NEW MEXICO OFFICE OF THE STATE ENGINEER
Dam Safety Bureau
Hydrologic Analysis for Dams
August 15, 2008

Hydrologic analysis requirements for dams are cited in the Rules and Regulations Governing Dam Design, Construction and Dam Safety, which were filed with the New Mexico State Record Center as Title 19, Chapter 25, Part 12 of the New Mexico Administrative Code (19.25.12 NMAC). Hydrologic analysis shall be performed in accordance with Subsection C of 19.25.12.11 NMAC. The design life of a dam is much longer than the record retention period of most engineering firms and memories of most design engineers. It is important that the analysis stand on its own in a manner that is comprehensible to future engineers who may be involved with the structure. Therefore, the Office of the State Engineer (OSE) requires that the hydrologic analysis be fully documented and supported independent of computer programs or other computational methodology used in the analysis.

Most dams are constructed on a watercourse or have a contributing drainage area upstream from the dam. Intense rainfall creates inflow to the reservoir of the dam, which is routed through the reservoir and allowed to pass the dam through a spillway or multiple spillways. Earlier dams typically were provided with spillways that were sized to pass the largest observed floods. These dams frequently overtopped and failed, and roughly half of all known dam failures have been the result of flood overtopping. During the 20th Century, methods were developed to better evaluate infrequent or extreme flood events, and provide adequate spillway capacity to safely pass these floods. Hydrologic analysis is one of the most important aspects in the design of a safe dam, and will be closely reviewed by the New Mexico Office of the State Engineer (OSE) Dam Safety Bureau.

Presented below is an outline of the typical steps for completing a hydrologic analysis satisfying the requirements outlined in Subsection C of 19.25.12.11 NMAC. In order to facilitate review by the OSE Dam Safety Bureau the hydrologic analysis report must be organized in an easy to follow layout and format. Submittals that are not consistent with this document and the requirements outlined in Subsection C of 19.25.12.11 NMAC will cause a delay in the review by the OSE Dam Safety Bureau and may be returned to the owner with no review provided. Inadequate hydrology submittals may also require review fees to be resubmitted prior to subsequent review by the OSE Dam Safety Bureau.

The following steps are typically required in completing hydrologic analysis for dams for submittal to New Mexico Office of the State Engineer:

1. Determine hazard potential classification for the dam location.
2. Determine appropriate design storm requirements for location.
3. Determine geographic location, limits and area of watershed contributing to dam and reservoir.
4. Divide watershed into subbasins as appropriate, and determine subbasin areas, channel locations for routing, etc.
5. Determine basin or subbasin geometry such as longest flow path for each basin or subbasin, channel slope and cross section, highest and lowest points, basin centroid(s), mean basin elevation, etc. as required for methodology to be used.

6. Determine appropriate timing and routing parameters for the elements in the watershed model.
7. Determine reservoir characteristics including stage-storage and stage-discharge relationships.
8. Develop total watershed model by arranging subbasins, routing reaches, etc. in the proper sequence with appropriate parameters.
9. Derive the precipitation to be used for design.
10. Develop incremental precipitation from depth-duration relationship and arrange increments to create an appropriate temporal distribution of precipitation.
11. Develop spatial distribution of precipitation if appropriate.
12. Determine loss parameters or functions and apply to incremental precipitation.
13. Deduct losses from precipitation increments to estimate precipitation excess.
14. Select an appropriate transform methodology for converting excess rainfall to runoff.
15. Apply the transform methodology to each subbasin using incremental precipitation excess.
16. Add stream base flow, etc., to obtain flood hydrograph for each subbasin.
17. Combine and/or route subbasin hydrographs to determine the inflow design flood.
18. Route flood through reservoir and spillway to obtain estimates of reservoir peak stage, peak outflow, peak storage, flood duration, etc.
19. Review results for reasonableness, comparing to known floods or otherwise calibrating if possible.
20. Adjust model parameters, spillway characteristics, etc. as necessary and appropriate and repeat process.
21. Prepare hydrologic analysis report for OSE review and for the permanent record.

