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July 28, 2008

Ms. Mimi Moss, A.I.C.P.
Community Development Director
Douglas County Administration Division
1594 Esmeralda Ave.
Room 201
Minden, Nevada 89423

RE: TECHNICAL MEMORANDUM
PEER REVIEW OF THE 2008 PRELIMINARY FLOOD INSURANCE STUDY
DOUGLAS COUNTY, NEVADA

Dear Mimi:

Please find attached our Technical Memorandum summarizing our Peer Review of the 2008 Preliminary Flood Insurance Study for Douglas County. As you recall, the purpose of our Peer Review was to provide a detailed listing of our technical review comments and recommendations to the County regarding opportunities to restudy or otherwise reconsider the findings and resulting flood hazard maps presented in the 2005 Northwest Hydraulic Consultants (NHC) study and subsequent 2008 Preliminary Flood Insurance Study (FIS). In the two Technical Review Committee meetings held during our investigation period, we discussed most of the comments you will read of in the memorandum. We believe our findings provide technical evidence that the NHC study and the FIS include assumptions, methodologies, and results that are questionable and warrant further investigation.

We stand prepared to further assist Douglas County at your convenience.

Yours truly,
MANHARD CONSULTING, LTD.

Denny Peters, PE, PH
West Region Director of Water Resources
Professional Hydrologist

Jeff House
National Director of Water Resources
Vice-President

Executive Summary

In July 2008, Douglas County entered into a contract with Manhard Consulting, Ltd (Manhard) to provide a technical peer review of the April 2008 Preliminary Flood Insurance Study completed by Northwest Hydraulic Consultants (NHC). The purpose of the peer review is to provide a detailed summary of technical review comments and recommendations the County may utilize to revise the peak flows and resultant floodplain elevations presented in the NHC study. A thorough review of the hydrologic/hydraulic models and supporting methodologies was performed in order to determine forward these comments and recommendations. The results of the peer review are summarized by the following primary observations, concerns, and recommendations.

The NHC study states the model was calibrated to the results of regression equations applied to the same watersheds. However, this approach is highly questionable because these equations are known to produce poor estimates of peak flow runoff rates for watersheds in the mountainous areas of northern Nevada. A better approach would be to calibrating the model using available precipitation and streamflow data for corresponding storm events recorded within the subject watersheds.

The precipitation data and its application in the NHC model require additional investigations. This includes the rainfall depths used for the different design storms and the use of the data for both the 3-hour and 24-hour storm distributions. Additionally, the NHC model used a simplified approach of assigning the precipitation depths to the watersheds that should be refined to better simulate natural rainfall patterns and dispersions. These model input parameters and methodologies may have the most significant influence on resulting peak runoff flow rates from the watersheds and corresponding flood hazard zone mapping efforts under consideration.

Input parameters incorporated into the NHC model for developing stormwater runoff peak flow rates/volumes and the routing of these resulting flow rates/volumes throughout the watershed need to be reconsidered and appropriately refined. These parameters include the SCS Unit Hydrograph peaking factor and Manning's roughness coefficients. Both were assigned in a simplified lumped parameter manner that discounts standards of practice and minimizes model precision. Furthermore, the model omits existing roadway culverts and corresponding impoundments – another simplification that further degrades the model's ability to simulate the natural system it is intended to replicate. Further compounding these simplifications, it appears the model includes an error resulting in an additional 1,300 cfs of peak flow to be routed through and downstream of Buckeye Creek. Appropriate revisions to the model and its modeling parameters would lead to a more realistic hydrologic simulation of the watershed as it exists and would most likely generate different (reduced) resulting peak runoff flow rates and volumes.

The Peer Review concludes with recommendations for follow-up investigations and analyses, including: (1) extensive coordination efforts with the National Weather Service to ensure the precipitation data used is appropriate and accurate, (2) the development of a comprehensive watershed model utilizing appropriate methodologies, inclusive of culverts and impoundments, and based on standards of practice so that input parameters can be optimized and the model can be calibrated to real-time watershed rainfall and runoff measurements, and (3) the reevaluation and re-mapping, if warranted, of the 100-year flood hazard zones throughout the study area within Douglas County as a result of the improved and calibrated model.

