Climate change impacts on hydrology and water level fluctuation indicators

EU ENPI –project Trilateral cooperation on Environmental Challenges in the Joint Border Area

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Juha Riihimäki
Finnish Environment Institute SYKE

Seppo Hellsten
Finnish Environment Institute SYKE

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1 Introduction

Climate change forecasts used in this study (see generally VEIJALAINEN et.al 2012) estimates annual mean temperature in Lake Inari watershed to increase 3,6 °C in 2040 – 2069 compared to annual mean temperature during 1971 – 2000 and increase on mean winter temperature(December – February) is estimated to be 5,1 °C. Annual mean precipitation is estimated to increase 12% and winter mean precipitation 16%. These changes would affect also on yearly hydrological cycle altering timing of high and low water levels and discharges on lakes and rivers.

2 Material and methods

The hydrological model, Watershed Simulation and Forecasting System (WSFS) (VEHVILÄINEN et al. 2005), was used to estimate climate change impacts on hydrology of River Pasvik catchment (Fig 1, Fig 2). Climate chance scenario used was mean of 19 global climate models calculated by Finnish meterological institute FMI (JYLHÄ et al. 2009) with emission scenario SRES A1B (IPCC 2000).

Effects of climate change induced changes on River Pasvik hydrology and Lake Inari water levels were analyzed using DHRAM calculation program on River Pasvik and water-level fluctuation analysis tool (Regcel) on Lake Inari. Scenario period used in this study was 2040-2069 and reference period used was 1971-2000.

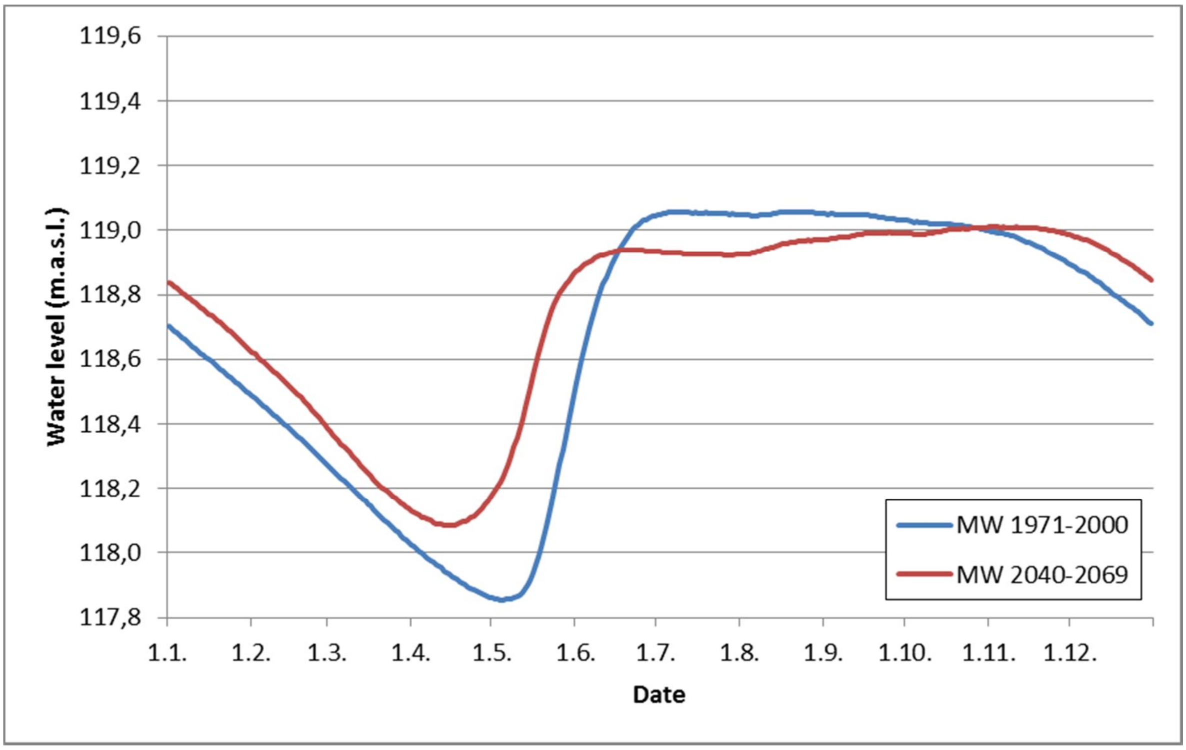

Figure 1. Simulated water level fluctuations for the reference period and the scenario period at Lake Inari.

