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# Flood-Frequency Analyses for U.S. Geological Survey Gaging Stations Based on Data through Water Year 2009

By

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A proposal prepared for the Montana Department of Transportation

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November 18, 2009

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## Problem statement

The U.S. Geological Survey (USGS) publishes flood-frequency estimates that are used for the economical design of water conveyance and storage structures such as culverts, bridges, storm sewers, dams, and levees.  Reliable flood-frequency information also is crucial for effective planning and management of water resources and floodplains, to protect lives and property in flood-prone areas, and for the determination of actuarial flood-insurance rates.  For several applications, including Federal Emergency Management Agency (FEMA) 100-year floodplain delineation and U.S. Department of Transportation Federal Highway Administration bridge and culvert design, USGS flood-frequency estimates generally are required.

Since the mid-1980's large parts of Montana have experienced two severe droughts.  Occurrence of these droughts during a relatively short time frame has the potential to substantially affect flood-frequency estimates for short-term gaging stations.  Further, recent climatic patterns, and uncertainties concerning the roles of natural versus anthropogenic factors as driving forces, have led some researchers to question some of the basic premises of typical flood-frequency methods.  There is a substantial need to evaluate the effects of differences in data-collection periods and variability in climatic conditions on our understanding of flood hydrology in Montana.

Flood-frequency estimation for northwestern Montana is complicated by infrequent unusually large floods.  Typical flood-frequency methods generally do not provide accurate flood-frequency estimates for this situation.  Previous flood-frequency analyses for northwestern Montana accounted for this issue by using an approach that was performed on a station-by-station basis.  There are two primary concerns relating to a station-by-station approach: 1) the ability to attain consistency in flood-frequency estimates for basins with similar climatic and hydrogeologic characteristics, but differing by whether or not the data-collection periods include any unusually large floods; and 2) the ability to accurately estimate the true frequency of occurrence of unusually large floods based primarily on the limited data available for a single gaging station.  There is a need to investigate the use of a regional approach to improve flood-frequency estimates for northwestern Montana.

***Up-to-date USGS flood-frequency estimates are of particular value to the Montana Department of Transportation (MDT) because they serve as the basis of hydrologic analyses for road structures with design criteria dependent on flood characteristics.*** The last USGS flood-frequency report for Montana was based on data through water year 1998.  Updated flood-frequency information would include 11 additional years of peak-flow records and 18 new stations that have achieved at least 10 years of record since 1998.  Although a substantial part of the proposed project involves a routine update of important hydrologic information, there are specific vital research activities that are proposed to improve flood-frequency estimates and investigate effects of recent climatic patterns on flood frequency estimates.

## Background summary

The purpose of this research is to determine flood-frequency estimates for USGS gaging stations in Montana. Flood-frequency estimates are determined by fitting a log-Pearson Type III probability distribution to the recorded annual peak flows using methods described in Bulletin 17B of the U.S. Interagency Advisory Committee on Water Data (1982). However, Bulletin 17B analyses using default procedures do not always provide the most accurate flood-frequency estimates for gaging stations with complicating factors. Research activities in the proposed project will focus on improving flood-frequency estimates for gaging stations and publishing the flood-frequency estimates along with detailed documentation of the specific methods used to develop the frequency estimates.

## Objectives

The primary objectives of the proposed project include:

1) Determine flood-frequency estimates (recurrence intervals of 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years) for more than 660 USGS gaging stations in Montana based on data through water year 2009. These flood-frequency estimates are routinely used by MDT for design purposes.
2) Investigate methods of adjusting flood-frequency estimates for short-term gaging stations with data restricted to either unusually wet or dry periods (including 1985-present).
3) Investigate the effects of climatic variability on our understanding of flood hydrology in Montana and potential emerging methods for determining more accurate flood-frequency estimates.
4) Investigate the use of a regional approach for flood-frequency analysis in northwestern Montana, where unusually large (but infrequent) floods complicate flood-frequency estimates.

## Benefits

Up-to-date flood-frequency estimates will meet critical needs for numerous structure-design and floodplain-management issues in Montana, especially for MDT. Further, the proposed research will provide valuable information for evaluating the effects of climatic patterns on flood-frequency estimates and investigating emerging flood-frequency methods that address climatic uncertainty. The final report from this study will be patterned after a report from a similar study in South Dakota (*http://pubs.er.usgs.gov/usgspubs/sir/sir20085104*) and readily available in hard-copy and on-line. The report will provide detailed documentation of methods, which will be of substantial value to MDT and other users in defending design flows and performing auxiliary analyses. This work also will substantially streamline the process of updating flood-frequency estimates and lower the cost of future updates.

**Specific benefits to MDT and the taxpayer include:**

- Economical hydraulic design. Updating and publishing flood-frequency estimates will allow MDT to use the most current hydrologic data available and will:
  - Assist designers in accurately selecting proper culvert sizes and bridge openings, and reduce the risk of over- or under-sizing.
  - Reduce construction costs that result from oversized culverts and bridge openings based on outdated hydrologic data.
  - Save a significant amount of preliminary-engineering time by being able to use published information when designing hydraulic features, assisting with MDT maintenance activities, and responding to damage claims.
- Establishment of road grades and low beam elevations. Setting road grades is predicated upon establishment of accurate flood elevation data. Updated flood-frequency estimates will allow MDT staff to more confidently provide the appropriate level of service to the road user, and evaluate risks to the road facility and upstream properties during flood events.
- Defending against lawsuits. It is important to be able to technically justify the specific flood-frequency estimates used in various design applications. Design flows should be based on the most up-to-date data and methods available. Design flows that are not accurately determined are subject to question by other engineers and might result in costly litigation.
- Securing floodplain permits. Permitting MDT facilities in floodplains is becoming increasingly common. The authorization of construction in floodplains is scrutinized by local floodplain authorities, FEMA and DNRC engineers. The most recent flood-frequency data is required for the permitting process.
- Stream restoration and fish passage. MDT projects sometimes require stream relocation and/or mitigation to reduce environmental impacts and allow fish passage. The design and implementation of mitigation activities requires up-to-date hydrologic data and is subject to review by other agencies.
- Preliminary-engineering and planning process. Up-to-date flood-frequency estimates will allow MDT to make good planning level decisions and preliminary engineering cost estimates for system facility upgrades or reconstruction efforts.

**Potential consequences of not updating flood-frequency estimates include:**

- **Under-design**, resulting in either flood or road damage, or **over-design**, resulting in unnecessary capital expenditures based on outdated analysis.
- Inability to defend against damage claims and lawsuits resulting from flood damage with potential substantial cost of fixing an existing problem or paying damage claims.
- Falling further behind in analyzing hydrologic data that is being collected annually by USGS in cooperation with MDT.
- Failing to remain current with emerging methods of flood-frequency analysis.

