Montana StreamStats

An overview of Montana StreamStats and methods for obtaining streamflow characteristics at gaged and ungaged locations in Montana

In cooperation with
Montana Department of Natural Resources and Conservation,
Montana Department of Transportation,
and Montana Department of Environmental Quality

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What is StreamStats?

- Web-based GIS system for retrieving basin and streamflow characteristics
- Delineates basins
- Computes basin characteristics
- Retrieves streamflow characteristics
- Solves regression equations for estimating streamflow characteristics
Who developed StreamStats?

- StreamStats platform developed by USGS StreamStats Team
- Data developed locally in cooperation with
  - Montana Department of Natural Resources and Conservation
  - Montana Department of Transportation
  - Montana Department of Environmental Quality
StreamStats Top Three

- How to use StreamStats
- StreamStats is dynamic
- Current data, methods, and qualifications of StreamStats are reported in Scientific Investigations Report 2015-5019
StreamStats Hydrography

- **NHDPlus Version 2: Application ready**
  - geospatial datasets


  - National Hydrography Dataset (NHD) 1:100K scale
    - Stream network represented by flowlines
    - Attributes of flow direction, length, name, and many others

  - Watershed Boundary Dataset (WBD)
    - Seamless national framework of drainage boundaries

  - 30-meter Digital Elevation Model (DEM)
    - Developed from the National Elevation Dataset (NED)
    - Raster (grid) data for elevations used to create flow accumulation and flow direction grids (for delineating basins)
StreamStats Hydrography

- NHDPlus Version 2 also includes
  - USGS gaging stations
  - Dams from the National Inventory of Dams
  - Transboundary data harmonization between Canada and United States
Montana Basin Characteristics

- CONTDA - Contributing drainage area
- ELEV - Mean basin elevation
- TEMP - Mean annual temperature
- ELEVMAX - Maximum basin elevation
- MINBELEV - Minimum basin elevation
- Relief - Maximum minus minimum elevation
- EL5000, EL6000 - Percent of basin above listed elevation
- IRRIGAT_MT - Percent of basin that is irrigated
- LAKESNHDH - Percent of basin in lakes, pons, and reservoirs
- LC01CRPHAY - Percent of basin with cultivated crops
- LC01DEV - Percent of basin with urban land
- LC01WTLND - Percent of basin with wetlands
Montana Basin Characteristics

- BSLDEM30M-Mean basin slope
- SLOP30_30M-Percent of basin with slopes greater than 30%
- NFSL30_30M-Percent of basin with north-facing slopes >30%
- SLOP50_30M-Percent of basin with slopes greater than 50%
- PRECIP-Mean annual precipitation for basin (PRISM & Natural Resources Canada; 1971-2000)
- LC01Forest-Percent of basin with forest cover
- ET0306MOD-Mean monthly evapotranspiration for March-June
- ET0710MOD-Mean monthly evapotranspiration for July-October

Due to server processing capabilities and speeds we are limited to 20 basin characteristics.
Montana Streamflow Characteristics

- One Scientific Investigations Report (SIR) with multiple chapters
  - Chapter A: Montana StreamStats introduction

Streamflow characteristics for USGS gages
  - Chapter B: Peak flow trends and stationarity
  - Chapter C: Peak-flow analyses
  - Chapter D: Methods for improving peak flow analyses
  - Chapter E: Streamflow characteristics (i.e. low flow, duration)

Streamflow characteristics for ungauged sites
  - Chapter F: Peak-flow regional regression equations
  - Chapter G: Streamflow statistics regional regression equations

https://pubs.er.usgs.gov/publication/sir20155019
Chapter A: StreamStats

- Description of hydrography and data used to develop StreamStats
- Regulation classification
  - Regulated: If the conjoined drainage area of all dams is greater than or equal to 20% of the basin
  - Major regulation: The drainage area of a single dam exceeds 20%
  - Minor regulation: The drainage area of no single dam exceeds 20%, however the conjoined drainage area exceeds 20%.
Chapter B: Peak flow trends
Chapter B: Peak flow trends

Annual peak flows, days of annual peak flows, and fitted trend lines

Statistical distributions for indicated periods

EXPLANATION

Water year is defined as the 12-month period from October 1 through September 30 and is designated by the year in which it ends.

Annual peak flows and days of annual peak flows
- Annual peak flow
- Day of annual peak flow

Fitted trend lines
- Start of systematic data collection through 1940
- 1930 through 1976
- 1967 through 2011
- Start of systematic data collection through 2011

Bold lines indicate statistical significance (p-value less than 0.05)

Boxplots
- Data value greater than 1.5 times the interquartile range outside the quartile
- Data value less than or equal to 1.5 times the interquartile range outside the quartile

Legend:
- 75th percentile
- Median
- Interquartile range
- 25th percentile
Chapter B: Peak flow trends

- 06324500-Powder River at Moorhead

![Diagram showing annual peak flows and flood frequency estimates for 1923-2011 versus 1979-2011.]

