Mathematical modelling for hydrological processes of Aiviekste river basin

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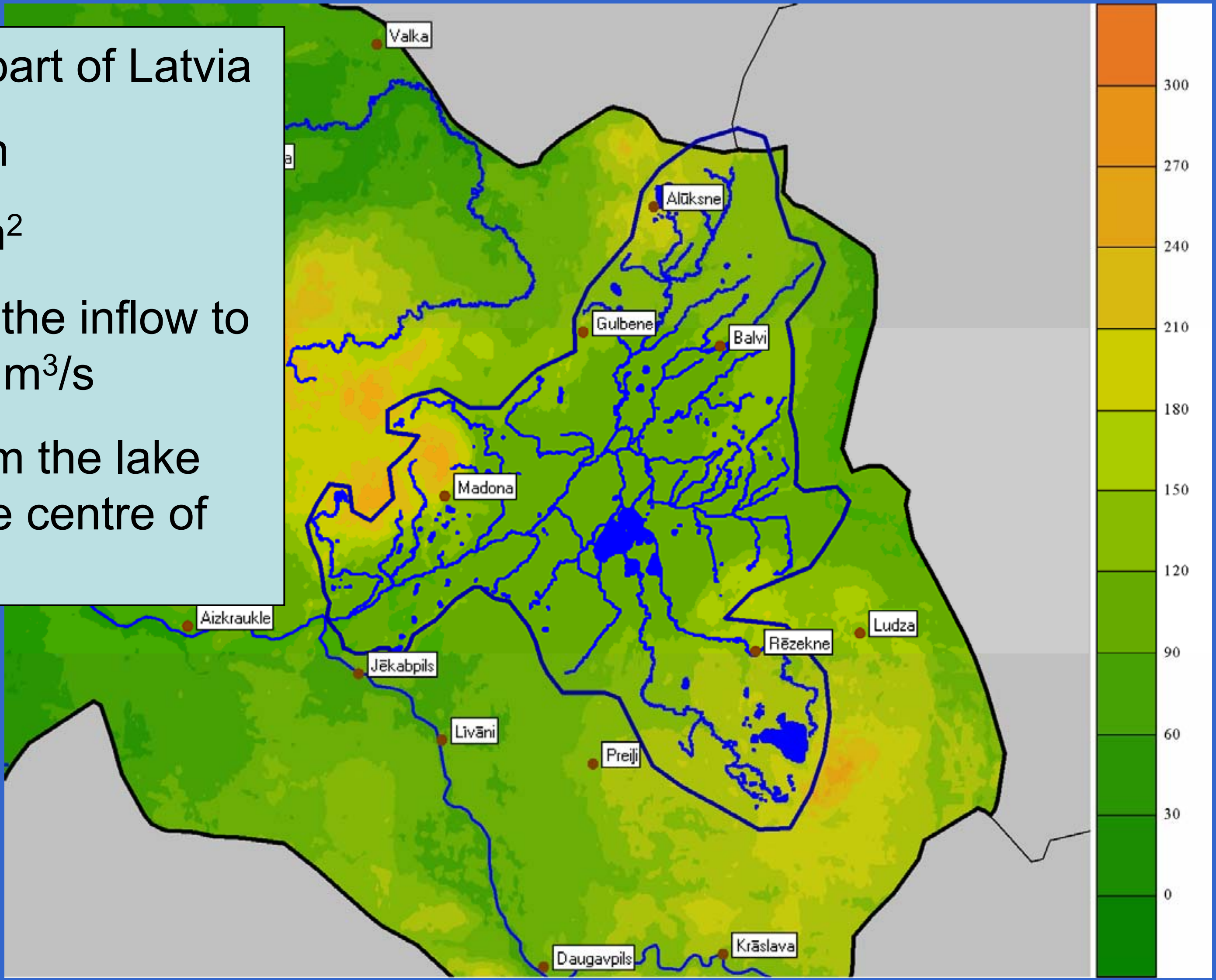
Distributed hydrological model of the Aiviekste river basin has been developed and calibrated to the typical, dry and wet hydrological regimes.

Several scenarious of impact of climatic changes to hydrological and nutrient load regime have been calculated.

Basin of the river Aiviekste

- Located in northeast part of Latvia
- Part of Daugava basin
- Area approx. 9000 km^2
- Average discharge at the inflow to Daugava – approx. 60 m^3/s
- Aiviekste outflows from the lake Lubanas situated in the centre of the basin



