
ICOLD Technical Committee Y « Climate Change »

Workshop « **Climate Change: Risks & Opportunities for Dams, Reservoirs and Hydropower** » - May 28, 2022

## Theme 1 case study:

# Optimizing reservoir management at Neustadt dam

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# Content

- Company and project overview
- Main issues & objectives
- Methodology
- Results
- Lessons learned and recommendations

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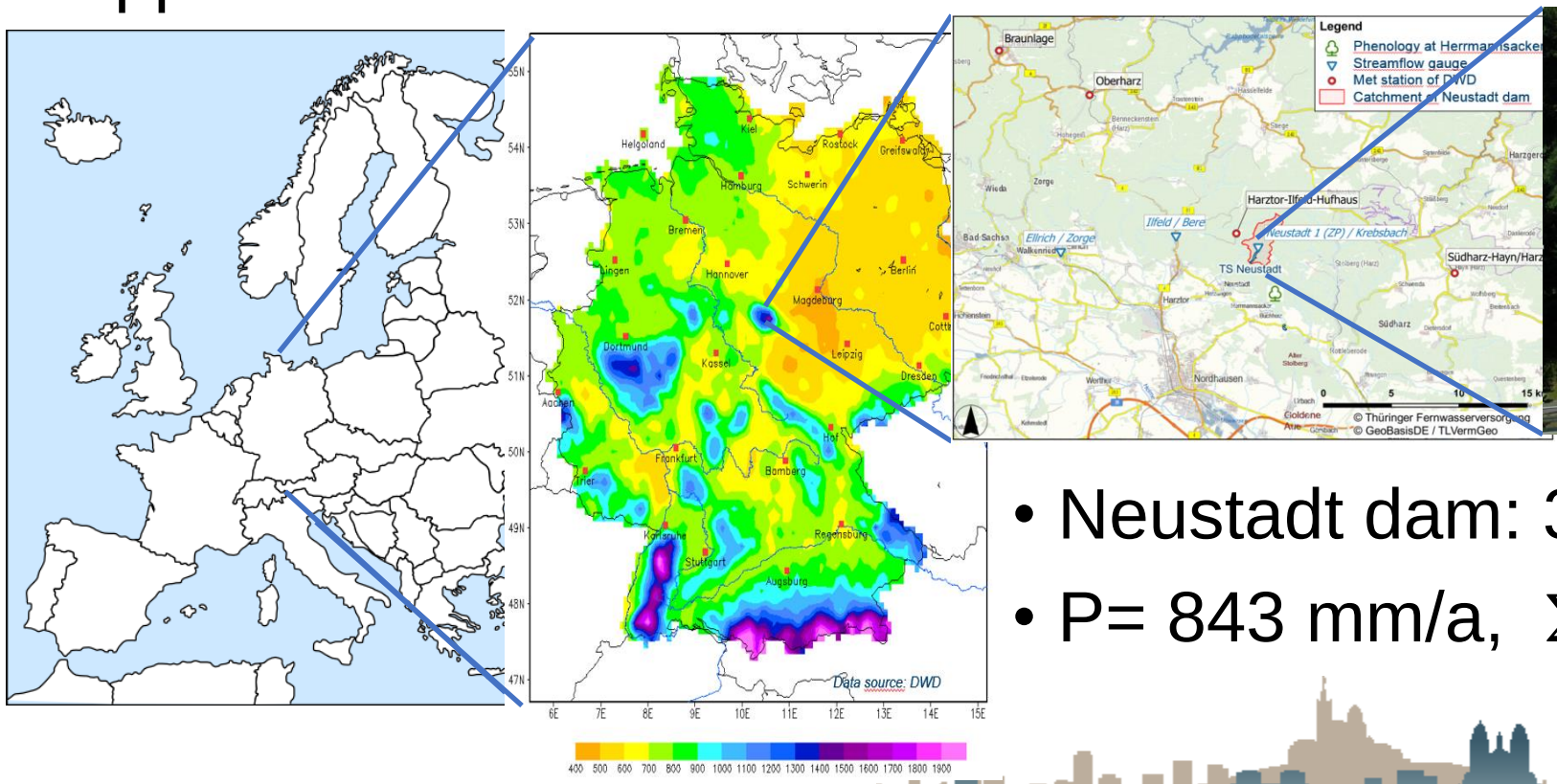
# Company and project overview

