concrete Tile	Good	NA	Concrete Tile	1.5	2,3
27	3	Commercial	EPDM	--	NA	Fully-Adhered	2.0+	1
31	3	Commercial	EPDM	Excellent	NA	60 mil, Gravel Ballast	2.5	2,3
38	3	Commercial	EPDM	Excellent	NA	Gravel Ballast	1.3	0
67	2	Commercial	Fiber Cement	Poor	NA	Fiber Cement	2.0+	2,3
18	2	Commercial	Fiber Cement	Good	Organic	Fiber Cement	1.8	1
51	S	Commercial	Fiber Cement Tile	Fair	NA	Simulated Shake	2.0+	0
60	2	Residence	Metal	Good	NA	Galvalume/Galvanized	0.5	4
98(a)	4	Government	Metal	Good	NA	Painted Standing Seam	2.5	4
40a	S	Government	Metal	Excellent	NA	Galvalume	1.5	1
70	2	Church	Metal	Good	NA	Galvanized Steel	1.5	0
71	1	Commercial	Metal	Good	NA	Galvalume	1.3	2,3
83	1	Commercial	Metal	Good	NA	Galvalume	1.0	2
40	S	Government	Metal	Excellent	NA	Galvalume	1.5	4
59	2	Church	Metal	Good	NA	Standing Seam	1.5	4
17	2	Residence	Metal Shingle	Good	NA	Aluminum Shake	1.8	4
22	2	Residence	Metal Shingle	Good	NA	Aluminum Shake	1.8	4
66	2	Commercial	Metal Shingle	Good	NA	Stone Coated	1.3	0
34	3	Commercial	Mod. Bit/Tile	Poor	Fiberglass	APP/Clay Tile	3.0	1
30	3	Commercial	Modified Bitumen	Excellent	Fiberglass	SBS	2.5	0
74	1	Residence	Modified Bitumen	Excellent	Fiberglass	SBS/APP	2.5	1,2
92	4	Commercial	Modified Bitumen	Good	Fiberglass	SBS	2.5	1,2,3
102	4	School	Modified Bitumen	Good	Fiberglass	SBS	2.5	1,2,3
91	4	School	Modified Bitumen	Good	Fiberglass	SBS	2.3	1,2,3
95(a)	4	School	Modified Bitumen	Fair	Fiberglass	SBS	2.3	2
26a	2	Residence	Modified Bitumen	Fair	Fiberglass	SBS	2.0	1,3
41	S	Government	Modified Bitumen	Good	Fiberglass	APP	2.0	1

Notes:

Hail Effects:
(1) Surface marks (no fractures)
(2) Fractures in edges (unsupported regions)
(3) Fractures in field areas
(4) Denting
(5) Coating fractures