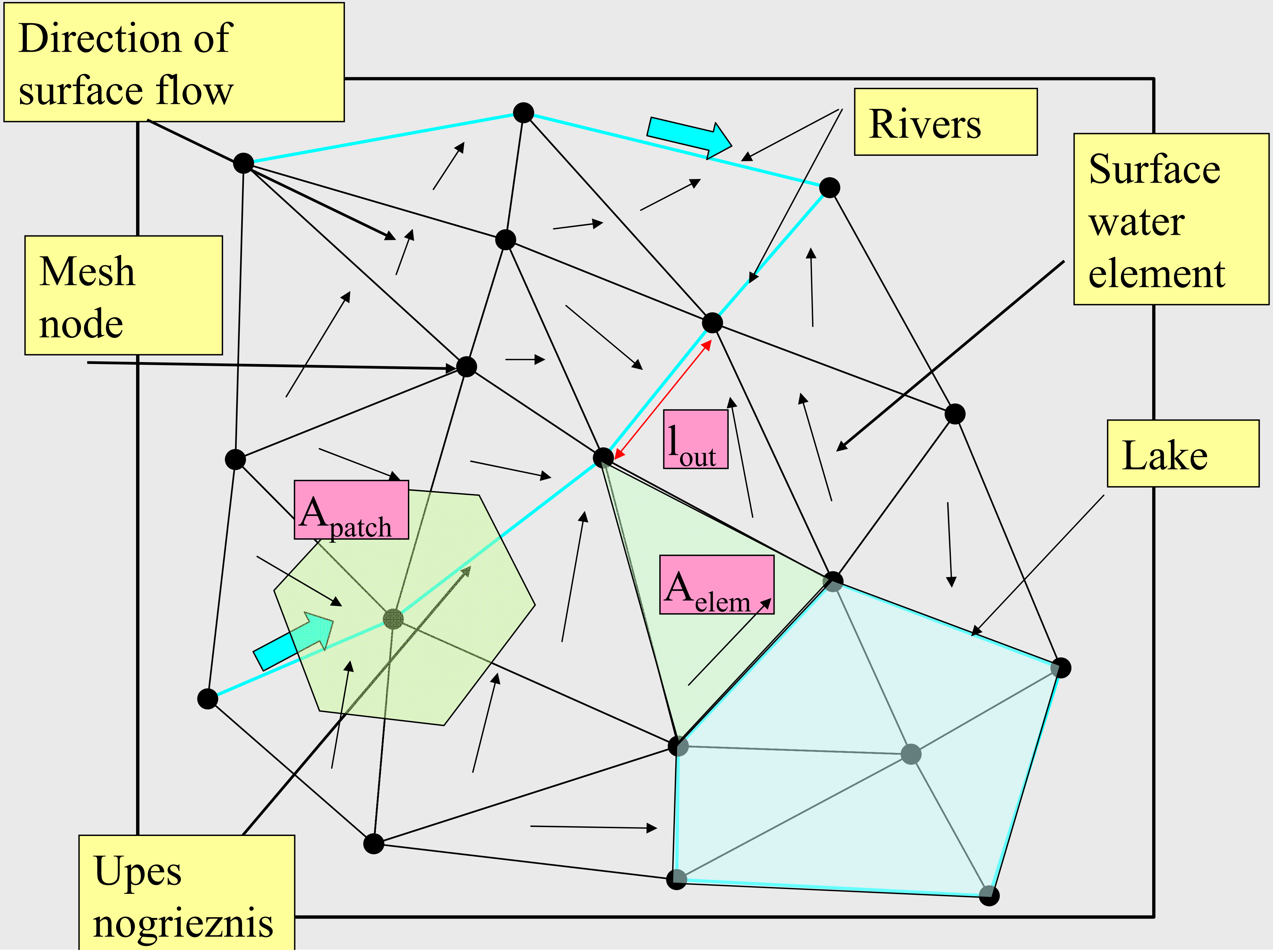
Approach to hydrological model

Physically-based spatially and temporally distributed dynamic modelling

The catchment is divided into hierarchical subbasins downscalable up to the finite element level. The hydrological cycle is resolved for the lowest hierarchical level, the hydrological cycle modelling is coupled with the dynamic routing of the water flow through the network of streams.

Principal components of model

- Surface water model – solves for surface water content (intercepted+ponded).
- Groundwater model – solves for groundwater level
- Flow routing model
- Lake model – solves for waterlevel of lake



Direction of surface flow

Rivers

Surface water element

Mesh node

Lake

l_{out}

A_{patch}

A_{elem}

Upes nogrieznis

Surface water model

Solves for surface water content (intercepted+ponded)

Principal components:

- Precipitation (in form of rain)
- Snowmelt
- Evapotranspiration
- Infiltration
- Groundwater saturation excess flow
- Overland flow - surface run-off

Finite volume model for triangular elements (variables at triangles)

Surface run-off path – according to surface level gradient

$$\frac{dw}{dt} = P - E - V_{\inf iltr} + V_{surface} - \sum_i V_{runoff}^{-(i)} + \sum_i V_{runoff}^{+(i)} + V_{snow}$$

P – precipitation (if rain)
w – surface water content (=$w_{intercepted}$+w_{ponded})
E – evapostranspiration
$V_{surface}$ – groundwater saturation excess flow
V^- - surface runoff from element
V^+- surface runoff entering element
V_{snow} – snowmelt rate

$$V_{runoff} = \frac{1}{n}\left(w - w_{\operatorname{int}ercepted}\right)^{2/3} S_0^{1/2} \cdot \frac{l_{out}}{A_{elem}}$$

If w>$w_{intercepted}$
n – Mannig coefficient for overland flow (land use dependent)
S_0 – surface slope

Evapotranspiration model

$$E = K_e(w)(e_{sat}(T) - e)$$

Snow-melt model

Solves for water content in snow

Melt rate degree-day dependent

$$\frac{dS}{dt} = P_s - V_{snow}$$

S – equivalent water content in snow
P_s – precipitation in form of snow
$V_{snow} = C_{MELT} (T-T_2)$
T_2 – reference temperature (>0ºC)

Ground water model

Solves for piezometric head in upper layer (2D)

Principal components:

- Storativity
- Darcy flow
- Infiltration from surface
- Overflow to surface water and directly to rivers
- Flow to/from lakes

