# Integration of Radar Rainfall into Hydrologic Models

Brian C. Hoblit (1) and David C. Curtis, Ph.D. (2)

(1) Hydrologist, NEXRAIN Corporation, 9267 Greenback Lane, Suite C4, Orangevale, CA 95662; PH 916-988-2771; bhoblit@nexrain.com
(2) President, NEXRAIN Corporation, 9267 Greenback Lane, Suite C4, Orangevale, CA 95662; PH 916-988-2771; dccurtis@nexrain.com

## Abstract

Accurate estimation of the spatial distribution of rainfall is critical to the successful modeling of hydrologic processes. In the past, rainfall distributions have been typically estimated by assuming a spatial geometry tied to point rain gage observations using Thiessen polygons, inverse distance squared weighting, or geostatistical Kriging techniques. Unfortunately, the spatial distributions inferred by these approaches have little connection with how rain actually falls. From a modeling perspective, these techniques too often place the wrong rain at the wrong place at the wrong time.

In recent years, the implementation of the NEXRAD (WSR-88D) radars has made radar a viable tool to improve estimation of rainfall between the gages. Radar provides a highly accurate spatial description of the rainfall and greatly improves the basin average rainfall estimates. Unfortunately, traditional hydrologic models such as HEC-1 and SWMM are not equipped to directly ingest radar rainfall estimates. One approach to model radar rainfall in these models is to treat each radar pixel as a rain gage and spatially weigh the rainfall from each radar pixel based on its contributing area to an individual subwatershed. These techniques are demonstrated for HEC-1 and SWMM.

HEC-HMS, the next-generation hydrologic model from the U.S. Army Corps of Engineers, allows for the more accurate modeling of highly variable rainfall using a quasi-distributed approach known as ModClark. ModClark is able characterize intrabasin variations in rainfall rates and route the runoff to the subbasin outlet based on the location of rainfall within the subbasin. Therefore, ModClark and HMS more accurately represent spatially variable rainfall and an example is demonstrated using radar rainfall.

Integration of radar rainfall data into established models such as HEC-1 and SWMM allows engineers and hydrologists to more accurately characterize rainfall through improved estimates of watershed volume. Next generation models such as HEC-HMS are equipped to handle the direct ingest of radar rainfall data and can more accurately characterize and model spatially

variable rainfall. All three hydrologic models are greatly enhanced by high definition radar rainfall data.

## Introduction

In recent years, the implementation of the NEXRAD (WSR-88D) radars has made radar a viable tool to improve estimation of rainfall between the gages. Radar provides a highly accurate spatial description of the rainfall and greatly improves the basin average rainfall estimates. Unfortunately, traditional hydrologic and water resource models such as HEC-1 and SWMM are not equipped to directly ingest radar rainfall estimates. One approach to model radar rainfall in these models is to treat each radar pixel as a rain gage and spatially weigh the rainfall from each radar pixel based on its contributing area to an individual subwatershed.

HEC-HMS, the next-generation hydrologic model from the U.S. Army Corps of Engineers, allows for the more accurate modeling of highly variable rainfall using a quasi-distributed approach known as ModClark (Feldman 2000, Scharffenberg 2000, Peters and Easton (1996). ModClark is able characterize intrabasin variations in rainfall rates and route the runoff to the subbasin outlet based on the location of rainfall within the subbasin. Therefore, ModClark and HMS more accurately represent spatially variable rainfall over each subbasin. The benefits of using ModClark are diminished when using smaller subbasins.

Integration of radar rainfall data into established models such as HEC-1 and SWMM allows engineers and hydrologists to more accurately characterize rainfall. Next generation models such as HEC-HMS are equipped to handle the direct ingest of radar rainfall data and can more accurately characterize and model spatially variable rainfall. All three hydrologic models are greatly enhanced by high definition radar rainfall data.