Discussion:

The steps taken in the analysis, along with assumptions made and parameters used, must be fully documented. Documentation requirements are discussed in the final section of this paper. Discussion of each of the steps for performing hydrologic analysis is as follows:

1. Hazard Potential Classification

Hazard Potential Classification is a function of dam location and downstream conditions, and is not a measure of the integrity of the dam or the adequacy of the design. High hazard potential classification applies if loss of life is probable if the dam fails catastrophically. This is usually fairly obvious, based on downstream development conditions. In some cases, breach and flood wave analysis is needed to establish hazard potential classification. If site is not High hazard potential, in most cases it will be Significant, due to substantial risk to property or assets (highways, barns, irrigation ditches, etc.) or potential for significant environmental consequences. Low hazard potential is typically limited to remote, small structures such as ranch ponds for cattle watering and limited irrigation. Flood control dams typically are High or Significant hazard potential, because the need to control flooding suggests life and/or assets being protected downstream. Evaluations for Low or Significant hazard potential dams must consider the potential for future downstream development.

2. Design Precipitation Requirements

Generally, high hazard potential dams require consideration of Probable Maximum Precipitation (PMP). Significant hazard potential dams require consideration of 50% PMP if 100 feet or less in height and having 50,000 acre-feet or less storage, or 75% PMP if greater than 100 feet in height or having over 50,000 acre-feet of storage. For significant hazard potential dams, percentages are applied to precipitation prior to hydrologic analysis. Low hazard potential dams require consideration of 100-year storm, expressed as a percentage of PMP. Therefore, most dams will require evaluation of PMP. In some cases, waiver of evaluation of PMP will be entertained for low hazard potential dams with no realistic possibility for future hazard potential change.

In addition to precipitation requirements for spillway design, flood control dams must be able to drain from spillway crest or 100-year, 24-hour peak reservoir level within 96 hours. This implies determination of 100-year, 24-hour precipitation in most cases. For high and significant hazard potential flood control dams conforming to local flood control authority or NRCS requirements for 100-year, 24-hour flood routing, OSE will defer to these requirements for determination of compliance with the 96-hour rule.

3. Watershed Location, Limits, and Area

Watershed location, limits and area have traditionally been obtained from 7-1/2 minute USGS quad maps by tracing the divide, and then determining the area by planimeter or other measurement. For smaller drainages, a site topo map is sometimes used. Recent analyses frequently use ArcView or other GIS software in conjunction with DEM or DTM. Determination of precipitation will require geographic location (latitude and longitude) of the approximate basin centroid or a georeferenced perimeter at an appropriate scale. Methodology used must be described and supported as appropriate. Drainage area for existing dams must be independently verified rather than relying on area indicated on drawings or in design report, particularly for older dams. Precipitation depths may require adjustment based on watershed area. Average elevation of the watershed is needed for determination of Local Storm PMP.

4. Subdivision of Watershed

Logical subdivision can be made where topography or surface features and development are dissimilar. SCS methodology would suggest maximum subbasin size of about 20 square miles. USBR – Cudworth recommends 500 square miles maximum area per subbasin. Subbasin areas should be reasonably similar – for example, don’t combine 20 square mile and 0.5 square mile subbasins in the same model if you can help it. Avoid dividing into unnecessary subbasins, as this complicates the model and usually does not improve results. Particularly, avoid overdividing small basins, such as dividing 5 square miles into 20 subbasins. Subbasins should generally correspond with logical junction points and routing reaches.

5. Basin and Subbasin Geometry

Specific information required will depend on methodology used for timing parameters and runoff transform. Typical requirements might include length of longest watercourse, length to a point opposite the basin centroid, watercourse slope, average basin slope, estimated length of overland flow, length, slope, and cross-section of channel reaches, etc.

