Draft Letter Report
Hydrologic Design Criteria Study
Lake Tahoe Basin, Nevada & California

SWQIC
Lake Tahoe Storm Water
Quality Improvement Committee

US Army Corps
of Engineers ®
Sacramento District

December 2006

1.0 Purpose: This letter report provides a description of the products produced for the Lake Tahoe Hydrologic Design Criteria Study by the U.S. Army Corps of Engineers. Technical users of the Corps products are directed to the Corps Summary Report (SPK, 2007) for more detailed guidance. The purpose of the study was to provide recommendations and tools for standardizing and improving hydrologic design methods within the Lake Tahoe basin. The products can be useful for traditional drainage design (e.g. storm drains) or for design of Best Management Practices (BMPs) such as detention basins for improving water quality. These recommendations are based on an analysis of current engineering practice in the basin, a review of recent scientific studies considered pertinent to Lake Tahoe, and detailed studies of the hydrologic characteristics for the study area. This study was initiated at the request of the Lake Tahoe Storm Water Quality Improvement Committee (SWQIC). The Corps Scope of Work (refer Table 1), negotiated and approved in coordination with SWQIC, did *not* include the development of a new Drainage Design Manual. The myriad of details typically provided in a Drainage Design Manual are beyond the scope and funding of this study. Rather, the products are 1) recommendations (rather than mandates) to SWQIC for standardizing hydrologic design practice within the basin and 2) the development of tools intended to improve the quality of the design. In addition, the Corps has written recommendations for future studies that it believes could be beneficial to the design community.

The Scope does not cover hydraulic criteria (as opposed to hydrologic); an example being friction coefficients for computing flow capacity in a corrugated metal pipe. In discussions with SWQIC members, the consensus was that hydrologic criteria (e.g., the estimation of runoff peak and volume from rain or melting snow) was the critical need. Runoff plays a major role in the conveyance of sediment and nutrients into Lake Tahoe; therefore, its quantification is critical.

Task	Description	Deliverable
1.0	INITIAL ASSESSMENT	Initial report describing state of the practice, ongoing studies and consensus on needed criteria
1.1.	Assess existing practice and ongoing studies	
1.2.	Define Criteria/Methods Selection Process, develop stakeholder consensus	
2.0	DATABASE	Hydro-meteorological time series and GIS data base
3.0	**PRECIPITATION/METEOROLOGIC EVALUATION AND ANALYSIS**	Report providing precipitation depth-duration frequency curves, snow-water equivalent mapping, and frequency based design storms with corresponding initial conditions
3.1.	Review current NWS depth-duration frequency study (NOAA 14)	
3.2.	Compare NOAA 14 vs. MM5 precip.	
3.3.	Snow-water equivalent mapping/frequency analysis	
3.4.	Develop design storms/antecedent conditions	
4.0	FLOW-FREQUENCY ANALYSIS	Report describing frequency curves for low and high flows, flow-duration curves, and regional regression equations for each flow type
4.1.	At-site Flood (high flow) frequency analysis	
4.2.	At-site low-flow-frequency analysis	
4.3.	At-site flow-duration analysis	
4.4.	Regional regressions for high flow-frequency curves, low-flow-frequency curves and flow-duration curves useful for ungaged watershed analysis	
5.0	**RECOMMENDED PRECIPITATION-RUNOFF MODELING APPROACHES**	Report describing recommended modeling approaches
6.0	**PERFORM WATERSHED MODEL CALIBRATION STUDIES TO IMPROVE MODELING APPROACH RECOMMENDATIONS**	Report describing water modeling effort to obtain regional loss rate values for drainage design applications.
7.0	**Evaluate NOAA 14**	Report evaluating applicability of NOAA 14 precipitation-depth-duration frequency curves to Lake Tahoe Basin
8.0	SUMMARY REPORT	Summary report

Table 1: Scope of Work

2.0 Background: In the future, each local jurisdiction will need to implement improved storm drain infrastructure and BMPs to meet regulatory TMDL limits for controlling nutrients and fine sediment through total maximum daily loads (TMDLs) assigned to the 63 watersheds and numerous intervening zones that comprise the basin. Hydrologic design criteria within the region vary between local jurisdictions, state departments of transportation, and even among federal agencies. This causes inequities to developers since they must mitigate the hydrologic impacts of urbanization as it occurs around the lake. Watershed boundaries cross county lines and jurisdictional boundaries, furthering the need to coordinate activities. SWQIC sees a need to regionalize hydrologic design methods within Lake Tahoe and asked the Corps to assist in this task.