**Figure 1.** Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

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**Percent difference in flood frequency estimates for 1923-2011 versus 1979-2011**

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</table>
Chapter B: Peak flow trends
Chapter B: Peak flow trends

- More research and analyses are needed to better understand downward trends of peak flow magnitudes and timing in Eastern Montana
  - Effects of smaller dams and land use practices
  - Effects of climate changes
- Be conservative!
Chapter C: Peak flow analyses

- Performed analyses using Bulletin 17B
- 725 streamflow gaging stations in and near Montana
  - 579 unregulated streamflow stations
  - 146 regulated streamflow stations
    - 100 analyzed for post-regulation period only
    - 17 analyzed for pre-regulation period only
    - 29 analyzed for both pre- and post-regulation
- Pre-regulation analyses used for regression equations
Chapter C: Peak flow analyses

- Analyses in downloadable file
- Tables 1-1 through 1-6 provide analyses info
- Tables provide NECESSARY background information
Chapter D: Improving peak flow analyses

- Why do peak flow analyses need to be improved?
  - Period of record (dry or wet period)
  - Length of record (short period of record)
  - Multiple gaging stations along same stream with different periods of record and results

- How are peak flow analyses improved?
  - MOVE.1 Record extension methods (66 gaging stations)
  - Weighting station analyses with regression equations (438 gaging stations)
Chapter E: Streamflow Characteristics

- Streamflow characteristics using daily mean streamflow
  - Annual and seasonal low flows
    - Annual based on climatic year (March 1-February 28)
    - March-June
    - July-October
    - November-February
  - Annual high flows
  - Mean annual and monthly streamflows
  - Annual and monthly durations
Chapter E: Streamflow Characteristics

- Performed analyses using SWSTAT
- 408 streamflow gaging stations in and near Montana
  - 281 unregulated streamflow stations
  - 127 regulated streamflow stations
    - 89 analyzed for post-regulation period only
    - 15 analyzed for pre-regulation period only
    - 23 analyzed for both pre- and post-regulation
- Pre-regulation analyses used for regression equations
Chapter E: Streamflow Characteristics

- Analyses served in downloadable file
- Table_1 provides station information
- Excel tab for each station
Chapter F: Peak-Flow Regional Regression Equations

- Regional Regression Equations for unregulated annual exceedance probabilities
  - 8 hydrologic regions
  - 537 gaging stations
    - Drainage area less than ~2,500 sq. mi.
    - Systematic record unaffected by major regulation
    - No redundancy with nearby stations
    - Representation of peak-flow characteristics in MT
  - 28 candidate basin characteristics
    - $A$, $EL_{5000}$, $EL_{6000}$, $ET_{SPR}$, $F$, $P$, $SLP_{30}$
Chapter F: Peak-Flow Regional Regression Equations

**Northwest**
- BCs: Drainage area, Average annual precip
- Northwest Foothills (n = 31)

**West**
- BCs: Drainage area, Average annual precip, % Forest
- West (n = 112)

**Southwest**
- BCs: Drainage area, % Basin above 6,000'
- Southwest (n = 50)

**Upper Yellowstone-Central Mountain**
- BCs: Drainage area, % Basin above 6,000', Mean monthly spring ET
- (n = 91)

**Northeast Plains**
- BCs: Drainage area, % Basin above 5,000'
- Northeast Plains (n = 64)

**East-Central Plains**
- BCs: Drainage area, % Basin with greater than 30% slope, Mean monthly spring ET
- East-Central Plains (n = 92)

**Southeast Plains**
- BCs: Drainage area, Mean monthly spring ET, % Forest
- Southeast Plains (n = 69)
Chapter G: Regional Regression Equations for Streamflow Characteristics

- **Annual and seasonal low-flow**
  - 7Q10
  - 14Q5

- **Annual and monthly**
  - Mean
  - Duration values for
    - Q20%
    - Q50%
    - Q80%

- **Explanatory Variables**
  - Drainage area
  - Mean annual precip.
  - Percent of basin with slopes greater than 50 percent.
Chapter G: Regional Regression Equations for Streamflow Characteristics
“Users should familiarize themselves with StreamStats Description, Instructions, and Limitations (using the links on the left) before utilizing the application”
Version History

- Version 2 included several tools related to stream-network navigation but changes to Arc tools required V2 to be retired in 2015.
- Version 3 was introduced as a temporary application with basic tools for basin delineations and flow computations until a more robust version could be developed.
- Version 4 Beta has been released; however, stream-network navigation and thorough testing has not been completed.

“Version 3 will remain available and should be used for official purposes until version 4 is available”
StreamStats Links

Welcome to StreamStats

Beta version 4 has arrived!

Beta version 4 is now available for most states on a trial basis, and version 3 remains available. Beta version 4 provides a single user interface (at http://streamstats.usgs.gov/streamstats/) for all states that are implemented, rather than separate applications for each state, as in versions 2 and 3, and the user interface is more user friendly than previous versions. Information for user-selected ungauged sites currently cannot be obtained using beta version 4 for the States of Arkansas, Arizona, Georgia, Iowa, Indiana, Maryland, North Carolina, Oregon, South Carolina, and Tennessee because of unique functionality for those states that is not yet implemented. Users are encouraged to read the Help button on the interface, which also provides access to limited beta version 4 documentation. See below for additional information about versions 3 and 4.

Please contact the StreamStats by email at support@streamstats.freshdesk.com if you have any questions.