## Gage and Radar Rainfall

Traditionally, rainfall distributions are estimated by assuming a spatial geometry tied to point rain gage observations using, for example, Thiessen polygons, inverse distance squared weighting, or statistical Kriging techniques. Unfortunately, the spatial distributions inferred by these approaches have little connection with how rain actually falls. From a modeling perspective, these techniques too often place the wrong rain at the wrong place at the wrong time.

In recent years, improvements in technology have made radar a viable tool to improve the estimation of rainfall between the gages. Radar provides a high-resolution view of the variability of rain falling over a region. Unfortunately, radar by itself has not proven to be a consistent estimator of the actual rainfall amounts.

The strength of a rain gage network is its ability to consistently estimate rain falling on a number of discrete points. Its weakness is the network's inability to estimate rain falling between the gages. On the other hand, radar's strength is its ability to see between the gages but radar lacks the consistency in estimating rainfall at a specific point. By merging rain data from a gage network and rain data derived from radar, hydrologists can take advantage of the strengths of each measurement system while minimizing their respective weaknesses. Essentially, a radar image is used as an areal template for the spatial distribution of rainfall. The rain gage data are used to scale the areal template. The net result is a gage-adjusted radar rainfall data set that combines the spatial distribution characteristics of the radar image with the scaling information from the gages.

Integration of gage-adjusted radar rainfall data in hydrologic and water resource models such HEC-1, HEC-HMS and SWMM greatly enhance the effectiveness of the models.

**Integration of Radar Rainfall into Hydrologic Models**

For any hydrologic and water resource model, gage-adjusted radar rainfall data can be used by treating the centroid of each radar pixel as a "pseudo" rain gage and then creating a basin-average rainfall estimate by weighing the contributing area of each gage within the basin. If each centroid were a gage, then the Thiessen polygon boundaries would correspond to the radar pixel boundaries and rainfall in the radar pixel is weighted based upon the area of the pixel within the basin. Figure 1 (left) shows an example of intersecting radar pixels with a subbasin and treating the centroid of the radar pixel as a pseudo rain gage.

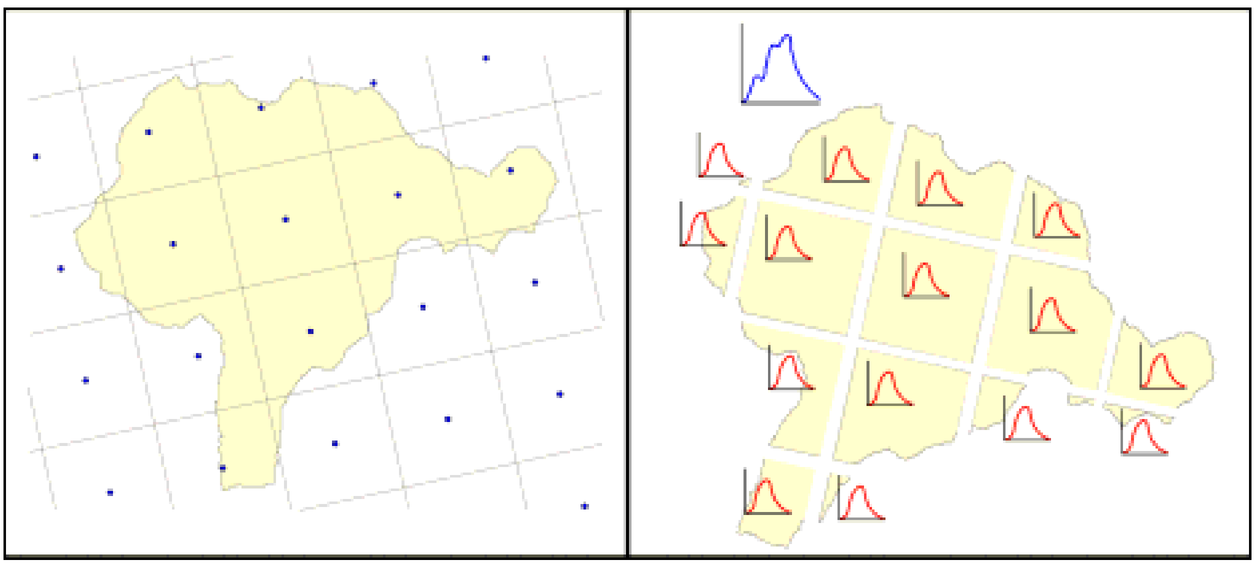

***Figure 1: Comparison between treating each radar pixel as a pseudo rain gage (left) and the ModClark technique used in HEC-HMS (right).***