6. Timing and Routing Parameters

Typical parameters may include time of concentration, lag time, time-to-peak, time of travel, kinematic wave travel time, channel geometry and roughness, etc. depending on requirements of the transform methodology and channel routing used. To add to confusion, a parameter may be defined in different ways for different methodologies, even if the name is the same. The parameter(s) used must be appropriate for and compatible with transform methodology as defined within that methodology. Also, assumptions or limitations for the timing parameters must be consistent with the watershed being studied. These may include basin size or watershed length, channel condition (natural vs. improved or hardened), degree of development, etc. Method of determining timing and routing parameters must be indicated and justified as appropriate for location and transform methodology, with sample derivation and references.

7. Reservoir Characteristics

This may be developed as elevation-area or elevation-storage, depending on modeling requirements or input parameters for the method used. However, OSE Rules and Regulations require reservoir characteristics to be reported as elevation-storage table in one-foot intervals. Water storage reservoirs generally are assumed to be full to the point of uncontrolled discharge, e.g. spillway crest. Flood control dams with uncontrolled outlets and no permanent storage generally are assumed to be empty at the start of the modeling period.

8. Watershed Model

The basin and subbasin geometry and characteristics, routing reaches and parameters, reservoir characteristics, etc. are assembled to create the watershed model for the dam. It is useful to create a schematic or flow chart for the watershed model, particularly if software being used does not provide a graphical or schematic representation. A schematic or graphical representation of the model and tables of relevant model parameters will be required in the report submitted to OSE.

9. Precipitation Derivation

PMP east of the Continental Divide is derived using methodology of HMR 55A, PMP west of the Continental Divide is derived using HMR 49. Both HMR documents provide for 1) a Local Storm (thunderstorm), with 6 hours total duration, and 2) a General Storm, with 72 hours duration. Neither HMR includes procedures or allowances for durations less than the complete storm, such as a 1-hour thunderstorm or a 24-hour general storm. If a shorter duration is used, justification must be provided.

Concerning durations less than the complete storm, FEMA as quoted in City of Albuquerque *Development Process Manual* states, "FEMA's position regarding the duration of rainfall is that the storm must extend for a period long enough to include all rainfall excess when the volume of the runoff hydrograph is an important consideration. This includes conditions when detention storage is involved, when sediment processes are a significant factor, and when combining and routing subbasin hydrographs to obtain watershed runoff. When the peak flow is the primary concern, and it is established that the use of a longer duration storm would not increase the peak flow, shorter duration storms are acceptable." This would suggest that using the most intense 24 hours of the General Storm would only be appropriate if it can be shown that no excess precipitation will occur outside of this period, or if it can be shown that the peak flow is not sensitive to storm volume if peak flow is the primary concern.

Both HMR documents require obtaining index precipitation from maps, and then adjusting precipitation depths for area, elevation, and orographic effects specific to the watershed being studied. The index precipitation depths are plotted against duration to develop a smooth depth-duration passing through the origin. Area adjustments typically are based on the total contributing area above the dam or other point of interest, rather than on individual subbasin areas. Since precipitation depth for PMP is adjusted for storm area during the derivation, no additional reductions should typically be taken during the hydrologic analysis.

The 1984 reprint of HMR 49 contains an Errata sheet following the title page. The entry for page 154 on this Errata sheet changes the basis for local storm elevation adjustments from the lowest elevation in the drainage to the mean elevation. This generally will result in greater reductions in precipitation depth for cases where the elevation adjustment applies. This change is not well documented anywhere else in the literature. Electronic versions of HMR 49 not containing this correction may still be available online.

Both Local and General Storm should be evaluated, unless clear evidence and justification can be provided showing that one storm or the other obviously controls. For example, in the Eastern portion of the New Mexico HMR 55A area, the 1- and 6-hour ordinates for the General Storm frequently are greater than the 1- and 6-hour ordinates of the Local Storm. Conversely, in certain locations of HMR 49 where the orographic component of General Storm precipitation is low, total storm volume for the General Storm can be less than the Local Storm. In most other cases, it is not sufficient to simply compare precipitation depths, since routing effects may result in greater spillway discharge from the General Storm, even though the Local Storm precipitation depths are greater at 1 and 6 hours.