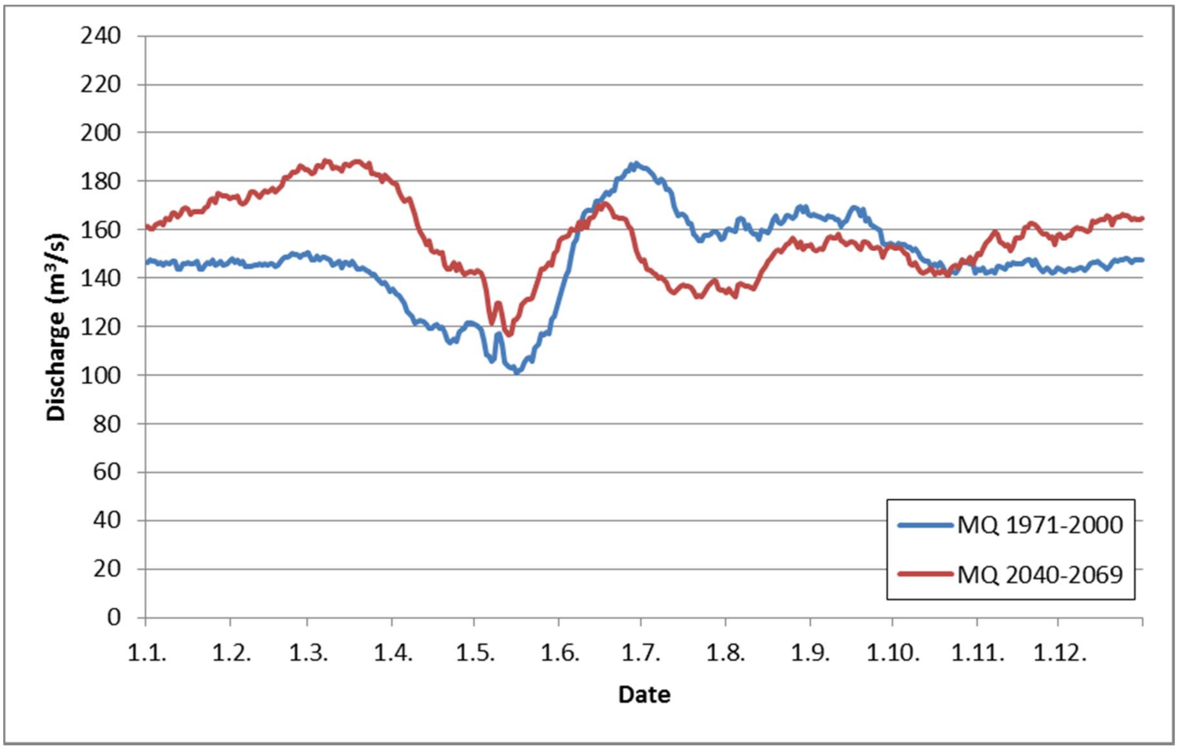

Figure 2. Simulated discharges for the reference period and the scenario period in River Paatsjoki at Kaitakoski power station.

3 Regcel tool

Regcel model enables assessment of the ecological impacts of water-level regulation on aquatic macrophytes, benthic invertebrates, fishes and nesting of water fowls. Model has been developed in the Finnish environment institute (SYKE) and it has been used also earlier in River Pasvik (HELLSTEN et al. 2002), Lake Inari (PURO-TAHVANAINEN et al. 2011) and over 200 other Finnish lakes (KETO et al. 2008).

Input data required for Regcel model is daily water levels, water colour (mg Pt l-1), maximum ice thickness (m) and yearly ice-off and ice-on days. In this study, the simulated water levels for reference period and scenario period were used in Regcel model. The input data for water colour for the reference period was taken from the databases of the Finnish Environment Institute. Daily values of air temperature for the used climate change scenario were used to calculate the ice thickness, ice-off and ice-on dates for scenario period. Equation was calibrated to the observed air temperature, ice-off and ice-on dates and the maximum ice thickness of reference period. Calculated Ice data based on air temperature was used in Regcel model for both reference period and scenario period.

Indicators for Lake Inari were calculated for reference period 1971–2000 and the average values of that period were compared to indicators calculated for the scenario period 2040-2069.

3.1 Regcel results

Results for the water level fluctuation indicators of Lake Inari are presented on table 1. Simulated water levels have quite clear influence in some of the indicators although there are many indicators where there is no change or it is negligible.

Magnitude of spring flood is an indicator that describes “cleaning effect” of spring high water levels transporting the dead organic material to upper shore areas. Higher spring flood is considered to inhibit excessive growth of shore vegetation. Spring flood magnitude in Lake Inari is very small in reference period and there is no spring flood at all in scenario period.

Water level change during growing season in Lake Inarijärvi is smaller in scenario period than in reference period. The change is calculated by subtracting 75 % fractal of water levels of the first ice-free month from the 75 % fractal of water levels of the rest of the growing season (from 30 days after ice-out to 30th September). If the indicator value of the water level change were negative (water level is lowering during the growing season), it would promote zonation of littoral vegetation and would have positive effect on shore habitat diversity. However, the indicator value is positive (water level is rising during the growing season) in both reference period and scenario period indicating unfavorable conditions. Nevertheless indicator value is smaller (and better) in scenario period.

Table 1. Water level fluctuation indicators calculated with Regcel model and assessment of effect of climate change on environment. "+" = positive effect, "-" = negative effect.

Water level fluctuation indicator	Reference period 1971-2000	Climate change scenario 2040-2069	Effect
Magnitude of spring flood (m)	0,03	-0,01	
Water level change during growing season (m)	0,21	0,10	+
Maximum vertical extension of the *Carex* zone (m)	0,24	0,25	
Extent of frozen productive zone (%)	33,63	21,99	+
Extent of ice pressure zone (%)	50,83	37,18	+
Extent of disturbed productive zone (%)	38,27	32,07	+
Water level rise during the nesting of birds (m)	0,18	0,13	+
Magnitude of winter drawdown = water level decrease during the ice cover period (m)	1,20	0,92	+
Decrease of water level during spawning of northern pike (m)	0,00	0,01	
Minimum water depth in the *Carex* zone during the spawning of northern pike (m)	-0,44	-0,23	+
Mean number of days per year when water level > 119,35	9,7	6,4	+

Carex zone is the optimum growing level of Carex species being important habitat for northern pike spawning. Change in maximum vertical extension of Carex zone and decrease of water level during spawning of northern pike is negligible. However, although indicator minimum water depth in the Carex zone during the spawning of northern pike is having negative value indicating that water levels at Lake Inari stays below optimum zone for Carex species during spawning period, the direction of the change between reference period and scenario period is positive.