3.0 Methodology: This work was performed by employees of the U.S. Army Corps of Engineers. The recommendations focus on watershed modeling methods for estimating high frequency and risk based design flows (examples being the 2- and 100-year peak flows). Separate recommendations are made for watersheds located at elevations above and below 7000 feet. This division is needed since long-term stream gage data is not available for small watersheds lying below 7,000 feet. Reviews of current local jurisdiction and professional practice (SPK, 2005b) and watershed calibration modeling studies (Cold Regions Research and Engineering Laboratory, 2005) provided the information needed to develop the recommendations for basins lying below 7000 feet.

4.0 Products and Recommendations: A more detailed description of the Corps analysis and results is provided in the Corps Summary Report (SPK, 2007). Key products include:

1. Report comparing National Weather Service (NWS) precipitation frequency study (NOAA Atlas 14, 2003) to Lake Tahoe region gaged precipitation data. The Corps concluded that NOAA 14 Atlas should be used for hydrologic design in the basin (see SPK, 2006).

   NOAA 14 Atlas precipitation depths can be accessed at the web link: < http://hdsc.nws.noaa.gov/hdsc/pfds/index.html >. The site provides point specific values for various frequency events and durations (5 minutes to 60-days). GIS based digital maps of the data can be downloaded for free. Originally, the NWS did not publish data for all of the California side of the basin! *Full coverage of the basin is now available as of 2006, after the U.S. Army Corps of Engineers paid the NWS to fill in the missing areas.*

2. Development of Regional Flow-Frequency Regression Equations for Lake Tahoe. The equations predict the following:

    a. Peak flow frequency curves
    b. 1, 3, 7, 10, 15, and 30-day annual maximum flow frequency curves
    c. 7-day annual *low flow* frequency curves (water quality applications, low-flow in summer can have highest concentration of some nutrients)
    d. Annual flow-duration curves (useful for ecosystem restoration or water quality analysis)

    Note: The equations are limited to watersheds that have a significant contributing area above 7,000 feet and which have a drainage area of at least 0.5 square miles or larger.

3. GIS Database: The Corps will provide three unique GIS maps, two of which are to be used as input parameters for the Regional Regression Equations. The Corps is working with TRPA to locate the data on the www.TIIMS.org website for use by designers.
    a. High Resolution Mean Annual Precipitation Map of Lake Tahoe derived using Oregon State University PRISM technology.
    b. High Resolution Mean Annual Snow for Lake Tahoe derived using Oregon State University PRISM technology.
    c. Antecedant Snow Water Equivalent (SWE): Shows the expected snowpack water content (inches) existing around Lake Tahoe when the one-day annual maximum discharge occurs. It is a synthetic snowpack derived for modeling hypothetical rain-on-snow events). **Note:** The Corps recent development of “effective soil loss rates” which incorporates snowpack effects has negated the need for this dataset. Nevertheless, it will be provided on TRPA’s TIIMS.org website for use by interested scientists and others.

4. Watershed Modeling Recommendations (detailed recommendations for engineers provided in SPK, 2007).

    The recommendations propose that watershed modeling methods derived from calibration to gaged precipitation and runoff data are better than those based on an ungaged analysis (i.e., determined from the physical characteristics of the watershed). Consequently, the regional regression estimates and results of the watershed model calibration studies should add value to the recommendations.

The calibration studies (CRREL, 2005) determined that snow-affected runoff is critical to determining design runoff within the Lake Tahoe basin. Of concern is that most text estimates of runoff parameters (loss rates, runoff coefficients and routing parameters) have been developed for snow-free ground situations. Consequently, although smaller drainage areas lie outside the range of those used in the regression and calibration studies, the finding that snow-affected runoff is dominant within the basin needs to be considered.