1.0 Chronological Timeline of Past Flood Studies

Following is a timeline of previous flood studies and revisions performed within Douglas County, Nevada:

- February 1979 – Original hydrologic and hydraulic study completed by U.S. Soil Conservation Service

- September 1992 Revision – Hydrologic and hydraulic analyses revised by U.S. Army Corps of Engineers (USACE), Sacramento District

- April 1994 Revision – Incorporated results of detailed study along the Carson River; Hydrology developed by Boyle Engineering; Hydraulic analysis performed by the U.S. Geological Survey (USGS)

- June 1997 Revision – Incorporated results of detailed study, by USACE (Sacramento District), along the East Fork Carson River, Cottonwood Slough, Henningson Slough, and Rocky Slough

- November 1999 Revision – Douglas County FIRM converted to digital format. In addition, detailed flood hazard data for Clear Creek was included at this time. Boyle Engineering performed the hydrologic and hydraulic analyses for the original Clear Creek study in December 1982.

- February 2005 Revision – Hydrologic and hydraulic analyses performed by Northwest Hydraulic Consultants (NHC) to provide detailed mapping along Airport Tributary Wash, Airport Wash, Airport Overflow Wash, Bobwhite Wash, Buckeye Creek, Calle de Asco Wash, Calle Hermosa Wash, Johnson Lane Wash, and Juniper Road Wash.

- December 2007 – MAP-IX Mainland re-delineated 6.5 stream miles along the Carson River, Clear Creek, Pine Nut Road Wash, Rocky Slough and Smelter Creek. In addition, the existing FIRMs were converted from National Geodetic Vertical Datum of 1929 (NGVD) to North American Vertical Datum of 1988 (NAVD) and the 2005 NHC study was incorporated at this time.

The November 8,1999 Flood Insurance Study (FIS) is the current Effective study for Douglas County. Any references made to the “1999 study” within this document is referring to this Effective study. Also, note that all modeling included in the 1999 study was completed *prior* to 1999.

Any references made to the “2005 study” refers to the study NHC completed in April 2005.

2.0 Technical Review Process

The County provided Manhard with fifteen DVDs containing the NHC reports, models and supporting data. These included the preliminary FIS, draft workmaps, hard copies of the preliminary FIRMS, the hydrologic and hydraulic models, the hydrology report, the hydraulic analysis report, and the Douglas County Technical Support Data Notebook (TSDN) submitted to FEMA IX. Upon receiving the data from the County, Manhard staff cataloged and documented the materials in order to properly plan the review process. Two Technical Review Committee meetings and a number of informal meetings with County staff have been conducted in order to solicit input, feedback, and historical perspective from local agencies, engineers and citizens. Over the course of these meetings, Douglas County staff provided some initial direction on specific areas they would like closely evaluated. It must be added that early input and direction from the County and the Technical Review Committee steered the prime focus of the Peer Review efforts toward the 2005 NHC study and the 2008 Preliminary FIS - detailed investigations into the 2007 MAP-IX Mainland re-delineations of County flood hazard areas outside of the NHC study area are still warranted.

Four primary documents were included within the technical review

- the *Hydrology Report for the Douglas County FIS*, NHC, April 2005, Douglas County, NV;
- the *Hydraulic Analysis, Douglas County, Nevada,* NHC, April 2005, Douglas County, NV;
- the preliminary *Flood Insurance Study, Douglas County, Nevada, and Incorporated Areas,* NHC, April 2005, Douglas County, NV; and
- the Effective *Flood Insurance Study, Douglas County, Nevada, and Incorporated Areas,* November 1999, Douglas County, NV.

These documents were evaluated in conjunction with the hydrologic and hydraulic models. Information and results presented within the reports were cross-referenced with the models for consistency and provided background on the approach used by NHC for model parameter development.

Physical parameters, professional assumptions, supporting calculations, and “real-world” comparisons were all evaluated during the review. Manhard’s findings are discussed in the following sections with conclusions subsequently summarized.

3.0 Hydrologic Modeling Review

Douglas County is located in the Northern portion of Nevada along the Nevada-California border. The County terrain is characterized by the steep, mountainous slopes of the Pine Nut Mountain range along the eastern perimeter, which gradually transition via alluvial fans into a flat valley floor along the Carson River floodplain. The Carson Range resides along the western Carson River floodplain and is bounded by Lake Tahoe on the County’s western border. Floodwaters from the Pine Nut Mountains flow in a westerly direction through steep valleys, to gentler slopes, through the alluvial fans, and ultimately terminate at the East Fork and main stem of the Carson River.

The U.S. Army Corps of Engineers HEC-HMS model was used by NHC for the hydrologic analyses. This nationally recognized model incorporates several different rainfall-to-runoff algorithms to produce hydrographs for individual subbasins and will route these hydrographs in-time through conveyance systems. HEC-HMS is the successor to HEC-1, the DOS-based version of the model that was used for the hydrologic analysis in the previous County flood studies.