The primary advantage of the basin-average approach is that most hydrologic and water resource models including HEC-1, HEC-HMS, and SWMM are equipped to handle basin-average rainfall, and are therefore able to indirectly ingest gage-adjusted radar rainfall estimates. Because gage-adjusted radar rainfall estimates more accurately capture the spatial distribution of rainfall, the modeling results using this technique should provide more accurate results of the hydrologic response of the modeled basin.

**Hydrologic Modeling Using ModClark and HEC-HMS**

HEC-HMS, HEC's next generation hydrologic model, can directly model gridded rainfall (e.g. gage-adjusted radar-rainfall estimates) using a quasi-distributed approach called ModClark (Peters and Easton, 1996). ModClark determines rainfall excess at each radar pixel and the excess from each pixel is lagged to the basin outlet. Figure 1 (right) shows an example of how the ModClark transform method works. At each radar grid cell inside of a subbasin, the rainfall excess (rainfall minus losses) is calculated and the excess is lagged to the outlet based on travel distance. The result is a quasi-distributed model and while a hydrograph is not calculated at each radar grid cell, the rainfall from each radar grid cell is tracked to the outlet for the creation of the subbasin hydrograph. The result is a hydrologic model that more accurately characterizes spatial rainfall patterns.

To create a HEC-HMS hydrologic model that takes advantage of ModClark, the authors used HEC-GeoHMS, an extension for ArcView® released in July 2000 by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). HEC-GeoHMS allows for the easy creation of the basic basin parameters of a hydrologic model based on topographic data (DEMs) that are freely available from the U.S. Geological Survey at 30 m horizontal resolution. HEC-GeoHMS uses DEMs to determine watershed boundaries and flow paths by analyzing the direction of steepest descent at each grid cell.

In Figure 2 (left), a hypothetical DEM (north is up) is shown with grid center elevations. Water from each grid cell will flow into one of the eight surrounding grid cells based upon steepest decent. For instance, in the northwest grid cell (elevation 59), water will flow directly to the east (elevation 56). In the grid cell immediately southeast of the original cell (elevation 58), water will either flow directly north to elevation 56, or will flow to the northeast to elevation 53. The slope to the path to the north would be (58-56)/1, or 2 elevation units per cell. The slope to the path to the northeast would be (58-53)/1.414, or 3.54 elevation units per cell. Therefore, water will flow to the northeast. In Figure 2 (right), the grid cell with elevation 53 (top row, third from the left) has a total of three upstream cells that flow into it. (Note that prior to analysis, HEC-GeoHMS creates a "hydrologically corrected" DEM, which insures that at least one of the eight neighboring cells is lower than the original cell.) Adjacent grid cells with no upstream contributing cells form the watershed divide, show as a black line. An in-depth description of these processes can be found in Kull and Feldman (1998).

