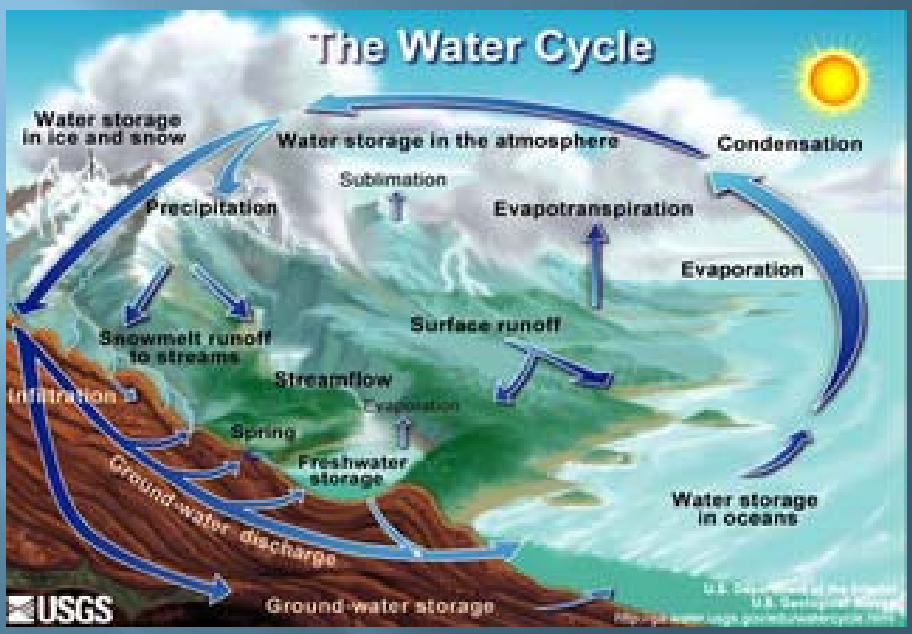
HYDROLOGY



Factors Affecting Flood Runoff

- Drainage area size
- Slope of the terrain
- Land use
- Soil type
- Infiltration
- Storage
- Geology

Sources of Information

- **Climatologic, Hydrologic, Rainfall**
  - MN Climatology Working Group
  - NOAA
    - Hourly Precipitation Map
    - Interactive Weather
    - Precipitation Analysis
    - HDSC Precipitation Frequency Data Server
    - National Weather Service Forecast
  - NEXRAD Viewer
  - WSI Daily Radar-Based Precipitation Estimate
- Flooding
  - DNR Watershed Assessment Tool
- NOAA
  - North Central River Forecast
- US Army Corp of Engineers Water Control Center
- FEMA
  - Map Service Center
  - National Flood Hazard Layer for Arcmap
  - National Flood Hazard Layer for Google Earth

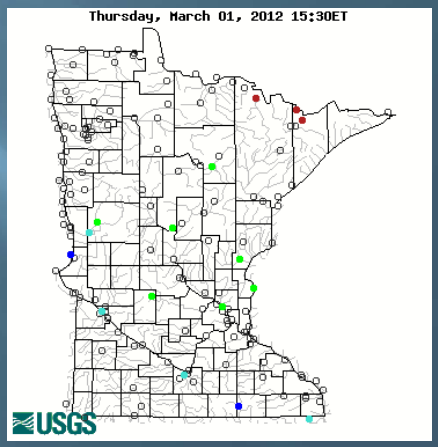
What procedure should I use

Selection of Discharge Computation Method

FACILITY DESCRIPTION	METHOD				
	Frequency Analysis	Regression Equations	SCS Hydr-ograph	SCS Peak Discharge	Rational
Stream Flow, Channels, Bridges, & Culverts Greater then 48"	customary method	alternate method	complex facilities or hydrograph needed	alternate method	
Culverts 48" and Smaller		alternate method	complex facilities or hydrograph needed	customary method	alternative method
Storm Drains, Roadside Ditches, & Side Culverts			complex facilities or hydrograph needed		customary method
Detention Basins			customary method		preliminary evaluation, or permit review

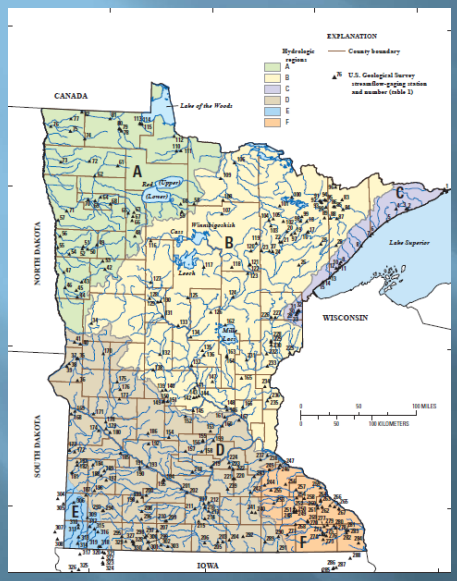
Frequency Analysis

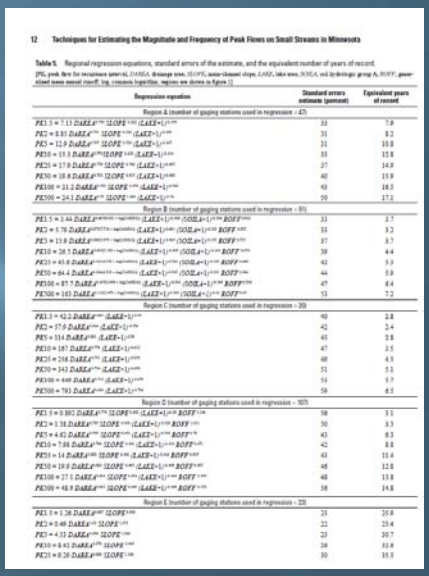
- Analysis of Stream Gage Data
- Log-Pearson Type III is used to analyze the data
- Need 10 years of continuous data for 10-year discharge estimates and 25-years for the 100-year estimate



Regression Equations

- Estimating peak flows at ungaged sites or sites with limited data
- Statistical method used to develop runoff equations
- $Q \ = \propto A^b S^c (St + 1)^d$
- Done every 10 years by the USGS





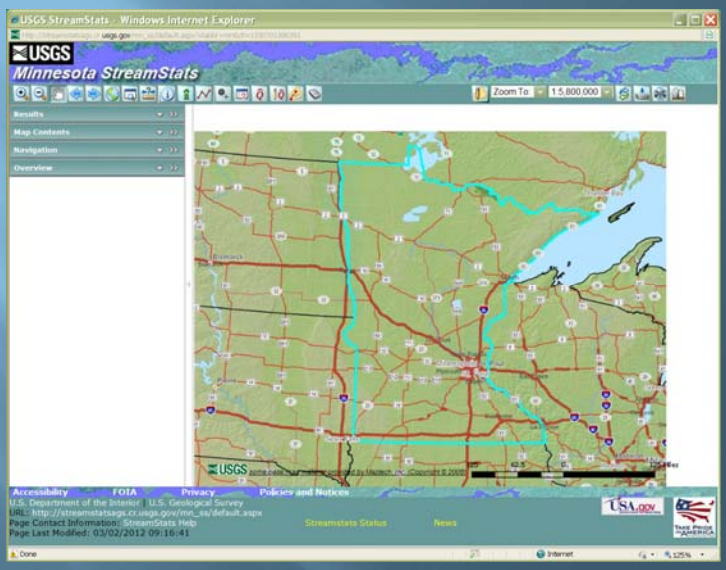
12 Techniques for Estimating the Magnitude and Frequency of Peak Flows on Small Streams in Minnesota