The StreamStats Program

StreamStats is a Web application that incorporates a Geographic Information System (GIS) to provide users with access to an assortment of analytical tools that are useful for a variety of water-resources planning and management purposes, and for engineering and design purposes. In version 3 as well as beta version 4, StreamStats users can select USGS data-collection station locations shown on a map and obtain previously published information for the stations, including descriptive information, and previously published basin characteristics and streamflow statistics. Currently, StreamStats provides additional tools that allow users to select sites on ungauged streams and do the following:

- obtain the drainage-basin boundary (version 3 and beta version 4),
- compute selected basin characteristics (version 3 and beta version 4),
- compute selected streamflow statistics using regression equations (version 3 and beta version 4),
- download a shapefile of the drainage-basin boundary, as well as any computed basin characteristics and flow statistics (version 3 and beta version 4),
- edit the delineated basin boundary (beta version 4 only),
- modify the basin characteristics that are used as explanatory variables in the regression equations and get new estimates of streamflow statistics (beta version 4 only),
- print the map (beta version 4 only),
- measure distances between user-selected points on the map (beta version 4 only),
- obtain plots of the elevation profile between user-selected points on the map (beta version 4 only).

The streamflow statistics that StreamStats can provide for data-collection stations and for user-selected ungauged sites vary among the states that are implemented in StreamStats and among data-collection stations within states. Unless otherwise noted on a state's introductory page, estimates obtained for ungauged streams assume natural flow conditions at the site.

StreamStats generally is implemented separately for each state, with the needed data preparation work accomplished through cooperative agreements with state or other agencies. When states have not been implemented, it is generally because no state or other agency has been willing to enter into a cooperative agreement with the USGS to assist with the needed work.

StreamStats applications for individual states are accessed separately in version 3, whereas beta version 4 provides a single national user interface for all state applications. Use the State Applications link at the left to access a web page that shows where StreamStats version 3 is available and where it is being implemented. Users can select an individual state application from the map or the pull-down list on the State Applications page to view an introductory page for the state, which contains a link to the StreamStats version 3 user interface. The introductory pages explain any unique functionality that is available for the state and provides citations to reports that document the methods implemented for the state. The StreamStats beta version 4 user interface may be accessed at http://ssdev.cr.usgs.gov/streamstats/.

Several tools, mostly related to stream-network navigation, were lost from StreamStats when version 2 was retired and version 3 was introduced on July 14, 2015, before all tools from version 2 were redeveloped for version 3. These tools allowed users to search upstream or downstream along the stream network from user-selected sites to identify stream reaches and water-related activities along the streams, such as dams and point discharges, and obtain information about those activities. In addition, users could (1) estimate flow statistics at ungauged sites based on the statistics at upstream or downstream streamgages, (2) trace the path of a drop of water that falls on any point on the land surface downstream through the stream network, and (3) obtain elevation profiles along stream channels and between points on the land surface. Version 2 was retired because it was operated on computers that used an older operating system that was considered a security risk for use on U.S. government servers. Beta version 4 restores some of the tools that were lost from version 2. Also, the outputs that list the basin characteristics and estimated streamflow statistics for user-selected ungauged sites now include maps of the site locations. All other functionality that was available in Version 2, including all tools that rely on stream-network navigation, is still in development, with a goal of having completing development by late spring of 2016. Version 3 will remain available and should be used for official purposes until version 4 is more thoroughly tested.
StreamStats Links

- Limitations
  - The StreamStats Web application provides access to automated procedures and very large, complex data sets. These data sets are known to contain occasional errors.
  - Basin delineations, in particular, frequently have been found to be erroneous.
  - Additional limitations listed for regression and similar gages tool.
StreamStats Links

- Beta Version 4 User Instructions
- PDF file of instructions
StreamStats Links

- **StreamStats Description**
  - **Ungaged Site Reports**
    - Requires a basin delineation
    - Estimates flows using published regression equations
    - Must first measure necessary basin or climatic characteristics used as explanatory variables
    - Calls the National Streamflow Statistics (NSS) program (available as a separate application- http://water.usgs.gov/software/NSS/)
    - Basin characteristics and streamflow statistics are provided
StreamStats Links

- Data-Collection Station Reports
  - Use the “Query Streamgages” tool
  - Select streamgage of interest
    - NWIS link for streamflow data
    - StreamStats link for computed basin and streamflow characteristics
- Citations
- Print to pdf or save as htm, txt, etc
StreamStats Links

- Troubleshooting
  - PDF document of common problems
    - Pop-up blocker
    - IE 8 and compatibility mode
    - Set usgs.gov as a trusted site
  - Contact your computer system administrator to assure that firewall or network settings are not blocking StreamStats
  - Contact StreamStats team at support@streamstats.freshdesk.com
StreamStats Links

- Definitions
  - Long lists of basin characteristics and streamflow statistics that are deployed in various states or regions
  - Basin characteristics
  - Streamflow statistics

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<td>square miles</td>
<td>km2</td>
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<tr>
<td>ACARBON</td>
<td>40</td>
<td>Area underlain by carbonate rock</td>
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<td>km2</td>
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StreamStats Links

- Stream Network Navigation
  (Not currently developed for version 4)
  - Tools to allow upstream and downstream traces along the stream network from a selected point
    - Raindrop Trace to Network
    - Show Network Path and Profile
    - Trace from Outlet
    - Ad Hoc Trace
    - Configure NHD Trace
    - Estimate Flows Based on Similar Streamgaging Stations
  - Can be used to obtain distances, slopes, and NHD points (i.e. dams, streamgages) on network
StreamStats Links

