Application of PaleoFlood Survey Techniques in the Black Hills of South Dakota
SD2008-01

Hermosa flood of August 17, 2007

Primary USGS Research Team
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The problem – a need for better flood-frequency information for design of highway infrastructure.

SD40 west of Hermosa following Aug. 17, 2007 flood
Storm of June 9-10, 1972

(From USGS Fact Sheet FS-037-02)

Storm totals of 6 – 8 inches over several hundred square miles

Maximum storm totals exceeded 14 inches

Storm duration was about 6 hours

Figure 2. Total storm rainfall for June 9-10, 1972 (from Schwartz and others, 1975). Locations of selected streamflow-gaging stations also are shown.
Plot showing annual peak flows for USGS gaging station 06406000, Battle Creek at Hermosa

1972 – 21,400 ft³/s

2007 – 18,600 ft³/s
Frequency analysis for Battle Creek (from Sando, Driscoll, and Parrett, 2008)

Standard log-Pearson III frequency analysis

Log-Pearson III neglecting 1972 outlier

1972 peak of (21,400 ft³/s)

Used for design of highway infrastructure
Previous reconnaissance-level study (SD2005-12) was completed in September 2007

Results available on www at:

SDDOT Office of Research

or

sd.water.usgs.gov

(click on Publications)
Project Objectives

1. Apply paleoflood hydrology techniques to obtain improved flood-frequency analyses for major streams within the study area.

2. Also investigate whether possible differences in storm potential across elevation gradients affect peak-flow potential.
## Cooperating agencies and funding

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<tr>
<th>Agency</th>
<th>Amount</th>
<th>USGS</th>
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<tr>
<td>SDDOT Research Program</td>
<td>*86,000</td>
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<td>FEMA</td>
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<td>West Dakota Water Development District</td>
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<td>City of Rapid City</td>
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<td>USGS &quot;special” funding (from HQ)</td>
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<td><strong>Totals</strong></td>
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<td><strong>Grand total</strong></td>
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* SDDOT contributed substantial additional funding in the form of “in-kind services.
What is “Paleoflood Hydrology”? 

• The science of reconstructing the magnitude and timing of large floods that precede modern streamflow records
  • Approaches use geologic evidence and various other interdisciplinary techniques
  • More simply … an exercise in forensic hydrology
Large floods can leave various evidence

- Maximum flood stage can be approximated
- Hydraulic analysis can determine discharge
- Various methods for dating of flood evidence

Boxelder Creek, 1972
Primary steps in process

1. Search for historical flood information pre-dating systematic peak-flow records.
2. Search along stream reaches for sites with flood evidence.
3. Conduct detailed site investigations in the best locations.
   A. Usually involves stratigraphic analysis of slack-water deposits
   B. Age-dating using radiocarbon analysis or other approaches
4. Detailed surveys of stream geometry for hydraulic analysis.
5. Estimate discharge associated with elevations of flood evidence using HEC-RAS flow modeling or other approaches.
6. Interpret the overall flood chronology for stream reach based on ages and discharges associated with flood evidence.
7. Perform frequency analyses incorporating systematic peak-flow records, historical accounts, and paleoflood information.
The best flood evidence ...
slack-water deposits in alcoves

Inferring flood stage and discharge from flood evidence
“Flood slack-water deposits” separated by “rockfall” layer

Twig for radiocarbon dating
Driftwood … … that was chewed by a beaver ~760 years ago
Dracula’s ledge along Elk Creek

Named for pre-1907 wooden construction stake. Railroad was destroyed during flood of June 12, 1907
Dracula’s ledge along Elk Creek. Drainage area = 41 mi²

“Modern” floods:
1972 ~10,500 ft³/s
1907 ~10,500 ft³/s

5 large paleofloods in last ~2,000 years

Discharge range: 51,000 to 83,000 ft³/s
Elk Creek flood chronology

Gage record (excluding 1972) for 1945-2009. Largest flow is ~1,600 ft³/s since 1945.