## Research Plan

The research plan for the proposed project includes the following major tasks:

*Task 1: Conduct and document Standard Log-Pearson III flood-flood frequency analyses for U.S. Geological Survey continuous and crest-stage gaging stations*

*Task 2: Investigate application of record-extension methods for improving flood-frequency estimates for short-term gaging stations with data restricted to either unusually dry or wet periods*

*Task 3: Investigate effects of climatic variability on Montana flood hydrology and initiate systematic tracking of stationarity (that is, does what happened in the past accurately reflect what will happen in the future) of flood-frequency data for Montana*

*Task 4: Investigate application of regional mixed-population analysis for northwestern Montana*

Detailed discussion of the tasks is presented below and in the attached appendices.

Flood-frequency estimates for USGS gaging stations generally will be updated using standard procedures presented in Bulletin 17B. However, if default Bulletin 17B methods are applied to gaging stations with short or unusually wet or dry data-collection periods (including the period 1985-2008 in some areas) there is potential for introducing substantial inconsistency between gaging stations. Specific methods that will be investigated for adjusting flood-frequency estimates to compensate for period-of-record effects are presented in more detail in Appendix A.

Recent climatic patterns, and uncertainties concerning the relative contributions of natural and anthropogenic factors as driving forces, have led some researchers to question some of the basic premises of typical flood-frequency methods, including stationarity of peak-flow records. There is a substantial need to begin systematic tracking of stationarity of peak-flow records in Montana. Specific methods that will be investigated to remain current with emerging climatic and hydrologic research, and initiate systematic tracking of stationarity of peak-flow records for Montana are presented in more detail in Appendix A.

Flood-frequency estimation for some gaging stations in northwestern Montana is complicated by the presence of a small number of unusually large floods during the period of record. In previous USGS flood-frequency reports, a mixed-population flood-frequency analysis was performed on a station-by-station basis to improve flood-frequency estimates for these gaging stations. However, a regional mixed-population analysis might provide further improvement to flood-frequency estimates in northwestern Montana, and also potentially have application to other parts of Montana. Specific methods concerning application of the regional mixed-population analysis are presented in more detail in Appendix B.

## Products

The following products will be produced as a result of the proposed project:

Quarterly progress reports

Draft report for review prior to publication

Final report

Various conference presentations and final presentation to MDT

As work progresses on the proposed study, preliminary results will be made available to MDT for review on a provisional basis to allow timely application of study results.

The final report will be a USGS Scientific Investigations Report similar to Sando and others (2008; *http://pubs.er.usgs.gov/usgspubs/sir/sir20085104*). This report will be available in hard copy and also on-line. Data presented will include default Bulletin 17b frequency estimates and also recommended frequency estimates when default Bulletin 17b methods do not provide accurate results. Detailed information on the specific parameters used to develop the frequency estimates will be presented to allow users to defend design flows and facilitate conducting auxiliary analyses. Frequency curves and annual peak-flow data will be presented in figures to show how well the frequency estimates represent the recorded data and also to show long-term patterns in annual peak flows for individual gaging stations. Further, some of the information produced from the proposed study will be made available on-line by link from the USGS Montana Water Science Center web site (for example, see: *http://mt.water.usgs.gov/freq?page_type=table*).

## Implementation

The results of the proposed project will be available to MDT and other users to aid in determining flood characteristics critical to structure design. Updating the flood-frequency estimates for the USGS gaging station network will ensure that flood-frequency information is current and based on up-to-date methods.

# Project Schedule

Table 1. Project schedule

| Work tasks | Milestone dates | FY 2010 | | | FY 2011 | | | | | | | | | | | | FY 2012 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| Project commencement | 07/15/10 | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1. Conduct and document standard log-Pearson III flood frequency analyses for about 650 USGS gaging stations | | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | |
| 1a. Document regulatory structures that influence peak flows at gaging stations | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| 1b. Construct table of regulating structures and stations influenced | | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| 1c. Retrieve and format peak-flow data | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1d. Perform flood-frequency analyses | | | X | X | X | X | X | X | X | | | | | | | | | | | | | | | | | | | |
| 1e. Construct figures and tables of frequency results and accompanying documentation | | | | | | | X | X | X | X | | | | | | | | | | | | | | | | | | |
| 2. Investigate application of record-extension methods for improving flood-frequency estimates for short-term gaging stations | | | | | | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | |
| 2a. Identify gaging stations with less than 15 years of record or with longer periods of record but substantially influence by unusual climatic conditions | | | | | | X | X | X | | | | | | | | | | | | | | | | | | | | |
| 2b. Conduct correlation analyses to determine appropriate index stations | | | | | | X | X | X | | | | | | | | | | | | | | | | | | | | |
| 2c. Conduct Bulletin 17b 2-station analyses and MOVE.1 analyses for record extension | | | | | | | X | X | X | X | X | X | | | | | | | | | | | | | | | | |
| 2d. Examine record-extension results for reasonableness of fit | | | | | | | | | | | X | X | | | | | | | | | | | | | | | | |
| 2e. Table record-extension results and accompanying documentation | | | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | |
| 3. Initiate systematic tracking of stationarity of flood-frequency data for Montana | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | | | | | | | | | |
| 3a. Identify long-term unregulated stations to serve as regional index stations | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | |
| 3b. Conduct statistical analyses of temporal variability in peak flows for regional index stations | | | | | | | | | | | X | X | X | X | X | X | | | | | | | | | | | | |
| 3c. Investigate emerging methods for addressing temporal variability in peak-flow analyses or nonstationary peak-flow records | | | | | | | | | | | | | | | | X | X | | | | | | | | | | | |
| 3d. Construct figures and tables presenting results | | | | | | | | | | | | | | | | | X | X | X | | | | | | | | | |
| 4. Investigate application of regional mixed-populations analyses for Montana | | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | | | |
| 4a. Investigate occurrence of high-outlier peak flows in northwestern Montana and define mixed-population region | | | | | X | X | X | X | | | | | | | | | | | | | | | | | | | | |
| 4b. Investigate relative probability of occurrence of independent ordinary peak flows and high-outlier peak flows | | | | | | | | X | X | X | X | X | X | X | X | | | | | | | | | | | | | |
| 4c. Construct normalized high-outlier peak-flow probability distribution | | | | | | | | | | | | | X | X | X | X | X | X | | | | | | | | | | |
| 4d. Conduct regional mixed-population frequency analyses for northwestern Montana gaging stations | | | | | | | | | | | | | | | | | X | X | X | X | | | | | | | | |
| 4e. Construct figures and tables presenting results | | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | |
| 5. Quarterly progress reports | | | | | X | | | X | | | X | | | X | | | X | | | X | | | X | | | X | | |
| 6. Report preparation | | | | | | | | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X |
| 6a. Prepare draft tables and figures | | | | | | | | | | | | | | | | | X | X | X | | | | | | | | | |
| 6b. Prepare draft text and submit draft report | 03/31/12 | | | | | | | | | | | | | | | | | | X | X | X | X | | | | | | |
| 6c. Review and address comments; prepare for publication | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | X | X |
| 6d. Submit final report | 09/30/12 | | | | | | | | | | | | | | | | | | | | | | | | | | | X |

## Staffing

Pete McCarthy will serve as the project chief and co-principal investigator. Pete has been a hydrologist with USGS for 8 years, and has worked on various hydraulic and hydrologic studies, including managing the data-collection activities of the crest-stage gaging station network, and conducting time-of-travel and geomorphologic studies. Pete will conduct most of the analyses for the proposed project and will serve as the primary point of contact with MDT.