Extent of frozen productive zone describes how much of the littoral productive zone is frozen during winter. It is important factor effecting on organisms (aquatic vegetation, invertebrates and eggs of autumn spawning fish species) that can't tolerate freezing. Decrease of extent of frozen productive zone over 10 percentage points is positive effect. Also changes in other similar indicators depending of water level changes during ice covered period i.e. extent of ice pressure zone and magnitude of winter drawdown have similar positive effects.

Productive littoral zone between MHW and MLW is disturbed by wave action during open water period and by freezing and ice pressure during ice covered period. These disturbances also have an effect on littoral biota restricting survival of sensitive species. Change in extent of disturbed productive zone, although only 6,2 percentage points, is positive.

Water level rise during the nesting of birds can destroy nests of bird species near the water level. Decrease in water level rise is only 0,05 m but the direction of change is positive and it can have an positive effect on nesting success of birds.

Wave action induced erosion is significant disturbance affecting littoral habitats on Lake Inari and water levels above 119,35 m.a.s.l. are considered to be the conditions when erosion in Lake Inari is increasing substantially (PURO-TAHVANAINEN et al. 2011). Decrease in mean number of days per year when water level is greater than 119,35 m.a.s.l. has an positive effect on erosion sensitive shores mitigating disturbance caused by erosion..

4 DHRAM-calculation program

The Dundee Hydrological Regime Assessment Method (DHRAM) method was used for water flow analysis. This analysis is based on the Indicator of Hydrologic Alteration (IHA) method developed by RICHTER et al. (1996). The method has been largely applied in Scotland by BLACK et al. (2000). This approach compares differences between the impacted and un-impacted flow data and is therefore descriptive. It resembles the REGCEL application, but uses only discharge data without any measured biological response. In Scotland it will obviously be a factor in the designation process of heavily modified water bodies (HMWB) covered by the EU Water Framework Directive (BLACK et al. 2000).

The DHRAM method assesses the degree of hydrological alteration presuming that the change is having an ecologically harmful impact on naturally adapted biota. Discharge factors are divided into five different groups, in which both mean value (A) and coefficients of variation (B) are used as indicators. Comparisons between un-impacted and impacted situations are calculated as an absolute change (%). At total of ten summary indicators are used from 1A to 5B. The groups are as follows:

- Group 1. Magnitude of monthly water conditions is calculated for every month (12) of time span as (1A) mean discharge (m^3/s) and (1B) coefficient of variation (%). Changes in monthly water condition measures general availability or suitability of habitats (RICHTER et al. 1996). Visual comparison shows a general ecological tendency e.g. in trout spawning environments.
- Group 2. Magnitude and duration of annual extremes is calculated from 1-Day, 3-Day, 7-Day, 30-Day and 90-Day minimum and maximum flow values. The number of zero-flow days is also calculated but not taken into account. These extreme values measure environmental stress and disturbance in general (RICHTER et al. 1996).
- Group 3. Timing of annual extremes is counted as the Julian date of 1-Day annual maximum and the 1-Day annual minimum. This factor describes seasonal stress needed for specific life cycles, e.g. reproduction of fish (RICHTER et al. 1996).
- Group 4. Frequency and duration of high (over 75th percentile flow) and low (less 25th percentile flow) pulses are counted by number of pulses and duration (%). These factors are measures of environmental variation (RICHTER et al. 1996).
- Group 5. Rate and frequency of change in conditions are calculated by mean flow increase or decrease within consecutive days and by the number of flow reversals. This factor measures intra-annual environmental change in conditions (RICHTER et al. 1996).

Estimation of the change is based on change thresholds described by BLACK et al. (2000). The values presented in Table 2 derive from Scottish rivers, therefore results can be unreliable in a Scandinavian context. Five classes are given based on summarized final impact points (Table 3).

In our study DHRAM was applied to compare the regulated water flow (reference period) in Kaitakoski (1970-2000) and simulated flow for climate change scenario (2040-2069).

Table 2. Hydrological change thresholds used for allocation of final impact points according to BLACK et al. (2000).

IHA summary indicator	Lower Threshold (1 impact point)	Intermediate Threshold (2 impact points)	Upper Threshold (3 impact points)
1a	19.9	43.7	67.5
1b	29.4	97.6	165.7
2a	42.9	88.2	133.4
2b	84.5	122.7	160.8
3a	7.0	21.2	35.5
3b	33.4	50.3	67.3
4a	36.4	65.1	93.8
4b	30.5	76.1	121.6
5a	46.0	82.7	119.4
5b	49.1	79.9	110.6

Table 3. Definition of final impact classes according to BLACK et al. (2000).

