Evaluation of the methods used by NVE for flood frequency estimation

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Introduction

- Flood frequency estimation is important for dam design, flood defence schemes and spatial planning.
- Property, health and lives are at risk if dams or defence schemes fail to perform to the intended standard or if flood risks are ignored.
- Flood estimation is a difficult task, particularly for long return periods.
- Two methods available:
  - Flood frequency analysis (statistical method)
  - Rainfall-runoff modelling
Flood frequency analysis

- A statistical approach for estimating flood frequency characteristics based on observed data.
- A flood frequency curve plots magnitude versus return period.
- A flood frequency curve is constructed as the product of the index flood and the growth curve.

Index flood = mean/median of the annual maxima flood series.

A growth curve represents how floods increase at longer return periods.

Focus on:  
1. data
2. selection of the statistical distribution
3. assumption of stationarity
Where long records of data are available, in excess of the required return period, flood frequency analyses can be relatively straightforward.

…..Unfortunately, data are often not available for the site of interest.

Data
NVE’s recommended procedures based on available data

Recommended procedures for deriving the index flood and growth curve based on available station data

<table>
<thead>
<tr>
<th>Data available</th>
<th>Procedure for calculation of the index flood</th>
<th>Procedure for calculation of growth curve for target return periods between Q200 and Q1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 50 years</td>
<td>Calculated from observed series</td>
<td>Calculated from 2- or 3-parameter distribution, based on observed series</td>
</tr>
<tr>
<td>30-50 years</td>
<td>Calculated from observed series</td>
<td>Calculated from 2-parameter distribution, based on observed series</td>
</tr>
<tr>
<td>10-30 years</td>
<td>Calculated from observed series</td>
<td>Calculated by analysis of other long series in the area</td>
</tr>
<tr>
<td>&lt; 10 years</td>
<td>Calculated by correlation with other series and/ or from flood formulas.</td>
<td>Calculated by analysis of other long series in the area</td>
</tr>
<tr>
<td>Ungauged site in an ungauged catchment</td>
<td>Comparison with nearby sites or calculation from formulas</td>
<td>Use of regional flood frequency curves</td>
</tr>
</tbody>
</table>
Flood frequency analysis: (1) Data, (2) Selection of the statistical distribution, (3) Assumption of stationarity

Effect of using short records
(Lakshola, Northern Norway)

This short record underestimates the:
- 200 yr flood by 26m³s⁻¹ (±14%)
- 1000 yr flood by 34m³s⁻¹ (±16%)
relative to the longer record
Regional analysis

Strengths:
- Generates a flood estimate in the absence of site data.
- More accurate estimates can be obtained using regional analysis, compared to at-site analysis with limited data.

Weaknesses:
- Variations in catchment characteristics and climate can lead to different flood responses.
- Greater use could be made of observed data.

Flood frequency analysis: (1) Data, (2) Selection of the statistical distribution, (3) Assumption of stationarity

Regional growth curves (NVE, 2009).
Regional analysis: pooling data – a better approach?

• The regional approach used in some countries (e.g. UK, Germany, Italy, Slovakia) involves the pooling of station data.

• 5T station-years of data required.

• Not necessary to use fixed regions.

• Further research would be required to establish the suitability of such an approach for Norwegian sites.
Selection of the statistical distribution

- Selected distribution provides best fit to data.

- The best distributions for Norwegian data are often:
  - Gumbel or Log-Normal (2-parameter distributions)
  - General Extreme Value (3-parameter distribution)
Flood frequency analysis: (1) Data, (2) Selection of the statistical distribution, (3) Assumption of stationarity

Krinsvatn (Central Norway)

- 200 yr flood
  - Difference of 69 m\(^3\)s\(^{-1}\)
  - (301 m\(^3\)s\(^{-1}\) ± 12%)

- 1000 yr flood
  - Difference of 134 m\(^3\)s\(^{-1}\)
  - (368 m\(^3\)s\(^{-1}\) ± 18%)

- Uncertainty increases with increasing return periods
Comments regarding selecting a statistical distribution

- 3-parameter distributions can be very sensitive to outliers.
- Some countries (e.g. UK, Italy) recommend the use of a particular distribution.
- NVE’s guidelines are flexible, but:
  - specify minimum periods of record for use of 3-parameter distributions (i.e. 50 years)
  - recommend that several different distributions are compared.
- These are key strengths of the approach recommended by NVE.
  - A default distribution increases consistency between analysts, but could severely under or over-estimate flood magnitudes.
Assumption of stationarity

• Current methods assume that data are stationary.

• Environmental changes (e.g. climate change, urbanisation, extensive tree clearing) can lead to major changes in flood frequency.