- StreamStats Fact Sheet
  - Published in 2008
  - Based on StreamStats Version 2
  - Includes good description of stream network navigation tools

StreamStats: A Water Resources Web Application

Introduction

Streamflow statistics, such as the 1 percent flood, the mean flow, and the 7-day 10-year low flow, are used by engineers, land managers, biologists, and many others to help guide decisions in their everyday work. For example, estimates of the 1 percent flood (the flow that is exceeded, on average, once in 100 years and has a 1 percent chance of being exceeded in any year, sometimes referred to as the 100-year flood) are used to create floodplain maps that form the basis for setting insurance rates and land-use zoning. This and other streamflow statistics also are used for dam, bridge, and culvert design, water-supply planning, and management; water-use appropriations and permitting; wastewater and industrial discharge permitting; hydropower facility design and regulation; and the setting of minimum required streamflow to protect freshwater ecosystems. In addition, researchers, planners, regulators, and others often need to know the physical and climatic characteristics of the drainage basins (rainfall characteristics) and the influence of human activities, such as dams and water withdrawals, on streamflow upstream from locations of interest to understand the mechanisms that control water availability and quality at those locations. Knowledge of the streamflow network and downstream human activities also is necessary to adequately determine whether an upstream activity, such as a water...
StreamStats Links

- Frequently Asked Questions
- Available Web Services
- Batch Processor
- Talks and Other Info
StreamStats Application
StreamStats Application

StreamStats v4
- Green – implemented with the full functionality
- Purple – implemented, but not possible to get statistics for user-selected ungaged sites
- Orange – implemented internally and undergoing testing
- Blue – undergoing implementation
- White – no StreamStats activity
StreamStats Application

- **Sidebar**
  - Provides linear flow of steps
  - Includes short instructions
  - Occasionally going backwards causes problems, simply refresh and start over.
StreamStats Application

- Exploration Tools
  - Query Streamgages
  - Measure Tool
  - Elevation Profile Tool
  - Show your location
  - Reset the view

Geolocation error: This site does not have permission to use the Geolocation API.
StreamStats Application

- Map Legend
  - Base Maps
  - Regulation Points
  - MT Map Layers
  - National Layers
StreamStats Application

- Map Frame
  - Zoom tools
  - Legend for changing base maps
- Location Search for quickly selecting area
- Side Bar acts as a guide
StreamStats Application

- Zoom (level 15 or greater)
- Identify study area
- Select Delineate tool
- Click on Streamline*
StreamStats Application

- Delineated Basin

*StreamStats will delineate any selected grid point*
StreamStats Application

- Regulation
StreamStats Application

- Select Scenarios
  - Regression based scenarios
- Basin Characteristics
- Building a report
  - Download basin
  - Download CSV
  - Print report

USGS
StreamStats Application

- Regression Based Scenarios (Idaho)
  - Toggle scenarios
  - Continue
  - Build report
StreamStats Application

- Montana regression equations using internal version 3 development server

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http://dx.doi.org/10.3153/jdr20155019

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StreamStats Application

- **StreamStats Data-Collection Station report**
  - Many statistics (peak flow, low flow, seasonal low flow, duration, high flow duration)
  - Controlled=Regulation
  - Weighted peak flow (2 types)
    - At-site analysis weighted with regression equations
    - Record extension techniques to develop “nested” analyses

StreamStats Application

- **Demonstrations**
  - Public server V4
    - Limited basin characteristics
    - No regression equations
  - **Internal testing V4**
    - All basin characteristics
    - No regression equations
  - **Internal testing V3**
    - All basin characteristics
    - Regression equations enabled

- Version 3 is still the official version while version 4 is being developed and tested
StreamStats – Other Topics

- State boundaries
  - High resolution vs. medium resolution
  - Flow lines, DEMs
StreamStats – Other Topics

- If a delineated basin for an ungaged site is in more than one region
  - StreamStats will compute area averaged streamflow statistics
  - \[ Q = \frac{Q_{R1} \cdot A_{R1} + Q_{R2} \cdot A_{R2}}{A_{R1} + A_{R2}} \]
- If a delineated basin for an ungaged site is in more than one state
  - StreamStats will not automatically compute
  - Use area weighting and regression equations from applicable state
StreamStats – Other Topics

- Exclusion Polygons
  - Streamlines
  - Areas
  - Exclusion levels

- Montana currently only excludes at state boundaries
StreamStats – Other Topics

- Basin delineation edits

Your delineation is complete. You can now clear your basin, edit your basin, or choose a state or regional study specific function (if available). Click continue when you are ready.

To edit your basin, first click the ‘Add Area’ or ‘Remove Area’ button below. Use your mouse or finger to draw a polygon.

If adding an area be sure your drawn polygon starts and ends within the yellow basin boundaries.

If removing an area, be sure your drawn polygon starts and ends outside of the yellow basin.