Class	Points range	Description
1	0	Un-impacted condition
2	1-4	Low risk of impact
3	5-10	Moderate risk of impact
4	11-20	High risk of impact
5	21-30	Severely impacted condition

4.1 DHRAM application

DHRAM analysis was applied to water flow data from the Kaitakoski station, situated at the outlet of Lake Inari (Fig. 3). The difference between flow situations was also quite clear; with very much higher spring flow and lower flow during summer.

The main results of the DHRAM analysis between reference period and climate change scenario period flow situations are presented in Table 4. Despite of relative large changes, only the timing of annual extremes has changed and gave 2 final impact points. The change of flood timing was the main reason for the change.

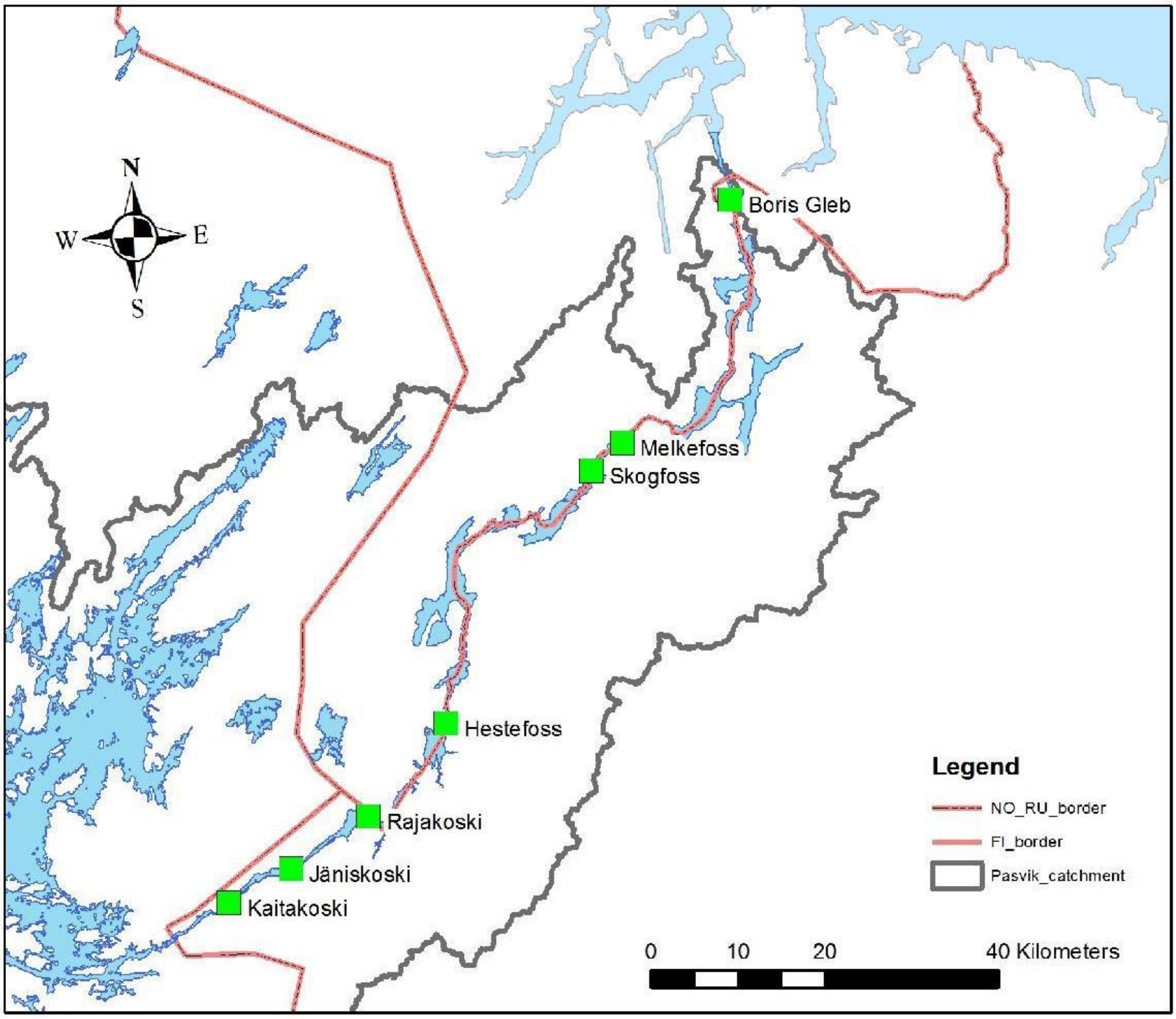

Figure 3. Hydro power plants in River Pasvik.

When comparing monthly water level fluctuations, there is a clear change with the change from summer months to winter as a consequence of climate change. However, summer and the increase in variation are the main factors affecting the situation (Fig. 4).

Magnitude and duration of annual extremes shows no significant change in terms of final impact points although the values of the extremes have changed slightly (Table 2, Fig. 5). The timing of annual extremes has changed significantly, but there has been also increasing variation as a consequence of climate change (Fig. 6). Change in flood timing reaches 2 final impact points, which is quite significant from the point of view of ecology.

Table 4. DHRAM analysis in River Paatsjoki with Kaitakoski data. Comparison of current (1970-2000 regulated) and climate change (2040-2069 recalculated) hydrology.