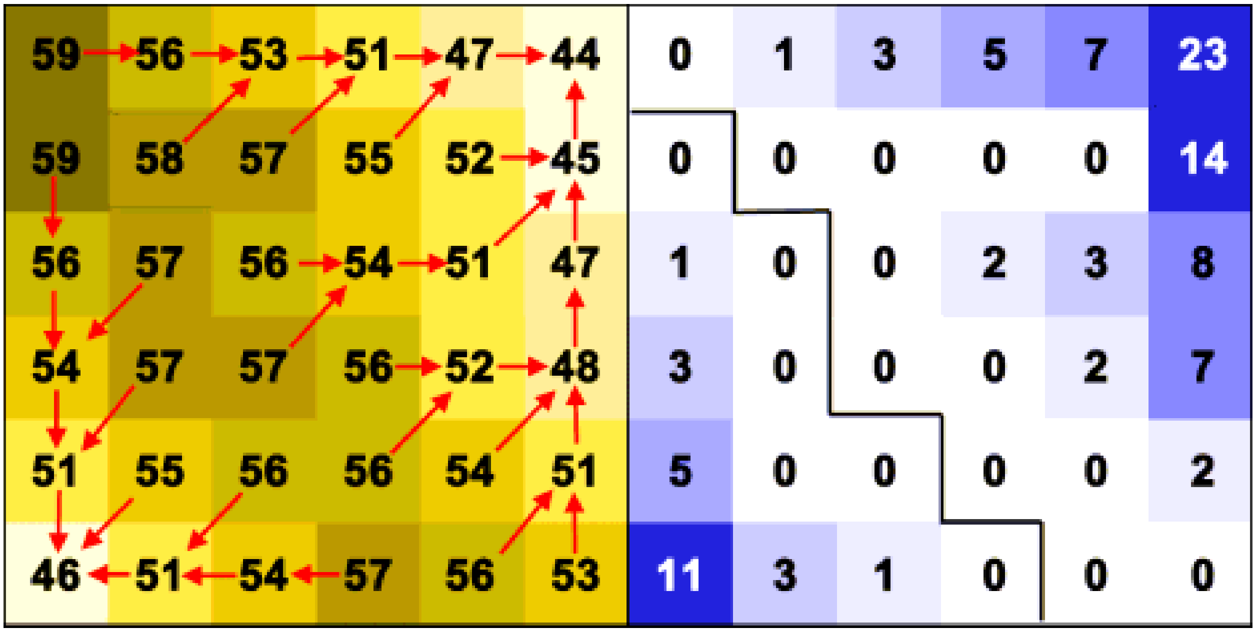


***Figure 2: DEM elevations and flow directions are shown on the left, and number of contributing upstream cells used by HEC-GeoHMS to determine watershed boundaries are shown on the right.***

Figure 3 shows a schematic of the processing steps used to create a hydrologic model incorporating the ModClark to directly model gridded rainfall. HEC-GeoHMS and ArcView® use DEMs to create a watershed boundaries and basic hydrologic parameters. The user has the ability to split and merge watersheds after the initial processing, allowing the user to customize outlets for gage locations, etc. The basic basin model including basin boundaries, basin areas, reach lengths, etc. is exported to HEC-HMS. Land use and soil data, also freely available on the Internet, can be merged within ArcView® to determine curve numbers, which are used to estimate loss rates. These curve numbers can incorporated into a basin-average curve number, or the user can average the curve numbers over the grid cells. Most hydrologic parameters for each basin (time of concentration and storage) and each reach (travel time, etc.) need to be calculated separately and entered directly into HEC-HMS. Radar rainfall data are entered into the HEC-HMS and the model calculates the hydrologic response of the river basin. Further discussion of the methodology for creating such a model can be found in Hoblit and Curtis (2001) and Doan (2000).