NHC developed a single HEC-HMS model for the entire study area, generally located on the eastern side of Highway 395 and encompassing the following watersheds and corresponding waterways: Buckbrush Wash, Johnson Lane Wash, Sunrise Pass Wash, Airport Wash, and Buckeye Creek. Subbasins were delineated by NHC using 10-meter digital elevation models (DEMs) and ranged in size from 136 acres (0.212 square miles) to 9950 acres (15.55 square miles).

3.1 PRECIPITATION

Precipitation amounts and areal reduction factors for the modeling included within the 1999 study were based upon data derived from the National Weather Service's (NWS) National Oceanic and Atmospheric Administration Atlas 2 (NOAA 2) for Nevada. However, effective August 6, 2003, NOAA Atlas 2 data was superceded by NOAA Atlas 14 (NOAA 14) rainfall data. The 2005 study incorporated the NOAA 14 precipitation data into the HEC-HMS modeling.

Manhard compared the NOAA 2 and NOAA 14 values at various points within the County, taking care to sample a representative cross-section of locations varying in elevation, latitude and longitude. This comparison indicated an overall *increase* in absolute precipitation depths from NOAA 2 to NOAA 14 in the eastern two-thirds of the County and along the Pine Nut Mountain range. For a point on reference, this refers to the majority of the County east of the City of Minden. The increases were found to be in the range of 33% to 71% at sampled locations. The remaining third of the County (the western portion) showed an overall *decrease* in precipitation depths from NOAA 2 to NOAA 14, in the range of 8% to 21% at sampled locations.

Manhard performed a sensitivity analysis using the Buckeye Creek watershed to determine the potential effects on peak flows by varying the precipitation within the HEC-HMS model. With the exception of the incorporated rainfall data, all model parameters were kept the same as within the original NHC model. The 100-year, 24-hour event was evaluated. The resultant peak flow at model node BC-A (located on Buckeye Creek, approximately 0.25 miles upstream of East Valley Road) using NOAA 14 precipitation is 6,870 cfs. The model structure was then modified to incorporate NOAA 2 precipitation, which resulted in a peak flow of 2,878 cfs at the same location - over a 40% decrease. **This analysis does not set forth that using NOAA 14 versus NOAA 2 precipitation is an error, but simply indicates that the difference between the two datasets can lead to considerably different results.** Note that the peak flow at this same location in the 1999 study is 3,500 cfs.

While performing the above sensitivity analysis, an issue was discovered that involves the process NHC used to model precipitation within the individual subbasins. This issue is discussed in further detail in section 3.3 - Storm Distribution.

3.2 DESIGN STORMS

Both the 1999 and the 2005 studies analyzed a 100-year, 3-hour “cloudburst” or ”summer convection” storm event and a 100-year, 24-hour “general” or “winter frontal” storm event.

The 1999 FIS indicates that both storms were calculated to determine which would produce the higher peak flows. However, the publication date of this report, it is not clear exactly how the peak flows were incorporated into the effective hydraulic model. That is, it is unclear where the 3-hour peak flows are applied and where the 24-hour peak flows are applied in the effective models because Manhard was unable to locate copies of the 1999 effective models.

The 2005 study performed the same comparison – modeled both the 3-hour and 24-hour storm events within HEC-HMS – and indicated that resultant peak flows from the 3-hour event were used for basins with drainage areas less than 20 square miles and peak flows from the 24-hour event were used for basins with drainage areas over 20 square miles. On page 10 of the *Hydrology Report for the Douglas County FIS*, the statement is made “The cloudburst storm was assumed to produce the more critical scenario for all basins with less than 20 square miles of drainage area, while the frontal storm was deemed more critical in the larger basins (Airport and Buckeye Creek)”.

Upon review of NHC’s HEC-HMS model, Manhard found a discrepancy with the above statement. The 24-hour storm event was selected and used within the NHC modeling for the Buckeye Creek watershed analysis. Although the Buckeye Creek watershed covers approximately 67.5 square miles, the watershed itself was delineated into eleven contributory subbasins, all under 20 square miles in area. Applying the logic previously stated, the case could be made that any/all of these individual subbasins could experience a 3-hour cloudburst event that proves to be more significant or physically plausible. **Manhard is not stating that we believe the 3-hour storm should be used for hydrologic analysis of the study area, but rather that the approach that was applied is not entirely consistent and requires further review to determine the validity.**