- Thüringer Fernwasserversorgung: dam operator and bulk water supplier







- Neustadt dam: 33 m high, 1.24 MCM
- P= 843 mm/a, $\Sigma Q_{in}$= 2.45 MCM/a

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# Main issues & objectives

- Very tight water budget with very little spare capacity
- Changes in runoff pattern are likely to impact safe water withdrawal $RWW_{365}$ from the reservoir ($\boldsymbol{P_{D,100}}$= 99.0 % and $\boldsymbol{P_{D,90}}$= 99.9 % for 0.9 $RWW_{365}$)
- Evidence of decreases in mean annual inflow in recent years
- → Re-evaluate safe water withdrawal from the reservoir
- → Objectively determine periods of possible additional water withdrawals without compromising long-term safe yield

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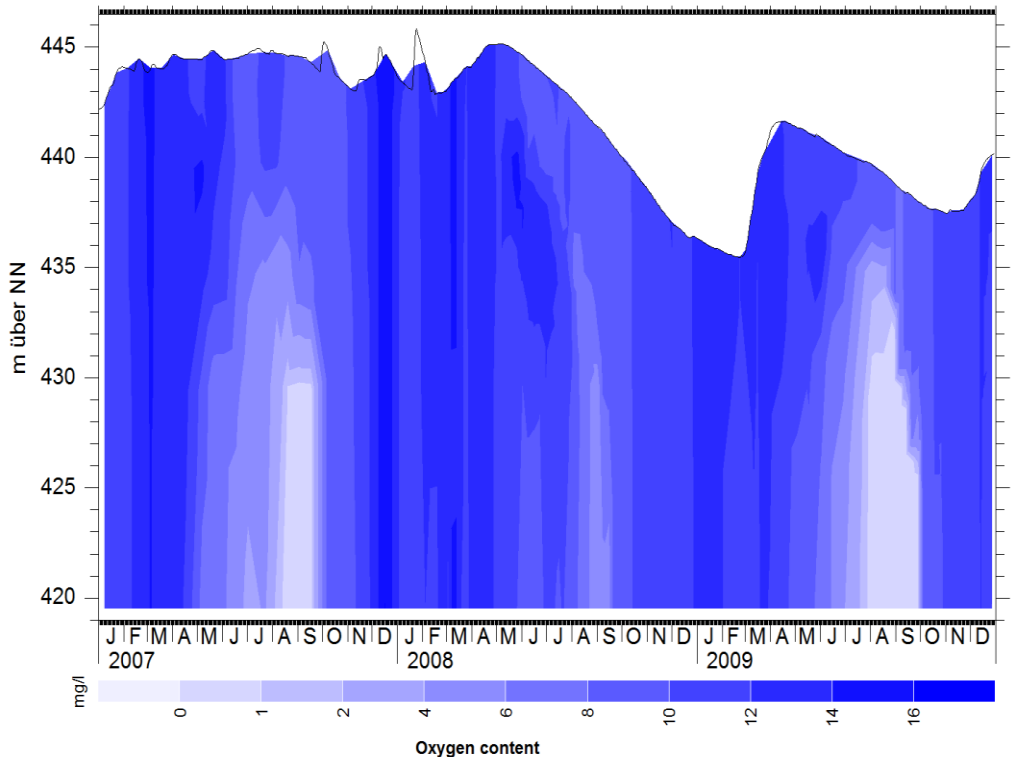
# Main issues & objectives




Isopleth diagram of oxygen content measured at Neustadt dam during 2007 - 2009.