Group 1: Magnitude of monthly water conditions	Mean (m3/s)		CV (%)	
	Mean Regulated	Mean Recalculated	CV Regulated	CV Recalculated
Jan-mean	145,85	167,56	16,64	20,14
Feb-mean	146,92	177,52	16,97	19,11
Mar-mean	144,25	185,27	15,59	13,87
Apr-mean	121,96	156,02	16,54	19,92
May-mean	111,64	133,26	18,09	33,53
Jun-mean	168,59	162,46	56,61	53,00
Jul-mean	168,36	137,65	49,97	45,07
Aug-mean	162,89	144,97	45,99	48,37
Sep-mean	163,45	153,80	47,34	55,15
Oct-mean	147,50	145,74	26,48	30,72
Nov-mean	144,45	156,67	19,29	29,23
Dec-mean	145,49	162,44	16,19	21,75
Group 2: Magnitude and duration of annual extremes				
	Mean Regulated	Mean Recalculated	CV Regulated	CV Recalculated
1-day-minimum flow	84,70	86,80	6,90	6,42
1-day-maximum flow	274,66	277,97	46,21	39,65
3-day-minimum flow	88,24	90,39	5,30	6,31
3-day-maximum flow	272,49	277,19	46,71	39,93
7-day-minimum flow	92,59	95,13	8,07	11,07
7-day-maximum flow	269,12	275,94	46,71	39,68
30-day-minimum flow	101,01	103,65	12,75	13,81
30-day-maximum flow	244,97	250,61	45,70	34,51
90-day-minimum flow	112,16	112,42	13,81	18,35
90-day-maximum flow	200,06	213,58	34,28	23,20
Zero-flow days	0,00	0,00	0,00	0,00
Group 3: Timing of annual extremes				
	Mean Regulated	Mean Recalculated	CV Regulated	CV Recalculated
1-Day-Min-Date	150,20	146,45	33,97	46,17
1-Day-Max-Date	202,45	145,95	40,81	83,77
Group 4: Frequency and duration of high and low pulses				
	Mean Regulated	Mean Recalculated	CV Regulated	CV Recalculated
Number of High-Pulses	5,12	5,40	73,84	64,37
Number of Low-Pulses	14,70	8,33	79,46	58,98
Duration-Hi-Pulse	25,19	32,34	77,52	97,62
Duration-Lo-Pulse	15,63	26,01	145,60	174,61
Group 5: Rate and frequency of change in conditions				
	Mean Regulated	Mean Recalculated	CV Regulated	CV Recalculated
Mean-increase	7,83	10,80	38,61	35,03
Mean-decrease	-7,08	-10,55	-32,85	-36,44
No-rises	202,44	266,32	28,19	16,27

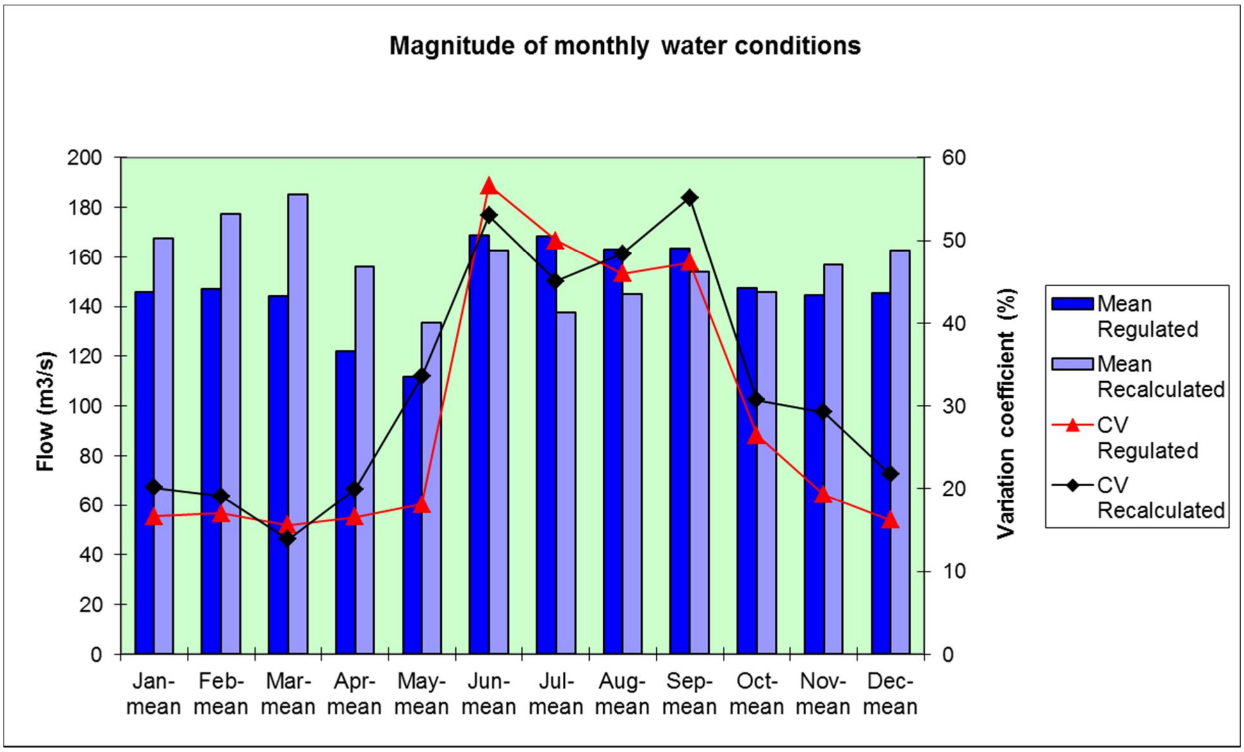

Figure 4. Magnitude of monthly water conditions in River Paatsjoki. Comparison of current (1970-2000,deep blue, red line) and climate change (2040-2069, light blue, black line) hydrology