Steve Sando will serve as co-principal investigator. Steve has been a hydrologist with USGS for over 20 years and has worked on various hydrologic studies, including several flood-frequency and streamflow characteristics studies in both Montana and South Dakota. Steve will serve primarily in an oversight role, providing guidance for the proposed project, which is very similar to a project that was completed in South Dakota (Sando and others, 2008; *http://pubs.er.usgs.gov/usgspubs/sir/sir20085104*).

Table 2. Summary of hours

| Name or title | Role in study | Task | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Peter McCarthy | Co-principal investigator | 430 | 330 | 330 | 530 | 100 | 480 |
| Steve Sando | Co-principal investigator | 60 | 80 | 80 | 125 | 0 | 80 |
| Support staff | Report editing | 0 | 0 | 0 | 0 | 0 | 100 |
| | Total | 490 | 410 | 410 | 655 | 100 | 660 |

## Facilities

All facilities, equipment, and workspace necessary for completing the project tasks will be provided by the USGS.

## MDT Involvement

All of the proposed work will be conducted by USGS. MDT involvement primarily will include review of the draft report for technical content. Periodic consultation with MDT will be conducted

## Budget

This project is being supported by funding from the USGS Cooperative Water Program ($100,000) (*http://water.usgs.gov/coop/*) and the Montana Department of Natural Resources and Conservation ($20,000) (MDNRC), matched by $130,000 in MDT funding (table 3). The budget summary with breakdown by major cost category is shown in table 4. ***It should be noted that the $100,000 funding by USGS represents the maximum funding currently available.***

Table 3. Budget summary by State and Federal fiscal year.

| State fiscal year | USGS | MDT | MDNRC | TOTAL |
|---|---|---|---|---|
| 2011 | $48,750 | $56,875 | $16,250 | $121,875 |
| 2012 | $39,800 | $55,950 | $3,750 | $99,500 |
| 2013 | $11,450 | $17,175 | $0 | $28,625 |
| TOTAL | $100,000 | $130,000 | $20,000 | $250,000 |
| **Federal fiscal year** | **USGS** | **MDT** | **MDNRC** | **TOTAL** |
| 2010 | $18,000 | $22,000 | $5,000 | $45,000 |
| 2011 | $41,000 | $46,500 | $15,000 | $102,500 |
| 2012 | $41,000 | $61,500 | $0 | $102,500 |
| TOTAL | $100,000 | $130,000 | $20,000 | $250,000 |

Table 4. Budget summary by major cost category by State and Federal fiscal year.

| State fiscal year | Salaries | Benefits and overhead | Printing | TOTAL |
|---|---|---|---|---|
| 2011 | $74,345 | $47,530 | $0 | $121,875 |
| 2012 | $60,695 | $38,805 | $0 | $99,500 |
| 2013 | $15,020 | $9,605 | $4,000 | $28,625 |
| TOTAL | $150,060 | $95,940 | $4,000 | $250,000 |
| **Federal fiscal year** | **Salaries** | **Benefits and overhead** | **Printing** | **TOTAL** |
| 2010 | $27,450 | $17,550 | $0 | $45,000 |
| 2011 | $62,525 | $39,975 | $0 | $102,500 |
| 2012 | $60,085 | $38,415 | $4,000 | $102,500 |
| TOTAL | $150,060 | $95,940 | $4,000 | $250,000 |

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# APPENDIX A: INFORMATION SUPPORTING THE NEED FOR RESEARCH ON PERIOD-OF-RECORD AND STATIONARITY ISSUES

## Problem

Since the early to mid-1980's large parts of Montana have experienced two severe droughts. Occurrence of these dry periods during a relatively short time frame has the potential to substantially affect flood-frequency estimates for gaging stations with relatively short periods of record. Further, recent climatic patterns, and uncertainties concerning the relative contributions of natural and anthropogenic factors as driving forces, have led some researchers to question some of the basic premises of flood-frequency methods typically used for structure design (Milly and others, 2008). There is a substantial need to evaluate the effects of differences in period-of-record on our understanding of flood hydrology in Montana, and also to begin systematic tracking of stationarity of peak-flow records in Montana.

Percent differences in peak-flow characteristics for the period 1985-2008 relative to long-term periods-of-record (table 5, fig. 1) indicate substantial deviation from normal for a large area of Montana. This is especially true for gaging stations on or near the Rocky Mountain Front, and the eastern plains. Figure 2 presents locations of peak-flow gaging stations in Montana; about 50 stations with peak-flow records restricted to post-1985 are specifically identified. Areas with high densities of stations with peak-flow records restricted to post 1985 (indicated on fig. 2) have potential for producing flood-frequency estimates with substantial inconsistencies between stations.

Comparison between flood-frequency curves based on 1985-2008 data and flood-frequency curves based on long-term period-of-record data (figs. 3 and 4) shows effects of recent climatic patterns on flood-frequency estimates. In areas where streamflow conditions during 1985-2008 were substantially lower than long-term streamflow conditions (represented by gaging station 06062500 – Ten Mile Creek near Rimini, Mont.; map number 3, fig. 1; fig. 3), flood-frequency estimates for gaging stations with recent short-term records, might be expected to be relatively lower than nearby gaging stations with longer-term records. In areas where streamflow conditions during 1985-2008 were moderately lower than long-term (represented by gaging station 12354500 – Clark Fork at St. Regis, Mont.; map number 11, fig. 1; fig. 4), flood-frequency estimates for gaging stations with recent short-term records, might be expected to be moderately lower than longer-term stations.

The proposed study will investigate methods of adjusting flood-frequency estimates for gaging stations with anomalous periods of record. Further, temporal patterns in peak-flow records of long-term gaging stations will be investigated to begin systematic tracking of stationarity of peak-flow records in Montana.

## Methods

Fitting the LPIII distribution to systematic records of annual peak flows is the currently accepted methodology for estimating flood frequency for design purposes. However, if default Bulletin 17b methods are applied to gaging stations with anomalous periods-of-record (including the period 1985-2008 in some areas) there is potential for introducing substantial inconsistency between gaging stations.