One addition observation needs to be outlined in relation to the storm types (convection or winter frontal) established in the creation of the NOAA 14 as described in the 2006 *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States – Volume 1* documentation. For this atlas, two precipitation areas were defined over the Volume I study area corresponding to regions where weather station data indicates “general” storms and “convection” storms prevail. Maximum rainfall events recorded in the “general” area were dominated by winter season frontal precipitation storms of long durations (24-hours or more) while maximum events in the “convection” areas occurred during summer seasons. The Pine Nut Mountain range and all of Douglas County reside within the “general” precipitation pattern area. This suggests two possible situations: (1) the weather stations reporting precipitation readings within the Pine Nut Mountain region (see following section for more discussion on weather station locations) typically do not record short duration “convection” storm events - whether by station location or limited number of stations; and (2) the precipitation data available through NOAA 14 is likely inappropriate for modeling summer-time convection storms of short duration (3 to 6-hours). **In either case, it appears it may be inappropriate to model the subject watershed using 3-hour storm distributions and NOAA 14 precipitation data without fully understanding the sources, nature, and applicability of the data.** Additional investigation into the appropriate use of NOAA 14 precipitation data for the Pine Nut Mountain range, up to and including correspondence or meetings with the NWS, seems warranted.

3.3 STORM DISTRIBUTIONS

A HEC-HMS model consists of three main interface components – the basin model, the meteorologic model, and the control specifications. The meteorologic model manages the precipitation data and methodology that will be applied within the hydrologic analysis.

For the 2005 study, NHC developed balanced input hyetographs that distributed the total precipitation over 5-minute incremental intensities. The "user specified hyetograph" option within HEC-HMS allows the modeler to reference (or "call in") a separate hyetograph for each individual subbasin. The advantage to using this option is that the modeler can accurately simulate varying precipitation amounts across a watershed. **This increased accuracy is directly dependent on the proper delineation of subbasins and the proper determination of the precipitation.** This is explained further below.

As described in section 3.1 – Precipitation, the Buckeye Creek watershed was delineated into eleven contributory subbasins within the HEC-HMS model. **Upon review of the model, Manhard determined that the same hyetograph is referenced into all eleven of the subbasins.** The total precipitation modeled over each subbasin for the 100-year, 24-hour storm is 4.93 inches. This equates to the NOAA 14 rainfall depth of 5.23 inches with a 6% areal reduction. This overall depth for Buckeye Creek is stated in Table 4.3 of the *Hydrology Report for the Douglas County FIS.* Upon further review, Manhard determined that NHC likely calculated the centroid of the entire Buckeye Creek watershed and used the NOAA 14 published precipitation depth at the location. That precipitation depth (4.93 inches) was then applied over the entire 67-square-mile Buckeye Creek watershed.

A potential problem with the approach described above is that the published NOAA 14 precipitation data for this watershed indicates an isopluvial range of 3.0 to 6.0 inches during a 100-year, 24-hour storm event. While the eastern portion of the Buckeye Creek watershed may receive up to 6.0 inches of rain during this storm, the western portion will statistically receive considerably less. Even if the average of the two extreme values was computed and the 6-percent reduction applied, the result would be a total of 4.2 inches of rain. It was determined this same generalized storm distribution approach was applied for the other study watersheds within the NHC HEC-HMS model. **This approach could potentially overestimate the actual precipitation and, ultimately, overestimate the resultant downstream peak flows.**

Through additional investigation into the data and methodologies used by the NWS in the development of NOAA 14, interesting observations can be made regarding appropriate precipitation depth selection for the subbasins modeled in the NHC study. As described in the NOAA 14 documentation, the main objective of the atlas is to present precipitation estimates over a variety of frequencies and durations spatially across large regions and outside of point precipitation data obtained from weather stations. **It must be noted that no weather station or precipitation gage is located within the portion of the Pine Nut range specific to the watersheds analyzed in the NHC study.** However, three such stations are located adjacent to the Pine Nut watershed – one in Minden, NV immediately west of the watersheds, one at Topaz Lake immediately south of the watersheds, and one in the Smith Valley immediately east of the watershed. The underlying assumption to the regional approach is that data from scattered weather stations can be grouped together within "homogeneous regions" subjectively based on climate, prevalent storm patterns, topography, and other physiographic features in order to estimate precipitation depths within the regions.

For the western areas of northern Nevada, two such homogeneous regions were defined for the NOAA 14 data analysis. The first region, Region No. 3, spans in a north-south trending alignment from Minden, NV north to and beyond the Nevada state border. This region encompasses the Truckee Meadows and other western Nevada areas typified by the easterly or leeward Sierra Nevada range slopes. The other region, Region No. 10, also tends to span in a north-south direction from Topaz Lake but it spreads easterly into the middle areas of the State. This region includes the more arid interior portions of the State, such as the cities of Fernley, Fallon, Lovelock, and Tonopah. Interestingly, it appears that the Pine Nut Mountain Range forms the boundary between these regions. Furthermore, through an inspection of NOAA 14 precipitation data for the three identified weather stations, there are distinct precipitation depth differences. It seems clear the NOAA Atlas 14 data for the Buckeye Creek subbasin is more reflective of the wetter characteristics of Region No. 3 and does not resemble the drier nature of Region No. 10 – creating a data application and statistical homogeneity dilemma where a regionalization may not reflect a local condition.