- Oxygen depletion in the summer
- Shifting to higher outlets, but requiring additional releases impacting safe yield $RWW_{365}$
- → Consider water quality when determining safe water withdrawal from the reservoir

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# Methodology

- Water quality: continuous monitoring of raw water oxygen content
- Bi-weekly vertical profiles of oxygen, temperature and turbidity
- → Determine water withdrawal depth
- Water quantity:

1) Breakpoint analysis of precipitation and inflow data
2) Determine safe water withdrawal $RWW_{365}$ from water balance calculations using stochastic inflow time series with base data starting in 1912, 1974 and 1989
3) Test application of medium-range reservoir management model (MBM) for additional releases

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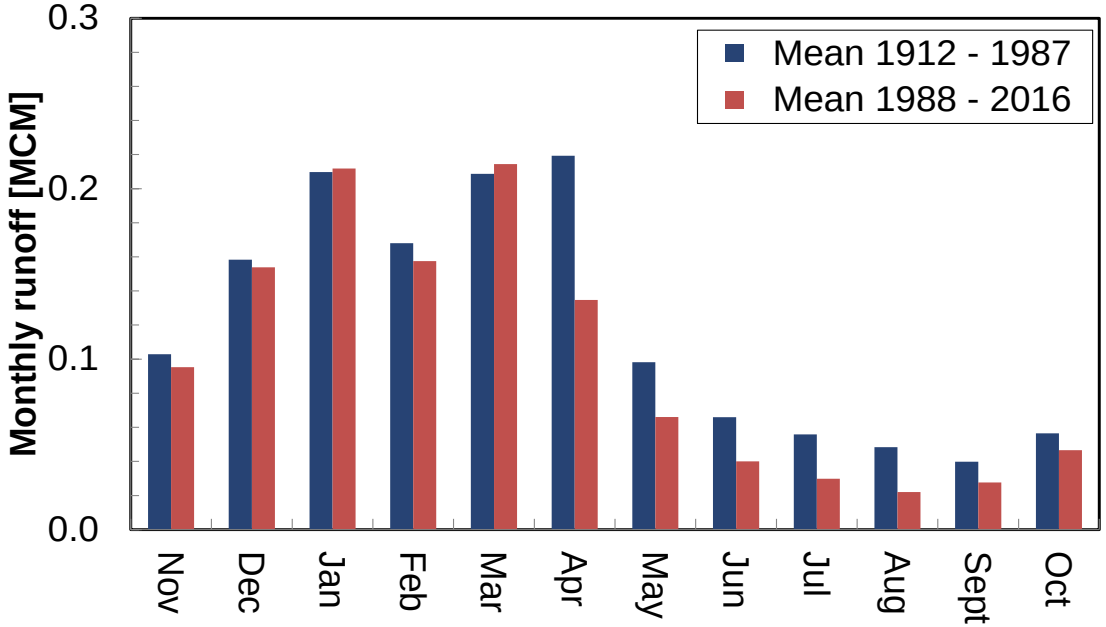
# Results – stationarity in question




Changes in mean monthly runoff at Neustadt 1 streamflow gauging station after the 1988 breakpoint

| *Neustadt 1/ Krebsbach* | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Wi | Su | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean 1912-2016 [MCM]** | 0.10 | 0.16 | 0.21 | 0.17 | 0.21 | 0.19 | 0.09 | 0.06 | 0.05 | 0.04 | 0.04 | 0.05 | 1.04 | 0.32 | 1.36 |
| **Trend 1912-2016 [Tm$^3$ a$^{-1}$]** | 0.0 | 0.1 | -0.4 | -0.2 | 0.1 | -0.5 | -0.2 | 0.0 | -0.1 | **-0.1** | 0.0 | -0.1 | -1.5 | -0.7 | -2.2 |
| **Breakpoint in year** | 1995 | 1954 | 1938 | 1928 | 2010 | ***1988*** | *1987* | *1990* | **1988** | ***1988*** | 1994 | 1989 | 1995 | ***1987*** | *1988* |
| **Mean 1988-2016 [MCM]** | 0.09 | 0.15 | 0.21 | 0.16 | 0.21 | 0.13 | 0.06 | 0.04 | 0.03 | 0.02 | 0.03 | 0.05 | 0.96 | 0.23 | 1.19 |
| **Change from 1988 [%]** | -12 | -4 | 2 | -5 | 1 | -40 | -35 | -42 | -47 | -54 | -33 | -20 | -10 | -38 | -17 |
| **Trend 1988-2016 [Tm$^3$ a$^{-1}$]** | -0.7 | -2.2 | -0.4 | -0.6 | **-7.0** | -1.3 | 0.4 | -0.1 | 0.0 | -0.1 | -0.2 | -0.1 | *-12* | -0.3 | -14 |