- Add Area
- Remove Area
- Undo Edits
- Finished

Click first point to close this shape.
StreamStats – Other Topics

- Dams layer for regulation
  - National Inventory of Dams in NHD (2,817)
  - Not all inclusive
StreamStats – Other Topics

- **Regulation**
  - 20 percent of drainage area
  - Large diversion structures
  - “Check for upstream regulation” tool
  - Major vs. Minor

*Public version of StreamStats currently does not shade in orange showing dam drainage areas*
StreamStats – Problem Areas

- NHDPlus v2 is no longer being supported (fixes to flowlines or watershed boundaries are not being made)
- MT StreamStats should move to NHD high resolution ASAP
StreamStats – What’s Missing?

- Regression equations
- Drainage area adjustments methods using a nearby gaging station
- Prediction intervals for all regression equations
When will StreamStats be available?

- **National StreamStats Version 4 Beta**
  - Continued development of stream-network navigation
  - Continued testing

- **Montana StreamStats Application**
  - Currently able to compute basin characteristics
  - Regression tools developed, internal testing
  - Fully implemented Montana StreamStats application 2-4 weeks
  - Watch for USGS press release
StreamStats – Upcoming Changes

- Several basin characteristics erroneously showing extra precision in the Station Reports.
- Five of the basin characteristics are rounding to the nearest whole percentage but need further precision.
- Complete the development and release of Montana’s regression equations.
StreamStats Developments

- National development of NHDPlus High Res.
  - 2-3 years out
  - Will include value attributes for high resolution hydrography (1:24K NHD, 10-meter DEM)
- Updated basin and streamflow characteristics
  - Regulation (better methods, more inclusive)
  - Trends (land use and climate effects on peak flows)
- Spinoff applications
  - Time of travel
  - Real-time streamflow estimation for ungaged sites
- USGS WY-MT WSC – Wyoming StreamStats
StreamStats Developments

- StreamStats is dynamic
  - Streamflow statistics will be updated
  - New regression equations will be developed
  - National Hydrography Dataset will be modified
Data qualifications, and limitations of a StreamStats determined discharge...

- Peak-flow data
- Peak flow trends
- Peak flow analyses
- Adj. peak flow analyses
- Low flow data
- Low flow frequency
- Gage history
- Regulation
- Regression equations

StreamStats

Q
are described in USGS Reports

StreamStats

https://pubs.er.usgs.gov/publication/sir20155019
Clark Fork River at Milltown Dam, June 1908
http://www.floodsafety.noaa.gov/states/mt-flood.shtml

$Q_{\text{peak}} = 48,000 \text{ cfs}$
Flood frequencies were updated for USGS gaging stations using data through 2011.

Long-term gages were investigated for trends and stationarity.

Regression equations were developed for estimating flood frequencies at ungaged sites.

At-site flood frequencies were adjusted using weighting methods with regression equations or using record extension methods.
Floods and Flood Frequencies

some definitions

- A **flood** is any relatively high streamflow that overtops the natural or artificial banks of a river. This definition varies by agency.

- **Annual peak flows** are the instantaneous peak flow for a given year which are used to determine flood frequencies. Individual peak flows may not necessarily be a flood.

- **Discharge** is another term for streamflow (or magnitude of flood); it is the measured volume of water that moves past a point in the river in a given amount of time. Discharge is usually expressed in cubic feet per second.
Floods and Flood Frequencies

Introduction

- **Flood frequency** is the concept of determining the probability of a given flood occurring in any given year.
- Flood frequencies are expressed in Annual Exceedance Probabilities (AEP). A 1-percent AEP has a 1 percent probability of occurring in any given year. The 1-percent AEP is commonly referred to as the 100-year flood.
Floods and Flood Frequencies

Introduction

“I only need the 100-year flood for…”

- Purpose of this presentation is to provide basic information and methods necessary for deriving the range of peak-flows for your design criteria.
Floods and Flood Frequencies

Introduction

“I only need the 100-year flood for…”

- Methods for obtaining flood frequency
  - Gaged sites
    - At-site flood frequency analysis
    - At-site flood frequency analysis weighted with regression equations
    - At-site flood frequency analysis after performing record extension methods
  - Ungaged sites
    - Regional regression equations
    - Drainage-area adjustment
Floods and Flood Frequencies

Introduction

“I only need the 100-year flood for…”

- Understanding uncertainty
  - Flood mechanisms
  - Extreme flood events
  - Confidence intervals
  - Period of record
USGS stream gages record streamflow at various streams. The largest instantaneous streamflow for each water year is recorded and stored in NWIS.

Flood Frequencies
How are they computed?