Fortunately, the developers of NOAA 14 produced 90% confidence intervals coincident with the precipitation depth data to assist in the understanding of precipitation data in the regional margins. The confidence intervals define upper and lower confidence limits that can be considered for any NOAA 14 point precipitation value to "allow users a greater understanding of the uncertainty and will thus improve the utility of the estimates in engineering and environmental design practice." The statistical variability at any location is reflected by the confidence intervals - especially those in difficult areas where weather station data is lacking, where extreme convection storms drive short duration data, or where physiographic features vary. It appears that in the case of the Pine Nut range, the lower confidence interval bound might represent the most reliable precipitation data for use in hydrologic modeling based on the arid nature of these mountains. Again, citing the example above for the 100-year, 24-hour rainfall depth for the Buckeye Creek subbasin, the 4.93-inch depth has a corresponding 90% confidence lower bound of 4.26 inches. **It is suspected that this is a more realistic approach to assigning NOAA 14 precipitation to the subbasins used in the NHC report as it includes an adjustment based upon local information and physiographic interpretations anticipated in the NOAA 14 documentation and program usage protocol.** Again, additional investigation into the appropriate use of NOAA 14 precipitation data for the Pine Nut Mountain Range, up to and including correspondence or meetings with the NWS, seems warranted.

3.4 RUNOFF TRANSFORMATION

Runoff transformation within the HEC-HMS model was performed using the Soil Conservation Service (SCS) Unit Hydrograph method. This method, developed by the SCS in 1957, is based on a dimensionless hydrograph. The hydrograph is based upon input values for specific parameters, including rainfall duration, time to peak, basin area, and basin shape. The equation that solves for the SCS Unit Hydrograph method includes an inherent "peaking factor" (or conversion constant) of 484, which is directly related to the computation of runoff within a given subbasin. The simplified form of this equation is:

$$\mathbf{Q_p = 484A/T_p,}$$

where: Q_p = Peak flow (cfs), A = Basin Area (sq mi), T_p = time to peak (hr).

The use of SCS methodologies is widely accepted and prevalent in the engineering community. The method is robust and provides the user with the flexibility to incorporate detailed data.

However, the method does contain some weaknesses in areas with high water tables and where antecedent soil conditions cannot be accurately accounted for in the solution. A 1984 study performed by Capece, Campbell, and Baldwin (1984) determined that the actual peaking factor may be as low as 10 - 50 in flat watersheds, with high water tables. They indicated that caution should be taken in the application of the SCS method in similar areas. Similarly, R.H. McCuen (1982) states the 484 peaking factor is a constant derived from the geometry of a triangular hydrograph, upon which, the SCS Unit Hydrograph was developed and that the value may range from 300 for flat areas to 600 for mountainous area. If used, this range can constitute as much as a 38% decrease in peak flow rates for flatter lands and a 24% increase for steeper areas. **As the subbasins analyzed in the NHC study consist of both low-lying and flat agricultural lands and steep mountainous regions at higher elevations, it seems an improvement in the SCS Unit Hydrograph methodology based on proper adjustments to the peaking factor should be considered. The resulting peak runoff rates within the current NHC study may be overestimated by ignoring this modeling refinement.**

3.5 CHANNEL (REACH) ROUTING METHODOLOGY

Reach routing performed within the NHC HEC-HMS model used the Muskingum Routing method. The accuracy at which the model can solve this method is dependent on the specification of appropriate time steps and distance steps. The two main parameters the user determines are the Muskingum "K" and "X". Muskingum K is the estimated travel time of the floodwaters through the respective channel reach. More precisely, "'K' can be estimated as the elapsed time between the centroid of areas of the two hydrographs, [or] as the time between the hydrograph peaks, or as the time between midpoints of the rising limbs" (USACE, 2000). Muskingum X is a coefficient that can range between 0.0 and 0.5 that relates to the channel slope and definition. For instance, for channels with mild slopes and flows that exceed bank capacities (over-bank flow), the parameter X will approach 0.0. For steeper streams, with well-defined channels that do not have over-bank flows, X will be closer to 0.5. Most natural channels lie somewhere in between these two limits, leaving room for engineering judgment. (USACE, 2000)

A statement on page 8 of the *Hydrology Report for the Douglas County FIS* indicates that the Muskingum X parameter was initially estimated as 0.2 (for all reaches), but ultimately the value was reduced to 0.1 (for all reaches).