Finite element model, head at triangular grid nodes

$$\left(h - z_g\right) S_s \frac{\partial h}{\partial t} = \nabla \cdot \left(K\left(h - z_g\right)\nabla h\right) + V_{\inf iltr} - V_{river} - V_{surface}$$

h – head equal to water level
z_g – level of aquitard
S_s – specific storativity
K - hydraulic conductivity

At lake node $h=h_{lake}$

Outflow to rivers at river nodes

$$V_{river} = \frac{K\left(h - h_{river}\right)}{\Delta l_{river}}$$

If $h>h_{river}$
Δl_{river} – empiric

Outflow to surface water at surface elements

$$V_{surface} = \frac{K\left(h - \left(h_{surface} - \Delta h_{surface}\right)\right)}{\Delta l_{surface}}$$

If $h>(h_{surface} - \Delta h_{surface})$
$\Delta l_{surface}$ – empiric
$\Delta h_{surface}$ – surface level correction

Flow routing model

Solves for river level and discharge

St Venant equations

Staggered finite difference model (level at points, discharge at segments)

Input data – river bed level, cross-sections are parametrized parabolic profiles

Inflow sources – surface runoff, groundwater overflow

Lake model

Solves for lake level and discharge

Inflow – surface run-off, rivers, groundwater

Outflow – rivers, groundwater

$$A_{lake}\frac{dh_{lake}}{dt} = \sum_i Q_{riverin}^{(i)} - \sum_i Q_{riverout}^{(i)} + \sum_i V_{runoff}^{(i)} l_{out}^{(i)} (w - w_{intercept})^{(i)}$$

$$+ \oint_{\Gamma} K \frac{\partial h}{\partial n}(h - z_g)\, d\Gamma \quad \{+P - E\}$$

Input data

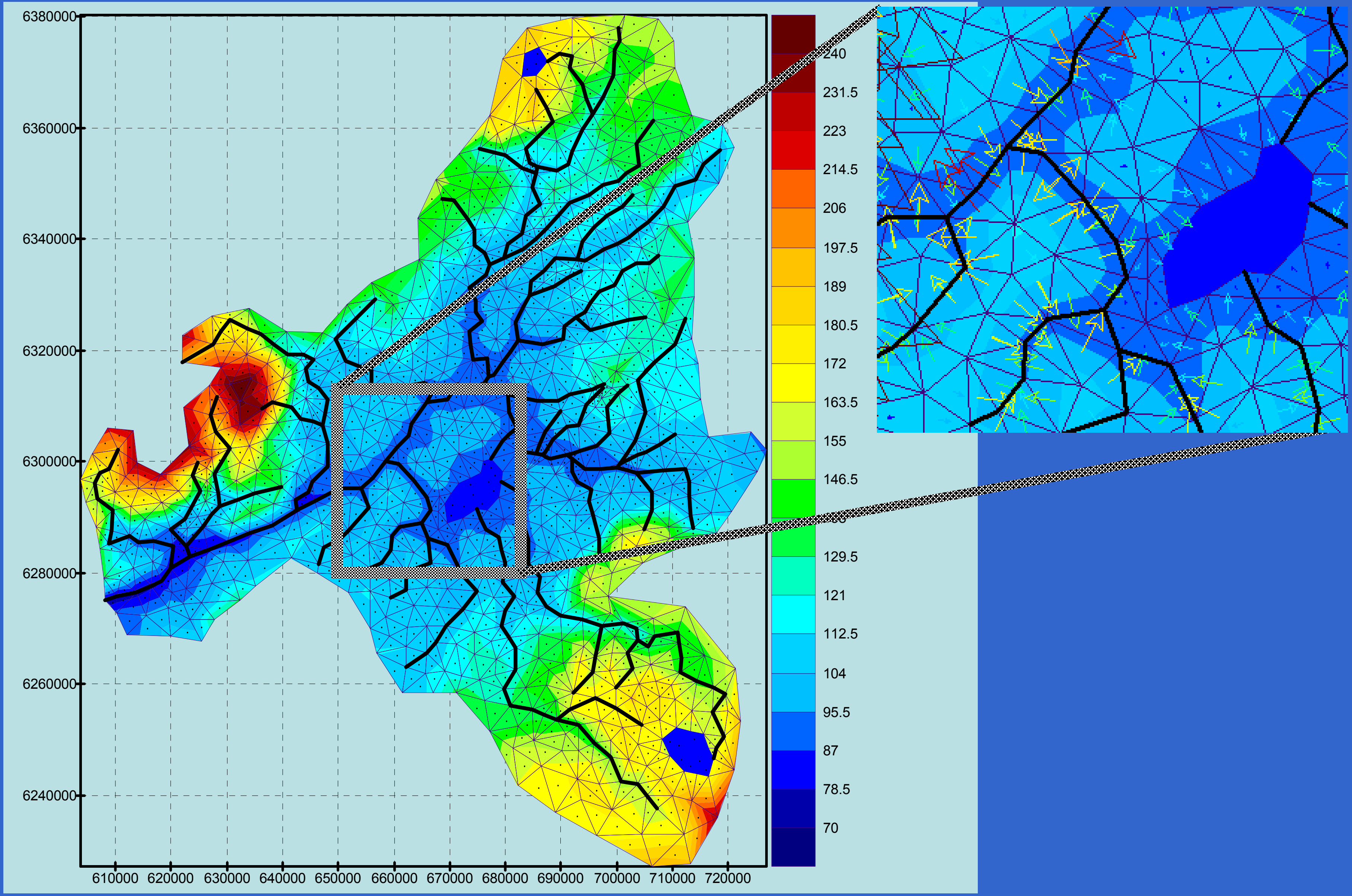
•**Digital terrain model + river network** -> model grid, model river network, model lake boundaries

