Indicators of Necessary Storages for Flood and Drought Management: Towards global maps (Theory)

Kuniyoshi Takeuchi and Muhammad Masood
International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute (PWRI), Tsukuba, Japan
and
Bangladesh Water Development Board (BWDB), Dhaka, Bangladesh
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Necessary storages

Storage is the only means to smooth out the variation of the flow and make hazards mitigated and resources useful.

How much smoothing is necessary depends on:

- Level of variation of inflow
- Level of necessary control
  - flood channel capacity
  - target release for water use
- Allowable rate of failure
Necessary storages

- There are various ways of calculating necessary storages under a given level of control and a rate of failure.
- Mass curve, simulation methods
  - The use of FDC and DDC is another. Flood Duration Curves and Drought Duration Curves

Intensity-Duration-Frequency curves

For Precipitation

- Instantaneous values
- Moving averages
- Discharge
- Longer time scale: ~ years
- Drought

http://rpitt.eng.ua.edu/Workshop/WS
ErorionControl/Module4/Module4.htm
**FDC-DDC**

Flood Duration Curves

Drought Duration Curves

MRI-AGCM3.2S
1979-2003
Bias corrected by EU WFD

Simulated by BTOP Model (Takeuchi & Ao, 1999)
daily in 20km mesh

The Brahmaputra discharge at the outlet Bahadurabad

Fix a time length and find the necessary storage within it.
Definitions of Flood Duration Curves $f_{\alpha}^*(m)$ and Drought Duration Curves $f_{\beta}(m)$

Annual max/min m-day moving average discharge

\[
\begin{align*}
\text{Prob} \left[ \max_{t_1 \in \text{year}} \min_{t=t_1} \frac{1}{m} \sum_{t=t_1}^{t_1+m-1} x_t \right. \\
&\geq f_{\alpha}^*(m) \left. \right] \leq \alpha
\end{align*}
\]

FDC

\[
\begin{align*}
\text{Prob} \left[ \min_{t_1 \in \text{year}} \max_{t=t_1} \frac{1}{m} \sum_{t=t_1}^{t_1+m-1} x_t \right. \\
&\leq f_{\beta}(m) \left. \right] \leq \beta
\end{align*}
\]

DDC
The maximum average discharge in the next $m$ days

Long term mean $Q_{\text{mean}}$

5% exceedance level discharge over $m$ days

$V_{fc}$

5% non-exceedance level drought

$V_{dm}$

Target release

$Q_{\text{Target}}$

$0$

$V_{fc}$

$V_{dm}$

$Q_{\text{mean}}$

Intensity

$Q$ $m^3/s$

Necessary storage to maintain the control level

$N_{0.05}(m)$

The maximum average discharge in the next $m$ days

$N_{0.05}(m)$

The minimum average discharge in the next $m$ days

$N_{0.05}(m)$

Move the point along the duration curve and find the largest rectangular. That is the necessary storage,
If control targets are different from the long term mean,
The Ganges-Brahmaputra-Meghna (GBM) Basin
India (64%), China (18%), Nepal (9%), Bangladesh (7%)

Over 1.7 million km²
Over 1100 km³

MRI-AGCM3.2S
1979-2003, 2075-2099
Bias corrected by EU WFD
Simulated by BTOP model daily in 20km mesh

Bhairab bazar
Hardinge bridge
Bahadurabad

MRI
AGCM3.2S
1979-2003,
2075-2099
Bias corrected by
EU WFD
Simulated by
BTOP model
daily in 20km mesh
MRF-AGCM3.2S
1979-2003,
2075-2099
Bias corrected by
EU WFD

Simulated by
BTOP model
daily in 20km mesh
Fig 5. Necessary storage (km$^3$) and Iso-necessary storage (months) at present with maintaining discharge $Q=Q_{\text{mean}}$.

$Q_{\text{Target}}=Q_{\text{mean}}$


FDC- Necessary Reservoir volume ($Q=3Q_{\text{mean}}$)

FDC- Iso-necessary volume

Droughts

DDC- Necessary Reservoir volume ($Q=0.5Q_{\text{mean}}$)

DDC- Iso-necessary volume

$Q_T=3Q_m \ & \ 0.5Q_m$
Long-term mean intensity

Climate change impact

FDC

DDC
Example of the FDC-DDC changes in GBM at their outlets.

MRI-AGCM3.2S 1979-2003, 2075-2099
Bias corrected by EU WFD
Simulated by BTOP model daily in 20km mesh

Reservoir volume necessary to maintain $Q=Q_{\text{mean}}$ (base period) with 5 years return period (black line for base period, 1979-2003 and red line for future period, 2075-2099)
Fig 7. Changes of Iso-necessary storage (future-present) with maintaining discharge \( Q=3Q_{\text{mean}} \) during flood and \( Q=0.5Q_{\text{mean}} \) during drought.