Manhard performed a sensitivity analysis to determine the effect the modification of the Muskingum X parameter would have on the resultant peak flows. It was determined that the value change from 0.2 to 0.1 would result in a negligible flow variance of no more than 3 percent at any location.

3.6 STORAGE ROUTINGS

No storage routings were included within the HEC-HMS model to account for peak flow attenuation (reduction) that could result from existing culvert crossings along the studied washes. The *Hydraulic Analysis, Douglas County, Nevada* states on page 25 that "no culverts were modeled during base runs as it was assumed that existing culverts would have negligible effect on flow conveyance". This negligible effect was attributed to minimal conveyance capacities and lack of maintenance that has lead to complete obstruction of the structures.

A small or obstructed culvert does not necessarily indicate that no attenuation will be realized at that location. A completely blocked culvert under a roadway embankment may actually function as an impoundment with no "low level" outlet to release the floodwaters until the top of road is overtopped, similar to a retention pond. Depending on the height of the embankment and the topography immediately upstream of the crossing, floodwaters could be attenuated considerably regardless of the culvert size of maintenance.

3.7 LOSS RATE METHODOLOGY

The Green and Ampt loss rate method was used within the NHC HEC-HMS model. This method simulates the infiltration of precipitation in a watershed. According to the 1994 US Army Corps of Engineer's publication EM 1110-2-1417…"the transport of infiltrated rainfall through the soil profile and the infiltration capacity of the soil is governed by Richard's equation….[which is] derived by combining an unsaturated flow form of Darcy's law with the requirements of mass conservation." To use the Green and Ampt method within HEC-HMS, the parameters that must be specified are: initial loss, volumetric moisture deficit, wetting front suction, hydraulic connectivity, and percent imperviousness.

The use of this methodology for the study region is considered appropriate and applicable. However, a statement made on page 7 of the *Hydrology Report for the Douglas County FIS* warrants further review. The NHC report states "Soil parameter values were adjusted based on published ranges to better simulate peak magnitudes." Within the same report, on pages 5 and 12, a case is made to justify the "refinement of the hydrologic models" to "roughly reproduce the regression flow estimates."

No information is available to clarify what specific adjustments or modifications were made to the model parameters to "roughly reproduce" the regression flow estimates, but the concern regarding these adjustments is discussed in the following section.

3.7(a) Regression Equations Used For Model "Refinement"

The *Hydrology Report for the Douglas County FIS* states that certain hydrologic model parameters were adjusted to "better fit" peak flows estimated using the National Flood Frequency (NFF) regression equations. **While it is not clear exactly what modifications were made within the HEC-HMS models in order to achieve these comparable peak flows, there is strong evidence that the regression equations for the Douglas County, Nevada region are not appropriate for this exercise.**

Large standards of error (upwards of 100 percent) are inherent to the equations in the western United States, especially in areas where the USGS gage station network is sparse. This is certainly the situation in Douglas County. The Water Resources Investigations Report no. 02-4168 (USGS, 2002) includes technical findings involving the applicability and limitations of the regression equations. Included below are two pertinent statements from this report:

> "…the flood hydrograph estimation procedure might not be applicable to watersheds in the semiarid/arid regions of the Nation because the procedure is based on data from Georgia (Inman, 1987)"
>
> " The standards of error of estimate or prediction range from 30-60 percent for most of the equations; however, some equations have

standard errors near 15 percent and some equations have standard errors greater than 100 percent. **The largest standard errors generally are for equations developed for the western part of the nation** where the at-site variability of the flood records is greater, where the network of unregulated gaging stations is less dense and there are more difficulties in regionalizing flood characteristics."

3.8 AVAILABLE GAGE DATA

In addition to the weather stations in the vicinity of the Pine Nut Mountains, there are several streamflow gages located within and downstream of the watersheds analyzed in the NHC study. Unfortunately, the gage records are short in length (10 to 15 years maximum) and include record gaps that prohibit the creation of a justifiable hydrologic frequency analyses for the watersheds. However, gages for the Buckeye Creek and Johnson Wash watersheds simultaneously recorded peak flows for four storm events of interest. Two of the captured events (July 14, 1992 and July 22, 1994), could provide insights into the watersheds' hydrologic responses during short-duration, summer time convection storms. The other two events (March 10, 1995 and January 2, 1997) could assist in the understanding of the watersheds' rainfall-runoff characteristics during longer-duration, winter frontal storms. **By using NEXRAD Doppler radar rainfall data, ground correlated with weather station data, these four storm events could be analyzed, the input parameters could be optimized, and a resulting calibrated model could be used to more precisely estimate runoff from the subbasins under consideration. Although available to the modelers and authors of the NHC study, it seems this real-time calibration methodology was not undertaken. Instead, the NHC model was calibrated using questionable USGS regression equation results.**

4.0 Hydraulic Modeling Review

NHC utilized two different hydraulic modeling packages to determine the floodplain boundaries for the study limits. Within the steeper regions where runoff was considered "confined" within a definitive channel section, the U.S. Army Corps of Engineers HEC-RAS model was utilized. Within the lower reaches where alluvial fans and braided streams are more prevalent, hydraulic modeling was performed using MIKE 21, a two-dimensional modeling system commonly used to evaluate estuaries and coastal waters. The MIKE-21 software is available through DHI, Inc.