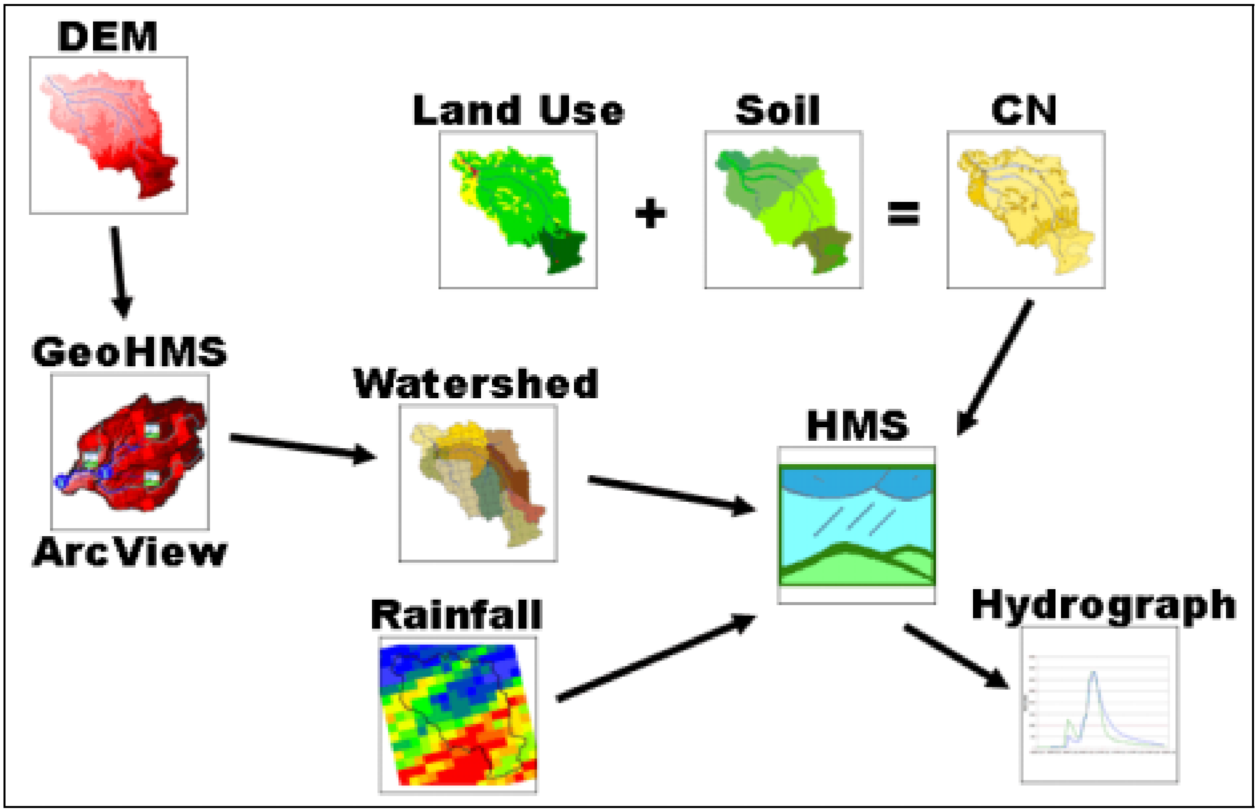


*Figure 3: Processing steps using HEC-GeoHMS and HEC-HMS for hydrologic modeling.*

Because the model tracks rainfall excess at each radar pixel, the model should be able to more accurately characterize the hydrologic response from rainfall events with significant amounts of intrabasin variation of rainfall.

**Case Study: Heppner, Oregon**

The City of Heppner, Oregon is located approximately 200 mi to the east of Portland, and about 40 south of the Columbia River. On average, the area receives about 18 inches of rainfall a year. In 1903, a severe storm hit the area and it was reported that the small watershed reached peak flow 15 minutes after the initial rainfall. In addition, almost 300 people died in the storm and over a third of the buildings were swept away. The storm was named the most significant weather event in the state of Oregon during the 20th century (National Weather Service Oregon 2002).

Obviously, radar rainfall data are not available for the storm and no rainfall records of the event are available because "the weather observing station was completely destroyed, drowning the observer and his entire family" (National Weather Service Oregon 2002). During the event, the

USGS estimated a peak flow at the Balm Fork Gage (Figure 4) of 36,000 cfs, which has an upstream area of 26.3 $mi^2$ (68.1 $km^2$) (USGS 2001).