•**Land use data** [*National CORINE Land Cover 2000 in Latvia*] ->grouped to 6 main land use types (agricultural, forests, bushes/grasslands, swamps, artificial and waterbodies), model accounts for fraction of each type at each surface water element

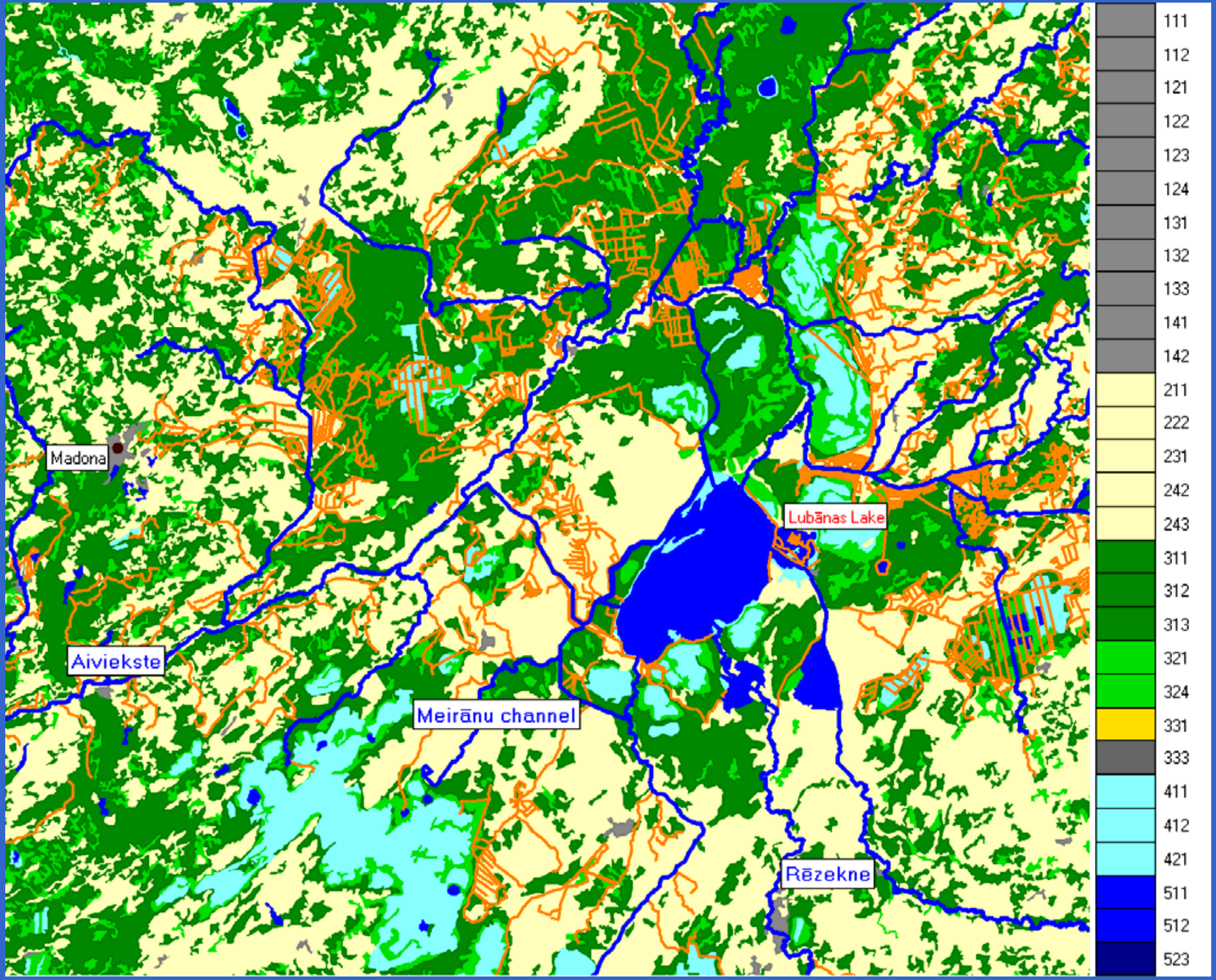
•**Observations of the river discharge** at 7 stations [*Ziverts*]

•**The daily meteorological data (precipitation and air temperature)** at Rēzekne, Zīlāni and Gulbene [*LEGMA*]