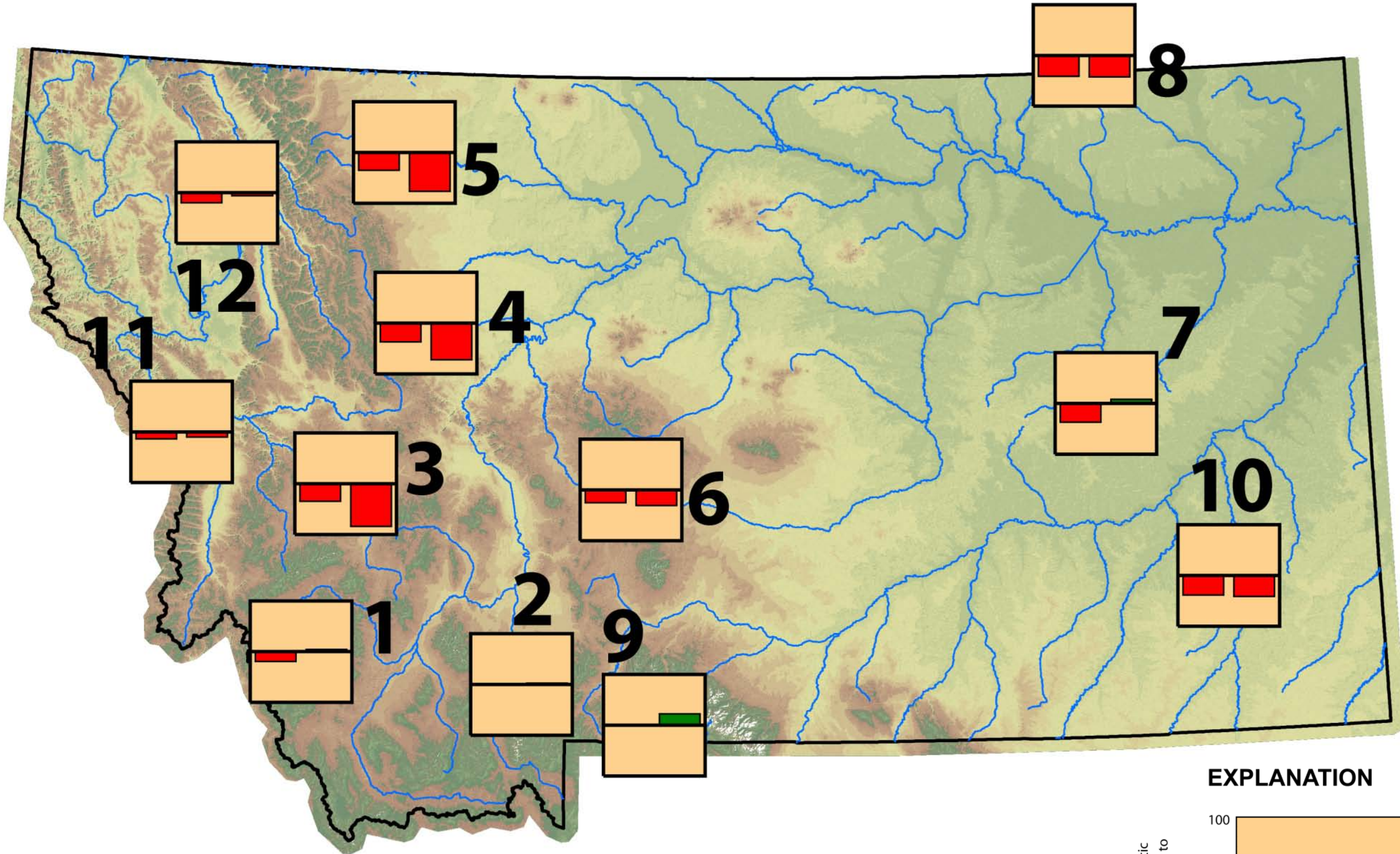
Record extension methods, including the Bulletin 17b 2-station analysis (Matalas and Jacobs, 1964) and the Maintenance of Variance type I analysis (MOVE.1; Alley and Burns, 1983) provide methods for adjusting flood-frequency estimates to compensate for period-of-record effects. Figures 5 and 6 show application of the Bulletin 17b 2-station and MOVE.1 analyses to two gaging stations with peak-flow records restricted to post-1985. Adjustments to the flood-frequency estimates for these gaging stations range from very large (fig. 5) to moderate (fig. 6).

Where applicable, record-extension methods will provide improved flood-frequency estimates for some short-term gaging stations. Further, consistency in flood-frequency estimates between closely-located gaging stations with different periods of record will be improved. Thus, application of currently accepted flood-frequency methods will be improved. However, uncertainties in the driving forces of recent climatic patterns and whether the recent patterns will actually prevail on a long-term basis might have substantial effects on what are considered appropriate flood-frequency methods in the future.

To remain current with emerging climatic and hydrologic research, initiation of systematic tracking of stationarity in peak-flow records for Montana is proposed. Temporal patterns in statistics of peak-flow records (that is, the mean, standard deviation, and skew) will be investigated for long-term stations. Spatial variability in any apparent temporal trends also will be investigated. Further, a literature review and consultation with USGS researchers will be conducted on nonstationary probabilistic models and the potential for application to flood-frequency analyses in Montana.

Table 5. (Appendix A) Selected long-term gaging stations with 72 or more years of systematic peak-flow records.

| Map number (figure 1) | Station identification | Station Name | Drainage area ($mi^2$) |
|---|---|---|---|
| 1 | 06025500 | Big Hole River near Melrose | 2,476 |
| 2 | 06052500 | Gallatin River at Logan | 1,795 |
| 3 | 06062500 | Tenmile Creek near Rimini | 31 |
| 4 | 06089000 | Sun River near Vaughn | 1,849 |
| 5 | 06099500 | Marias River near Shelby | 3,242 |
| 6 | 06120500 | Musselshell River at Harlowton | 1,125 |
| 7 | 06177500 | Redwater River at Circle | 547 |
| 8 | 06178000 | Poplar River at international boundary | 358 |
| 9 | 06192500 | Yellowstone River near Livingston | 3,551 |
| 10 | 06326500 | Powder River near Locate | 13,068 |
| 11 | 12354500 | Clark Fork at St. Regis | 10,709 |
| 12 | 12372000 | Flathead River near Polson | 7,096 |