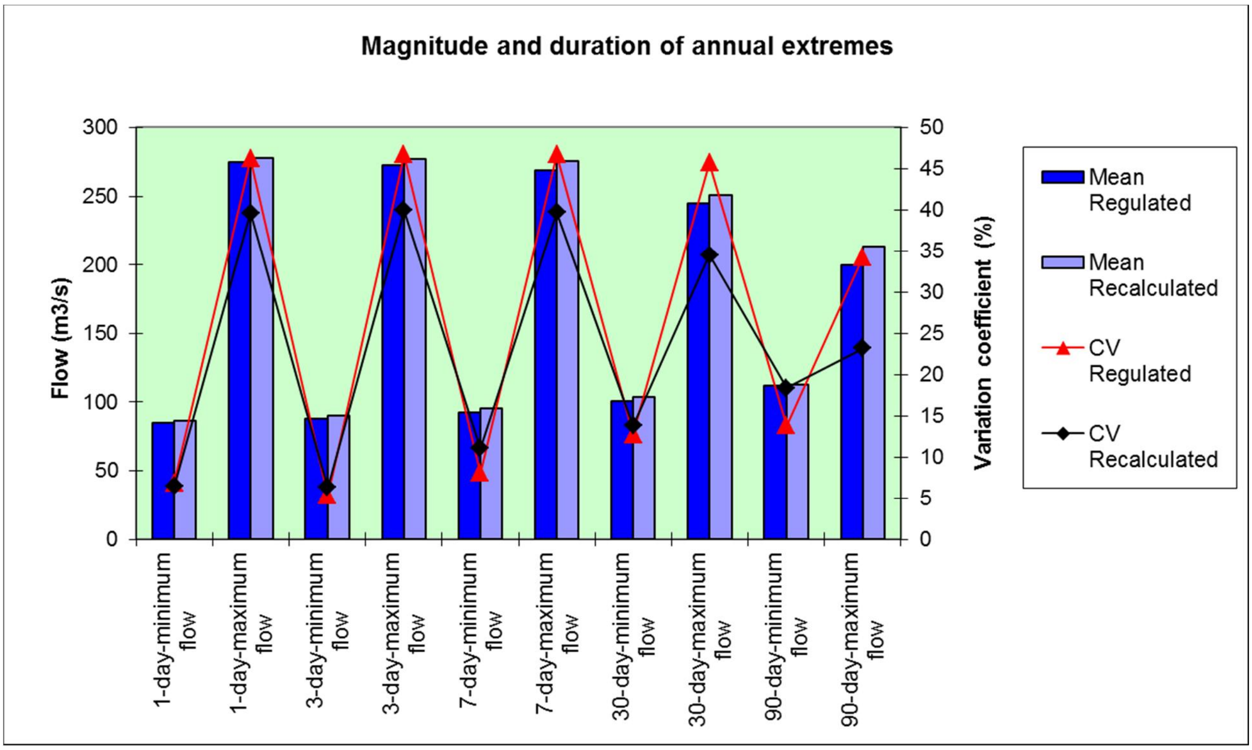

Figure 5. Magnitude and duration of annual extremes in River Paatsjoki. Comparison of current (1970-2000,deep blue, red line) and climate change (2040-2069, light blue, black line)