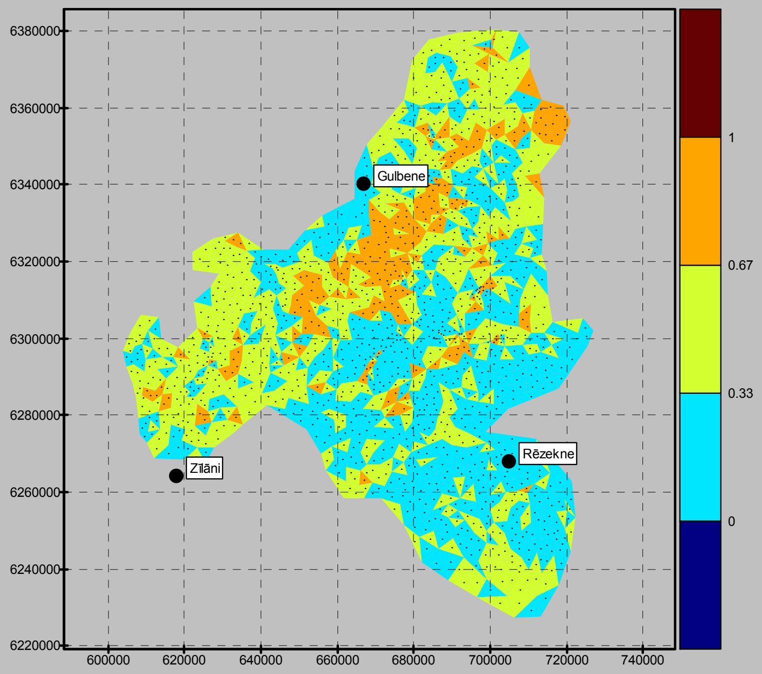
Model grid and river network



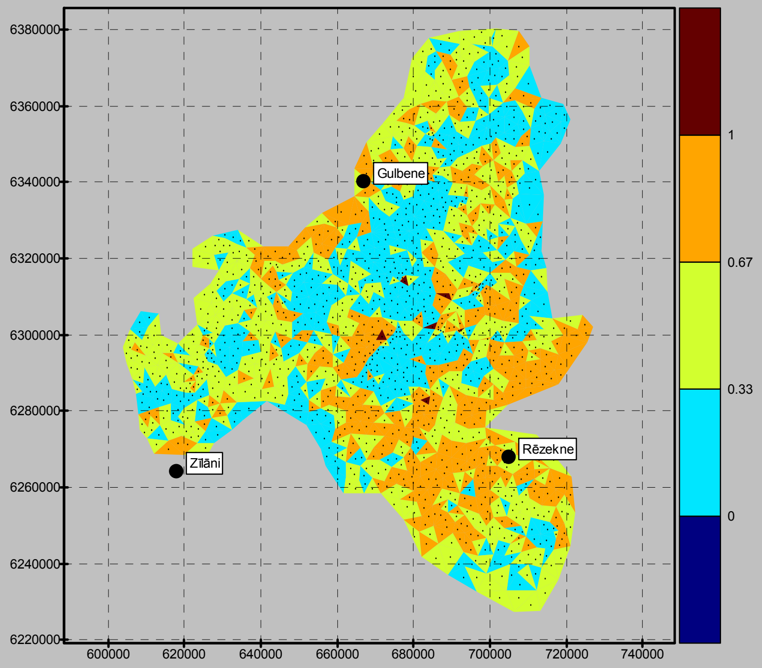
Land use according to CORINE



Distribution of area percentage of land use types

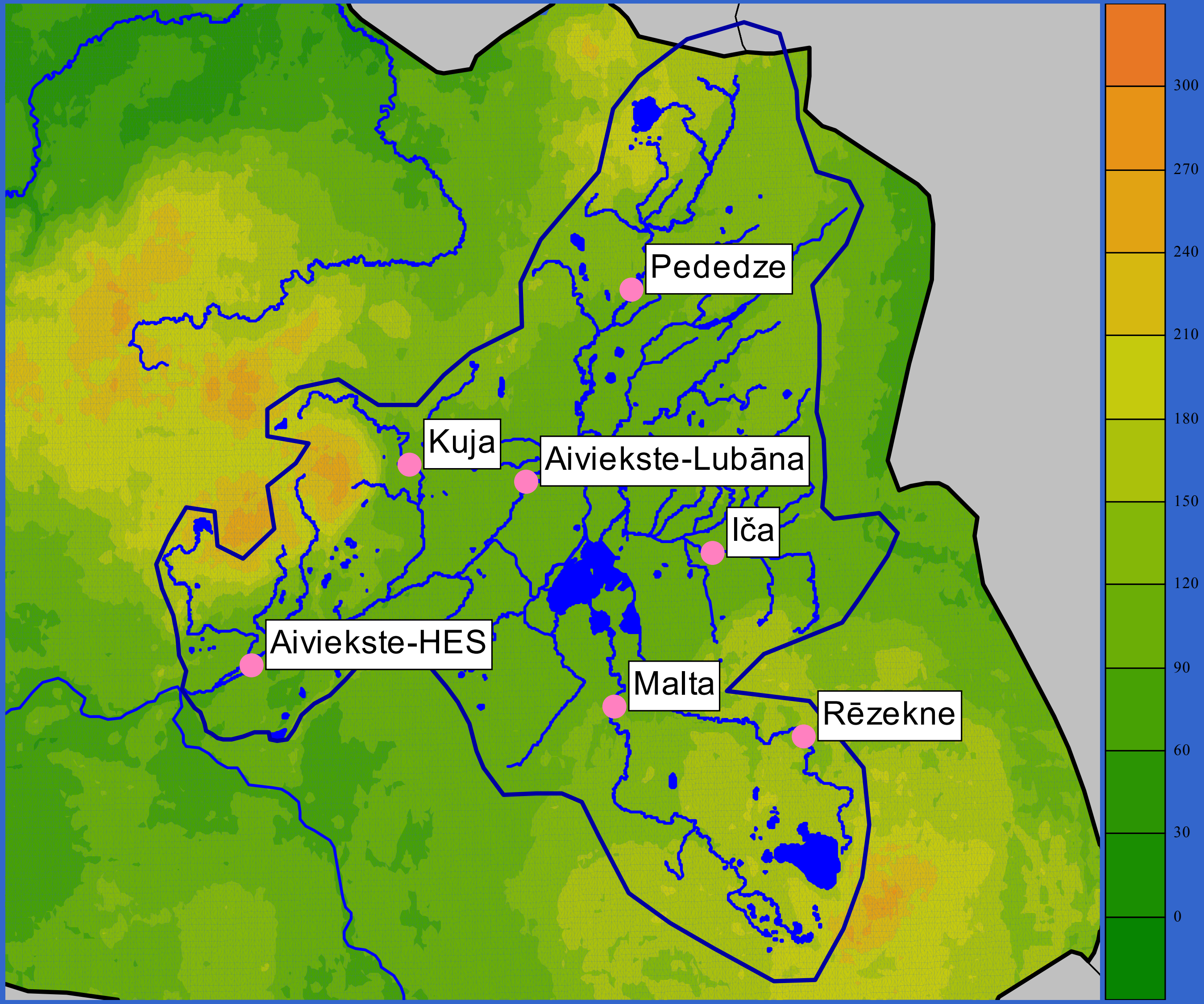


Forests



Agricultural

Location of hydrometric stations



Selection of calibration scenario

Three different Years are considered.

- Jul/76 to June/77 is dry Year, precipitation 518 mm average run-off at Aiviekste HPP 35 m^3/s
- Jul/77 to June/78 is average Year, precipitation 660 mm average run-off at Aiviekste HPP 57 m^3/s
- Jul/79 to June/80 is wet Year, precipitation 762 mm average run-off at Aiviekste HPP 92 m^3/s

Selection of calibration scenario, meteorological parameters

Stacija	Gulbene	Rēzekne	Zīlāni
T ave, °C	4.28	4.42	4.87
P ave, mm/year	632	608	647
T ave, “dry” 76/77, °C	4.49	4.76	5.09
P sum, “dry” 76/77, mm	477	451	518
T ave, “average” 77/78, °C	4.43	4.50	5.06
P sum, “average” 77/78, mm	635	626	660
T ave, “wet” 78/79, °C	3.92	4.00	4.45
P sum, “wet” 78/79, mm	785	747	762

Selection of calibration scenario, discharge measurements

	Area of catchment, km^2	“Dry” 1976/77, m^3/s	“Average” 1977/78, m^3/s	“Wet” 1978/79, m^3/s
Aiviekste HPP	8660	34.85	58.60	91.75
Aiviekste Lubāna	7200	24.18	42.57	62.81
Kuja, Aizkuja	268	1.47	2.82	3.65
Pededze, Litene	978	4.67	7.24	12.95
Iča, Kuderi	674	2.37	5.76	
Rēzekne, Griškāni	505	1.49	3.37	5.06
Malta, Viļāni	782	2.71	6.14	8.29

Selection of calibration scenario

The most downstream gauge is Aiviekste HPP (basin area 8660 km^2). The discharge at this gauge is, respectively 25%, 32%, and 44% of the precipitation for three respective Years.

Dry Years – lower percentage due to the relatively higher evaporation (high T, low e) and higher infiltraton (low soil moisture, low groundwater level). Wet Years – higher percentage doe to the lower evaporation (low T, high e) and lower infitration (high soil moisture, high groundwater level).