• Two main considerations are that:
  
  (1) past observations may not be stationary
  
  (2) flood frequencies in the future may not be stationary

• If a data series has a trend, flood estimates may give a poor representation of current or future flood frequencies.
Past trends in the spring flood

Project changes in 200-year flood
(between 1961-1990 and 2071-2100)

Ensemble median

Ensemble 90th percentile


Flood frequency analysis: (1) Data, (2) Selection of the statistical distribution, (3) Assumption of stationarity
Comments regarding stationarity

New approaches are needed for the analysis of non-stationary series.

**Past trends:**
- Timeseries from some stations have been analysed for trends, but this information is not considered in routine flood frequency analysis.

**Future changes:**
- Currently no guidance for dealing with projected environmental change
- Results from climate change projections are being used to develop guidance for incorporating the effects of climate changes into flood estimates.
Rainfall-runoff modelling

- A rainfall input (for a particular return period) is converted to a flow output using a model of the catchment response.
- A simple, lumped, event based precipitation model (PQRUT) is used.
- The method and computer program for this model were developed in the 1980’s and are still in use with few modifications.
- Focus on:
  1. PQRUT
  2. rainfall inputs
  3. snowmelt
PQRUT

- Model parameters are calculated from equations based on catchment descriptors or by calibration against observed flows.
- Model calibration is rarely achieved using observed data.
- Can be run for any time resolution.

Constants for calculation of faster and slower flow rates

\[
\begin{align*}
K1 &= 0.0135 + 0.00268*HL - 0.01665 \times \ln (ASE) \\
K2 &= 0.009 + 0.21*K1 - 0.00021*HL \\
T &= -9.0 + 4.4*K1-0.6 + 0.28*QN
\end{align*}
\]

Threshold level

H = accumulated rainfall and snowmelt

Faster rate

Slower rate

The PQRUT model
Equations used to derive the model parameters were developed for 20 catchments with relatively small catchment areas (<500km²).

Recommended for use in catchments from 1-800km².

Model performance varies from catchment to catchment.

Known to perform less well for larger catchments or in catchments with a high lake percentage.

More problematic in catchments where snowmelt is a key factor.
Comments regarding PQRUT

- Simplified version of the HBV model - simple and quick to use.
  - In Norway there are over 2000 (~ 300 highest class) dams which are subject to review every fifteen years.
- High-resolution precipitation and discharge data are being used to improve model output at a series of test sites.
- It would be informative to compare the performance of PQRUT against:
  - the full scale HBV model
  - alternative event-based rainfall-runoff modelling methods
  - newer approaches such as continuous simulation modelling.
- NVE are involved in two projects comparing the rainfall-runoff model used in Norway with those used in other European countries.
Areal rainfall

- Estimates of extreme rainfall are required (e.g. 200 year, 1000 year, PMP).

- Point rainfalls are only representative of a very small area. Average rainfall over a catchment is likely to be much smaller.

- Aerial reduction factors (ARFs) are used to account for the effect of space and time variations.

- Met.no plans to reassess estimates of extreme precipitation, using grid based data observations.

ARF as a function of catchment size and storm duration (Førland, 1992).
Rainfall profile

- The design storm depth is distributed with a design storm profile.
- The distribution can be symmetrical, skewed and/or peaked, but the rainfall profile does not necessarily reflect typical catchment conditions.
- Ideally the storm profile will be representative of the typical storm profile (if such a profile exists).
In many parts of Norway, flood events are generated by a combination of both extreme precipitation and simultaneous snowmelt.

PQRUT has a simple routine for estimating snowmelt

\[ S = Cs \times TL \]

Where:

- \( S \) = snowmelt in mm/day
- \( Cs \) = degree day factor in mm/°C/24 hours (varies depending on presence of rainfall and dominant land use)
- \( TL \) = air temperature

Snowmelt is added as a fixed amount in the PQRUT model.

This approach is conservative, generally overestimating flood magnitudes.

What snowmelt event should be combined with a 1000 year rainfall event (or less) to generate a 1000 year flood event?
Frequency curves for peak flows resulting from rain-on-snow and rainfall events for a Canadian catchment (Harr, 1981)

Generating mechanisms for a peak flow of 10 l/s per ha:

- Peak caused by rain alone has a return period of 15 years
- Peak caused by rain-on-snow has a return period of only 3 years

Flood is 5 times more likely to result from rain-on-snow than rain alone.
Comments regarding snowmelt

- A greater understanding of the combined incidence of rainfall and snowmelt is required.
Final comments

- Focussed on 3 issues related to flood frequency analysis, and 3 issues related to rainfall-runoff modelling. There are other issues which it has not been possible to discuss.

- The procedures used by NVE are robust, with the rainfall-runoff method providing conservative flood estimates. However, the procedures need to be subject to continual review and development.

- NVE are currently:
  - Developing procedures for including projected climate change
  - Improving PQRUT parameter estimation
  - Met.no plan to reassess estimates of extreme precipitation.

- NVE are also working with various European partners to compare and evaluate methods, particularly:
  - regional approaches
  - selection of statistical distributions
  - rainfall-runoff model performance
  - inclusion of snowmelt