The Corps suggests using event-oriented models such as HEC-1 or HEC-HMS as opposed to more sophisticated continuous simulation or physically based models, given our knowledge of current practice. This is done with the caveat that the work being performed in support of the TMDL program (in conjunction with the Lahontan Regional Water Quality Control Board (Lahontan) and the Nevada Department of Environmental Protection (NDEP)) should also be considered. Local jurisdictions may wish to consider applications with new models being developed for this program depending on their success.

a. **Watersheds > 0.5 mi^2 and at or above 7,000 feet:** Peak flow and volume frequency can be estimated using the Regional Regression Equations. In the case where applicable streamgage data is available nearby, a frequency curve derived from the gage record might be more accurate, depending upon the quality and number of years of the data. Comparison of streamgage frequency curves and those derived from the regression equations is recommended. When hydrologic modeling is desired, watershed modeling parameters can be obtained in model calibration studies with the regional regression equations or available streamgage frequency curves.

   Comparison of regional regression estimates and watershed model simulation of design storms might be used to judge the value of model parameters for areas smaller than 0.5 square miles (see recommended future studies).

b. **Watersheds between 6200 – 7000 feet:**

   The Corps performed watershed modeling calibration studies of observed historical storms including snowpack accumulation and melt (Cold Region Research and Engineering Laboratory, 2005) to develop recommended <u>soil loss rates</u> for areas between 6200 – 7000 feet. These rates are important to hydrologic modeling near the lake elevation. Around the basin, modeling is complicated by 1) frozen ground (zero loss rates) 2) snowpack absorption of rainfall and 3) snowpack melt. The Corps has derived “effective loss rates” which take into account snowpack effects, thus negating the need to perform snowpack simulation as part of the hydrologic design process. See table below.

Table 2: Recommended constant loss rates (in/hr) for open areas between elevations (6200-7000 feet)

Watershed	100-year	2-year
Upper Truckee	0.2	0.1
General	0.2	0.1
Ward	0.05	0.1
Incline	0.3	0.1
Third	0.3	0.1
Glenbrook	0.3	0.1
Trout	0.3	0.1

Note: Interpolation and judgment can be used to determine loss rates for other locations and return periods. The above loss rates may not be representative of urban areas.

There are no studies available which provide loss rates from snow-covered urban areas. The movement of snow by snowplows further complicates the issue.

c. **Drainage Areas < 200 acres**

Runoff coefficient methods are recommended instead of watershed models for very small watersheds (< 200 acres) irrespective of the elevation. Gage information for these small basins does not exist. Consequently, ungaged analysis approaches accepted in professional practice were relied upon for the recommendations. Typically, the Rational Method is used in estimating design peak discharges for these small drainage areas. Unfortunately, published Rational Method coefficients are not particularly relevant to the snow-affected runoff in the Lake Tahoe Basin. In lieu of further studies, a conservative approach, with a runoff coefficient in the range 0.9 – 1.0, is suggested in applying the Rational Method. However, there is an issue that needs to be considered when modeling the effects of urban development (i.e., increasing the drainage area percent impervious). Under these circumstances, existing natural (forest and pasture) or previously landscaped drainage areas might be considered to have less runoff potential than the urbanized condition. Assuming less runoff potential would require a greater effort to mitigate the potentially increased runoff from the future development. Given the lack of data, this may require an operational decision by regulatory agencies. Further studies might use watershed models to estimate the runoff coefficients for the Rational Method. Here, the information gained from the large watershed model calibration studies could be used to simulate the precipitation – runoff estimates needed to calibrate the runoff coefficients.

The maximum basin size to use for application of this method depends largely on the variation in runoff properties and complexity of the drainage system in the area being analyzed. Estimating a composite runoff coefficient and the appropriate time of concentration for a drainage area becomes increasingly difficult as the drainage area contributions to runoff become more varied or distributed. The typical rule of thumb is to limit application to drainage areas less than 200 acres with relatively simple drainage patterns (e.g., no detention/retention storage).

d. **Design Storms and Precipitation:**

The NOAA 14 (NWS) precipitation depth-duration frequency curves should be used in estimating design precipitation in application with either the Rational Method or in creating design storms for watershed modeling studies. These precipitation frequency curves were found to be consistent with local Lake Tahoe basin gage data, although the user should be aware of the limitations of the results, given the lack of precipitation data for durations less than 60 minutes and elevations greater than 7000 feet (see SPK, 2006).