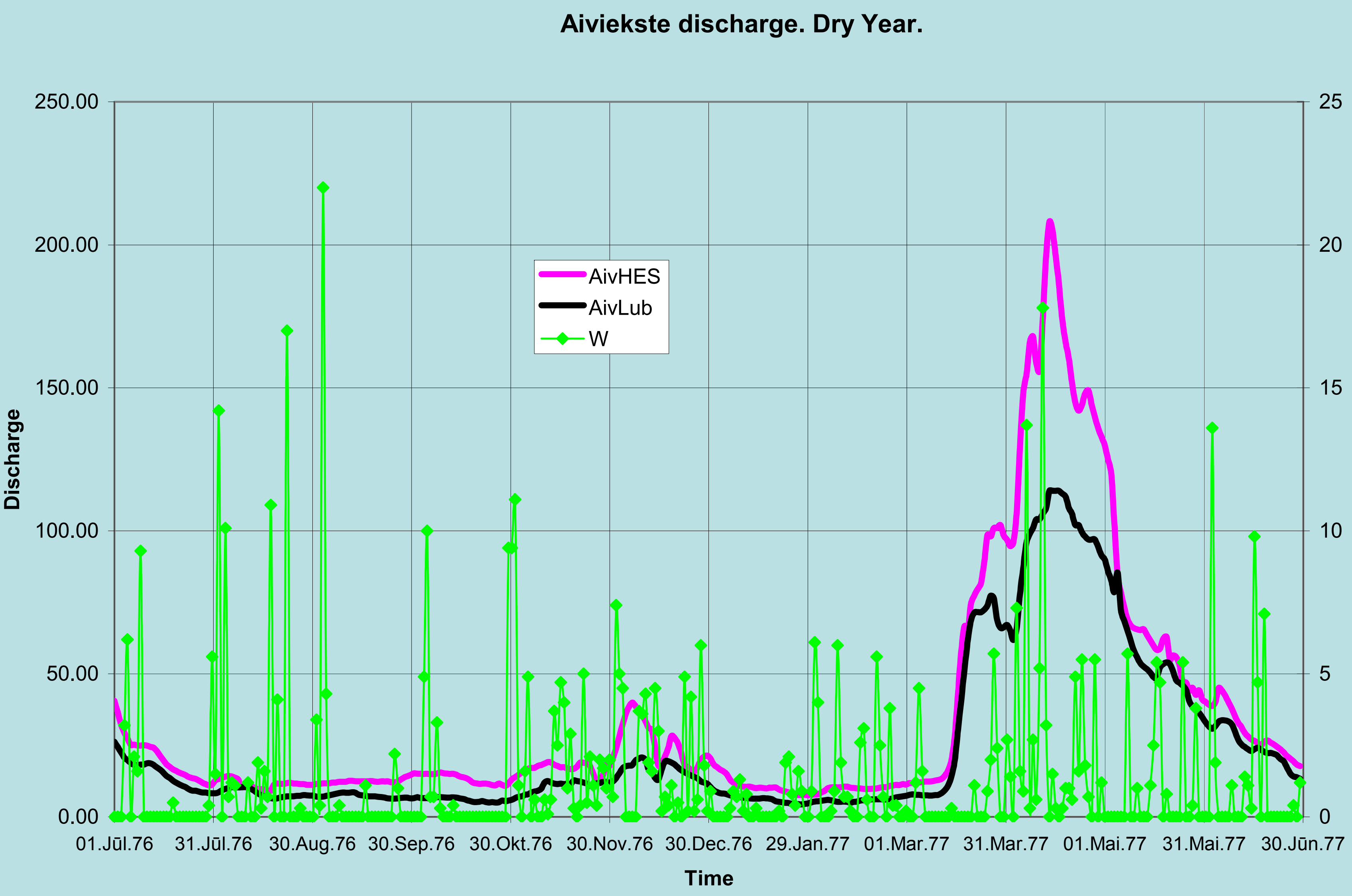
Selection of calibration scenario

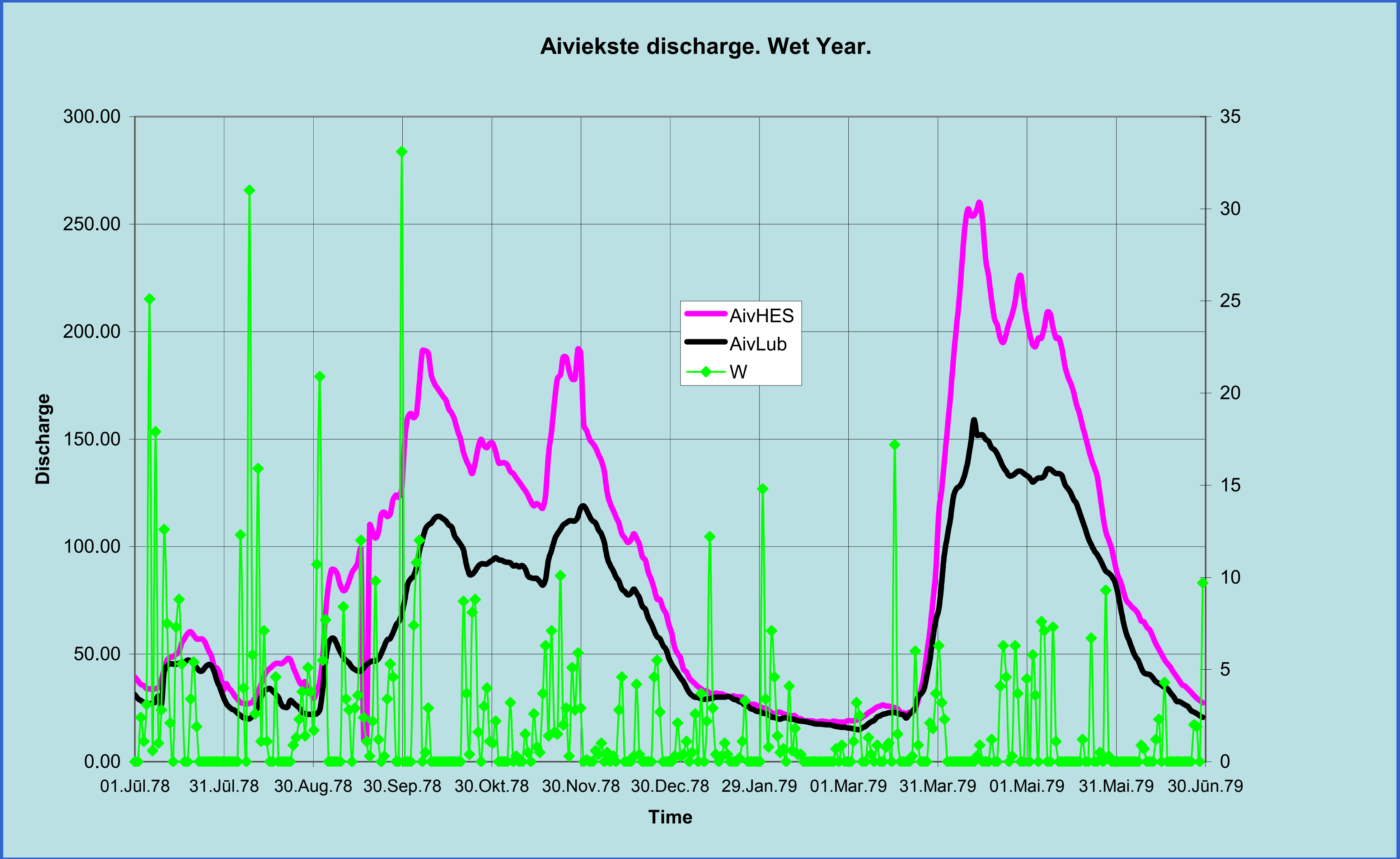
The hydrometric stations are located rather far upstream on the tributaries. The particular tributaries with the available discharge time series (Pededze, Rēzekne, Malta, Ič̌a, Balupe, Kuja) cover only 42% of the catchment area, producing (on average) also 42% of the River Aiviekste run-off. therefore the calibration of each particular tributary is important for the adjustment of the land-use dependent parameters, whilst the most of the river basin is accounted by the total, i.e. Aiviekste HPP hydrometric station.

