Streamlining Hydrologic Prediction Processes Using New and More Accurate Techniques and Methods
Project Overview
Research Project Purpose

1. Streamline hydrologic prediction for design of NDOT drainage infrastructure
2. Develop a design storm that is more representative of rainfall in Nevada than assuming uniform depth or a synthetic hyetograph (SCS)
3. A design storm for the intended application for NDOT drainage infrastructure design is composed of the following:
   a) Hyetograph
   b) Depth-area-reduction-factor (DARF)
Data
NEXRAD radar coverage over western United States
NEXRAD Old and New Data Products
Radar Stations

- Radar Stations and Data:
- National Weather Service (NWS) NEXRAD (Next Generation Radar) data (2005 – 2014) from four radar stations:
  - KRGX (Reno, NV)
  - KLRX (Elko, NV)
  - KESX (Las Vegas, NV)
  - KICX (Cedar City, UT)

Coverage of Hydrometeorologically Homogeneous Areas (HHAs)
All gauge networks considered: SNOTEL, CDEC, RWIS, AGRIMET, ARL-SORD, CEMP, CRN, DRI, HADS, and SCAN.

Gauge Networks

<table>
<thead>
<tr>
<th>Gauge Network</th>
<th>Gauges</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOP</td>
<td>59</td>
</tr>
<tr>
<td>ASOS</td>
<td>6</td>
</tr>
<tr>
<td>RAWS</td>
<td>49</td>
</tr>
<tr>
<td>CCRFCD</td>
<td>24</td>
</tr>
</tbody>
</table>

Total used = 138
Total considered = 545
<table>
<thead>
<tr>
<th>Gauge Source</th>
<th>Description</th>
<th>Continuous Period of Record</th>
<th>No. of Gauges Possible</th>
<th>No. of Gauges Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOP Hourly</td>
<td>The National Weather Service (NWS) Cooperative Observer Program</td>
<td>1948 - 2012</td>
<td>68</td>
<td>20</td>
</tr>
<tr>
<td>ASOS</td>
<td>Automated Surface Observing System</td>
<td>1996 - 2012</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>CCRFCD</td>
<td>Clark County Regional Flood Control District</td>
<td>1988 - 2014</td>
<td>177</td>
<td>24</td>
</tr>
<tr>
<td>RAWS</td>
<td>Remote Automated Weather Stations</td>
<td>1997 - 2014</td>
<td>56</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td><strong>Totals =</strong></td>
<td><strong>371</strong></td>
<td></td>
<td><strong>147</strong></td>
</tr>
</tbody>
</table>

Period of record for gauge sources in Nevada
Combined precipitation gauges from COOP, ASOS, RAWS, and CCRFCD networks
Determine Duration-Based Storm Event Totals

1. Each storm is summed to produce 1-, 2-, 3-, 6-, 12-, and 24-hour storm totals.

2. For the 547 individual events, 2,797 duration-based storm totals were visually inspected for use in the analysis.

3. After QC of the radar data, there remained 1,720 duration-based storm totals that met the standard for inclusion, having valid radar storm totals.
Distribution of Storm Events

1,720 duration-based storm peak value locations
Storm Event Selection
Spatial Distribution

• Flash flood report polygons
• Flash flood reports, classified as either flood warnings or flood advisories, sometimes overlapped more than one HHA.
• In these cases, the polygon was assigned to the HHA containing the center of the warning/advisory.
Storm Event Selection
Distribution Among HHAs

• Events assigned to closest HHA based on peak rainfall depth
• Events with overlapping times were merged into single events to reduce likelihood of using a specific storm more than once.
• Flash flood events that were remotely sensed by more than one radar station were assigned to the dominant or closest radar for each HHA