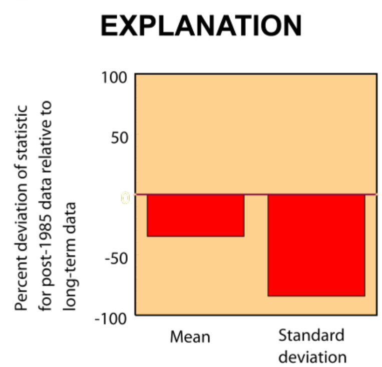
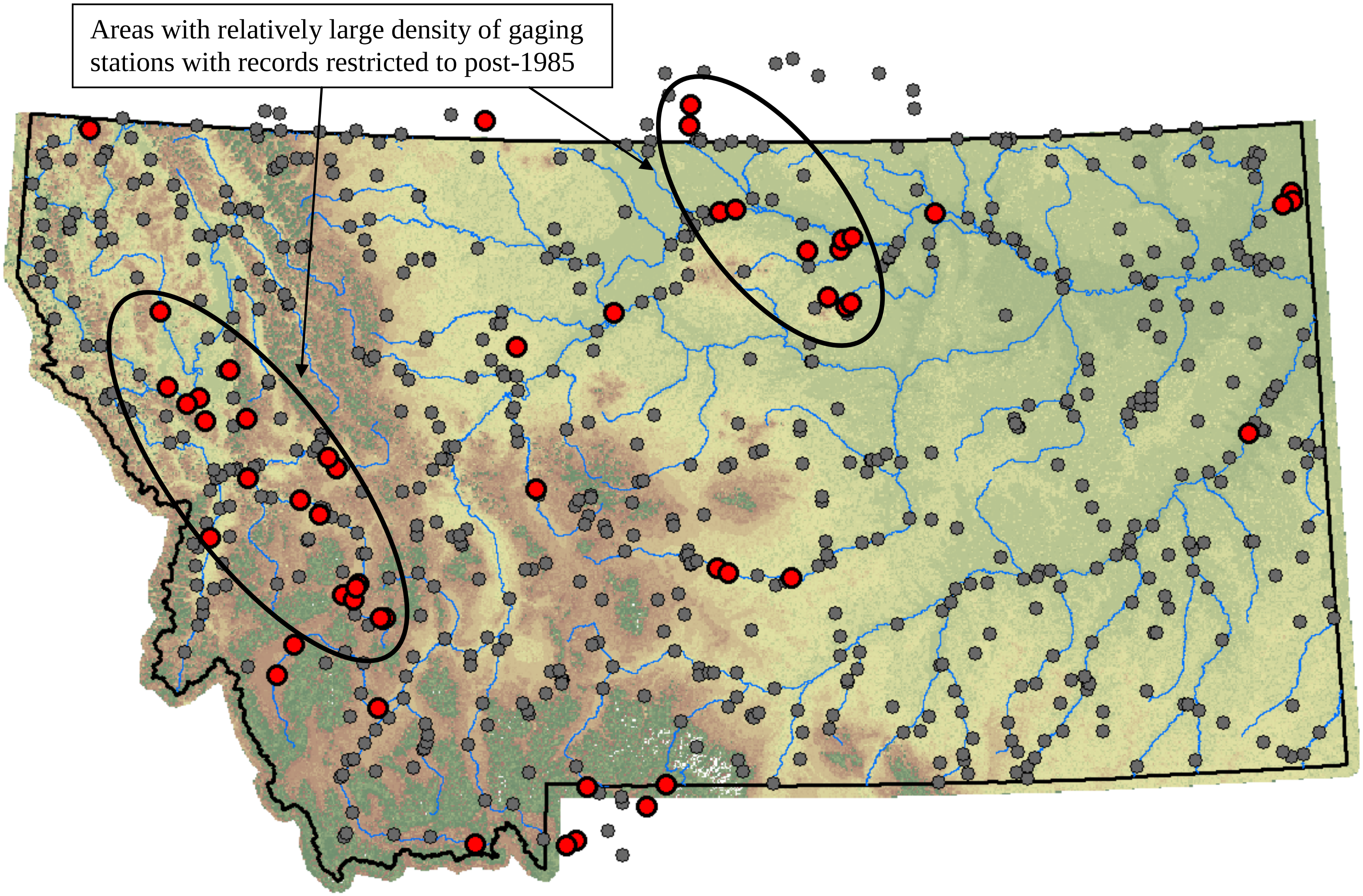



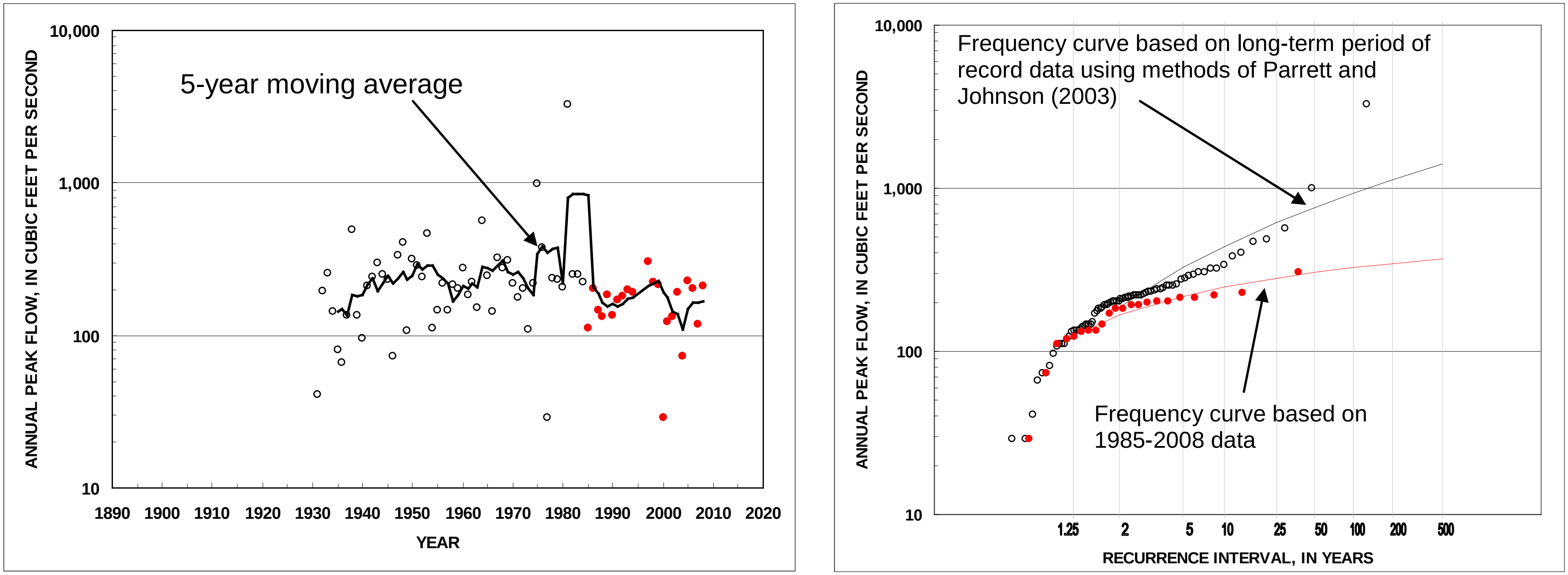

Figure 1. (Appendix A) Difference in peak flow characteristics for 1985-2008 relative to the long-term period-of-record for selected unregulated gaging stations with 72 or more years of record.


Areas with relatively large density of gaging stations with records restricted to post-1985

**EXPLANATION**

- Stations reported in Parrett and Johnson (2003) (660)
- Stations with records restricted to post-1985 (53)

Figure 2. (Appendix A) Locations of selected peak-flow gaging stations.