The Corps recommends a balanced design storm approach using NOAA 14 Atlas depth duration frequency curves. A dimensionless, regional synthetic storm hyetograph was derived during the Corps study (see Cold Region Research and Engineering Laboratory, 2005) that was considered representative of Lake Tahoe storms. It was intended to provide more realistic ratios between multiple durations (for example, the 1-, 3-and 6-hour depths) than a storm balanced to all three durations using NOAA14. Nevertheless, the Corps is recommending the more conservative balanced storm. The Corps recommends using no areal reduction factors (decreasing rainfall factor as the storm size increases). This provides consistency when using the soil loss rates provided in Table 2, since storm templates, balanced to NOAA14 without areal reduction, were part of the multiple step process to derive the final adopted soil loss rates for elevations between 6200 – 7000 feet.

e. **Runoff routing (rainfall to runoff transform)**

For natural or open areas, use TR-55 (NRCS, 1986) methods including NRCS Lag Unit Hydrograph. Latest research indicates the use of 100 feet maximum length for sheet flow when computing time of concentration.

For urban areas, use Kinematic Wave overland flow panes including Muskingum Cunge channel routing.

e. **Channel Routing**: Use Muskingum-Cunge routing method with standard roughness coefficients derived from TR-55 publication. As an alternative, one may use Muskingum routing method in reaches where travel time can be estimated.

5. Possible Future Studies

The following future studies would provide additional information and guidance for estimating discharges for drainage design:

- Published coefficients for application of the Rational Method to small drainage areas (< 200 acres) are probably not relevant to the snow-affected runoff problem important to the Lake Tahoe basin. A watershed model simulation study, much as was done for the Placer County Manual (1990), using the results of the model calibration study (Cold Regions Research and Engineering Laboratory) could be performed to develop more appropriate coefficients.
- A national study (WRC, 1981) of flow-frequency curve estimation methods demonstrated that regional regressions were somewhat more accurate than simulation of design storms with watershed models in application to ungaged watersheds. Consequently, a future effort to develop guidelines for use of the Lake Tahoe basin regional regression equations (SPD, 2005a) to aid in watershed model calibration would improve model prediction accuracy.

6. Recommendations for Best Management Practice Hydrologic Design

Recommendations for best management practice hydrologic design criteria focused on developing design water quality volumes (WQVs). Using WQVs for design is commensurate with standard practice in the profession and can be used easily with the design event concepts recommended for drainage design. The Tahoe Regional Planning Agency (see LRWQCB, 1994) and Caltrans (2003) currently employ this approach. It is also used in the well-known Denver Drainage Manual (see USDCM, 2003).

The current TRPA criteria are not well substantiated by studies that relate the WQV to water quality objectives for the Lake Tahoe basin. Modeling studies are needed to derive WQV values for this purpose. Current TMDL modeling studies being performed by Lahontan/NDEP may serve this purpose. The major challenge to new modeling studies will be:

- The lack of precipitation-runoff data. In particular, very little short interval precipitation exists. Furthermore, data does not exist for the urban watersheds, which are the focus of the hydrologic design criteria.

- Modeling studies need to assess the margin of safety (MOS) required by EPA (1999) to assure that a particular design will meet TMDL constraints. Currently, MOS is implemented without regard to the tradeoff between water quality benefits and design costs. New modeling studies need to examine the tradeoff between incremental benefits and costs as a function of incremental increases in MOS.

7. NOAA14/MM5 Data Comparison

The Corps produced a report comparing NOAA14 depth duration frequency curves against curves derived from a statistical analysis of the 40 years of synthetic hourly precipitation produced in the MM5 meteorological model for the TMDL Program (SPK 2005b). The report also compared MM5 precipitation to observed precipitation in the basin. The results indicate that producing DDF curves from MM5 data may have limitations for applicability. This is important to know the differences as both data sets may be used for design where TMDL regulations could apply.