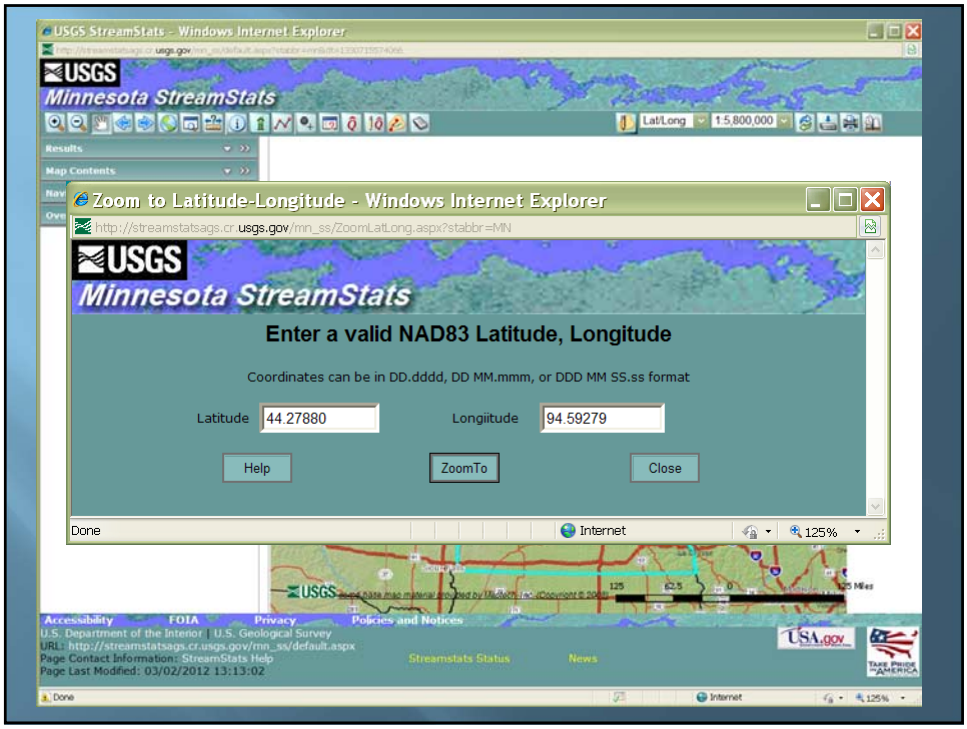
Table 5. Regional regression equations, standard errors of the estimate, and the equivalent number of years of record.

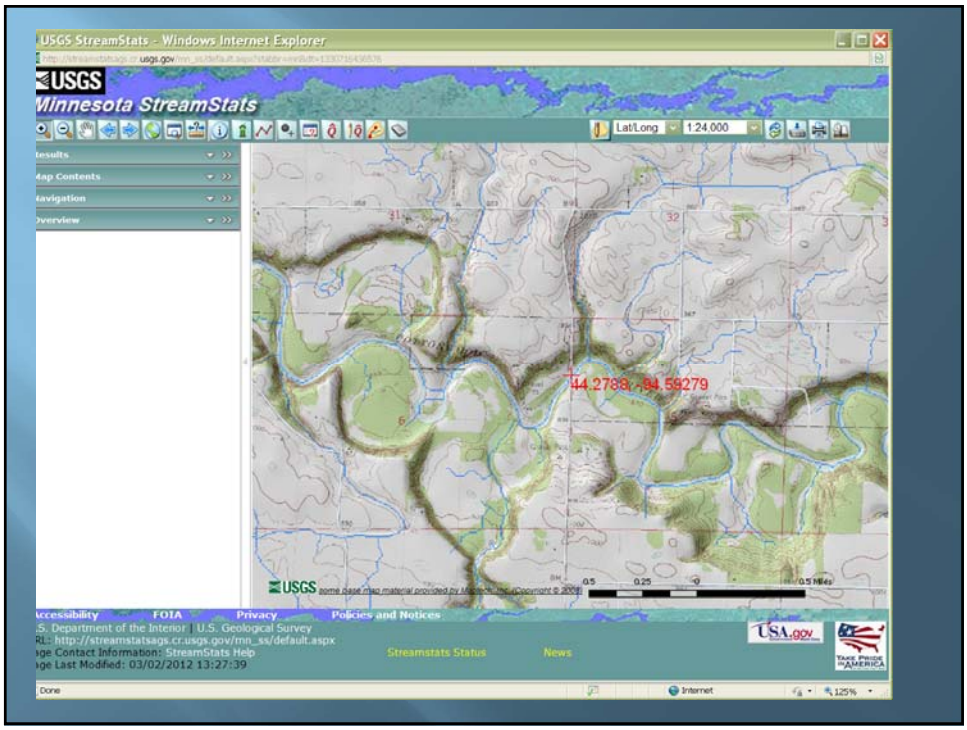
[PE, peak flow for recurrence interval; DAREA, drainage area; SLOPE, main-channel slope; LAKE, lake area; SOIL, soil hydrologic group A; ROFF, percent mean annual runoff; log, common logarithm; regions are shown in figure 1]