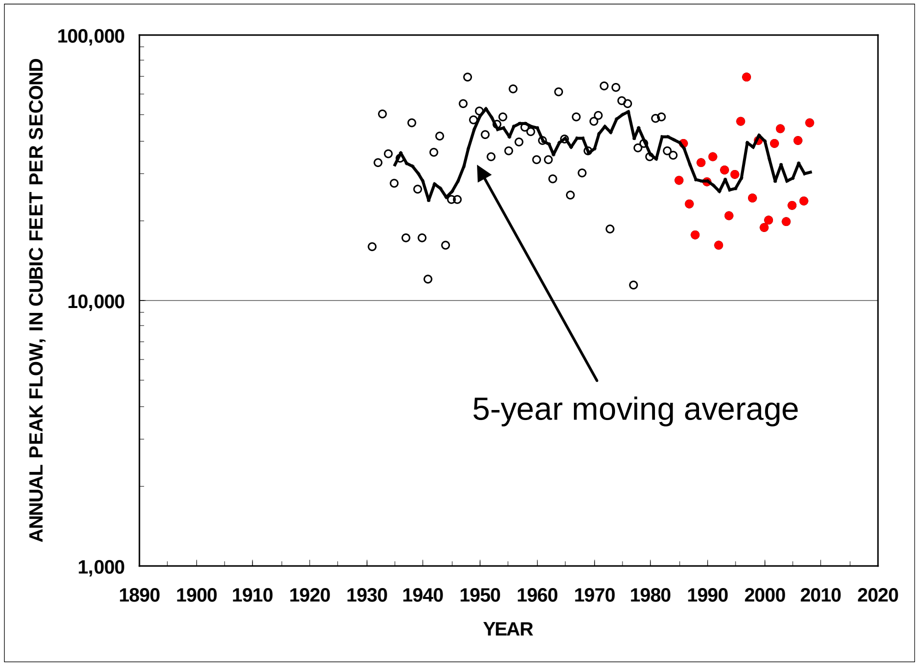


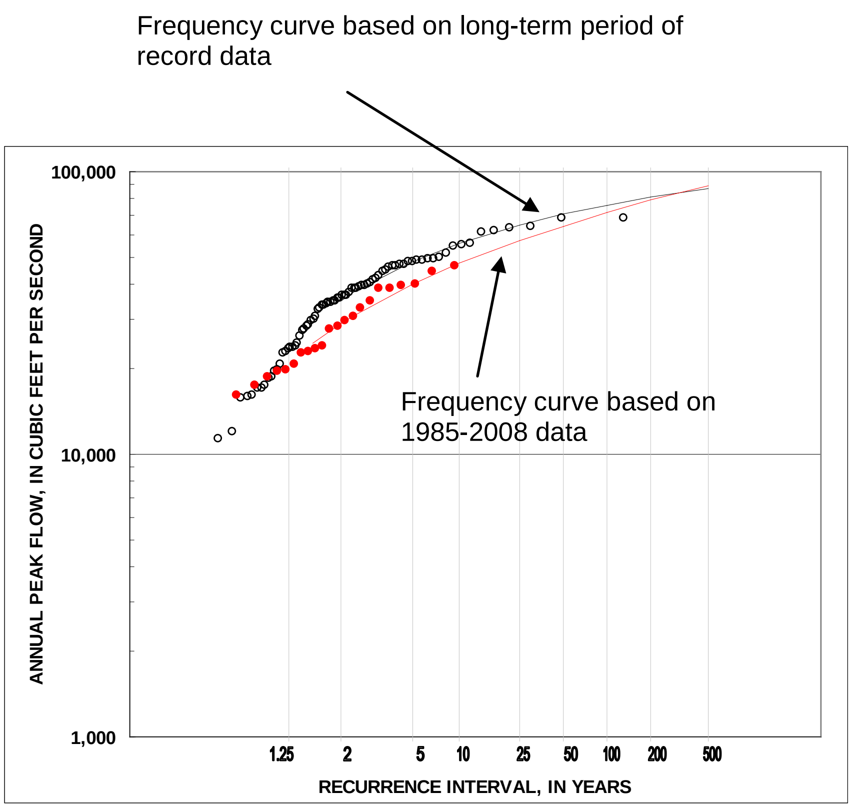

**EXPLANATION**

○ **Long-term period-of-record systematic peaks**

● **Post-1985 systematic peaks**

Figure 3. (Appendix A) Comparison of systematic peak-flows and flood-frequency curves between the periods 1985-2008 and the long-term period of record for gaging station 06062500 – Ten Mile Creek near Rimini, Mont. (map number 3, figure 1; table 5).