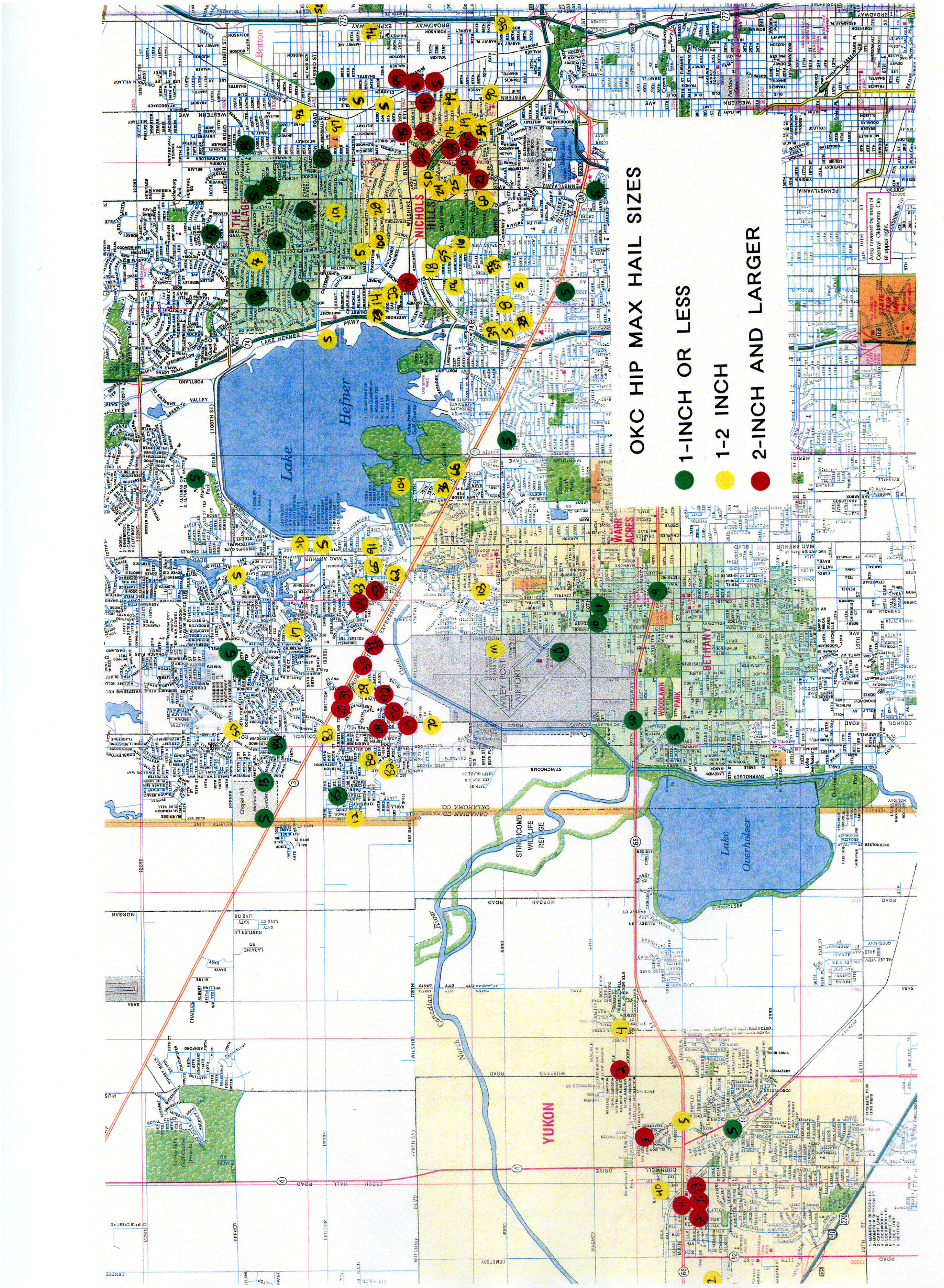
APPENDIX C: Continued

Inves. No.	Team No.	Building Type	Roof Type	Condition	Felt Type	Detail	Maximum Hail Size Inches	Hail Effects See Notes
42	S	Commercial	Modified Bitumen	Fair	Fiberglass	Granule Surfaced	2.0	2
76(a)	1	Residence	Modified Bitumen	Good	Fiberglass	SBS	1.8	1,2
103	4	School	Modified Bitumen	Good	Fiberglass	SBS	1.8	2,3
106	S	Commercial	Modified Bitumen	Good	Fiberglass	APP	1.8	2
39	3	Commercial	Modified Bitumen	Good	Fiberglass	APP	1.5	4
88(a)	4	Commercial	Modified Bitumen	Fair	Fiberglass	APP, Aluminum-Coated	1.5	1,2,3
90(a)	4	Government	Modified Bitumen	Fair	Fiberglass	SBS	1.5	1,2
7a	1	Residence	Modified Bitumen	Fair	Fiberglass	SBS	1.3	0
50a	3	School	Modified Bitumen	Excellent	Fiberglass	SBS	1.3	3
35	3	Commercial	PVC	Good	NA	Reinforced	2.5	0
29	3	Commercial	PVC	Fair	NA	Reinforced	1.8	2,3
37	3	Commercial	Replaced After Storm	NA	NA	NA	1.3	NA
90(c)	4	Government	Slate Shingles	Good	NA	Natural	1.5	0
93	4	School	SPF	Good	NA	Elastomeric Coated	1.8	1,5
94(a)	4	School	SPF	Fair	NA	Elastomeric Coated	1.8	1,5
97(b)	4	School	SPF	Poor	NA	Elastomeric Coating	1.8	1,5
49	S	Commercial	SPF	Fair	NA	Elastomeric Coating	1.5	0
96	4	School	SPF	Poor	NA	Elastomeric Coating	1.3	5
100(a)	4	School	SPF	Good	NA	Elastomeric Coating	1.0	1
9	1	Commercial	Standing Seam Metal	Good	NA	Copper	0.75	4
20	2	Residence	Tile	Fair	NA	Clay	2.0	2,3
64	2	Residence	Tile	Excellent	NA	Tile	2.0	2
19	2	Residence	Tile	Excellent	NA	Concrete	1.75	0
76	1	Residence	Tile	Good	NA	Clay	1.75	2
88(b)	4	Commercial	TPO	Good	NA	Reinforced	1.5	1

Notes:

Hail Effects:
(1) Surface marks (no fractures)
(2) Fractures in edges (unsupported regions)
(3) Fractures in field areas
(4) Denting
(5) Coating fractures

APPENDIX D: Oklahoma City Hail Sizes Map



APPENDIX E: RICOWI Hail Investigation Team Members

HIP Participants from left: Tom Kelly, Vickie Crenshaw, Jim Koontz, Dave Fulton, Helene Hardy-Pierce, Ken Hunt, Richard Herzog, Jason Smart, Ross Robertson, Lynne Lawry, Dave Roodvoets, Dave Hunt, Joe Wilson. Not pictured: Mike Barton, Mike Vaille, Tim Marshall, Rick Olson and LaFayette Bruner.

Team 1
Helene Hardy-Pierce (Captain), GAF Corporation
Jason Smart, Insurance Institute for Business & Home Safety
Dave Fulton, Whirlwind Steel Systems
Tim Marshall, Haag Engineering Co.
David Hunt, Revere Copper Products

Team 2
Joe Wilson (Captain), Metro Roof Products / Metal Construction Association
Rick Olson, Tile Roofing Institute
Mike Vaille, Cedar Shake & Shingle Bureau
Jason Smart, IBHS (one-day)

Team 3
Vickie Crenshaw (Captain) Crenshaw Consulting Group
Tom Kelly, 2001 Company
David Roodvoets, DLR Consultants / Single Ply Roofing Institute
Jim Koontz, Jim D. Koontz & Associates

Team 4
Ken Hunt (Captain), Performance Roof Systems
Ross Robertson, Firestone Building Products
Mike Barton, Armko Industries
LaFayette Bruner, Armko Industries

Report Task Group:
Richard Herzog (HIP Site Coordinator & principal writer), Haag Engineering Co.
David Roodvoets, DLR Consultants / Single Ply Roofing Institute
Vickie Crenshaw, Crenshaw Consulting Group
Jason Smart, Insurance Institute for Business & Home Safety