<table>
<thead>
<tr>
<th>HHA</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Events</td>
<td>39</td>
<td>48</td>
<td>36</td>
<td>42</td>
<td>103</td>
<td>34</td>
<td>144</td>
<td>101</td>
<td>547</td>
</tr>
</tbody>
</table>
HHA 1 Events ≥ 0.25 inches by year
Zone 6 Events ≥ 0.25 inches by year
EXTREME STATISTICAL AND RADAR DATA CRUNCHING!
Hyetograph Development
1. The design storm hyetographs were developed using point rain gauge measurements for the period of record.
3. Of these gauges, 147 had sufficiently reliable records.
4. The range of elevations covered by these gauges is between 480 and 9,000 feet.
5. Rain gauge data was processed into 16,771 distinct storm events.
6. A cumulative hyetograph was developed for each storm event, consisting of accumulated rainfall depth versus time for the event duration.
7. Hyetographs were made dimensionless by dividing each depth by the total depth AND each time step by the total storm duration.

8. A key characteristic of the dimensionless hyetograph is the maximum slope (maximum increase in percentage depth versus percentage duration), which corresponds to the maximum rainfall intensity during that event.

9. This maximum intensity is referred to as the median maximum intensity (MMI). The MMI is equivalent to the 50th percentile maximum intensity.
Hyetograph Development Results

1. The MMI was found to be invariant for storm durations up to 24-hours.
2. No strong correlation with rainfall depth was found.
3. The MMI associated with summertime convection (July) dominates regardless of the location across the state, and,
4. The MMI varies geographically across the state.
Hyetographs

1. Given the maximum intensity, a hyetograph at any particular location could be determined using a generalized logistic equation (GLE) applied to the cumulative rainfall depth.

2. The GLE has the form:

\[ Y(t) = A + \frac{K - A}{1 + Q e^{-B(t-M)}}^{1/v} \]

where

- \( Y(t) \) = depth fraction at time fraction, \( t \)
- \( A \) = lower asymptote = 0
- \( K \) = upper asymptote = 1
- \( B \) = is a parameter that controls the maximum intensity
- \( v \) = fitting parameter set equal to \( Q \)
- \( Q \) = Fitting parameter affecting slope before max intensity
- \( M \) = Location of maximum intensity = 0.50
The results of this research recommend the hyetograph shape be determined as a function of the maximum intensity.
1. Based on these results, a single hyetograph shape can be developed anywhere in the state based on a specified maximum intensity value. Placement of the MMI within the center of the storm duration is recommended for conservatism even though the first quartile storms were predominant.

2. Maximum intensity maps were provided, one based on the MMI (50th percentile), and the other based on the 90th percentile maximum intensity (NEXT SLIDE).

3. These maps were based on advanced climate-aided interpolation (CAI).
50th Percentile Median Maximum Intensity (MMI)

90th Percentile Maximum Intensity

CAI (100yr - 1hr) MMI

- 1.7 - 2.7
- 2.8 - 3.1
- 3.2 - 3.4
- 3.5 - 3.7
- 3.8 - 4.1
- 4.2 - 4.5
- 4.6 - 4.8
- 4.9 - 5.3
- 5.4 - 5.8
- 5.9 - 6.9

CAI (100yr - 1hr) Max Intensity 90th

- 2.4 - 3.9
- 4 - 4.4
- 4.5 - 4.9
- 5 - 5.3
- 5.4 - 5.8
- 5.9 - 6.3
- 6.4 - 6.9
- 7 - 7.5
- 7.6 - 8.3
- 8.4 - 9.8
DARF Development
DARF Development Overview

1. Establish Radar Based Storm Event List
2. Convert Radar to Rainfall
3. Determine Duration-Based Storm Event Totals
4. Develop Depth-Area-Duration (DAD) Values
5. Develop DARF Relationships
6. Compare Results to Historical Studies in Western US
Develop DARF Relationships

\[ DARF = 1 - \frac{aA^c}{b + A^c} \]

- DARF is the reduction expressed as a decimal fraction;
- A is area (sq. mi.), and
- Parameters, a, b, and c are fitting parameters that control the shape of the curve
DARF Development Methodology

1. DARFs were developed using precipitation estimates derived from 547 actual storm events, observed by radar, from 2005 through 2014.

2. The events were grouped based on flooding potential and Hydrometeorological Homogeneous Area (HHA), and then aggregated by rainfall duration.