| *Ilfeld/ Beere* | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Wi | Su | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean 1952-2015 [MCM]** | 2.1 | 3.8 | 4.5 | 3.4 | 4.6 | 3.9 | 1.7 | 1.3 | 1.0 | 0.7 | 0.7 | 1.2 | 22 | 7 | 29 |
| **Trend 1952-2015 [Tm$^3$ a$^{-1}$]** | 1 | 1 | *32* | 8 | 8 | -23 | -4 | *-8* | **-7** | **-7** | -3 | -3 | 2 | ***-68*** | -51 |
| **Breakpoint in year** | 1977 | 1977 | *1973* | 1979 | 1977 | **1988** | 1987 | **1988** | **1988** | **1987** | 1958 | 1958 | 1977 | ***1987*** | 1995 |
| **Mean 1988-2015 [MCM]** | 2.26 | 3.57 | 5.0 | 3.55 | 4.9 | 2.85 | 1.37 | 0.78 | 0.62 | 0.43 | 0.66 | 1.08 | 22 | 4.95 | 27.1 |
| **Change from 1988 [%]** | 11 | -10 | 25 | 10 | 14 | -39 | -28 | -54 | -50 | -51 | -14 | -20 | 0 | -37 | -10 |
| **Trend 1988-2015 [Tm$^3$ a$^{-1}$]** | -14 | -47 | 4 | -24 | -124 | -15 | 16 | -2 | -4 | 4 | 2 | 0.5 | -150 | 7 | -157 |

| *Ellrich/ Zorge* | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Wi | Su | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean 1970-2015 [MCM]** | 2.2 | 3.1 | 3.8 | 2.6 | 3.5 | 2.7 | 1.4 | 1.1 | 0.8 | 0.7 | 0.7 | 1.2 | 18 | 6 | 24 |
| **Trend 1970-2015 [Tm$^3$ a$^{-1}$]** | -9 | -4 | 7 | -4 | -21 | ***-57*** | **-16** | ***-21*** | **-10** | -7 | -4 | -8.5 | -128 | ***-77*** | ***-248*** |
| **Breakpoint in year** | 1997 | 1998 | 1980 | 2003 | **2008** | ***1995*** | *1986* | ***1987*** | *1988* | 1988 | 1993 | 2000 | **2000** | **1986** | ***2000*** |
| **Mean 1988-2015 [MCM]** | 2.19 | 2.92 | 3.8 | 2.62 | 3.51 | 1.95 | 1.13 | 0.68 | 0.53 | 0.51 | 0.68 | 1.1 | 17 | 4.58 | 21.6 |
| **Change from 1988 [%]** | 0 | -13 | 2 | 4.9 | 0 | -51 | -35 | -58 | -58 | -44 | -15 | -28 | -12 | -41 | -20 |
| **Trend 1988-2015 [Tm$^3$ a$^{-1}$]** | -42 | **-79** | -40 | -50 | ***-161*** | ***-77*** | -3 | -1 | -5 | -2 | -9 | -7 | ***-437*** | -35 | ***-600*** |

Significe level of trends and breakpoints: p > 0,1 (standard); *p < 0,1 (italic)* ; **p < 0,05 (bold)**; ***p < 0,01 (bold italic)***

Color code of changes from 1988 [%]:

| < -50 | > -50 | > -40 | > -30 | > -20 | > -10 | > -5 | > 5 | > 10 | > 20 | > 30 |
|---|---|---|---|---|---|---|---|---|---|---|

Monthly and seasonal runoff totals at stream gauging stations Neustadt 1 (1 gap year), Ilfeld (no gap years) and Ellrich (no gap years). Data source: TLUG.