4.1 HEC-RAS MODELING

The U.S. Army Corps of Engineers HEC-RAS model version 3.1.1 was used to evaluate the hydraulic performance of Calle Hermosa, Calle de Asco, Juniper Road Wash, Bobwhite Wash, and Buckeye Creek. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a network of natural and constructed channels. The basic computational procedure is based on the solution of the energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The HEC-RAS model is used extensively by hydraulic engineers for open channel analysis in support of flood studies, system analysis/design and master planning.

4.1(a) Manning's 'n' Roughness Coefficients

Manning's 'n' is a measure of channel resistance to the flow of water within it. Smoother channel surfaces have lower coefficient values; rougher surfaces will have comparably higher values. For example, a new concrete-lined channel would be assigned a Manning's 'n' value of 0.011 to 0.013 (dimensionless). A natural, winding stream channel with some pools and shoals could be assigned a value of 0.033 to 0.045. (Brater & King,1976) The proper determination of Manning's 'n' is not an exact science and therefore requires specific background, expertise and professional experience when providing a designation.

A Manning's 'n' of 0.07 was used in the NHC HEC-RAS model for all channel and over-bank sections. The NHC hydraulic analysis report includes a number of photographs documenting the surface conditions along the study reaches. Thick desert shrub appears to be prevalent within, and adjacent to, many of the channels illustrated. **Review of the available data indicates that this value appears to be within an acceptable range, although on the very high end of the range. It is common for channel 'n' values to be one-half (e.g., 0.035) of the 0.07 'n' value used in this report. Further review of the watershed conditions and the use of varying channel and overbank 'n' values are recommended.**

4.1(b) Culverts Not Modeled

The hydraulic analysis report indicates that there are five culverts along the reaches modeled within HEC-RAS (one along Bobwhite Wash, three along Calle Hermosa Wash and one of Calle de Asco Wash). It is stated that the culvert diameters are all 24-inches or less and none of the structures are included within the model. [Refer back to section 3.6 - Storage Routings for review comments also applicable to this section.]

Although the culverts and roadways were not included within the model, page 13 of the *Hydraulic Analysis, Douglas County, Nevada* indicates that cross sections were added to the model geometry file at the crossing locations to "simulate the obstruction posed by the road embankments".

4.1(c) Contraction/Expansion Coefficients

Contraction/expansion coefficients (dimensionless) were set at 0.1 and 0.3, respectively, for all river reaches within the NHC HEC-RAS model. This is indicative of waterways that contain no crossings or abrupt physical changes within the channel flow regime. The potential issue with the generalized application of these coefficients is that the effects of the existing culvert crossings in the study area may not properly accounted for in the model's solution of the base flood elevations and floodplain limits.

4.1(d) Peak flow discrepancy at River Station 1455 along Buckeye Creek

At River Station (RS) 1455 along the lower reach of Buckeye Creek, a 100-year peak flow of 8,206 cfs is coded into the NHC HEC-RAS model. This flow is markedly higher than the 6,890 cfs calculated at HEC-HMS model node "BC-OUT", which is at the same location as RS 1455 in the HEC-RAS model. This issue is discussed further in the "MIKE21 Modeling" section below.

4.2 MIKE21 MODELING

Within the lower reaches of the study area, where alluvial fans and braided streams are present, NHC performed the hydraulic modeling using MIKE 21. MIKE 21 is a professional engineering software package containing a comprehensive modeling system for 2D free-surface flows. MIKE

21 is applicable to the simulation of hydraulic and related phenomena in lakes, estuaries, bays, coastal areas and seas where stratification can be neglected.

4.2(a) Buckeye Creek Inflow Hydrograph

Manhard reviewed the inflow hydrographs, specifically the peak values, used in the MIKE21 modeling. It was determined that all reaches modeled in MIKE21 incorporated inflow hydrographs that were compatible with the computed HEC-HMS peak flows. **The exception to this case is the Buckeye Creek model**. Table 3.1 on page 35 of the NHC hydraulic report states a value of 8,206 cfs was used as the peak discharge in the Lower Buckeye Creek HEC-RAS analysis. Accordingly, Figure 4.7 on page 50 of the report includes a graphical illustration of the inflow hydrograph of Buckeye Creek. The value depicted in the graph for a peak flow of 8,206 cfs is noted as the **500-year event**, while the 100-year event appears to be accurately plotted to depict a value of 6,890 cfs, which is consistent with the HEC-RAS peak flow determination at that location.