3. Storms considered were either within a warning/advisory polygon issued by the NWS and/or included in the NCDC flash flood database.
4. These storms were extreme or at least with flood-producing rainfall depths and intensities.

5. Of the 547 individual events, there were 1,720 duration-based storm totals developed and used to determine DARF relationships at both the median (50th percentile) and 90th percentile.

6. Relationships were identified for each of the eight HHAs and for the 1-, 2-, 3-, 6-, 12-, and 24-hour durations for areas up to 500 mi² (NEXT 2 SLIDES).
Smoothed 50th Depth Area Reduction Factors (DARFs) for Storm Durations 1- through 24-hours
Smoothed 90th Depth Area Reduction Factors (DARFs) for Storm Durations 1- through 24-hours
Design Storm
Current design storm methods acceptable to NDOT (applicable outside of Clark County, Nevada) are provided in the 2006 NDOT Drainage Manual where:

- The rainfall distribution (temporal distribution) is based on the “Balanced Storm”, described in NOAA Atlas 14, Precipitation-Frequency Atlas of the Western United States, and
- DARFs are based on National Weather Service (NWS) Technical Paper No. 29 (TP-29), published by the U.S. Weather Bureau, 1957 through 1960.
The design storm approach presented in this research was divided into 2 main parts:

1. the temporal distribution defined by the hyetograph shape, and
2. the spatial distribution defined by the representative DARFs
Design Storm Overview

1. Components of the design storm include depth, duration, hyetograph shape, DARF, and return frequency.

2. Our research and hydrologic comparisons were made to design storms determined by the existing NDOT, CCRFCD, and the TMRDM (Washoe County) Drainage Design Manuals.

3. Rainfall depth obtained from NOAA Atlas 14, Volume 1; hyetograph shape is determined using a balanced distribution; and DARF values are based on TP-29.
Design Storm Methodology

1. This research used a 6-hour, 25-year storm for all cases.
2. Three locations were evaluated: Ely, Las Vegas, and Sparks, Nevada using the design methods presented in the respective Drainage Design Manuals.
3. The results are compared to those using the results of this research.
Design Storm Methodology (continued)

1. Each design storm is routed through a 100 mi$^2$ watershed with and without losses, using HEC-HMS Version 4.0 for peak flow and hydrograph comparisons.

2. Losses are modeled using Green & Ampt infiltration with parametric values representing soils composed of a mix of loamy sand and sandy loam.

3. These soils allow for moderate infiltration rates for evaluation of the impact on the hydrographs due to infiltration.
# Depth

<table>
<thead>
<tr>
<th>Location</th>
<th>Lat/Long</th>
<th>Depth (in)</th>
<th>Jurisdiction</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ely, NV</td>
<td>39.2482/-114.8880</td>
<td>1.41</td>
<td>NDOT</td>
<td>NOAA Atlas 14, Volume 1</td>
</tr>
<tr>
<td>Las Vegas, NV</td>
<td>36.1739/-115.1391</td>
<td>2.05</td>
<td>CCRFCD</td>
<td>CCRFCD Table 505</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>39.5403/-119.7851</td>
<td>1.27</td>
<td>TRMDM</td>
<td>TMRDM, Table 601</td>
</tr>
</tbody>
</table>

6-hour, 25-year storm depths for Ely, Las Vegas, and Sparks, Nevada
Depth-Area Reduction Factors (DARFs) for Ely, Las Vegas, and Sparks, Nevada using both jurisdictional values and those determined from this research for an area of 100 mi².

<table>
<thead>
<tr>
<th>Location</th>
<th>HHA</th>
<th>Jurisdictional</th>
<th>50th Percentile</th>
<th>90th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ely, NV</td>
<td>5</td>
<td>0.89&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.49</td>
<td>0.63</td>
</tr>
<tr>
<td>Las Vegas, NV</td>
<td>8</td>
<td>0.60&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.49</td>
<td>0.63</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>1</td>
<td>0.89&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.49</td>
<td>0.63</td>
</tr>
</tbody>
</table>