5.0 Conclusions:

a. Due to the varying hydrologic design criteria used in the Lake Tahoe basin by various agencies, the Corps was asked to assist in standardizing and improving hydrologic design within the Lake Tahoe basin. The Corps reviewed current hydrologic design practice in the Lake Tahoe region, but found that the current criteria in the county design manuals was not based on studies of the Lake Tahoe region itself. The criteria was derived for large areas including those unaffected by snow.

b. A nationwide study (U.S. WRC, 1981) demonstrated that, for the most part, the USGS regression equations were more accurate than event-oriented watershed models in predicting peak annual flow-frequency curves. This study provides good reason for using the Corps' regression equations to validate watershed model predictions in ungaged areas. These regression equations can be applied to calibrate/validate watershed model predictions by using any of the following approaches: (1) adjusting model loss rates so that the model-predicted frequency curves agree with the regression prediction within some reasonable tolerance; (2) adjusting the model loss rates, if necessary, to ensure that model predictions lie within predicted regression confidence limits on frequency curves of interest; or (3) averaging model- and regression-predicted frequency curves. Results from (1) or (2) could be used to estimate loss rates for open areas in urban watersheds, even though regressions are not directly applicable to these watersheds. The method to use will depend on the confidence placed in watershed model predictions.

c. Most hydrologic design is used for areas close to the lake elevation (6200 – 7000 feet). The 1997 flood was a warm, frontal rain on snow event which caused some of the highest peak flows recorded at streamgages within the basin, causing the Corps to see this phenomenon as important for hydrologic modeling of rare floods. Frozen ground and the impacts of a snowpack make hydrologic modeling in the Tahoe basin complex. A concern was expressed by the SWQIC that current drainage design manuals did not adequately address these issues. In response, the Corps performed model calibration studies of historic flood events to derive "effective loss rates" for open/natural areas below 7000 feet that were specifically suited for use with the recommended NOAA14 depth duration frequency curves. The loss rates effectively take care of the impacts of the snowpack and frozen ground without having to run a snowpack simulation. The Corps sees this product as an improvement to the older criteria found in the local jurisdiction drainage design manuals. The Corps has also provided recommendations for standardizing watershed modeling including: 1) use of the Rational Method 2) recommended design storms 3) runoff routing methods and 4) channel routing methods.

d. The Corps has recommended future studies that could be useful to further improving hydrologic design criteria in the Lake Tahoe region.

e. No specific recommendations have been made with respect to a basin-specific drainage design manual as part of this effort. Further discussions with SWQIC and basin designers will be needed to help formalize a scope for this effort.

f. Each local jurisdiction can consider the products be adopted formally for use in their jurisdictions for design of projects. The procedures for adoption will be the responsible of each jurisdiction.

REFERENCES

NRCS, (formerly, SCS). 1986. Urban Hydrology for Small Watersheds. Technical Report No. 55. Natural Resources Conservation Service (formerly Soil Conservation Service). Washington, D.C.

SPK, 2006. Precipitation Depth-Duration-Frequency Characteristics for Lake Tahoe Basin, An Evaluation of NOAA 14, Prepared for the Lake Tahoe Storm Water Quality Improvement Committee. Sacramento District, U.S. Army Corps of Engineers.

SPK. 2005a. Investigation of Regional Regression Equations for Flow Duration, Peak and Annual Maximum Flow, and Low-Flow-frequency Curves for the Lake Tahoe Basin. Prepared for the Lake Tahoe Storm Water Quality Improvement Committee. Sacramento District, U.S. Army Corps of Engineers.

SPK. 2005b. Recommended Watershed Modeling Techniques for Hydrologic Design and Best Management Practice. Lake Tahoe Storm Water Quality Improvement Committee. Sacramento District, U.S. Army Corps of Engineers.

SPK, 2004a. Defining the analysis issues and design problems to be addressed by the Lake Tahoe Hydrologic Design Criteria, Sacramento District, U.S. Army Corps of Engineers.

SPK, 2004b. Lake Tahoe Basin Comparison of Depth-Duration-Frequency Curves obtained from NOAA 14 and estimated from MM5 simulated precipitation. Sacramento District, U.S. Army Corps of Engineers.

SPK, 2007, Summary Report, Investigations to Determine Regional Flow-Frequency Equations and Watershed Modeling Recommendations Useful for Developing Hydrologic Design Criteria for the Lake Tahoe Basin.

U.S. WRC, 1981. Estimating Peak Flow Frequencies for Natural Watersheds, A Proposed Nationwide Test, Hydrology Committee, U.S. Water Resources Council, Washington, D.C.