If the Buckeye Creek floodplain and all associated downstream areas were delineated based on the inflow of 8,206 cfs, the resultant base flood elevations and floodplain limits would be overestimated.

4.2(b) Culverts Not Modeled

Similar to the methodology used in the HEC-RAS model, no culverts were included within the MIKE21 models. NHC performed a sensitivity analysis to determine what effects the inclusion of certain larger culverts would have upon the flood depths. The conclusion was made within the report that the differences in the modeling results "appear to be rather insignificant and do not affect flood zone designations" (page 26).

4.2(c) Manning's 'n' Roughness Coefficients

Consistent with the methodology used in the HEC-RAS model, Manning's 'n' of 0.07 was used as the "resistance" value for all simulations. NHC performed a sensitivity analysis to determine what effects varying the values would have upon the resultant flood depths. The conclusion was drawn within the report that the "differences in the modeling results caused by varying surface roughness appear to be insignificant" (page 25).

5.0 Results and Conclusions

The results of the Peer Review can be concluded by the following primary observations and concerns relating to the NHC modeling efforts:

1. The NHC study states the model was calibrated to the results of USGS regression equations for the same watersheds. This approach is highly questionable, even in accordance with the literature supporting the equations, as the USGS Regression Equations are known to poorly predict peak flow runoff rates for watersheds in the mountainous areas of northern Nevada. A better approach to calibrating the model would be to use the available precipitation and streamflow data for corresponding storm events recorded within the subject watersheds.

2. The use of NOAA Atlas 14 precipitation data requires additional investigation. This includes the depth values assigned to different storm return periods and the use of the data for both the 3-hour and 24-hour storm distributions. These input parameters may

have the most significant influence on resulting peak runoff flow rates from the watersheds and corresponding flood hazard zone mapping efforts under consideration.

3. The NHC model used a simplified approach of assigning the same precipitation depths to all defined subbasins with the studied watersheds. This approach may lead to overestimation of modeled peak runoff flow rates and volumes. A more appropriate method would be to define individual precipitation depths for each subbasin in accordance with the changing rainfall patterns and intensities witnessed across the watersheds.

4. The NHC model relied upon a constant peaking factor for the SCS Unit Hydrograph transformation that could be refined for flatter and steeper subbasins. This refinement should lead to more robust modeling results and may contribute to the calculation of reduced peak runoff flow rates for the watersheds under consideration.

5. The hydraulic routing of stormwater runoff hydrographs in the NHC model excluded existing roadway culverts and impoundments and included Manning's roughness coefficients that could be considered out of range. Appropriate revisions to the model and its modeling parameters would lead to a more realistic hydrologic simulation of the watershed as it exists and would likely generate peak runoff flow rate reductions.

6. It appears the hydraulic modeling for Buckeye Creek includes an error that may cause an additional 1,300 cfs of peak flow to be hydraulically routed downstream. This may lead to an overestimation of all base flood elevations and flood hazard inundation zones within Buckeye Creek and all associated conveyances downstream.

6.0 Recommendations for Next Steps

The following steps are recommended in accordance with the findings summarized herein:

1. An extensive effort should be made to coordinate NOAA Atlas 14 precipitation data for use in modeling of design storms with the National Weather Service for the subject watershed. In particular, a determination of the appropriate use of confidence interval bounds should be made and an attempt learn more about the data and methodology employed to create the two "homogenous regions" within which the Pine Nut Mountain range seems to be marginalized. Also, an understanding needs to be reached with the NWS as to how the NOAA 14 data reflects storm types – "general" storms vs. "convection" storms – and an approach to modeling short duration events, if needed, should be developed with relation to NOAA 14 data.

2. A dynamic rainfall-runoff model needs to be developed so that the watershed input parameters can be optimized and the model can be calibrated, using corresponding rainfall and streamflow records, to the measured 1992, 1994, 1995, and 1997 events. This will lead to a reasonable and defensible approach to parameter optimization and model calibration for the watershed under consideration. This model should also include approaches to hydrologic and hydraulic storage and channel routing consistent with standards of practice, including the modeling of culverts and impoundments.

3. As a result of the development of appropriate precipitation data and a calibrated watershed model, the 100-year flood hazard zones should be re-evaluated throughout the study area within Douglas County and remapped as warranted.

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