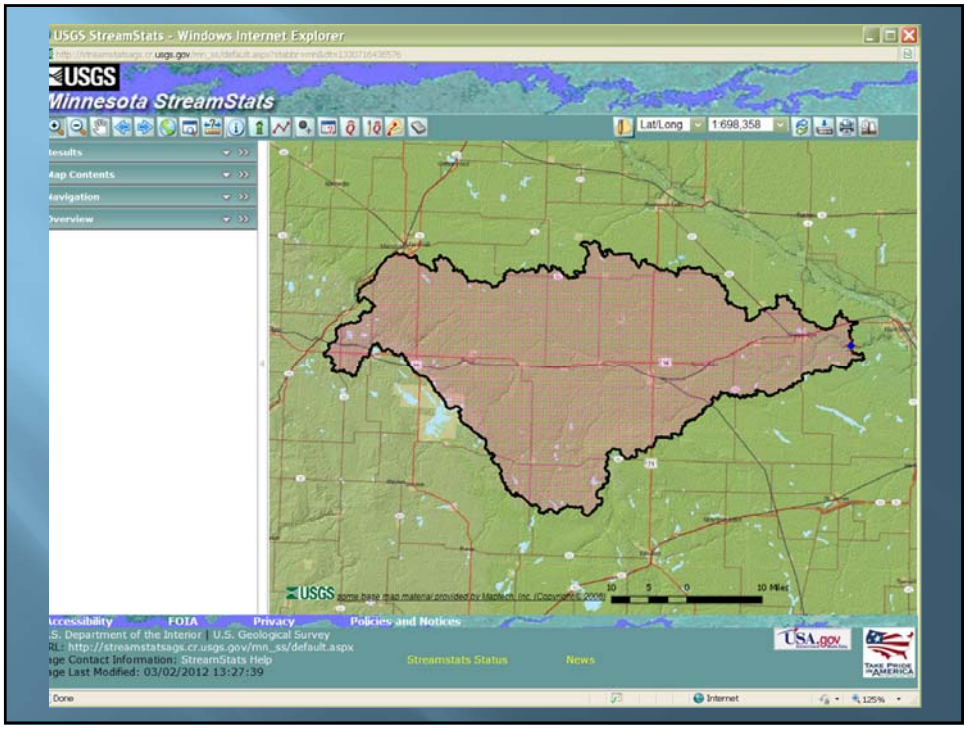
Regression equation	Standard errors estimate (percent)	Equivalent years of record
Region A (number of gaging stations used in regression = 47)		
$PE1.5 = 7.15\ DAREA^{0.794}\ SLOPE^{0.183}\ (LAKE+1)^{-0.159}$	33	7.0
$PE2 = 8.91\ DAREA^{0.785}\ SLOPE^{0.190}\ (LAKE+1)^{-0.199}$	31	8.2
$PE5 = 12.9\ DAREA^{0.767}\ SLOPE^{0.190}\ (LAKE+1)^{-0.247}$	31	10.8
$PE10 = 15.3\ DAREA^{0.753}\ SLOPE^{0.195}\ (LAKE+1)^{-0.271}$	33	13.8
$PE25 = 17.9\ DAREA^{0.735}\ SLOPE^{0.198}\ (LAKE+1)^{-0.287}$	37	14.9
$PE50 = 19.8\ DAREA^{0.721}\ SLOPE^{0.197}\ (LAKE+1)^{-0.292}$	40	15.9
$PE100 = 21.2\ DAREA^{0.709}\ SLOPE^{0.199}\ (LAKE+1)^{-0.296}$	43	16.5
$PE500 = 24.1\ DAREA^{0.70}\ SLOPE^{0.200}\ (LAKE+1)^{-0.29}$	50	17.1
Region B (number of gaging stations used in regression = 93)		
$PE1.5 = 1.44\ DAREA^{0.9[illegible]}\ (LAKE+1)^{-0.158}\ (SOIL+1)^{0.158}\ ROFF^{0.[illegible]}$	33	3.7
$PE2 = 1.76\ DAREA^{0.9[illegible]}\ (LAKE+1)^{-0.181}\ (SOIL+1)^{0.181}\ ROFF^{0.[illegible]}$	33	3.2
$PE5 = 11.9\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	37	3.7
$PE10 = 26.5\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	39	4.4
$PE25 = 81.8\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	42	5.3
$PE50 = 64.4\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	44	5.9
$PE100 = 87.7\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	47	6.4
$PE500 = 181\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ (SOIL+1)^{0.[illegible]}\ ROFF^{0.[illegible]}$	53	7.2
Region C (number of gaging stations used in regression = 39)		
$PE1.5 = 42.2\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	40	2.8
$PE2 = 57.9\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	42	2.4
$PE5 = 114\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	45	2.8
$PE10 = 167\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	47	3.5
$PE25 = 256\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	48	4.5
$PE50 = 343\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	51	5.3
$PE100 = 449\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	53	5.7
$PE500 = 781\ DAREA^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}$	59	6.5
Region D (number of gaging stations used in regression = 107)		
$PE1.5 = 0.001\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	50	3.1
$PE2 = 1.38\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	50	3.3
$PE5 = 4.85\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	43	6.3
$PE10 = 7.98\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	42	8.8
$PE25 = 14\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	43	11.4
$PE50 = 19.9\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	46	12.8
$PE100 = 27.1\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	48	13.8
$PE500 = 48.9\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}\ (LAKE+1)^{-0.[illegible]}\ ROFF^{0.[illegible]}$	56	14.8
Region E (number of gaging stations used in regression = 23)		
$PE1.5 = 1.36\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}$	21	26.0
$PE2 = 0.49\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}$	22	23.4
$PE5 = 4.52\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}$	23	30.7
$PE10 = 8.42\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}$	26	32.6
$PE25 = 0.26\ DAREA^{0.[illegible]}\ SLOPE^{0.[illegible]}$	30	35.3

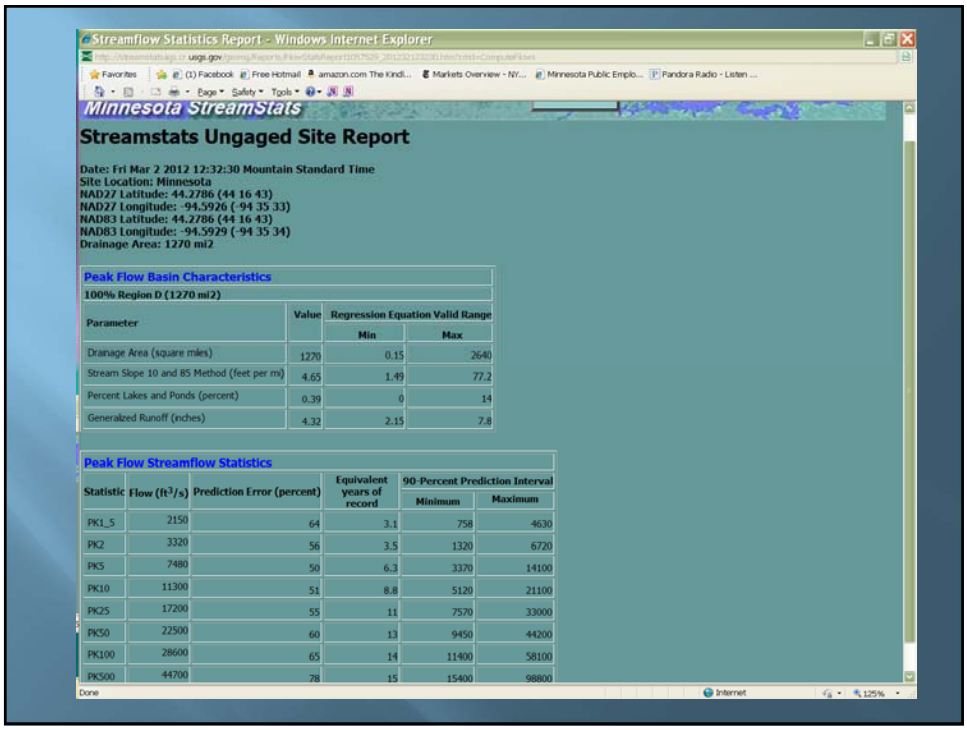
http://water.usgs.gov/osw/streamstats/




USGS StreamStats - Windows Internet Explorer
USGS
Minnesota StreamStats
Lat/Long
1:5,800,000
Results
Map Contents
Zoom to Latitude-Longitude - Windows Internet Explorer
http://streamstatsags.cr.usgs.gov/mn_ss/ZoomLatLong.aspx?stabbr=MN
USGS
Minnesota StreamStats
Enter a valid NAD83 Latitude, Longitude
Coordinates can be in DD.dddd, DD MM.mmm, or DDD MM SS.ss format
Latitude
44.27880
Longiitude
94.59279
Help
ZoomTo
Close
Done
Internet
125%
Accessibility
FOIA
Privacy
Policies and Notices
U.S. Department of the Interior | U.S. Geological Survey
URL: http://streamstatsags.cr.usgs.gov/mn_ss/default.aspx
Page Contact Information: StreamStats Help
Page Last Modified: 03/02/2012 13:13:02
Streamstats Status
News
USA.gov


USGS StreamStats - Windows Internet Explorer
USGS
Minnesota StreamStats
Lat/Long
1:24,000
44.2788, -94.59279
Accessibility
FOIA
Privacy
Policies and Notices
Streamstats Status
News
USA.gov





Streamflow Statistics Report - Windows Internet Explorer

Minnesota StreamStats

Streamstats Ungaged Site Report

Date: Fri Mar 2 2012 12:32:30 Mountain Standard Time
Site Location: Minnesota
NAD27 Latitude: 44.2786 (44 16 43)
NAD27 Longitude: -94.5926 (-94 35 33)
NAD83 Latitude: 44.2786 (44 16 43)
NAD83 Longitude: -94.5929 (-94 35 34)
Drainage Area: 1270 mi2