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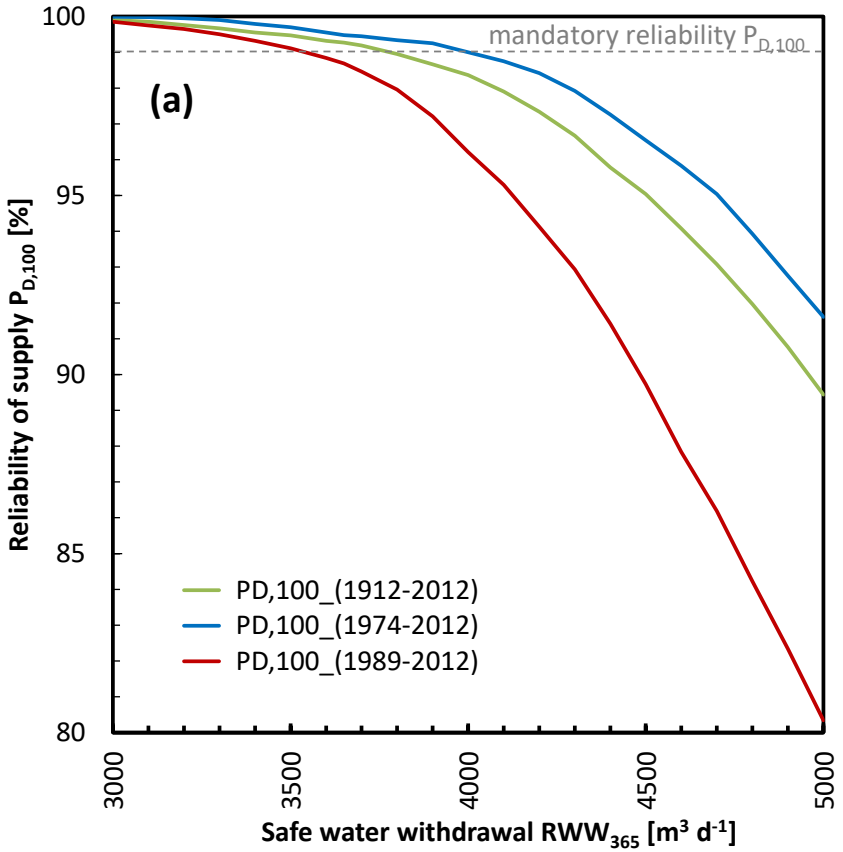
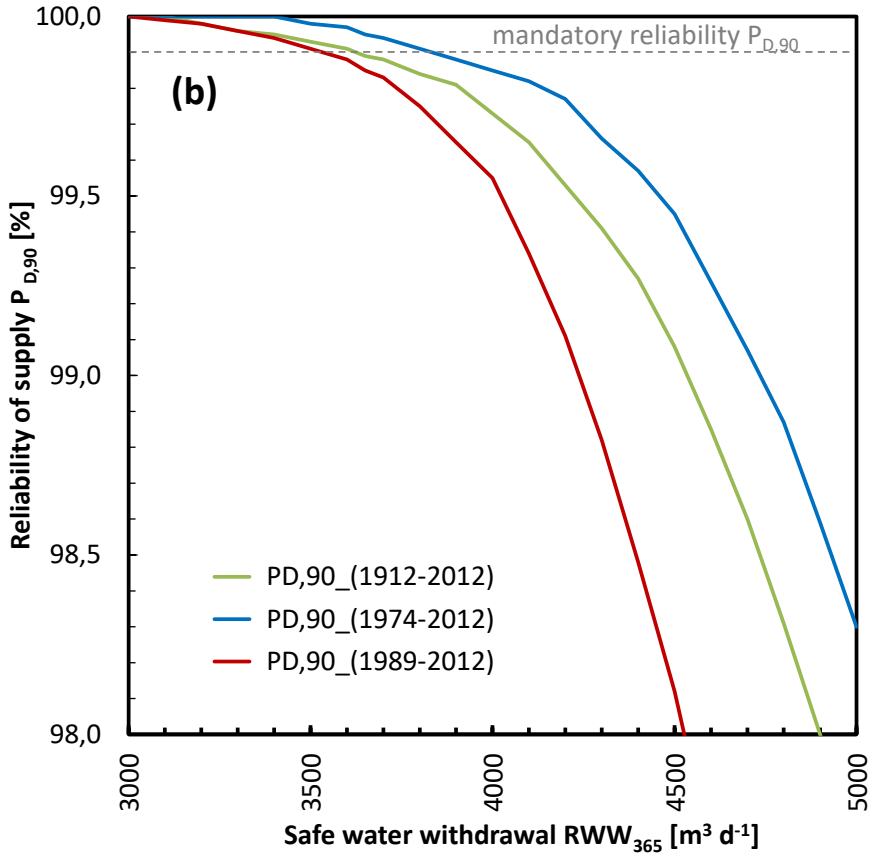
# Results – safe yield is shifting