Alternatives to HMR 49 and HMR 55A include site-specific analysis for PMP and Incremental Damage Assessment, either of which should be discussed first with OSE. In the future, an Extreme Precipitation Analysis Tool may be available for portions of the state, to provide an updated estimate of extreme precipitation.

Precipitation for frequency-based events, such as the 100-year storm, is obtained from NOAA Atlas 14, available online. Precipitation is obtained by latitude and longitude, and is point precipitation. The precipitation values from Atlas 14 are considered appropriate for storm areas of 10 square miles or less, and the full precipitation depth should be used for watersheds less than 10 square miles. For larger areas, an approved procedure for reducing precipitation based on area may be applied. The online documentation for Atlas 14 does not provide areal reduction factors specific to Atlas 14, but instead references three possible sources:

1. NOAA Atlas 2, *Precipitation-Frequency Atlas of the Western United States*, 1973. This method was originally presented in Technical Paper No. 40, *Rainfall Frequency Atlas of the United States*, U.S. Weather Bureau, 1961, and is incorporated into the Frequency Storm methodology in HEC-1 and HEC-HMS.

2. Technical Report 24, *A Methodology for Point-to-Area Rainfall Frequency Ratios*, NOAA, 1980.
3. Technical Memorandum HYDRO-40, "Depth-Area Ratios in the Semi-Arid Southwest United States," NOAA, 1984.

These methods will allow reductions for areas less than 10 square miles; however, Atlas 14 seems to recommend using the point precipitation values for 10 square miles or less. If areal reductions are made for drainage areas less than 10 square miles, justification must be provided. Areal reductions for frequency storms should be based on the total watershed contributing to the point of interest, and not on individual subbasin areas. For watersheds with total area exceeding the limits of the reduction method (400 square miles for NOAA Atlas 2/U.S. weather Bureau Technical Paper 40) the services of a qualified meteorologist may be necessary to determine appropriate reductions of point precipitation.

10. Precipitation Increments and Distribution

Precipitation increment size should generally correspond to the computational time step used, although this is not mandatory for many computer programs including HEC-HMS. Increments are obtained from the depth-duration curve by subdividing the curve by increment length and successively subtracting curve ordinates. For small, fast basins in particular it is important to use a sufficiently small increment size and computational time step to avoid under-prediction of peak runoff.

Once the increments have been determined, they must be arranged in an appropriate distribution. One of the most common arrangements sometimes called "center-peaking" or "balanced" distribution, places the largest increment at the center of the storm duration. The second largest increment is placed directly in front of the first, the third largest placed behind the first, and the procedure is continued with successively smaller increments until the distribution is filled. A similar distribution, favored by Bureau of Reclamation for 72-hour general storm PMP, can be termed "late-peaking." This distribution places the largest increment at the 2/3 point of the storm, then places the second and third largest increment successively in front of the largest increment, then the fourth largest increment immediately behind the largest increment, then continuing the sequence with two increments in front, one behind until the distribution is filled and all increments are used. Either the center-peaking or late peaking distribution will be acceptable for 72-hour General Storm PMP.

Both HMR 49 and HMR 55A refer to two recommended distributions for the 6-hour Local Storm. One is obtained from HMR 5, and the other from the USACE EM1110-2-1411. The distributions are similar, with the USACE EM1110-2-1411 distribution peaking later in the storm. HMR 49 states, "In application, the choice of either of these distributions is left to the user since one may prove to be more critical in a specific case than the other." This suggests that both methods should be evaluated and the more critical distribution should be used. In practice, the USACE EM1110-2-1411 appears to provide the higher peak discharge in the majority of cases. While not specifically discussed in either HMR 49 or HMR 55A, a center-peaking distribution of local storm PMP has been used in the past and is acceptable to OSE. In any case, the distribution used must be justified as being appropriate for the specific drainage area being evaluated.