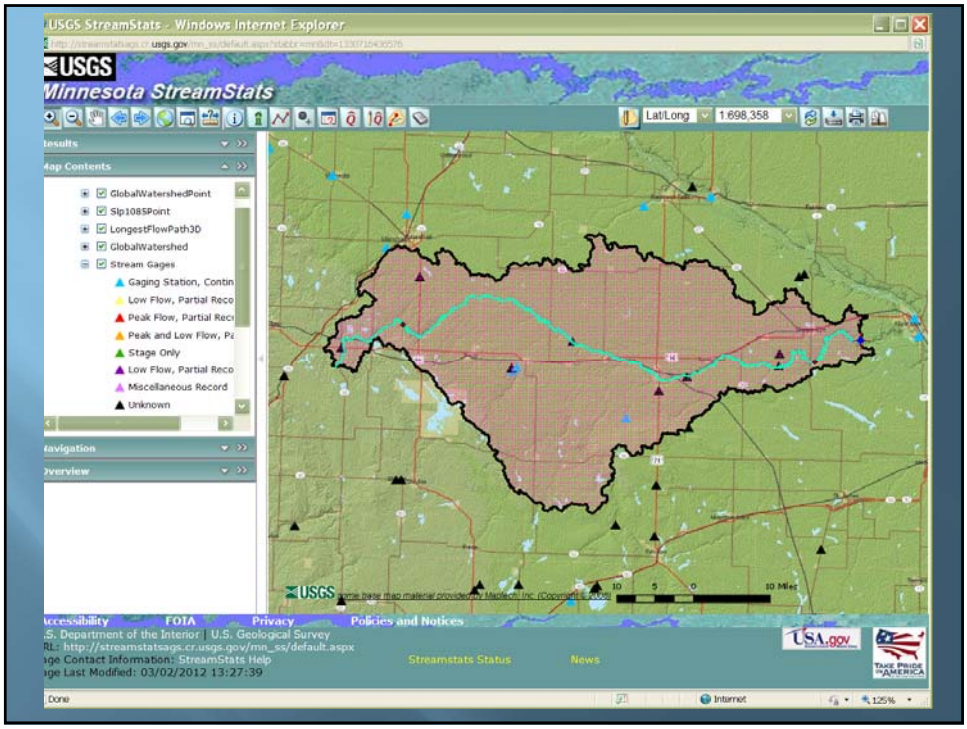
Peak Flow Basin Characteristics

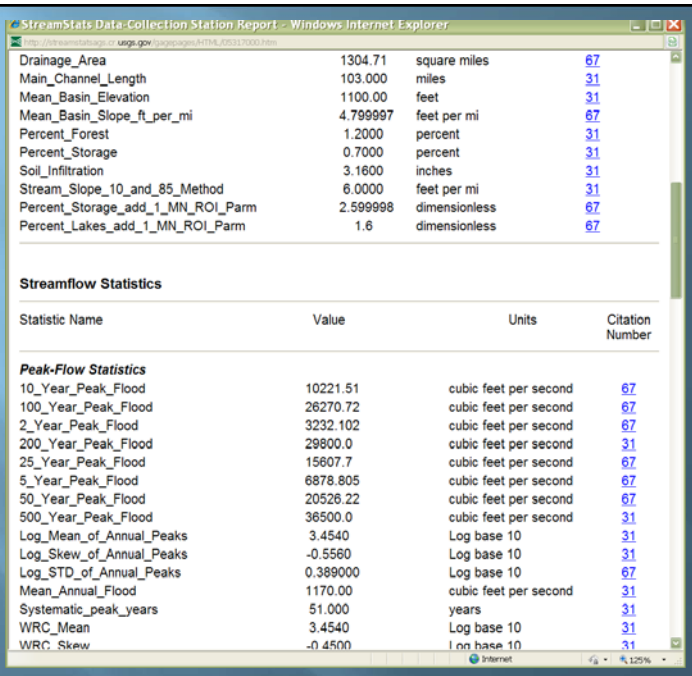
100% Region D (1270 mi2)

Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	1270	0.15	2640
Stream Slope 10 and 85 Method (feet per mi)	4.65	1.49	77.2
Percent Lakes and Ponds (percent)	0.39	0	14
Generalized Runoff (inches)	4.32	2.15	7.8

Peak Flow Streamflow Statistics

Statistic	Flow (ft^3/s)	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
PK1_5	2150	64	3.1	758	4630
PK2	3320	56	3.5	1320	6720
PK5	7480	50	6.3	3370	14100
PK10	11300	51	8.8	5120	21100
PK25	17200	55	11	7570	33000
PK50	22500	60	13	9450	44200
PK100	28600	65	14	11400	58100
PK500	44700	78	15	15400	98800





StreamStats Data-Collection Station Report - Windows Internet Explorer

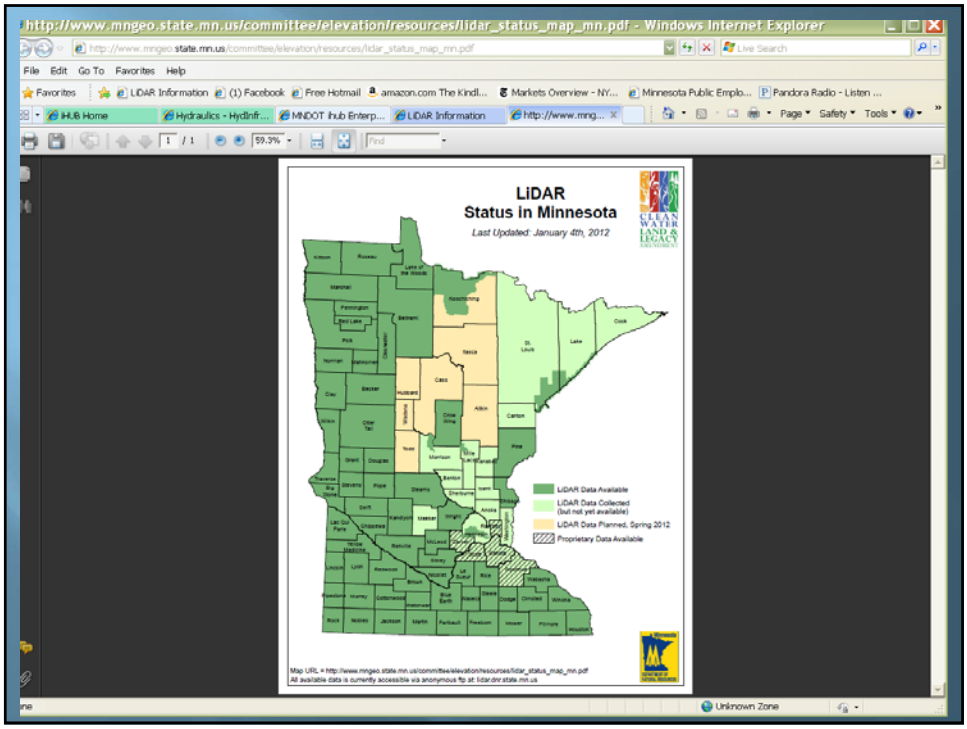
Drainage_Area	1304.71	square miles	67
Main_Channel_Length	103.000	miles	31
Mean_Basin_Elevation	1100.00	feet	31
Mean_Basin_Slope_ft_per_mi	4.799997	feet per mi	67
Percent_Forest	1.2000	percent	31
Percent_Storage	0.7000	percent	31
Soil_Infiltration	3.1600	inches	31
Stream_Slope_10_and_85_Method	6.0000	feet per mi	31
Percent_Storage_add_1_MN_ROI_Parm	2.599998	dimensionless	67
Percent_Lakes_add_1_MN_ROI_Parm	1.6	dimensionless	67