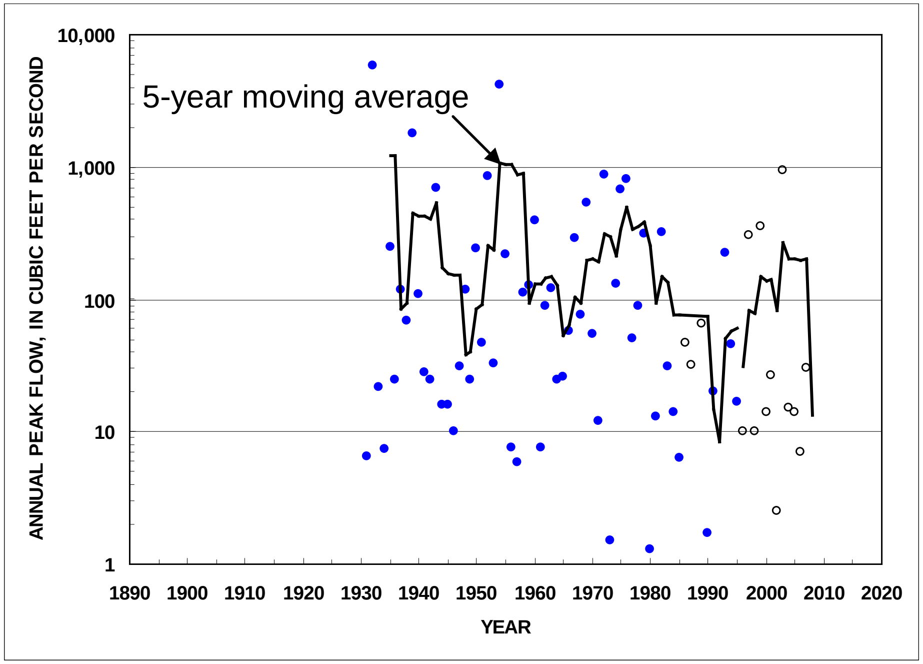


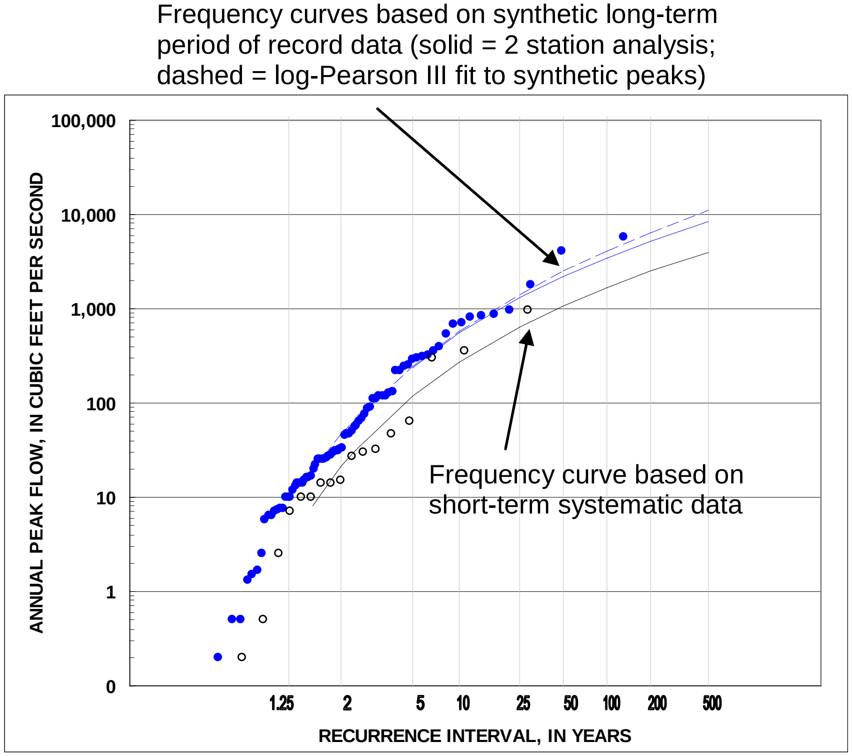




**EXPLANATION**

- ○ **Long-term period-of-record systematic peaks**
- ● **Post-1985 systematic peaks**

Figure 4. (Appendix A) Comparison of systematic peak-flows and flood-frequency curves between the periods 1985-2008 and the long-term period of record for gaging station 12354500 – Clark Fork at St. Regis, Mont. (map number 4, figure 1; table 5).




**EXPLANATION**

○ **Short-term period-of-record systematic peaks**

● **Synthetic (MOVE.1) long-term peak flows**

Figure 5. (Appendix A) Comparison of peak-flows and flood-frequency curves between the short-term systematic record and synthesized long-term record for gaging station 06183750 – Lake Creek near Dagmar, Mont.

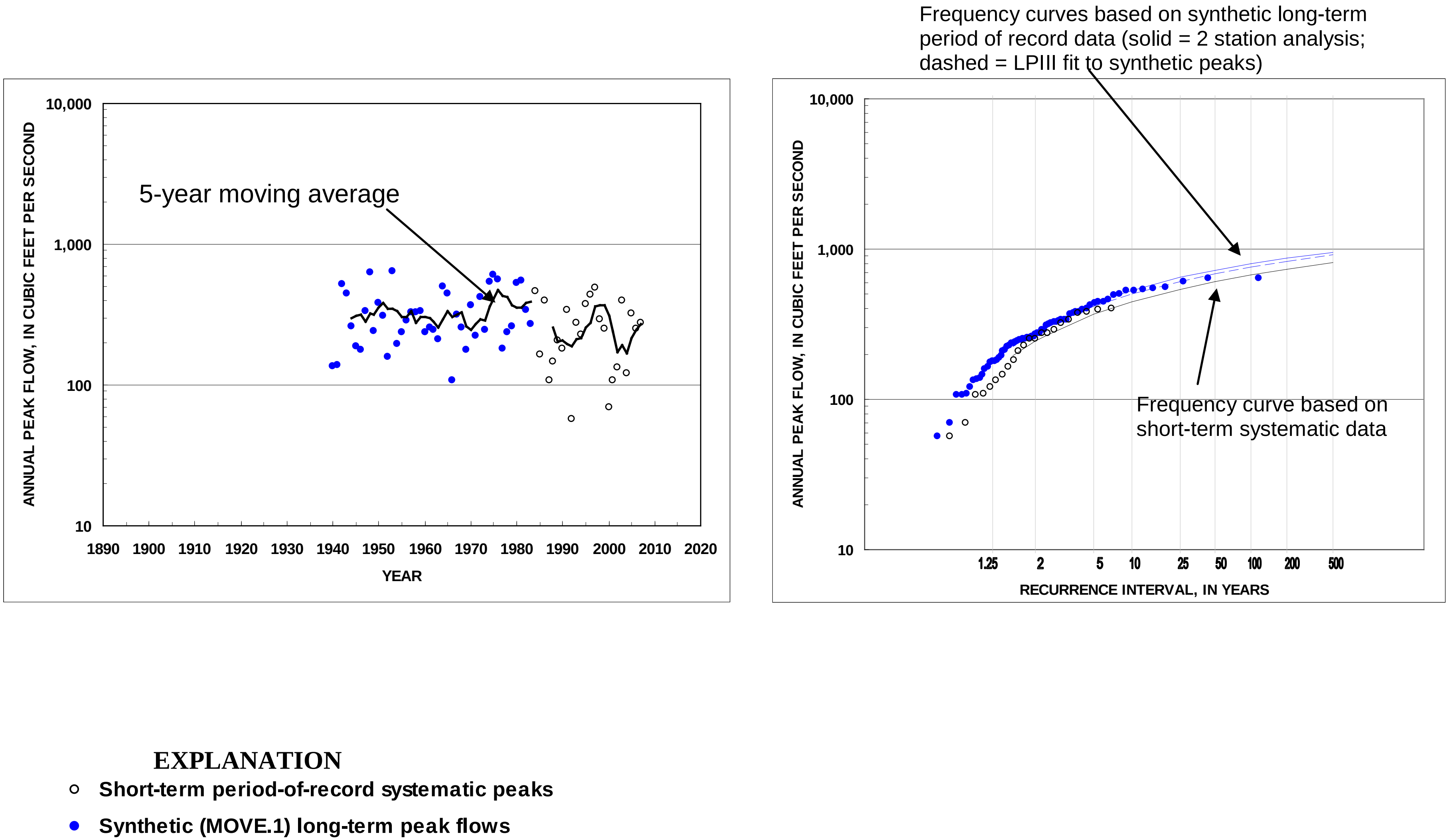



Figure 6. (Appendix A) Comparison of peak-flows and flood-frequency curves between the short-term systematic record and synthesized long-term record for gaging station 12323770 – Warm Springs Creek at Warm Springs, Mont.

# APPENDIX B: INFORMATION SUPPORTING THE NEED FOR RESEARCH ON MIXED-POPULATION FLOOD-FREQUENCY ANALYSES FOR NORTHWESTERN MONTANA

## Problem

Flood-frequency estimation for some gaging stations in northwestern Montana is complicated by the presence of a small number of unusually large floods during the period of record. For these gaging stations, the log-Pearson Type III probability distribution does not provide a good fit to annual peak flows when all data are combined. Thus, in previous USGS flood-frequency reports, a mixed-population flood-frequency analysis was performed (Parrett and Omang, 1981; Omang and others, 1986; Omang, 1992; Parrett and Johnson, 2003). For individual gaging stations, this involved: 1) investigating the peak-flow records and assigning two or more peak flows as being large rainfall-only peak flows; 2) determining separate probability distributions for the large rainfall-only peak flows and for the ordinary snowmelt/snowmelt-plus-rainfall peak flows; and 3) merging the two probability distributions using joint-probability theory.