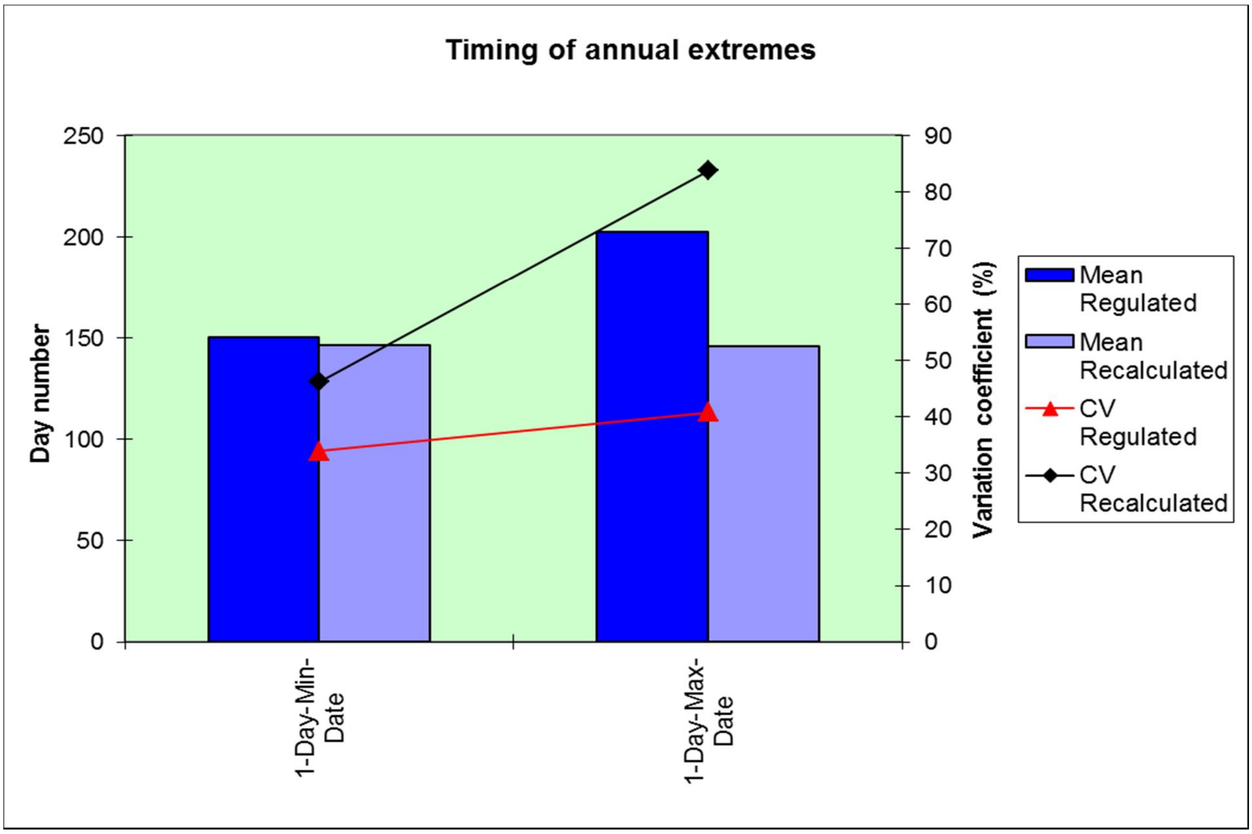

Figure 6. Timing of annual extremes in River Paatsjoki. Comparison of current (1970-2000,deep blue, red line) and climate change (2040-2069, light blue, black line)

More relevant ecological change is visible in the frequency and duration of high and low pulses (Fig. 7). There are more high and low pulses, but mean duration is significantly lower. This situation can cause environmental stress for most biota, which cannot adapt to rapid changes (RICHTER et al. 1996). There are not big differences in the rate and frequency of change in conditions (Fig. 8).

DHRAM analysis showed only a weak trend; a total of 2 points were reached, which according to BLACK et al. (2000) indicates a low risk of impact (see Table 3).

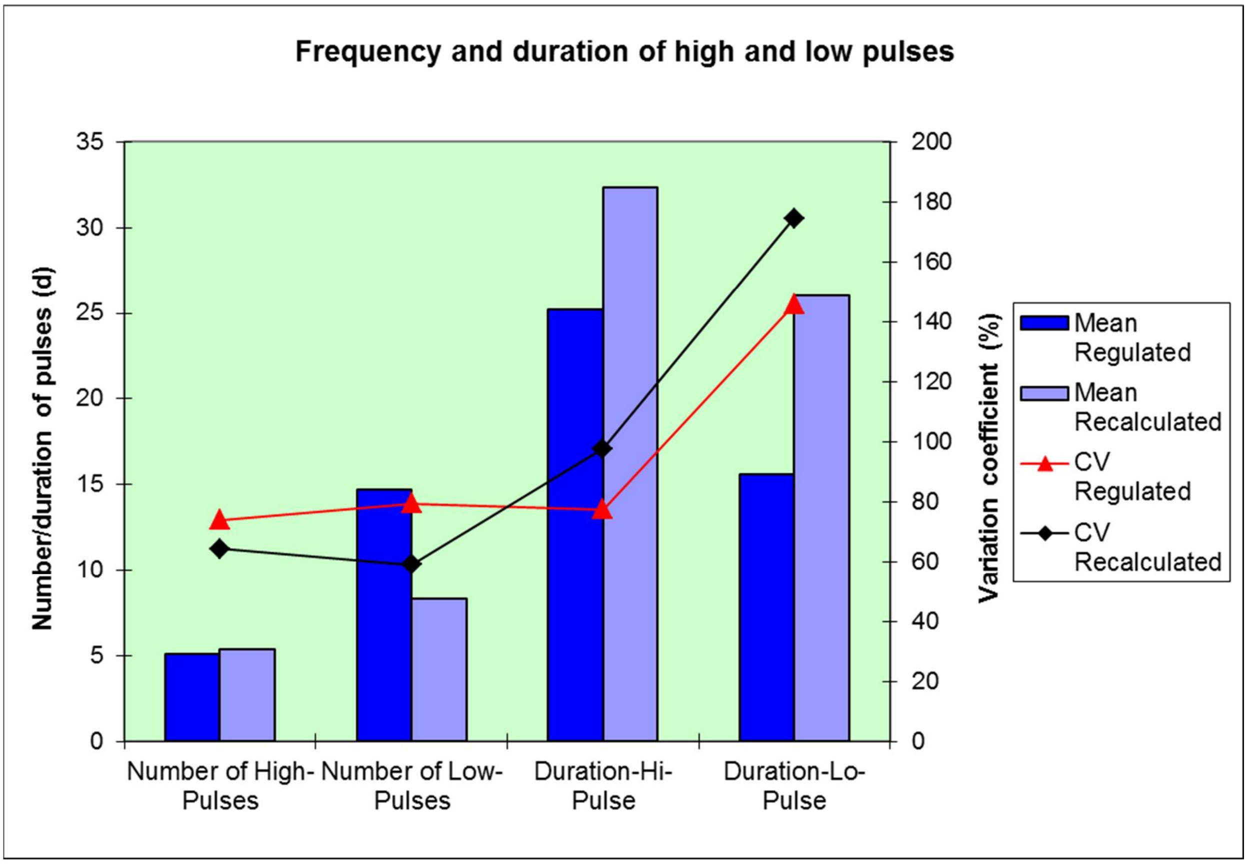

Figure 7. Frequency and duration of high and low pulses in River Paatsjoki. Comparison of current (1970-2000,deep blue, red line) and climate change (2040-2069, light blue, black line)