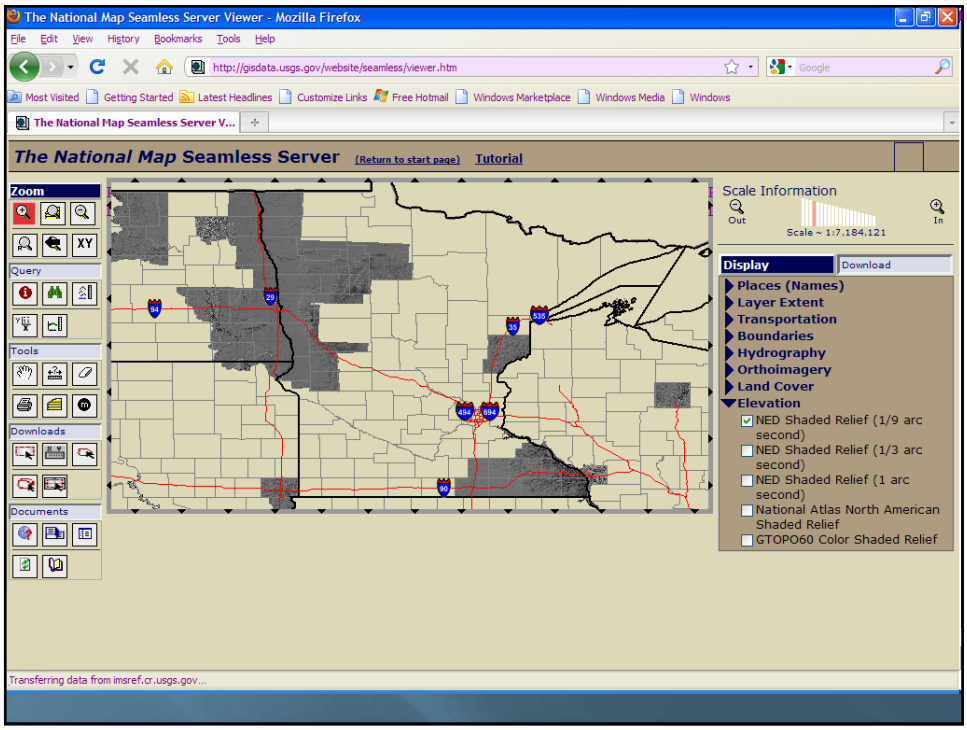
Streamflow Statistics

Statistic Name	Value	Units	Citation Number
Peak-Flow Statistics			
10_Year_Peak_Flood	10221.51	cubic feet per second	67
100_Year_Peak_Flood	26270.72	cubic feet per second	67
2_Year_Peak_Flood	3232.102	cubic feet per second	67
200_Year_Peak_Flood	29800.0	cubic feet per second	31
25_Year_Peak_Flood	15607.7	cubic feet per second	67
5_Year_Peak_Flood	6878.805	cubic feet per second	67
50_Year_Peak_Flood	20526.22	cubic feet per second	67
500_Year_Peak_Flood	36500.0	cubic feet per second	31
Log_Mean_of_Annual_Peaks	3.4540	Log base 10	31
Log_Skew_of_Annual_Peaks	-0.5560	Log base 10	31
Log_STD_of_Annual_Peaks	0.389000	Log base 10	67
Mean_Annual_Flood	1170.00	cubic feet per second	31
Systematic_peak_years	51.000	years	31
WRC_Mean	3.4540	Log base 10	31
WRC_Skew	-0.4500	Log base 10	31

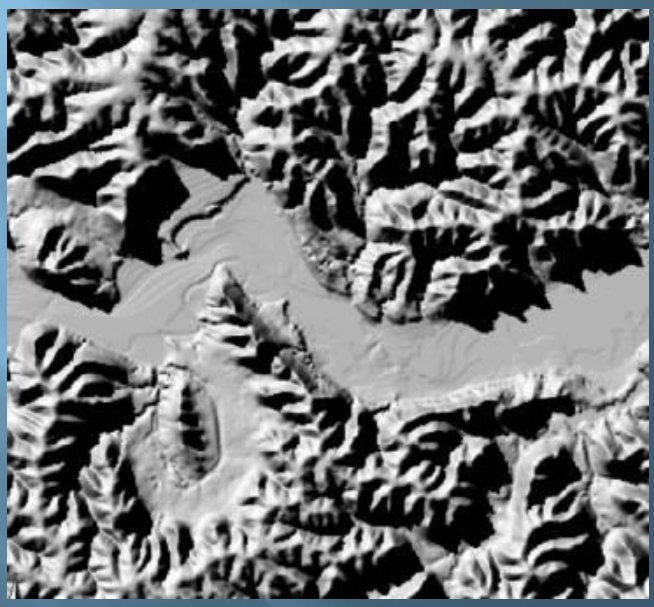
Internet 125%

Gage has 80 years of record


http://www.mngeo.state.mn.us/committee/elevation/resources/lidar_status_map_mn.pdf - Windows Internet Explorer
LiDAR
Status in Minnesota
Last Updated: January 4th, 2012
LiDAR Data Available
LiDAR Data Collected (but not yet available)
LiDAR Data Planned, Spring 2012
Proprietary Data Available


The National Map Seamless Server Viewer - Mozilla Firefox
http://gisdata.usgs.gov/website/seamless/viewer.htm
The National Map Seamless Server
(Return to start page)
Tutorial
Zoom
Query
Tools
Downloads
Documents
Scale Information
Out
In
Scale ~ 1:7,184,121
Display
Download
Places (Names)
Layer Extent
Transportation
Boundaries
Hydrography
Orthoimagery
Land Cover
Elevation
NED Shaded Relief (1/9 arc second)
NED Shaded Relief (1/3 arc second)
NED Shaded Relief (1 arc second)
National Atlas North American Shaded Relief
GTOPO60 Color Shaded Relief
Transferring data from imsref.cr.usgs.gov...

DNR Data Deli



Conclusion

- Hydrology is an "art"
- Verify results with multiple methods
- Don't average your multiple results
- Run your calculated flows through the inplace model. Does it give you sensible results.
- Check for other sources of hydraulic studies.
  - Watersheds
  - Flood Insurance Studies
  - Ditch Authorities

Hydraulic Engineers vs. the Elements

Washed Up or Washed Out

by

Woody Thorstenson
Assistant Road Design Engineer

A few weeks ago a local newspaper commented, "As far as the Minnesota Highway Department is concerned, this spring has been pretty much of a washout." To which we might add somewhat ruefully: it was the kind of spring that could well make a highway drainage engineer feel all washed up. With the floods of 1965 and the heavy storms of the past year still fresh in everyone's memory, it might be interesting to reflect on the occupational hazards of sizing culverts and bridge openings.