Dracula’s Ledge flood unit I:
41,500-124,500 cfs
1016-1155 AD

Beaver chewed driftwood:
25,500 - 65,500 cfs
1220-1284 AD

“Modern” floods:
1972 ~10,500 ft³/s
1907~10,500 ft³/s

Assumed uncertainty = +/- 50%

Dracula’s Ledge flood unit II:
40,000-120,000 cfs
869-1014 AD

Dracula’s Ledge flood unit III:
38,500-115,500 cfs
242-393 AD

Dracula’s Ledge flood unit IV:
37,500-112,500 cfs
85-238 AD
Frequency analysis for Elk Creek

0.01 annual exceedance probabilities (100-year recurrence interval)

Discharge, in cubic feet per second

Scenario 1
Gaged Record

2,200 ft³/s

Scenario 4
Gaged plus Paleoflood

13,500 ft³/s
Uncertainties regarding a discharge of about 10,000 cfs

Discharge ~3,500 to 80,000 ft³/s
Recurrence interval ~175 to 100,000+ (?) years

Discharge ~5,500 to 20,000 ft³/s
Recurrence interval ~65 to 130 years

Frequency analysis for Elk Creek

A large reduction in uncertainty
Major findings

1. Many locations with well-preserved flood evidence allowed development of viable long-term flood chronologies for primary stream reaches within the study area.

2. Flood-frequency analyses developed from the paleoflood chronologies represent a substantial improvement versus analyses from the relatively short-term systematic records available from streamflow gages.
Recommendations

1. Frequency analyses developed from the paleoflood chronologies are suitable for most typical applications of flood-frequency analyses.
   • A qualifier is that the analyses are best suited for the upper end of the frequency curves.

2. Resulting flood chronologies are applicable for important purposes beyond incorporation in peak-flow frequency analyses.
   • Given the potential for devastation from the extremely large floods, which frequently have exceeded 1972-scale flooding, future adaptation of flood management criteria might be warranted for the Black Hills area.
1972 Rapid City Flood

Rapid Creek
~50,000 ft³/s

238 lives lost
Rapid Creek – flood of ~128,000 ft³/s about 450 years ago
14 floods along Rapid Creek at least twice as large as 1972 in last 2,000 years
Frequency analysis for lower Rapid Creek (west end of Rapid City)

95% confidence limits for 10,000 ft³/s
- ~25 to 600 years
- ~25 to 80 years

Scenario 1
Gaged Record

Scenario 6
Gaged plus Paleoflood
Frequency analyses for:

A) Upper Rapid Creek

B) Lower Rapid Creek

\[ Q_{100} = 5,200 \text{ ft}^3/\text{s} \]

\[ Q_{100} = 24,000 \text{ ft}^3/\text{s} \]
3. Decisions regarding appropriate application of frequency analyses for Rapid Creek will need to be made by future users because of complications associated with recent flood-control regulation.

4. Patterns of reduced potential for exceptionally large floods in high-elevation areas, relative to lower elevations (addresses the second project objective) are becoming better understood; however, additional research will be needed for full quantification of these patterns.
Boxelder Creek (111 mi²)

Discharge in high alcove ~ 61,000 ft³/s
Flood Chronology for Boxelder Creek

- Trail Alcove and Custer Gap
  - 52,500 - 105,000 cfs (Custer Gap)
  - 1039 - 1208 AD (Trail)

- Kitty’s Corner (pit C, unit 2)
  - 16,900 - 33,800 cfs
  - 1490 - 1645 AD

- Kitty’s Corner (pit C, unit 3)
  - 15,900 - 31,800 cfs
  - 1485 - 1605 AD

- Kitty’s Corner (pit C, unit 4)
  - 15,500 - 31,000 cfs
  - 1414 - 1609 AD

- Kitty’s Corner (pit C, unit 7)
  - 14,200 - 28,400 cfs
  - 1030 - 1173 AD

Gaged record
1966 - 2009
(1972 peak is not shown)
More recommendations

5. Future paleoflood studies in the southern and northern parts of the Black Hills would provide additional beneficial information.

- Study SD2005-12 indicated excellent potential for sites with suitable paleoflood evidence in these areas.

6. Finally, comprehensive regional analyses following the separate (sub-regional) investigations throughout the Black Hills area would be highly beneficial.

- Assimilating results from throughout the entire area probably would identify regional patterns that can be used to improve final peak-flow characterization for specific streams or stream reaches.
Questions?

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Temple of Doom Alcove along Spring Creek