Recently, Tropical Storm Allison dropped over 35 inches of rainfall over parts of Houston, Texas, and caused over $5 billion in damages, causing it to be the most damaging tropical storm in U.S. history (Hoblit et al., 2002). The authors used the radar rainfall distribution from 4 $km^2$ grid cells from an earlier analysis of Tropical Storm Allison and centered the heaviest portion of rainfall over the Balm Fork subbasin. The goal was to compare the hydrologic response from using basin-average rainfall with using ModClark in HEC-HMS. In addition, the hydrologic response from this study will be used to compare a Tropical Storm Allison-like storm, to the storm that was considered the top weather event in Oregon in the 20$^{th}$ century.


***Figure 4: Topographic map and basin model of the Heppner, Oregon, watershed created by HEC-GeoHMS.***

Figure 5 shows a comparison at the Balm Fork Gage between the same gage-adjusted radar rainfall data set entered into the model using basin-average rainfall estimates and directly ingesting radar data using ModClark. Both modeled hydrographs follow each other almost directly, which is not surprising considering the size of the radar grid cells (4 $km^2$ or 1.54 $mi^2$) to the size of the watershed (68.1 $km^2$ or 26.3 $mi^2$). Neither modeled event approaches the severity of the 1903 event, assuming the estimated peak flow of 36,000 is accurate.