A drainage engineer in determining the amount of water which must be accommodated by a culvert or bridge invokes all kinds of hocus-pocus including records, charts, diagrams, and formulas. After delving into variables, unknowns, square roots, probabilities and various other functions, he crosses his fingers and predicts that a flow of so many cubic feet per second will not be exceeded oftener than once in 50 years. With a little bit of luck he'll be dead before nature proves him wrong. This is a facetious way of showing that a highway drainage engineer has to stick his neck out. If his structures wash out, he can well be washed up. Herein lies the hazard of the occupation.

Hydrology a Science

The science dealing with the risks which the highway drainage designer must take is called "hydrology". The term is derived from the combination of two Greek words, "hydor" and "logos", the first meaning "water" and the second "reasoning". Thus, hydrology has come to mean literally the science of water -- its properties, laws and distribution upon the earth. The phase of hydrology important to the highway drainage engineer deals with the nature of the runoff of water from land surfaces.

But no amount of hocus-pocus can account for all the vicissitudes of weather which make runoff from land surfaces so unpredictable. Nevertheless, experience has its applications. As an indication of what might happen in the future, we have to rely on past events. Therefore, record-keeping of past events is paramount. The records themselves become valuable sources of information. And the longer the record the more reliable the data.

Records Valuable

Everyone is familiar with Weather Bureau records and predictions. Other agencies also collect data on water. One of these is the U. S. Geological Survey which maintains records on the runoff of rivers and streams at key locations throughout the country. Two key stations operated by the Geological Survey in Minnesota are the Mississippi River at St. Paul and the Minnesota River at Mankato. The St. Paul record goes back almost 100 years to 1867 and the Mankato record 62 years to 1903 with some additional supplementary information on the flood of 1881. With this extended record one would think that the probability of future flooding could be projected with confidence, but the flood of 1965 took care of the confident ones.

This spring the flood at St. Paul was 40 per cent greater than the previous high of record. And in Mankato it was estimated to be over 10 per cent greater than the flood of 1881. These earth-shaking statistics were repeated at other locations throughout the state, and hydrologists made a mad dash for their sliderules -- the flood frequency curves needed to be recomputed.

Nature is always upsetting the applecart even on some of the small, culvert-size streams. Last year on Labor Day weekend an intense rainstorm flooded streams crossing new TH 61 between Duluth and Two Harbors. Practically all of the culverts handled the flows without undue stress, but an 7-foot-diameter culvert on Schmidt Creek proved to be far too small. The overflow surged across the highway and washed out part of the embankment on the downstream side. After considerable investigation, we have no logical explanation why the runoff on Schmidt Creek was proportionately greater than that of its neighboring streams. Perhaps it was a freak of nature, or perhaps it was just a bad hydrological guess.

Culvert Design Difficult

While records have been kept for many years on the larger rivers, little information is available on the culvert-size streams and channels which cross our highways. Drainage designers must rely on scanty and scattered observations of runoff from various sources or on formulas which at best provide questionable answers.

We were ill-prepared hydrologically to cope with culvert design for the Interstate System. Taking a tip from the old proverb. "Better late than never," the Department in 1958 entered into agreement with the Geological Survey to collect runoff data from small streams along the trunk highway system. This "crest-stage-gage" program keeps track of the maximum water elevations and the peak flows from runoff events at many sites throughout the state. Currently there are 137 observation stations and ten are equipped with automatic water-level recorders. The program now costs about $60,000 a year and trunk highway funds defray half the cost.

In addition, the cooperative program with the Geological Survey gives the Department the privilege to order special surveys and flood-flow determinations whenever floods strike vulnerable locations on the trunk highway system. For example, shortly after the program commenced, we designed a triple box culvert to replace a bridge at Willow Creek on TH 63 south of Rochester. Before the contractor started construction a flash flood washed out the old bridge. By special survey the Geological Survey determined that the flood flow was almost twice the capacity of the proposed box culvert. Fortunately, we were able to increase the size of the structure through a supplement to the construction contract.

Perhaps the average person is apt to ask: Why all this fuss over culverts and bridge openings? Why not make them large enough and quit worrying? This is a simple philosophy but an expensive one. With drainage facilities, exclusive of bridges accounting for 8 to 10 cents of every highway construction dollar, integrity and preciseness of design is a challenge to the highway drainage engineer. If he fails to meet the challenge, he could well be both washed out and washed up.

HYDROLOGY

INTRODUCTION

Analysis of peak rate of runoff, volume of runoff, and time distribution of flow is fundamental for design of highway drainage facilities. Most drainage facility designs require determination of a peak flow rate while others require a runoff hydrograph that provides an estimate of runoff volume. Peak flow rates are most often used for design of bridges, culverts, roadside ditches, and small storm sewer systems. Drainage systems involving detention storage, pumping stations and large or complex storm sewer systems require the development of a runoff hydrograph to estimate volume of runoff.

The relationship between the amount of precipitation on a drainage basin and the amount of runoff from the basin is complex, and too little data is available on the factors influencing the rainfall-runoff relationship to expect exact solutions. Any hydrologic analysis is only an approximation, though an error in the estimate of peak runoff effects the design. Under prediction of the peak runoff can result in a structure that is undersized and may contribute to flooding while over predicting the peak runoff may lead to an oversized drainage facility that costs more than necessary.

This chapter provides design procedures for hydrologic analysis. For a more detailed discussion refer to the publications, *Highway Drainage Guidelines - Volume II* , (AASHTO, 1999) or *Highway Hydrology - HDS-2*, (FHWA, 1996).

Definition
Hydrology is a science dealing with the interrelationship and movement of various forms of water on and under the earth surface and in the atmosphere. For the purpose of this manual, hydrology will deal with estimating flood magnitudes as the result of precipitation. In the design of highway drainage structures, floods are measured in terms of peak runoff or hydrograph having a discharge in cubic feet per second (cfs). Structures designed to control volume of runoff, like detention storage facilities, or situations where flood routing is used, the entire discharge hydrograph will be of interest.

Concept Definitions
The following terms will be important in a hydrologic analysis. These concepts will be used throughout the remainder of this chapter in dealing with different aspects of hydrologic studies.

Antecedent Moisture Conditions	Antecedent moisture conditions are the soil moisture conditions of the watershed at the beginning of a storm. These conditions affect the volume of runoff generated by a particular storm event. Notably they affect the peak discharge only in the lower range of flood magnitudes. Antecedent moisture has a rapidly decreasing influence on runoff as the flood recurrence interval becomes longer.
Depression Storage	Depression storage is the natural depressions within a watershed which store runoff. Generally after the depression storage is filled runoff will commence.
Drainage Area (A)	The area draining into a stream at a given point along the stream.
Frequency	Frequency is the number of times a flood of a given magnitude or greater can be expected to occur on average over a long period of time. Frequency analysis is the