<table>
<thead>
<tr>
<th>Water year</th>
<th>Date</th>
<th>Peak flow, in cubic feet per second</th>
<th>Gage height, in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1909</td>
<td>5/25/1909</td>
<td>1,410</td>
<td>--</td>
</tr>
<tr>
<td>1910</td>
<td>4/29/1910</td>
<td>680</td>
<td>--</td>
</tr>
<tr>
<td>1911</td>
<td>6/3/1911</td>
<td>2,590</td>
<td>--</td>
</tr>
<tr>
<td>1912</td>
<td>5/22/1912</td>
<td>1,410</td>
<td>--</td>
</tr>
<tr>
<td>1913</td>
<td>5/29/1913</td>
<td>1,250</td>
<td>--</td>
</tr>
<tr>
<td>1914</td>
<td>6/6/1914</td>
<td>1,490</td>
<td>--</td>
</tr>
<tr>
<td>1915</td>
<td>6/13/1915</td>
<td>1,000</td>
<td>--</td>
</tr>
<tr>
<td>1916</td>
<td>6/22/1916</td>
<td>1,240</td>
<td>--</td>
</tr>
<tr>
<td>1917</td>
<td>5/27/1917</td>
<td>4,020</td>
<td>--</td>
</tr>
<tr>
<td>1918</td>
<td>7/15/1918</td>
<td>2,500</td>
<td>--</td>
</tr>
<tr>
<td>1919</td>
<td>3/31/1919</td>
<td>748</td>
<td>--</td>
</tr>
<tr>
<td>1920</td>
<td>5/13/1920</td>
<td>1,570</td>
<td>--</td>
</tr>
<tr>
<td>1921</td>
<td>6/9/1921</td>
<td>564</td>
<td>--</td>
</tr>
<tr>
<td>1922</td>
<td>6/11/1922</td>
<td>1,690</td>
<td>--</td>
</tr>
<tr>
<td>1923</td>
<td>6/21/1923</td>
<td>2,140</td>
<td>--</td>
</tr>
<tr>
<td>1924</td>
<td>5/18/1924</td>
<td>1,160</td>
<td>--</td>
</tr>
<tr>
<td>1925</td>
<td>7/24/1925</td>
<td>1,960</td>
<td>--</td>
</tr>
<tr>
<td>1926</td>
<td>5/22/1926</td>
<td>873</td>
<td>--</td>
</tr>
<tr>
<td>1927</td>
<td>6/12/1927</td>
<td>2,420</td>
<td>--</td>
</tr>
</tbody>
</table>

http://nwis.waterdata.usgs.gov/mt/nwis/peak
Flood Frequencies
How are they computed?

- PEAKFQ software which uses approved methods to compute flood frequencies from annual peak flow data.
  
  http://water.usgs.gov/software/PeakFQ/

  

- Bulletin 17C will replace Bulletin 17B and is currently out for public comment
  
  http://acwi.gov/hydrology/Frequency/b17c/bulletin17c_draft_for_public_review.pdf
Flood Frequencies PEAKFQ

- Download peakfq (watstore) format data from NWIS for desired USGS gage
- Open data in PEAKFQ
- Follow guidelines for B17B or B17C for computations
Peak flow data recorded as part of the normal streamflow gaging operations are considered the systematic record.

A peak flow data from a single year (separate from the systematic record) and considered largest in some period of time is a historic peak.

B17B and B17C use different methods for handling historic peaks.
Analysis assumes that the recorded peak flow data is a sample of the TRUE population of peak flow data, and this population remains constant or stationary through time. Thus, the population of peak flows is not changing due to climate or anthropogenic changes.

Statistical methods test for stationarity and trends in peak flow data.

Are peak flow data ever stationary?
Flood frequencies assume that all floods for a given site have a similar cause of flooding; thus, they are considered a single population. Sites with multiple causes (2 or more) of flooding are considered a mixed population. A classic mixed population is rain caused floods and hurricane caused floods which is common on the east coast. In a classic mixed population, the peaks can be separated by cause of flooding and a mixed-population flood frequency analysis performed.
Flooding Mechanisms in Montana

- Snowmelt
- Rainfall
- Ice/debris jams
- Others
  - Rain on snow
  - Burn areas
  - Dam failures
Mixed population of floods

- 2 or more causes of flooding
- Classic example is hurricanes vs. rainfall on east coast.
- Does Montana have mixed-population floods and can we separate the populations?
Significant Montana Floods

- According to National Weather Service\(^1\)
  - 1908
  - 1948
  - 1964
  - 1978
  - 2011

- Others
  - 1952-North-central MT
  - 1953-Central MT
  - 1975-Statewide
  - 1981-Central MT

\(^1\)http://www.floodsafety.noaa.gov/states/mt-flood.shtml
Precip. for 1964
Classic mixed population
Trends and stationarity

Figure 1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve

<table>
<thead>
<tr>
<th>Period</th>
<th>66.7</th>
<th>50</th>
<th>42.9</th>
<th>20</th>
<th>10</th>
<th>4</th>
<th>2</th>
<th>1.0</th>
<th>0.5</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1923-2011</td>
<td>3,879</td>
<td>5,424</td>
<td>6,238</td>
<td>10,680</td>
<td>15,390</td>
<td>22,920</td>
<td>29,780</td>
<td>37,820</td>
<td>47,190</td>
<td>61,930</td>
</tr>
<tr>
<td>1979-2011</td>
<td>2,625</td>
<td>3,526</td>
<td>3,981</td>
<td>6,172</td>
<td>8,198</td>
<td>11,020</td>
<td>13,300</td>
<td>15,710</td>
<td>18,250</td>
<td>21,850</td>
</tr>
</tbody>
</table>

Percent difference in flood frequency estimates for 1923-2011 versus 1979-2011

Regional trends study
Regulation review

- **Regulated**
  - 20 percent or more of basin is upstream from dams
  - Determined using GIS analyses and NHDPlusV2 dams layer

- **Major regulation**
  - 20 percent or more of basin is upstream from a single dam
  - Major diversion from stream

- **Minor regulation**
  - No single dam exceeds 20 percent, but cumulative area exceeds 20 percent
Classic major regulation