Future - Present

FDC - Necessary volume (future-present) \( (Q=Q_{\text{mean}}) \)

Droughts

DDC - Necessary volume (future-present) \( (Q=Q_{\text{mean}}) \)

Floods \( (2075-2099)-(1979-2003) \)

FDC - Necessary volume (future-present) \( (Q=3Q_{\text{mean}}) \)

DDC - Necessary volume (future-present) \( (Q=0.5Q_{\text{mean}}) \)
Fig 7. Changes of Iso-necessary storage (future-present) (Q=Q\text{\tiny mean}) with maintaining discharge Q=Q\text{\tiny mean}.


Floods

Droughts
Fig 7. Changes of Iso-necessary storage (future-present) with maintaining discharge $Q=3Q_{\text{mean}}$ during flood and $Q=0.5Q_{\text{mean}}$ during drought.

$Q=3Q_m$ & $0.5Q_m$
Other uses of FDC & DDC

- Necessary storages
  - Hydro-climatological assessment of difficulty or ease of water resources management
  - Reservoir design
- Reservoir operation
  - Expected precipitation or inflow under a given rate of failure
- Palm print of basin hydrology
  - Hydrological characterization
Chance constraint reservoir operation

\[
P \left( V + \sum_{\nu=0}^{m-1} I_{\tau+\nu} \leq \sum_{\nu=0}^{m-1} R_{\tau+\nu} \right) \leq \beta_m \quad m = 1, \ldots, M
\]

Fig. 5. DDC rule curves of Fukuoka municipal water supply reservoirs for a constant exhaustion probability 5%.
Palm Prints of basin hydrology

FDC-DDC of river discharge

FDC-DDC of local precipitation

Warsaw
Krynica
三面(新潟)
厚東川(山口)
冲浦(青森)

Poznan
Poland

JH 102, 1988

Fig. 4. (continued) For caption see p. 61.

Fig. 6. Duration curves of daily streamflow series.
Why Global Maps?

- Global distribution of hydro-climatological, land cover, and geological **heterogeneities** in terms of necessary storages to smooth out variations.
- Global maps of **relative difficulty or ease** of managing hydrological floods and droughts.
- Examine **scale effects** such as

\[
\frac{V_{fc}}{Q_m}, \frac{V_{dm}}{Q_{mean}} \sim A \left(\frac{PET}{P}\right)
\]
Necessary storage
and long memory

- Assuming a constant release of the long term mean, Hurst (1951) found the adjusted range $R_n^* \sim n^H$, $H \sim 0.72 > 0.5$ in the Nile
  - $R_n^* = \max S_t^* - \min S_t^*$, $S_t^* = S_t - (t/n)S_n$
- Feller (1951) $H \sim 0.5$ (Brownian motion)
- Mandelbrot (1982) fractal $1/f$
- Klemes, Moran, Lloyd, ....
Necessary storage
From time to space

- Relation between $V_{fc}$, $V_{dm}$ and $R_n^*$
- Hurst (1951) $R_n^* \sim n^H$
- What about $V_{fc}/Q_m$, $V_{dm}/Q_m \sim A^K$?

Time domain
Space domain

Different hydro-climatic zones
Budyko’s aridity index

$V/Q_m$
(months or days)

$A$ (km$^2$)
MRI-AGCM3.2S
1979-2003,
2075-2099
Bias corrected by
EU WFD

Simulated by
BTOP model
daily in 20km
mesh

$Q_T = Q_{\text{mean}}$
Let us look into diversity of global hydrology from a storage domain!
Thank you!
FDC-DDC publications

- Masood, M and K. Takeuchi (2015.7) Climate change impact on the manageability of floods and droughts of the Ganges-Brahmaputra-Meghna basins using Flood Duration Curves and Drought Duration Curves, J. Disaster Research, 5(10), 991-1000
Climate change impact

- Increase by climate change
- Long term mean
- Increase by climate change
- Flood channel capacity
- Water supply target

Q vs t graph showing:
- FDC (Flood Channel Capacity)
- DDC (Duration Duration Curve)

Climate change impact on:
- Intensity
- Duration
Climate change impacts on necessary storages

<table>
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<tr>
<th></th>
<th>FDC</th>
<th>DDC</th>
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<tbody>
<tr>
<td></td>
<td>Target discharge</td>
<td>Target discharge</td>
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<tr>
<td>Q_mean km(^3)/month</td>
<td>Q=Q_mean months %</td>
<td>Q=3*Q_mean months %</td>
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<td>Brahma-putra</td>
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<td>present</td>
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<tr>
<td>present</td>
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<td>6.0</td>
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<td>future</td>
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<td>15</td>
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<td>6.1</td>
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<tr>
<td>future</td>
<td>12.4</td>
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</table>

The smaller the smoothing capacity, the larger the climate change impact. For annual smoothing for drought, climate change would work favorably.
DDC:渇水持続曲線法

\[ f_k(m) = \left( k^{th} \text{smallest} \right) \cdot \min_{j=1,\ldots,N} \left( \frac{1}{m} \sum_{t=t_1}^{t_1+m-1} x_t \right) \]

富士川 船山橋

年最小30日流量

年最小15日流量

年最大流量
15日～120日