The center-peaking and late-peaking distributions described above are frequently approximated in HEC-HMS or HEC-1 using the Frequency Storm definition for precipitation. Using the Frequency Storm to distribute PMP can cause unintended consequences if one is not careful, and probably should be avoided by infrequent users. The Frequency Storm requires input of precipitation depths for durations corresponding to the frequency series of 5 min, 15 min, 1 hour, 2 hours, 3 hours, 6 hours, 24 hours, 48 hours, etc. The frequency series does not include a 72-hour duration, and so will not emulate the full General Storm PMP. The General Storm index values from HMR 55A do not include values for 5 min, 15 min, 2 hour, 3 hour, or 48 hour durations, and the index values from HMR 49 do not include 5 min, 15 min, 1, 2, or 3 hour values, requiring values to be interpolated or read from curve plots, introducing a possible source of error. The Frequency Storm method can result in unintended reductions of precipitation due to inappropriate use of Storm Area and Probability inputs in HEC-HMS and HEC-1. It is probably best to discuss with OSE before using the Frequency Storm to distribute PMP.

In cases where 100-year precipitation is required (primarily for low-hazard potential dams) the preferred distribution is a center-peaking distribution based on the frequency series from NOAA Atlas 14. The Frequency Storm functions in HEC-HMS, HEC-1, and possibly other programs, are suitable and are intended for this type of storm. Since the precipitation from Atlas 14 is point precipitation, reductions for storm area may be taken as appropriate. The common SCS Type II distribution used for most of the US east of New Mexico will not be appropriate in New Mexico in most cases. The Type IIA distributions used by NRCS in New Mexico may be appropriate, but it is recommended that their use be discussed with OSE prior to using these distributions.

The following distribution methods, which have all been used in submittals to OSE, are not generally appropriate:

- Using the depth-duration curve as the distribution.
- Straight-line distribution of equal increments throughout the storm or during peak periods of the storm.
- Using SCS Type II or NRCS Type II-a distribution for PMP.
- Compressing SCS or NRCS distributions for durations less than 24 hours
- Using a Huff distribution.

11. Spatial Distribution of Precipitation

Spatial distribution of precipitation intensity within a basin through use of isohyetal storm patterns is typically done only for relatively large basins. This method is not common in submittals to OSE, and the services of a qualified meteorologist is required if this method is used. The method is illustrated in HMR 52, which contains information for applying this method east of the 105th meridian, comprising roughly the eastern third of New Mexico.

The more typical submittal applies precipitation uniformly across the basin, with reductions in precipitation depth for larger areas as appropriate. The reductions in these cases are applied during the derivation of precipitation using HMR 49 or HMR 55A. When the isohyetal method of spatial distribution is used, the full index precipitation is used without reduction, since reduction is effected by application of the isohyetal pattern.

12. Loss Function Parameters

Not all of the precipitation that falls is available to generate runoff. The primary losses to precipitation are interception, evaporation, retention, and infiltration. The first three of these are grouped, along with part of the infiltration loss, and termed "initial losses." For large, infrequent events such as the PMP, initial losses are relatively low compared to infiltration losses, and are assumed to have occurred due to antecedent rainfall prior to the start of the PMP. Therefore, initial losses are commonly neglected in evaluating PMP. Common loss characterizations include SCS curve numbers, initial/constant loss rates, exponential losses, and Green-Ampt method. Other methods are available as well. SCS curve numbers are typically used with SCS hydrograph methodology, and are not recommended for other hydrograph methods. Initial/Constant loss rate methodology is used with USBR and other unit hydrograph methods. Green-Ampt and exponential methods have not been frequently used in submittals to OSE. Parameters must be justified, both in terms of appropriateness for basin conditions (soil and vegetative cover or land use) and appropriateness with the selected transform methodology. For PMP, loss rates frequently are lower than those used with typical return frequency storms such as the 100-year event. Constant loss rates in excess of 0.5 inches/hour will require adequate supporting justification. Typical loss rates for the four SCS soil groups are as follows:

SCS Soil Group	Descriptive Characteristic	Ultimate Infiltration Rate
A	Low Runoff Potential	0.3 to 0.5 inches/hour
B	Moderate Infiltration Rate	0.15 to 0.30 inches/hour
C	Slow Infiltration Rate	0.05 to 0.15 inches/hour
D	High Runoff Potential	0 to 0.05 inches/hour

Source: USBR *Flood Hydrology Manual*, 1989, P. 112

13. Precipitation Excess

Determination of precipitation excess typically is embedded in hydrology software program, but is a straightforward step that can be assumed to be handled correctly with reputable software. The total rainfall excess must be determined and reported, in addition to instantaneous peak discharge. As a rule of thumb for General Storm PMP, rainfall excess less than 70% of total storm volume for 72-hour precipitation depth greater than 25 inches, or less than 60% of 72-hour storm volume for total precipitation depth less than 25 inches, will require justification. Loss parameters and precipitation increment size and distribution can have significant effect on rainfall excess.

14. Transform Methodology

The most common transform methodology is some sort of synthetic unit hydrograph procedure. SCS is fairly common, but may not be the best choice for PMP of extreme storms. SCS parameters are interrelated, and any deviation from the methodology (e.g. Initial-Constant loss rates rather than Curve Numbers) must be justified. The USBR *Flood Hydrology Manual* methodology is also commonly used. USBR is developed for the West, and has three regional unit hydrograph lag relationships that apply within New Mexico: "Great Plains," "Rocky

Mountains," and "Southwest Desert, Great Basin, and Colorado Plateau." Additionally, the Manual contains information for urban basins. It is important to select the correct relationship for the watershed being evaluated. Other unit hydrograph procedures include Clark's and Snyder's unit hydrographs. If these are used, parameters must be provided and justified. User-specified unit hydrographs or other relationships derived from gaging records are possible, but submittals to OSE using these methods have been rare. SCS, Clark's and Snyder's unit hydrographs are available in HEC HMS, and parameters must be provided and justified but unit hydrographs need not be provided. IF USBR methodology or other user-specified unit hydrographs are used, unit hydrograph ordinates must be provided. Kinematic Wave methodology is sometimes used, and is probably most suitable where the watershed can be conveniently be described as rectangular plane surfaces draining into lateral channels. Other distributed-model methodologies may exist or emerge, and should probably be discussed with OSE before submittal.

15. Application of Transform Methodology for Each Subbasin

For computer-based analysis, this is primarily a matter of properly configuring subbasin models and hydrologic parameters within the program.

16. Evaluation of Base Flow

In New Mexico, stream base flow is usually minimal or non-existent except in response to storm events. A possible exception might be snowmelt in mountainous regions. The USBR *Flood Hydrology Manual* discusses modeling base flow and snowmelt. If base flow in the stream will contribute significantly to the hydrograph, it should be considered, and base flow modeling assumptions documented. It may be desirable to model a token base flow if the resulting flood hydrograph will be analyzed in a program such as HEC-2 or HEC HMS for downstream water surface profiles under unsteady-flow conditions.

17. Hydrograph Combining and Routing to Determine IDF

Combining and routing is generally done by the computer model. Model input and output must be carefully scrutinized to make sure that the model is performing as intended