12325500 Flint Creek near Southern Cross
95.2 percent basin upstream from dam (Georgetown)
Minor regulation

- 06120500-Musselshell River at Harlowton
  - 24.7 percent of basin is upstream from dams (R)
  - No single dam exceeds 20 percent = minor
  - Total period of record used in analysis
  - Used in regression equations

19.9% in 1956
Confidence Intervals

- Reported at 95 percent
- Longer records typically have tighter confidence intervals

### Table: Peak Flow Data

<table>
<thead>
<tr>
<th>Drainage area, square miles</th>
<th>Number of years of peak-flow records in analysis period</th>
<th>Skew type used in analysis</th>
<th>Low-outlier threshold, cubic feet per second</th>
<th>Type of low-outlier threshold</th>
<th>High-outlier threshold, cubic feet per second</th>
<th>Type of high-outlier threshold</th>
<th>Water year of peak flow for user or historic high-outlier threshold</th>
<th>Length of historic period, in years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>825</td>
<td>98</td>
<td>WEIGHTED</td>
<td>1,345</td>
<td>default</td>
<td>13,219.5</td>
<td>default</td>
<td>--</td>
</tr>
</tbody>
</table>

Peaks flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent:

<table>
<thead>
<tr>
<th>Drainage area, square miles</th>
<th>Number of years of peak-flow records in analysis period</th>
<th>Skew type used in analysis</th>
<th>Low-outlier threshold, cubic feet per second</th>
<th>Type of low-outlier threshold</th>
<th>High-outlier threshold, cubic feet per second</th>
<th>Type of high-outlier threshold</th>
<th>Water year of peak flow for user or historic high-outlier threshold</th>
<th>Length of historic period, in years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4,620</td>
<td>5,280</td>
<td>5,580</td>
<td>6,790</td>
<td>7,700</td>
<td>8,750</td>
<td>9,490</td>
<td>10,200</td>
</tr>
</tbody>
</table>

Upper and lower 50-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent:

<table>
<thead>
<tr>
<th>Drainage area, square miles</th>
<th>Number of years of peak-flow records in analysis period</th>
<th>Skew type used in analysis</th>
<th>Low-outlier threshold, cubic feet per second</th>
<th>Type of low-outlier threshold</th>
<th>High-outlier threshold, cubic feet per second</th>
<th>Type of high-outlier threshold</th>
<th>Water year of peak flow for user or historic high-outlier threshold</th>
<th>Length of historic period, in years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4,860</td>
<td>5,560</td>
<td>5,890</td>
<td>7,240</td>
<td>8,300</td>
<td>9,560</td>
<td>10,400</td>
<td>11,300</td>
</tr>
</tbody>
</table>

**Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.**
Confidence Intervals

- Some sites have extremely large confidence intervals
Confidence Intervals

- Record length

Musselshell at Harlowton vs. Shawmut
Regional regression equations

- Regional Regression Equations provide estimates of flood frequencies at ungaged sites where we don’t have peak-flow data and computed flood frequencies.
- Equations are developed for regions with similar hydrologic characteristics. Unfortunately there are still boundaries.
- Equations also are weighted with at-site flood frequencies for sites with a short period of record.
Regional regression equations

Northwest
(n = 28)

BCs:
- Drainage area
- Average annual precip
- % Forest

Northwest Foothills
(n = 31)

BCs:
- Drainage area
- Average annual precip

East-Central Plains
(n = 64)

BCs:
- Drainage area
- % Basin above 5,000'

Southeast Plains
(n = 69)

BCs:
- Drainage area
- Mean monthly spring ET
- % Forest

West
(n = 112)

BCs:
- Drainage area
- Average annual precip

Southwest
(n = 50)

BCs:
- Drainage area
- % Basin above 6,000'

Upper Yellowstone-Central Mountain
(n = 91)

BCs:
- Drainage area
- Mean monthly spring ET
- % Forest
Standard Error of Prediction (SEP)

“The 1982 report has a lower SEP so I decided to use those equations....”

- The **standard error of prediction** is a measure of how well the regression equations predict flood frequency magnitudes and is used for selecting the best equation for the given data.
- New study has **different SEPs** because we are using **different data, gages, and methods**.
- Comparing SEPs from 2 data sets, is like comparing apples to oranges.
Example

- Excel tools (not reviewed/published but can get from me)
- Input variables
- Predicted Q
- Confidence intervals are generally quite large
- Check leverage
Limitations

- Regulation: <20% and no major diversions
- Basin characteristics within limits
- Leverage (combined BCs within limits)

Table 3. Ranges of values of basin characteristics used to develop regional regression equations.