There are two primary concerns relating to application of the mixed-population analysis on a station-by-station basis: 1) the ability to attain consistency in flood-frequency estimates for basins with similar climatic and hydrogeologic characteristics, but differing by whether or not systematic records include an unusually large peak flow; and 2) the ability to accurately estimate the true frequency of occurrence of unusually large peak flows based primarily on the limited systematic record available for a single gaging station.

Figure 7 shows gaging stations in the regions of Parrett and Johnson (2003) where mixed-population analyses were applied (the West, Northwest, and Northwest Foothills Regions). In Figure 7, gaging stations where mixed-population analysis was applied are indicated, and also gaging stations that were not operated in 1964 are indicated. The unusually large flood of 1964 serves as a definitive event in performing the mixed-population analysis for many gaging stations in northwestern Montana. Patterns that are apparent in Figure 7 include: 1) some gaging stations that were reported in Parrett and Johnson (2003) that did not include the mixed-population analysis are located in close proximity to gaging stations that did include the mixed-population analysis; 2) several gaging stations reported in Parrett and Johnson (2003) that did not include the mixed-population analysis were not operated during 1964; and 3) several gaging stations that were not reported in Parrett and Johnson (2003) were not operated during 1964. Detailed investigation of factors contributing to these patterns is beyond the scope of this proposal. However, it seems apparent that flood-frequency estimates for gaging stations in northwestern Montana might be improved by using a regionally based approach to mixed-population analysis.

## Methods

Sando and others (2008) applied a regional mixed-population analysis to the Black Hills area of South Dakota, where infrequent unusually large flood events complicate flood-frequency estimates. Investigating the application of that method to northwestern Montana is proposed.

Application of the method involves the following primary steps:

1) define the region where the mixed-population analysis applies;
2) determine the relative frequency of independent ordinary peak flows and independent unusually large rainfall-only peak flows in the regional systematic record;
3) normalize the independent unusually large peak flows based on drainage area and fitting a probability distribution to the normalized large peak flows;
4) for each gaging station, determine the probability distribution of ordinary peak flows;
5) for each gaging station, define the site-specific probability distribution of large rainfall-only peak flows by rescaling the normalized large-flow probability distribution on the basis of drainage area; and
6) for each gaging station, merge the ordinary peak-flow distribution and the site-specific large rainfall-only peak flow distribution using joint probability theory.

Application of the regional mixed-population analysis in northwestern Montana should improve the accuracy and consistency of flood-frequency estimates. Also, this method will simplify periodic updates of flood-frequency estimates as additional data collected during periods of varying climatic conditions are incorporated.

The regional mixed-population analysis might also have application in other parts of Montana, including the eastern plains, where infrequent unusually large flood events complicate flood-frequency estimates. Application of the mixed-population analysis to other parts of Montana will be investigated in the proposed study.

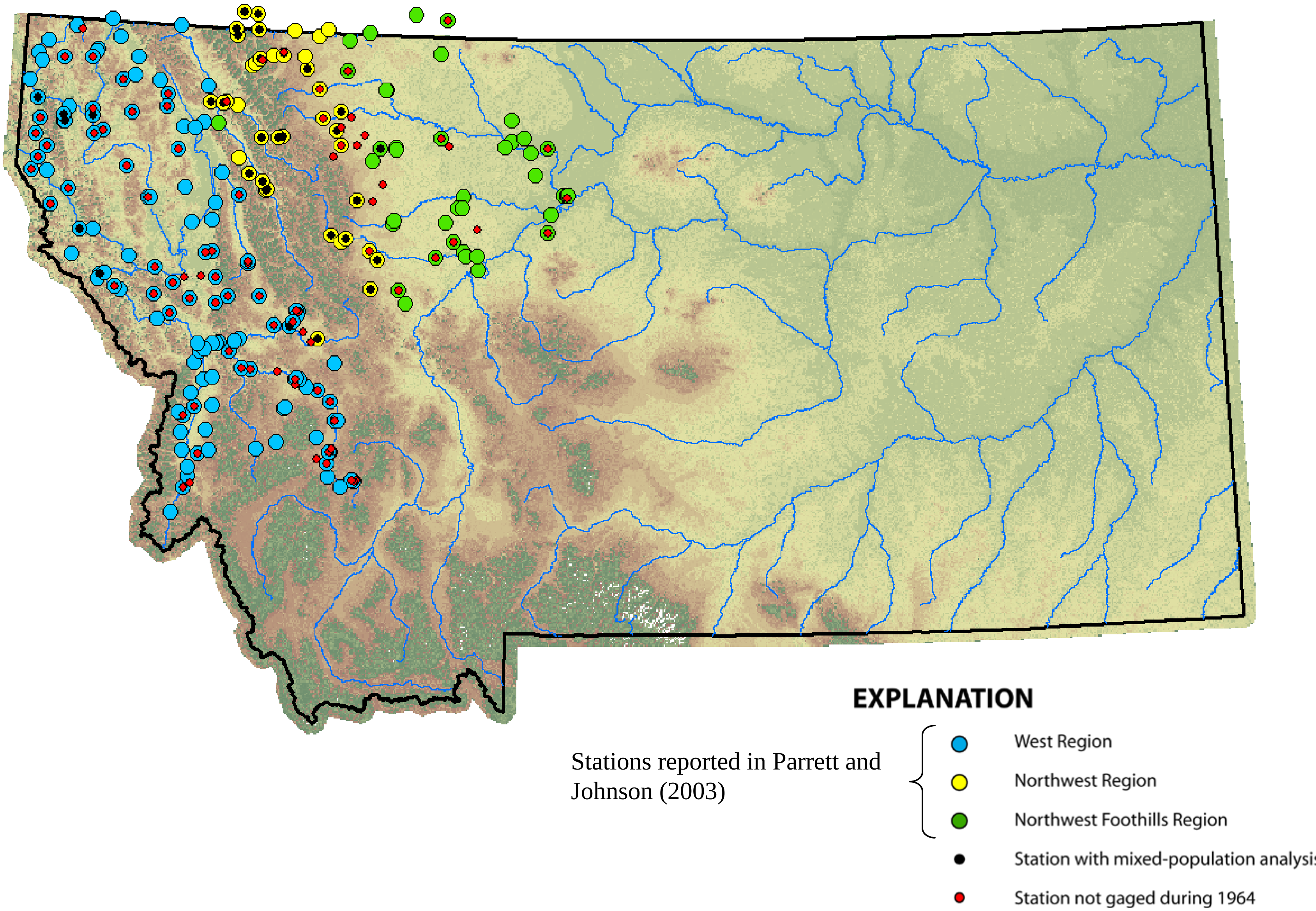



Figure 7. (Appendix B) Selected gaging stations in northwestern Montana.