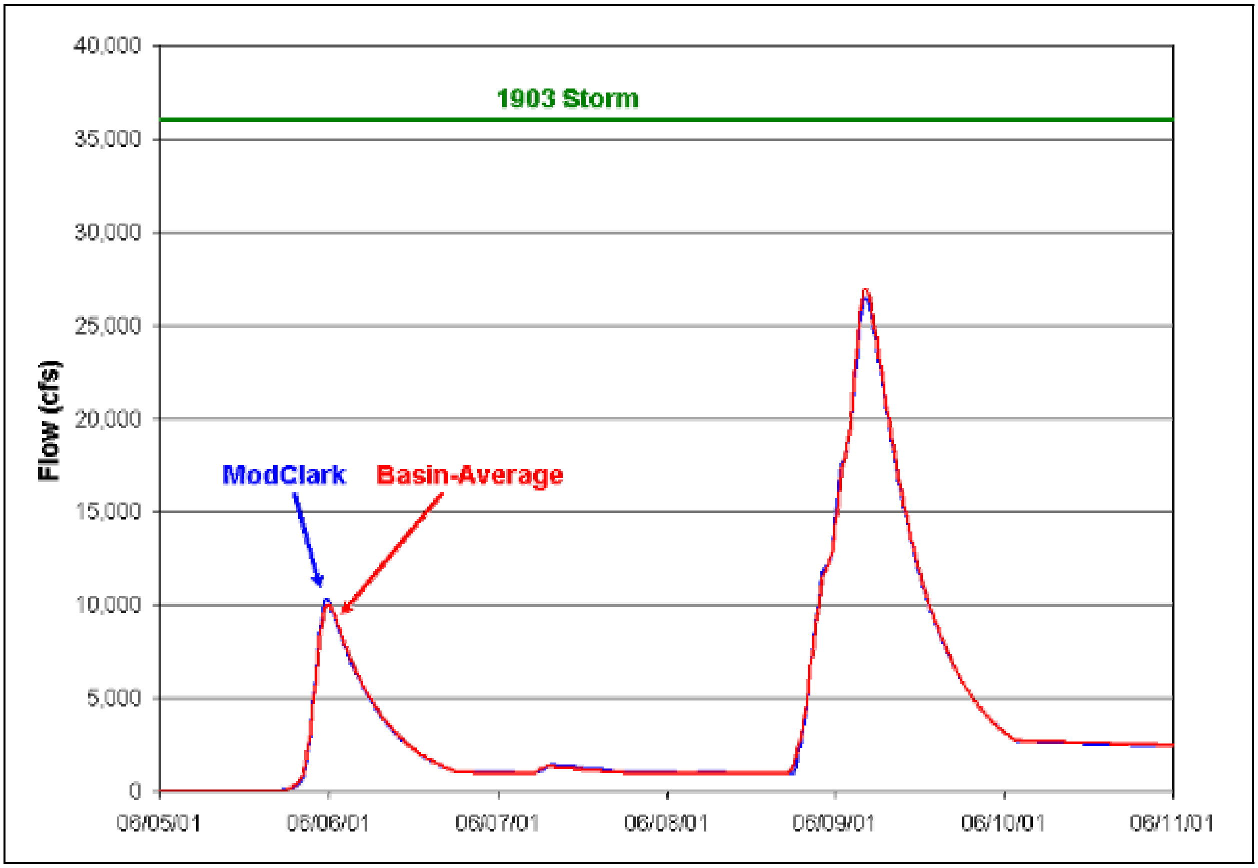


*Figure 5: Comparison of modeling results for ModClark and basin-average rainfall input for Tropical Storm Allison-like event to 1903 event.*

**Conclusions**

Integration of radar rainfall data into established models such as HEC-1 and SWMM allows engineers and hydrologists to more accurately characterize rainfall events. Next generation models such as HEC-HMS are equipped to handle the direct ingest of radar rainfall data and can more accurately characterize and model spatially variable rainfall. The authors created a hydrologic model over a watershed near Heppner, Oregon, to demonstrate the applicability of using gage-adjusted radar rainfall data in hydrologic modeling. Here are some of the key findings:

1. Use of gage-adjusted radar rainfall improves the effectiveness of hydrologic and water resource models by more accurately placing the right rain at the right place at the right time.

2. Use of ModClark and HEC-HMS, which allow for the direct ingest of gridded precipitation rainfall data, more accurately characterize intrabasin variations in rainfall than using a basin-average rainfall estimates.

3. Over watersheds with basin delineations that are not much larger than the radar rainfall grid cells, there is not significant difference between using ModClark and using basin-average rainfall estimates from gage-adjusted radar rainfall estimates. More research is needed to quantify the improvement in modeled hydrologic response at various subbasin scales.

**References**

Doan, James. (2000). Geospatial Hydrologic Modeling Extension HEC-GeoHMS - User's Manual - Version 1.0. Davis, California.

Feldman, Arlen, Editor. (2000). *Hydrologic Modeling System - HEC-HMS - Technical Reference Manual*. Davis, California.

Hoblit, B.C. and Curtis, D.C. (2001). "Integrating Radar Rainfall Estimates with Digital Elevation Models and Land Use Data to Create an Accurate Hydrologic Model." Presented at the Floodplain Management Association Spring 2001 Conference, San Diego, California, March 13 – 16, 2001. Available at <www.nexrain.com>.

Hoblit, B.C., Liu, L., and Curtis, D.C. (2002). "Extreme Rainfall Estimation Using Radar for Tropical Storm Allison." Scheduled for publication in *Proceedings of 2002 Water Resources Planning & Management Conference*, Environmental & Water Resources Institute, Washington, D.C.

Kull, D.W., and Feldman, A.D. (1998). "Evolution of Clark's Unit Graph Method to Spatially Distributed Runoff." *Journal of Hydrologic Engineering*, 3(1): 9-19.

National Weather Service, Oregon. (2002). "Oregon's Top Weather Events of the 20th Century." <nimbo.wrh.noaa.gov/Portland/OR_top10.html>.

Peters, J.C. and Easton, D.J. (1996) "Runoff Simulation Using Radar Rainfall Data." Water Resources Bulletin, 32(4): 753-760.

Scharffenberg, William A. (2000). *Hydrologic Modeling System - HEC-HMS - User's Manual - Version 2.0*. Davis, California.

United States Geological Survey. (2001). “Water Resources Data – Oregon – Water Year 2000.”

# LEARN MORE

The Rainfall Company

OneRain Incorporated
1531 Skyway Drive, Unit D
Longmont, Colorado 80504, USA

+1-303-774-2033
www.onerain.com