<table>
<thead>
<tr>
<th>Hydrologic region (ordered clockwise from northwestern Montana)</th>
<th>A Min</th>
<th>A Max</th>
<th>E5000 Min</th>
<th>E5000 Max</th>
<th>E6000 Min</th>
<th>E6000 Max</th>
<th>ET_{spr} Min</th>
<th>ET_{spr} Max</th>
<th>F Min</th>
<th>F Max</th>
<th>P Min</th>
<th>P Max</th>
<th>SLP_{30} Min</th>
<th>SLP_{30} Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td>0.60</td>
<td>2,465.66</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>14.62</td>
<td>62.02</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Northwest</td>
<td>2.43</td>
<td>1,556.17</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>20.74</td>
<td>83.16</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Northwest Foothills</td>
<td>0.19</td>
<td>1,238.09</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>10.13</td>
<td>23.36</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Northeast Plains</td>
<td>0.18</td>
<td>2,747.31</td>
<td>0.00</td>
<td>30.52</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>East-Central Plains</td>
<td>0.11</td>
<td>2,550.96</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.90</td>
<td>1.57</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.00</td>
<td>31.87</td>
</tr>
<tr>
<td>Southeast Plains</td>
<td>0.10</td>
<td>1,962.05</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.96</td>
<td>1.67</td>
<td>0.00</td>
<td>57.64</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Upper Yellowstone-Central Mountain</td>
<td>0.39</td>
<td>2,039.76</td>
<td>--</td>
<td>--</td>
<td>0.00</td>
<td>100.00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Southwest</td>
<td>0.42</td>
<td>2,472.17</td>
<td>--</td>
<td>--</td>
<td>0.00</td>
<td>100.00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Drainage-area adjustment

- **Gage selection**
  - Same stream and similar flow regime
  - 0.5-1.5 DA
  - Regulation

- Regulation
  - Upstream or downstream of 1 gage
  - Between 2 gages

\[
Q_{AEP,U} = Q_{AEP,G} \left( \frac{DA_U}{DA_G} \right)^{\exp_{AEP}}
\]

\[
\log Q_{AEP,U} = \log Q_{AEP,G_1} + \left[ \frac{\log Q_{AEP,G_2} - \log Q_{AEP,G_1}}{\log DA_{G_2} - \log DA_{G_1}} \right] (\log DA_U - \log DA_{G_1})
\]

Table 5. Regression coefficients for ordinary least squares (OLS) regressions relating AEP-percent peak flow ($Q_{AEP}$) to contributing drainage area for use with ungaged sites on gaged streams.
Equations vs. drainage area ratio

- **Regression equations**
  - Only for unregulated sites
  - Hydrologically similar to sites in region
  - Provides prediction intervals

- **Drainage area ratio**
  - Same stream with similar flow regime?
  - How many years of record for index gage?
  - Extreme floods or variance in flood events?
  - Period of record (wet/dry periods)?
  - Confidence intervals are not computed
Examples

Remember this?

“I only need the 100-year flood for…”

- Purpose of this presentation is to provide basic information and methods necessary for deriving the range of peak-flows for your design criteria.
## Comparison of analyses

### Table 11. Discharge Estimate Summary for USGS gage 06120900

<table>
<thead>
<tr>
<th>Recurrence Interval</th>
<th>WRIR 03-4308</th>
<th>SIR 2015-5019</th>
<th>EMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Systematic</td>
<td>BC Regression</td>
<td>Systematic At-site</td>
</tr>
<tr>
<td>10 yr</td>
<td>1,520</td>
<td>1,040</td>
<td>2,650</td>
</tr>
<tr>
<td>25 yr</td>
<td>4,370</td>
<td>1,600</td>
<td>8,010</td>
</tr>
<tr>
<td>50 yr</td>
<td>8,820</td>
<td>2,090</td>
<td>15,400</td>
</tr>
<tr>
<td>100 yr</td>
<td>16,800</td>
<td>2,650</td>
<td>26,500</td>
</tr>
<tr>
<td>500 yr</td>
<td>64,400</td>
<td>4,250</td>
<td>71,000</td>
</tr>
</tbody>
</table>

Selected discharges are shown in RED.

BC = Basin Characteristics
AC = Active Channel
BF = Bankfull Width

Written comm., Steve Story, DNRC
Updating at-site frequencies

- Current flood frequency reports used data through 2011. Already outdated?

- When to update at-site?
  - General rule of thumb is if you have 10% new peaks, or a peak in the top 10%.
  - Chapter C table 1-5 includes all specifics of how analyses were performed. Use this as a guideline if you’re updating an at-site.
  - Don’t forget historic peaks at discontinued sites can be updated as well if the historic period of record is through 2011.
General Thoughts

- 725 gaging stations with at-site analyses statewide
- Lots of variability within the state, regions, and even locally
- Skew map and station skews provides some insight on complexities in Montana
- Historic analyses, below-gage base peaks, mixed population analysis increase complexity
General Thoughts

- Regression equations
  - Unregulated sites with 10+ years record included
  - GLS regressions, accounts for time and sampling variability
  - Provides better fits than OLS, but generally results in larger prediction intervals

- New regional skew study
  - All of Montana will be included
  - May address extremes skew issues in mixed population regions
  - EMA analyses of gages with 25+ yrs
General Thoughts

- **EMA methods**
  - Handles historic peaks differently
  - Multiple Grubbs-Beck low outlier test
  - Will require additional documentation of peaks and data in the peak flow file.

- **Regulation**
  - Percent of area not a great indicator of regulation
  - Need to study regulation specifically
    - Storage to mean annual streamflow?
  - Small dams and reservoirs
General Thoughts

- Trends and stationarity
  - Is there such a thing as stationarity?
  - Long term vs. short term trends
- Channel width based regression equations
  - Update channel width data base
  - Explore remote sensing methods to measure
  - MDT research proposal