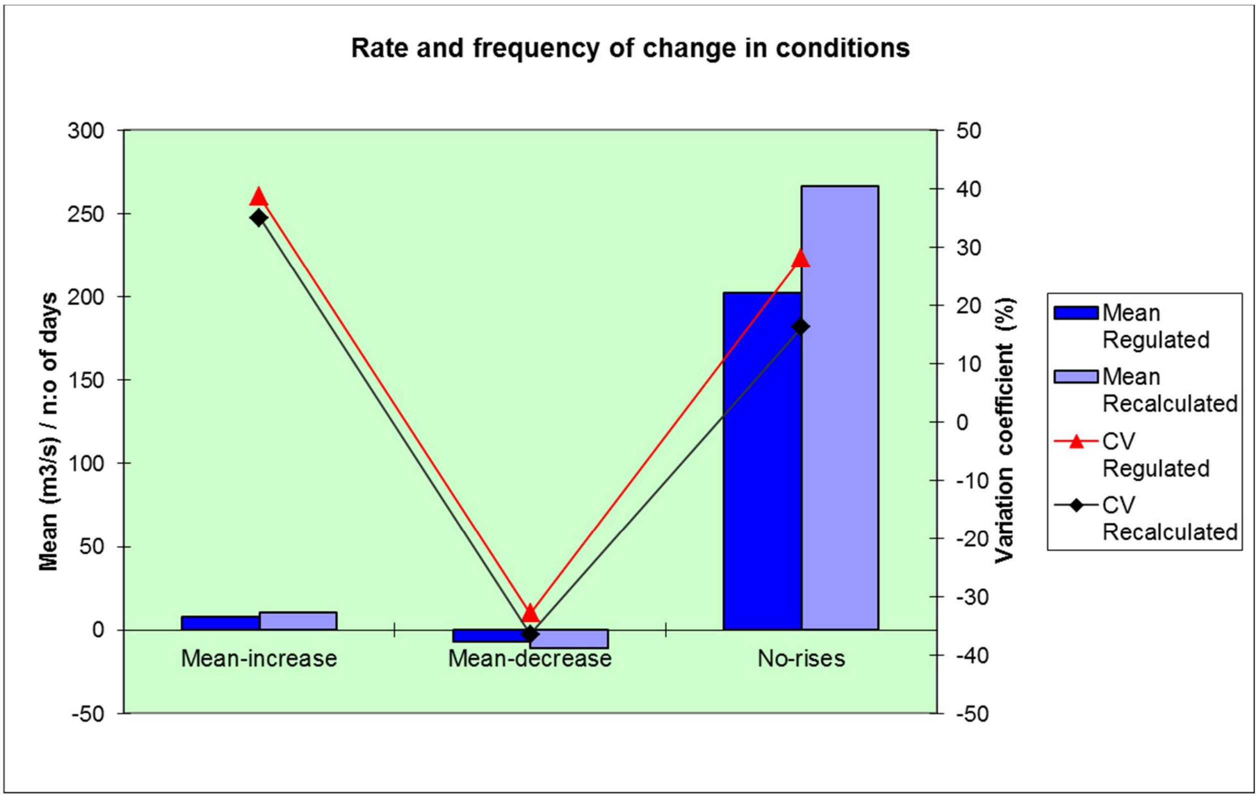

Figure 8. Rate and frequency in conditions in River Paatsjoki. Comparison of current (1970-2000,deep blue, red line) and climate change (2040-2069, light blue, black line).

5 Conclusions

Climate change impacts on hydrology and water level fluctuation indicators were analysed in the River Pasvik catchment. Two different hydrological analysis systems were applied. Water level data for Lake Inari was analysed using Regcel model. The model enables assessment of the ecological impacts of water-level regulation on aquatic macrophytes, benthic invertebrates, fishes and nesting of water fowls.

The results in water level fluctuation indicators showed that changes in water level fluctuation would have mainly positive effects on environment brought by decrease in fluctuation. Water level change during growing season in Lake Inari being smaller in scenario period than in reference period promotes zonation littoral vegetation and would have positive effect on shore habitat diversity. Decrease of extent the zone disturbed by wave action, extent frozen productive zone, extent of ice pressure zone and magnitude of winter drawdown all have positive effects on survival of sensitive littoral biota. Decrease in water level rise can have an positive effect on nesting success of birds and decrease in mean number of days per year when water level is greater than 119,35 m.a.s.l. has an positive effect on erosion sensitive shores.

General flow data for River Pasvik was analysed by the DHRAM program. The method is rapid, but the biological response was partly unclear. The analysis showed that the climate change induced change in flow regimes would have low risk of impact.

Both Regcel and Dhram method can be effectively used to assess hydrological and ecological effects of climate change on lakes and rivers using measured and simulated water level and discharge data.

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