Relationship between $RWW_{365}$ and $P_D$ for the full withdrawal amount (a) and the reduced withdrawal of 90 % (b) based on the Siko/Simo model for the following reference periods: 1912 - 2012 (green), 1974 - 2012 (blue) and 1989 - 2012 (red)
→ Safe yield currently 3600 $m^3$ $d^{-1}$

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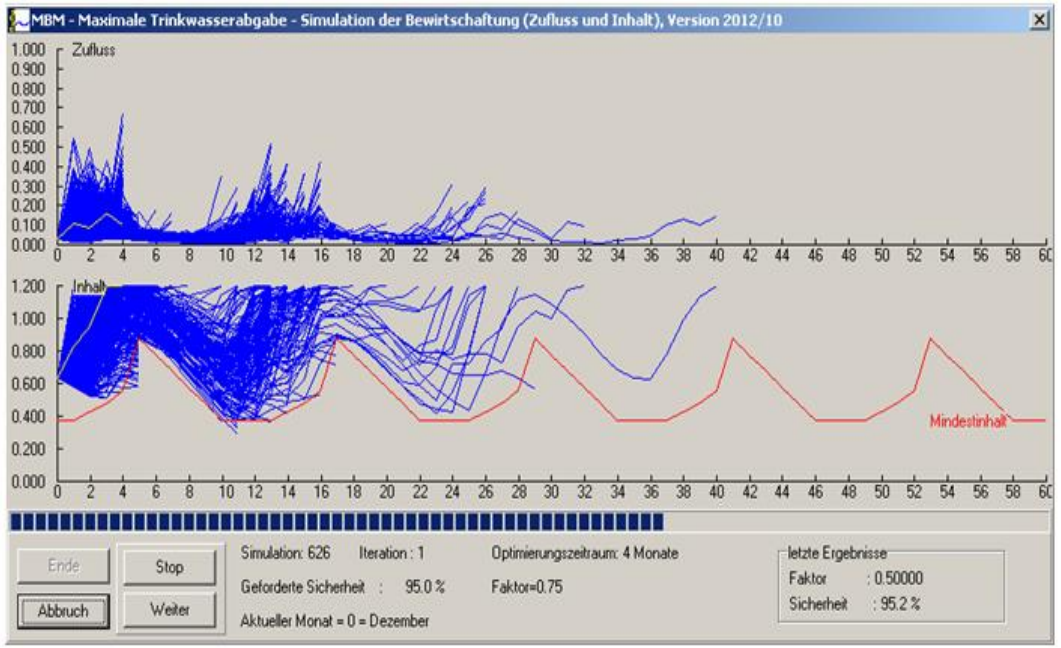
# Results – non structural adaptation