18. Reservoir Routing

Stage-storage information used in routing must be provided; the Rules and Regulations require this to be in elevation intervals of 1 foot. Outlet and spillway capacity rating curve or table must be developed and provided. Relying on older, previously generated rating curves without independently verifying their appropriateness is not acceptable. Spillway capacity is most frequently based on the Weir Equation, $Q = CL(H)^{1.5}$, Where Q is discharge, L is weir length perpendicular to flow, H is head on the weir typically taken as reservoir elevation minus weir elevation, and C is a discharge coefficient for the weir. The weir equation is only appropriate if flow passes through critical depth over the weir and supercritical flow will be present a sufficient distance downstream from the weir that backwater effects will not constrain flow over the weir. If supercritical flow is not assured, then a backwater analysis such as HEC-2 or HEC-RAS is needed to validate spillway capacity. Also if a significant channel exists between the weir and the reservoir, a backwater analysis is needed to confirm that the reservoir stage remains below the dam crest at the anticipated spillway capacity. Care must be exercised in selecting the coefficient C, as it is not constant with respect to flow depth and is sensitive to geometry of the spillway crest and entrance. Textbook values for typical broad-crested and ogee weirs may not be appropriate. The most common error is to select too high of a coefficient, for example, 3.0 or 3.1 for an open-cut spillway for which 2.6 or 2.7 may be more appropriate.

19. Review of Results for Reasonableness

It is tempting to assume that if the computer program gives an answer and doesn't crash that this is the correct answer. In reality, the computer is not especially intelligent and will do exactly what you tell it to, whether this makes any sense or not. This is not just a matter of "garbage-in, garbage-out." Sometimes, parameters that are in the ballpark when taken individually can compound to skew results in one direction or another. Also, sometimes the program will perform functions not intended by the analyst, such as inappropriate reduction of precipitation for storm area, if you do not tell it exactly what you want and understand the significance of program defaults. Therefore, a review of intermediate steps and final results for reasonableness is important. Calibration of the hydrologic model for PMP is difficult since storms approaching this magnitude are rare. Calibrating against lesser storms such as the 100-year or smaller events may not be appropriate for PMP. Reasonableness of results compared to past experience with similar input parameters may be the best tool available. It is important not only to ensure that the spillway design flood is not underestimated for reasons of public safety, but also that it is not overestimated for reasons of economics. Often, the predicted flood is significantly less probable than the precipitation, which in the case of PMP already has an essentially indefinable but extremely low probability. In some cases, particularly for rehabilitation projects, this can have a substantial impact on project costs.

20. Adjustment of Model Parameters

Based on review of results for reasonableness, it may be appropriate to adjust parameters and recalculate. This will obviously be necessary if the selected spillway turns out not to be adequate for the computed flood. Sensitivity analysis with respect to critical parameters is sometimes useful in forming an opinion with regard to the appropriateness of the result.

21. Hydrologic Analysis Report

Assuming the hydrologic analysis has included the required steps previously discussed, it is important that the methods and parameters used, the results obtained, and supporting justification be documented in a coherent report. This will allow OSE staff to verify that regulatory requirements for hydrology have been satisfied and evaluate whether the proposed design adequately addresses the required design storm. A secondary, but equally important purpose is to provide documentation of methods and assumptions to assist future engineering consultants and OSE staff in understanding the basis for design and assessing adequacy and safety of the structure. Personnel can turn over rapidly, analysis methods change over time, and the structure will almost certainly outlast both the designers and their methods. The hydrology report will serve as a guidance document to help future engineers understand the analysis. As a general principle, the information submitted must be adequate to allow an independent analyst, possibly at some point in the future, to replicate the analysis with comparable results. The information must be transparent and independent of the software program used for computation. The following are some of the items required in the report and supporting documentation:

1. Identification of the hazard potential classification, and any assumptions used in determining this classification. If the classification is anything other than High, supporting documentation, potentially including breach analysis and flood studies, may be required.
2. Determination of appropriate design precipitation based on hazard potential classification and size of structure. Provide detailed analysis report if design precipitation is based on incremental damage assessment or site-specific PMP study, either of which must be discussed with OSE in advance.
3. Location map and topographic map of drainage area contributing to the dam and reservoir, with drainage boundary and total area indicated.
4. Map indicating subbasin boundaries with areas indicated, hydrograph combination points, channels for routing, etc. This may be superimposed on the topographic map described in 3. above if of suitable scale.
5. Table of relevant basin and channel characteristics to be used in the analysis as dictated by the selected analysis methodology, including flow path lengths, centroid distances, mean basin elevations, channel slope, roughness, and cross-section, etc.
6. Discussion of timing and routing parameter derivation including methods or equations used and their applicability to this particular project, example calculations, and summary tables of input data and computed parameters.
7. Narrative discussion of watershed model accompanied by schematic showing the interrelation of various components of the model.
8. Elevation-storage and elevation-discharge tables for reservoir, outlets and spillways. These should be in 1-foot increments unless the dam is very high, in which case the appropriate interval must be discussed in advance with OSE.
9. Worksheets for Local Storm and General Storm PMP derivation from HMR 49 or 55A as appropriate. For Low hazard potential dams, copies of tables from NOAA Atlas 14 website, indicating latitude and longitude of point precipitation, must be included.
10. Table of distributed precipitation increments, distribution curve and/or hyetograph illustrating graphically how precipitation is distributed, and narrative describing and justifying the methodology for distributing precipitation.
11. If spatial distribution is used, full documentation of methodology and assumptions by qualified meteorologist is required.
12. Discussion of loss methodology and documentation of derivation of parameters, tables of soil and land use areas and percentages for each subbasin, and justification of the appropriateness of the parameters and methodology in the context of the overall analysis.
13. Table or graph of precipitation excess for each increment for which excess exists, and identification of total precipitation excess in inches and percentage of rainfall.
14. Discussion of transform methodology used. Coefficients or parameters for common synthetic unit hydrograph procedures (e.g. SCS. Snyder, Clark). If other than a common synthetic unit hydrograph procedure is used, unit hydrograph ordinates must be provided.
15. Table or computer echo of input parameters, with parameters identified or notated for each subbasin, routing reach, or other element.
16. Discussion of base flow or snowmelt methodology or considerations.
17. Table of combining and routing results, supported by computer output. Results must be concurrent with model schematic discussed in 7. above.

18. Elevation-storage and elevation-discharge tables for the reservoir in 1-foot increments, and table of routed hydrograph ordinates with peak inflow to reservoir and routed peak outflow identified. Inflow and outflow hydrographs plotted on same figure of appropriate scale.
19. Discussion of reasonableness of results, including any calibration or comparison information available.
20. Discussion of any parameter adjustments or sensitivity analysis performed in order to validate or improve reasonableness of results.

Special Case – Perimeter Dams:

An increasing number of dams regulated by OSE are perimeter embankments with no contributing watershed outside of the reservoir, interior slopes, and embankment crest. These dams may include wastewater pond dams, industrial evaporation pond dams, municipal raw water storage dams, tailings dams, etc. Water or potentially mobile contents are pumped or discharged to the reservoir as part of a controlled process.

For these perimeter dams, hydrology typically is greatly simplified. The contributing area (reservoir surface, interior slopes, and crest) is determined, and the design precipitation depth is applied to this area to determine the volume contribution of the storm to the reservoir. Where the design storm is all or a percentage of the PMP, the General Storm 72-hour index precipitation should be used. Losses are neglected, and the full precipitation depth is treated as excess contributing to the reservoir. In most cases, storage for this volume of water is provided above the normal maximum water level, with additional freeboard above flood stage to satisfy the freeboard requirements of OSE Rules and Regulations. In some cases, a spillway may be designed to allow routing and discharge of some of the flood volume, thereby reducing embankment height above normal maximum water level.

In addition to water from extreme precipitation events, perimeter embankments are susceptible to misoperation, where discharge into the reservoir continues past the design maximum reservoir level and eventually overtops the embankment, resulting in failure. For this reason, perimeter embankments must be provided with an overflow section with capacity equal to or greater than the discharge capacity into the reservoir, so that misoperation or failure of reservoir controls does not lead to embankment failure.

References:

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NOAA, USACE Hydrometeorological Report No. 49 (1984), *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages*.

NOAA, USACE Hydrometeorological Report No. 52 (1982), *Application of Probable Maximum Precipitation Estimates – United States East of the 105th Meridian*.

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