<sup>1</sup>TP-29, <sup>2</sup>CCRFCD Table 502
Project Study Areas
Combined Hyetographs
Figure 6: Jurisdictional hyetographs (6-hour, 25-year design storms) for the cities of Ely (NDOT) – balanced storm using depth from NOAA Atlas 14 Volume 1, Las Vegas (CCRFCD) – SDN3 storm distribution from CCRFD Table 503 using depth from CCRFCD Table 505, and Sparks (TMRDM) balanced storm using depth from TMRDM, Table 601.
Figure 7: 6-hour, 25-year hyetographs for Ely, Nevada (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 8: 6-hour, 25-year hyetographs for Las Vegas, Nevada (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 9: 6-hour, 25-year hyetographs for Sparks, Nevada (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 10: 6-hour, 25-year hydrographs for Ely, Nevada (no losses) for a hypothetical 100mi² basin (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 11: 6-hour, 25-year hydrographs for Ely, Nevada (Green and Ampt Infiltration) for a hypothetical 100m² basin (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 12: 6-hour, 25-year hydrographs for Las Vegas, Nevada (no losses) for a hypothetical 100mi² basin (Median HHI = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 13: 6-hour, 25-year hydrographs for Las Vegas, Nevada (Green and Ampt Infiltration) for a hypothetical 100m$^2$ basin (Median HHI = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Figure 14: 6-hour, 25-year hydrographs for Sparks, Nevada (no losses) for a hypothetical 100m² basin. Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity. Balanced = hyetograph determined using a balanced storm approach.
Figure 15: 6-hour, 25-year hydrographs for Sparks, Nevada (Green and Ampt Infiltration) for a hypothetical 100mi² basin (Median HHA = median of actual hyetographs, 50th Maximum Intensity = GLE hyetograph using median maximum intensity, 90th Maximum Intensity = GLE hyetograph using 90th percentile intensity, Balanced = hyetograph determined using a balanced storm approach).
Research Summary

- The existing jurisdictional methods that are based on a balanced storm and DARFs and NOAA Atlas precipitation depths result in higher peak flows and runoff volumes than those determined from the results of this research, with or without losses.

- Within the CCRFCD jurisdiction (HHA 8), the jurisdictional hydrograph (without losses) falls between the hydrographs from this study. With losses, the jurisdictional hydrograph falls closest to the hydrograph generated by the MMI GLE and 90th percentile DARF hyetograph. The 6-hour, 100 mi² DARF from CCRFCD (0.60) is closest to the 90th percentile DARF (0.63) from this research.

- Without losses, there is little difference between the non-jurisdictional hydrographs when the DARF is determined from the same curve. As expected, 90th percentile DARF values result in higher peak flows and runoff volumes. There is little difference in hydrograph peak, whether the MMI or 90th percentile hyetograph is chosen.

- There is little difference between the hydrographs generated by the logistic curve hyetographs or the median hyetographs, indicating that the smoothed tales of the logistic curve hyetographs have little impact.

- Balanced storm hyetographs produce the highest peak flows with or without losses introduced by the Green and Ampt infiltration. Depending on the Green and Ampt parameters, higher intensities will generally result in more runoff.
Recommendations and Procedure

Recommendations are made for a conservative combination of hyetograph and DARF as follows:

1. Depth-areal reduction factor at the 90\textsuperscript{th} percentile, and
2. Hyetograph at the 90\textsuperscript{th} percentile maximum intensity smoothed by the GLE and centered within the storm duration.

The procedure for applying the DARF and hyetograph consists of determining the design storm duration for the watershed or subwatershed. Then from the statewide 90\textsuperscript{th} percentile DARF curves, select reduction factor for the watershed area. For larger watersheds, no further reduction should be applied than the lowest reduction at 500 mi\textsuperscript{2}. For watershed areas less than 5 mi\textsuperscript{2}, no reduction is recommended. The hyetograph should be selected for a watershed or subwatershed from the 90\textsuperscript{th} percentile maximum intensity CAI interpolated map of values (Figure 2). Values can be selected at the centroid of the watershed area. The temporal distribution should be centered with the maximum intensity occurring at the center of the storm duration.
QUESTIONS?