	estimation of peak discharges for various recurrence intervals. Another way to express frequency is with probability. Probability analysis seeks to define the flood flow with a probability of being equaled or exceeded in any year.
Hydraulic Roughn+ess	Hydraulic roughness is a composite of the physical characteristics which influence the flow of water across the earth's surface, whether natural or channelized. It affects both the time response of a watershed and drainage channel as well as the channel storage characteristics.
Hydrograph	The hydrograph is a graph of the time distribution of runoff from a watershed.
Hydrologic Soil Group	A group of soils having the same runoff potential under similar storm and cover conditions.
Hyetographs	The hyetograph is a graph of the time distribution of rainfall over a watershed.
Infiltration	Infiltration is a complex process of allowing runoff to penetrate the ground surface and flow through the upper soil surface. The infiltration curve is a graph of the time distribution at which this occurs.
Interception	Storage of rainfall on foliage and other intercepting surfaces during a rainfall event is called interception storage.
Lag Time	The lag time is defined as the time from the centroid of the excess rainfall to the peak of the hydrograph.
Peak Discharge	The peak discharge, sometimes called peak flow, is the maximum rate of flow of water passing a given point during or after a rainfall event or snowmelt.
Rainfall Excess	The rainfall excess is the water available to runoff after interception, depression storage and infiltration have been satisfied.
Rainfall Intensity (I)	Amount of rainfall occurring in a unit of time, converted to its equivalent in inches per hour.
Recurrence Interval	The average number of years between occurrences of a discharge or rainfall that equals or exceeds the given magnitude.
Runoff (Q)	The part of the precipitation which runs off the surface of a drainage area after all abstractions are accounted for.
Runoff Coefficient	A factor representing the portion of runoff resulting from a unit rainfall. Principally dependent on terrain, topography, slope, land use and soil type.
Time of Concentration	The time of concentration is the time it takes a drop of water falling on the hydraulically most remote point in the watershed to travel through the watershed to the point under investigation.
Ungaged Stream Sites	Locations at which no systematic records are available regarding actual stream flows.
Unit	A unit hydrograph is the direct runoff hydrograph resulting from a rainfall event which

Hydrograph has a specific temporal and spatial distribution and which lasts for a unit duration of time. The ordinates of the unit hydrograph are such that the volume of direct runoff represented by the area under the hydrograph is equal to one inch of runoff from the drainage area.

Factors Affecting Flood Runoff

In the hydrologic analysis for a drainage structure, there are many variable factors that affect floods. Some of the factors which need to be recognized and considered on an individual site by site basis are such things as:

- Drainage basin characteristics
  - drainage area size,
  - drainage area shape,
  - drainage area orientation,
  - slope of terrain,
  - land use; consider watershed development potential,
  - geology,
  - soil type,
  - surface infiltration,
  - storage,
  - antecedent moisture condition, and
  - storage potential: overbank, ponds, wetlands, reservoirs, channel, etc.
- Stream channel characteristics
  - channel slope,
  - channel geometry,
  - channel configuration,
  - natural and artificial controls,
  - channel modification,
  - aggradation/degradation, and
  - ice and debris.
- Flood plain characteristics
  - type of soil, and
  - ground cover.
- Meteorological characteristics
  - precipitation amount,
  - time rate of precipitation, hyetograph,
  - storm cell size,
  - storm cell distribution,
  - storm direction, and
  - type of precipitation: rain, snow, hail, or combinations thereof.

Sources of Information

The type and source of information available for hydrologic analysis will vary from site to site. It is the responsibility of the designer to determine what information is available and applicable to a particular analysis.

All hydrologic analysis shall consider the flood history of the area and the effect of these historical floods on existing and proposed structures. The flood history shall include the historical floods and the

flood history of any existing structures. Files should be reviewed for documentation of relevant communications, studies and investigations. Surveys should be conducted to provide enough field data for analysis. Typical data that is obtained in such surveys or studies are: topographic maps, aerial photographs, streamflow records, historical highwater elevations, flood discharges, and locations of hydraulic features such as reservoirs, water projects, and designated or regulatory flood plain areas.

Interagency coordination is necessary since many levels of government plan, design, and construct highway and water resource projects which might have an affect on each other. Agencies can share data and experiences within project areas to assist in the completion of accurate hydrologic analysis. Agencies include: Department of Natural Resources (DNR), U. S. Fish and Wildlife Service, U. S. Army Corps of Engineers (USACE), Watershed District & Management Organizations, Counties, Cities, Pollution Control Agency (PCA), Natural Resources Conservation Service (NRCS) previously Soil Conservation Service (SCS) and U. S. Geologic Survey (USGS).

HYDROLOGIC PROCEDURE SELECTION

Streamflow measurements are usually unavailable for determining flood frequency relationships at a site. In such cases, it is accepted practice to estimate peak runoff rates and hydrographs using statistical or empirical methods. The design discharge for other structures on the stream and historical data should be reviewed, and consideration given to previous studies and Flood Insurance Studies. Mn/DOT's practice shall be to use the discharge that best reflects local project conditions with the reasons documented.

Peak Flow Rates or Hydrographs

Determination of peak runoff rates for design conditions is generally adequate for conveyance systems such as storm drains or open channels. However, if the design includes storage basins or complex conveyance networks, a flood hydrograph is usually required. The development of runoff hydrographs is usually accomplished using computer programs.

Hydrologic Procedures Options

The recommended hierarchy for selecting a method of computing discharge for design of highway structures in Minnesota and the circumstances for their use are listed below and shown in Table 3.3. Where feasible, the hydrologic model should be calibrated to local conditions and tested for accuracy and reliability. Consider design discharges for other structures in the area and historical data for the area. In general the results from different hydrologic models should not be averaged.

- Minnesota USGS regression equations should be used for routine designs of bridges and culverts with 54" or larger widths and in accordance with the other limitations of the regression equations, unless there is gaging station data or historical evidence suggesting other alternatives.
- Log Pearson III analyses of stream gaging station data should be used for all routine designs with gaging station data, provided there is at least 10 years of continuous record for 10-year discharge estimates and 25 years for 100-year discharge estimates.
- Rational method shall be used only for drainage areas less than 200 acres, and preferably only for developed areas.
- The SCS unit hydrograph method contained in TR-20 should be used for storage routing or storage design.
- Both the graphical peak discharge and tabular hydrograph method available in TR-55 are simplified procedures are derived from TR-20.

- The TR-55 graphical method may be used for small rural watersheds (1 - 2000 acres).
- TR-55's tabular hydrograph method can be applied to larger watershed areas by splitting a non-homogenous watershed into homogenous subareas.
- Suitable computer programs such as HEC HMS, TR-20, TR-55, and HYDRAIN may be used for hydrologic calculations. Other computer programs that incorporate the recommended methodology may also be used. Output from all programs must be reviewed to see that the answers are reasonable.
- The 100-year discharges specified in the FEMA flood insurance study shall be used to analyze impacts of a proposed crossing on a regulatory floodway. However, if these discharges are deemed to be outdated, discharges based on current methods may be used subject to receipt of necessary regulatory approvals.

Rainfall vs. Flood Frequency

Drainage structures are designed for a designated flood frequency. However, certain hydrologic procedures use rainfall and rainfall frequency as the basic input. Thus it is commonly assumed in most cases that the 10-year rainfall will produce the 10-year flood. In general, rainfall is used to design storm drains and culverts with small drainage areas. The rational method and SCS methods use the assumption that a rainfall of a certain frequency will produce a flood of the same frequency.

Selection of Discharge Computation Method

FACILITY DESCRIPTION	METHOD				
	Frequency Analysis	Regression Equations	SCS Hydrograph	SCS Peak Discharge	Rational
Stream Flow, Channels, Bridges, & Culverts Greater then 48"	customary method	alternate method	complex facilities or hydrograph needed	alternate method	
Culverts 48" and Smaller		alternate method	complex facilities or hydrograph needed	customary method	alternative method
Storm Drains, Roadside Ditches, & Side Culverts			complex facilities or hydrograph needed		customary method
Detention Basins			customary method		preliminary evaluation, or permit review

USGS REGRESSION EQUATIONS

Regional regression equations are a commonly accepted method for estimating peak flows at ungaged sites or sites with insufficient data. Regression studies are statistical practices used to develop runoff equations. These equations are used to relate peak flow at a specified recurrence interval to the watershed's physiographic, hydrologic and meteorological characteristics The U.S. Geological Survey (USGS) developed the regression equations for Minnesota and published them in *Techniques for Estimating Magnitude and Frequency of Floods in Minnesota* (Guetzkow, 1977). Since then regression analysis was redone and new equations developed and published twice. Once with the same title *Techniques for Estimating the Magnitude and Frequency of Floods in Minnesota* (Jacques and Lorenz, 1988) developed in 1987 and published in 1988, and also as *Techniques for Estimating Peak Flow on Small Streams in Minnesota* (Lorenz, Carlson and Sanocki, 1997).