- Water quality induced change of withdrawal depth leads to additional downstream releases of 4 – 8 % of mean annual inflow

| Parameter | 2013 | 2014 | 2015 |
|---|---|---|---|
| Date of shift to upper outlet pipe | 5 August | 27 June | 5 August |
| Raw water temperature [°C] prior to / after the shift | 8.2 / 12.1 | 4.3 / 10.8 | 7.9 / 14.1 |
| Raw water $O_2$ [mg $l^{-1}$] prior to / after the shift | 4.6 / 8.1 | 3.9 / 7.5 | 2.9 / 5.0 |
| Date of shift to bottom outlet pipe | 7 Jan. 2014 | 10 Dec. | 16 Nov. |
| Raw water temperature [°C] prior to / after the shift | 2.0 / 3.9 | 3.0 / 2.7 | 8.8 / 8.3 |
| Raw water $O_2$ [mg $l^{-1}$] prior to / after the shift | 12.9 / 11.4 | 12.7 / 12.5 | 9.8 / 10.6 |
| Additional downstream release during upper withdrawal depth period [MCM]/[% of annual inflow] | 0.115 MCM 5.2 % | 0.125 MCM 7.6 % | 0.081 MCM 4.4 % |




- Operational reservoir model (MBM) allows additional withdrawals of 6 – 13 %

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# Lessons learned and recommendations

- Rising temperatures and evaporation reduce catchment runoff
- Particular attention to sudden shifts and breakpoints
- Selection of reference data period affects results of safe yield
- Regular hydrology updates: basis for sound water management
- CC affects limnological processes which impacts water availability
- → integrated management approach of water quantity and quality
- Mid-term reservoir management model: low cost alternative to increase safe water withdrawal from the reservoir
- Outlook: re-afforestation with deciduous tree species

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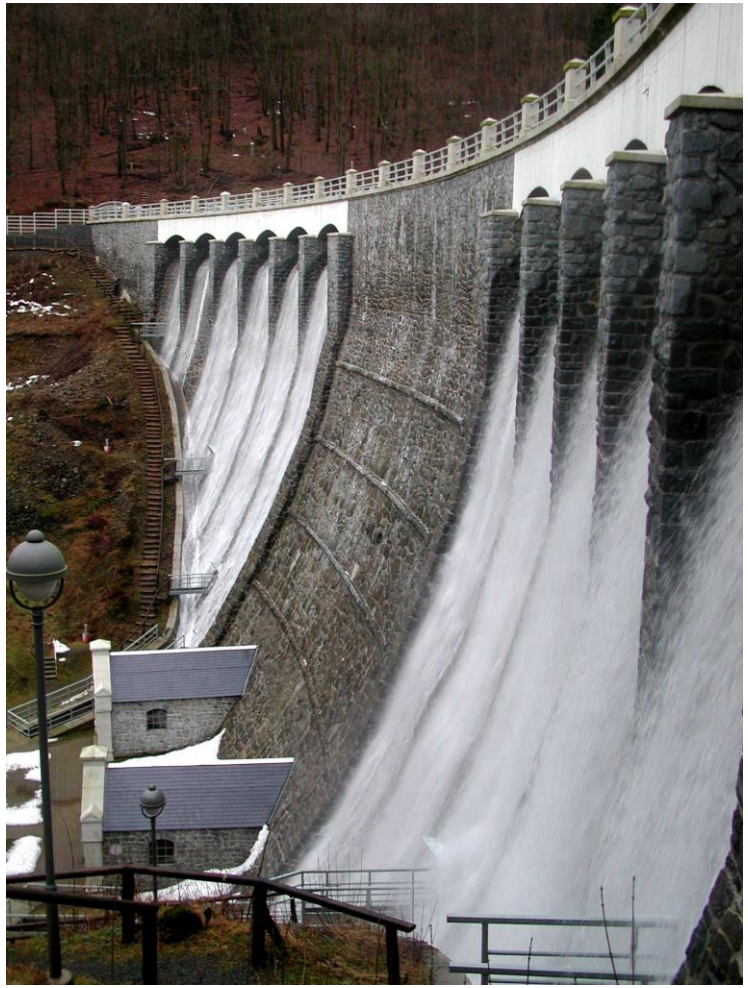
# Thank you for your attention!



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