Regression analyses use stream gage data to define hydrologic regions. These are geographic regions having very similar flood frequency relationships and, as such, commonly display similar characteristics. Separate regression analysis were performed and equations developed at 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals for each hydrologically similar region. The most significant characteristic of the equations is the drainage area size above the point of interest. Additional basin characteristics such as main channel slope, lake storage, total storage and mean annual runoff are included as independent variables when they were determined to be statistically significant.

Application

The USGS Regression Equations may be used to design culverts and bridges in Minnesota. The USGS Regression Equations, obtained from multiple-regression analyses of gaging-station data in each hydrologic region, can be used to obtain flood-frequency estimates for ungaged sites on unregulated streams. Peak discharges for selected recurrence intervals can be computed from the empirical equations that relate flood magnitude to basin characteristics. Historical observations and other methods, should be used to evaluate the results. Where there is stream gage data, the findings from a Log Pearson III method should govern, provided there is at least 10 years of stream gage record. Reasonable and prudent judgment along with consideration of the standard regression error shall be used in reaching a design decision. Typical regression equation format:

$$\mathrm{Qi} = \alpha A^{b} S^{c} (St + 1)^{d}$$

Where: Q_i = flood frequency estimate for recurrence interval i
A = drainage area in square miles
S = main channel slope in feet per mile
St = percent of drainage area occupied by lakes, ponds or wetlands
a, b, c, d = variables

The regression equations, hydrologic region boundaries, variable definitions, procedures for use and discussion on accuracy and limitations are provided in the USGS reports..

Limitations

The basin characteristics of the stream being analyzed should be within the limits of those used to develop the equations. Each USGS report has a table showing the upper and lower limits for basins characteristics used in the regression analysis; care should be exercised using equation outside of the specified limits. The regression equations are intended to be used on streams which are not significantly

affected by manmade regulation, urbanization, or diversion. The equations should not be used immediately downstream of a lake or ponding area, but may be used to determine the peak inflow to be routed through an impoundment.

Procedure

There are three sets of equations that can be applied to a particular site. These include the 1997 regression equations developed by Lorenz, Carlson and Sanocki; 1987 regression equations developed by Jacques and Lorenz; and the 1977 regression equations developed by Guetzkow. Although the later equations were intended to supersede earlier equations, it is advisable to compute the discharge using multiple methods, and compare to other historical data or methods. The 1987 procedure divides the state into 4 hydrologic regions, where the 1977 procedure used 8 different hydrologic regions in the state and the 1997 procedures use 6 regions. Although the later reports used gaging stations with longer periods of records and more stations, it is valid to use the earlier 1977 and 1987 equations as a check. Problems related to hydrologic boundaries may occur in selecting the appropriate regression equation. Because of the distance between stream gages, the regional boundaries cannot be considered as precise. The watershed of interest may lie partly within two or more hydrologic regions or it may lie totally within a hydrologic region, but close to a hydrologic region boundary. In these instances care must be exercised in using regression equations. A field visit is recommended to first collect all available historical flood data as well as to compare the project's watershed characteristics with those of the abutting hydrologic regions. For drainage areas near regional divides, the equations for both regions should be evaluated and the results compared. The coefficients in the equations can also be used to transfer flood flows from a gaged site to an ungaged site on the same stream. The regional boundaries generally follow watershed basin divides.

ANALYSIS OF STREAM GAGE DATA

Many gaging stations exist throughout Minnesota where data can be obtained and used for hydrologic studies. If a project is located near one of these gages and the gaging record is of sufficient length of time, a frequency analysis may be made. The most important aspect of applicable station records is the series of annual peak discharges. It is possible to apply a frequency analysis to that data for the derivation of flood-frequency curves. Such curves can then be used in several different ways.

- If the subject site is at or very near the gaging site and on the same stream and watershed, the discharge for a specific frequency from the flood-frequency curve can be used directly.
- If the facility site is nearby or representative of a watershed with similar hydrologic characteristics, transposition of frequency discharges is possible.
- If the flood-frequency curve is from one of a group of several gaging stations comprising a hydrologic region, then regional regression relations may be derived. Regional regression relations are usually furnished by established hydrologic agencies and the designer will not be involved in their development.

Application

Mn/DOT may use a frequency analysis of stream gage data at appropriate locations when there is sufficient years of measured stream gage record. The preferred method of estimating flood frequency curves from stream gage data is a statistical method, which makes use of the Log Pearson Type III frequency distribution.

The analysis of gaged data permits an estimate of the peak discharge for the desired return period at a particular site. Experience has shown that statistical frequency distributions may be more representative

of naturally occurring floods and can be reliable when used for prediction. Although several different distributions are used for frequency analysis, experience has shown the Log-Person Type III distribution to be one of the most useful. The Log-Pearson III distribution and the process of fitting it to a particular data sample are described in detail in Water Resources Council Bulletin 17B, *Guidelines for Determining Flood Flow Frequency*, (WRC, 1981). Special handling of outliers, historical data, incomplete data, and zero flow years is covered in detail in Bulletin 17B.

There are two alternative methods for determining the value of the skew coefficient to be used in calculating the Log-Pearson Type III curve fit. The value of skew that is calculated directly from the gage data using the above formula is called the station skew. This value may not be a true representation of the actual skew of the data if the period of record is short or if there are extreme events in the period of record. Often, the station skew and the generalized skew can be combined to provide a better estimate for a given sample of flood data.

Transferring Gaged Data

Gaged data may be transferred to an ungaged site on the same river as the gaged site provided such data are nearby, within the same hydrologic region, and there are no major tributaries or diversions between the gage and the site of interest. These procedures make use of the constants obtained in developing the regression equations. To transfer discharge data from a gaged site to an ungaged site on the same stream:

$$\mathrm{Qu} = \mathrm{Qg}\left[\frac{\mathrm{Au}}{\mathrm{Ag}}\right]^{B}$$

Where: Q_u = flood frequency estimate to ungaged site
Q_g = flood frequency estimate for gaged site
A_u = drainage area for ungaged site
A_g = drainage area for gaged site
B = exponent for drainage area from the appropriate regression equation

This transfer relation can be used where drainage area size differs by no more than 50%. If other basin characteristics differ significantly, they should also be included by taking the ratio of the parameters raised to the power given in the regression equation. If the period of record at the gaged site is short, a weighted average of the results of the transfer equation and regression equation should be used.

The transposition of design discharges from one basin to another basin with similar hydrologic characteristics is accomplished by multiplying the design discharge by the direct ratio of the respective drainage areas raised to the drainage area exponent given in the appropriate regression equation. Thus on streams where no gaging station is in existence, records of gaging stations in nearby hydrologically similar watersheds may be used. The discharge for such an ungaged stream may be determined by the transposition of records using a similar procedure. This procedure is repeated for each available nearby watershed and the results are averaged to obtain a value for the desired flood frequency relationships in the ungaged watershed.