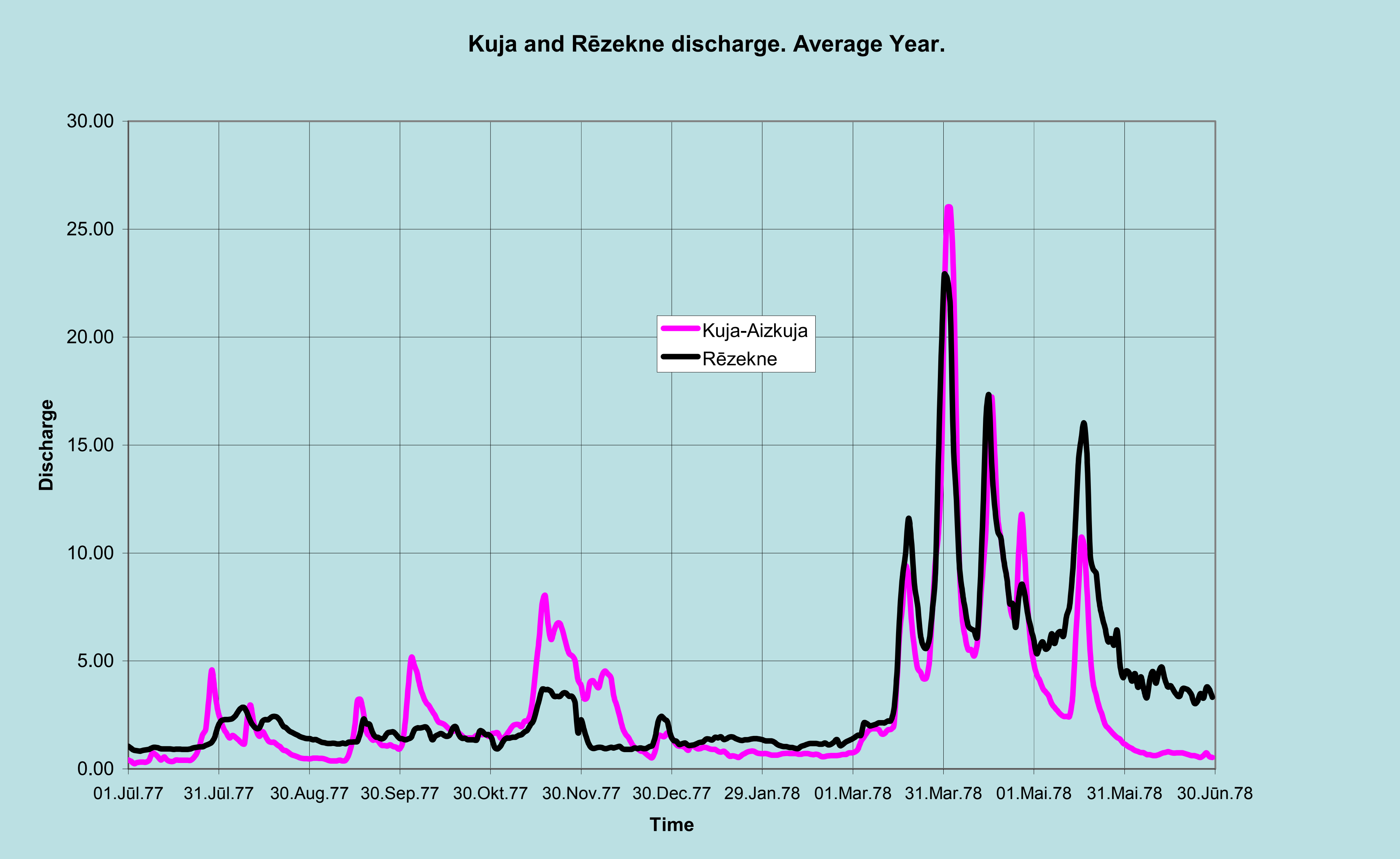
Selection of calibration scenario

Dry Years are characteristic with the single snow-melt flood.No travel time of the flood signal may be distinguished. There is no immediate response of the precipitation signal in the discharge time-series.

Wet Year is characterised by multiple rain events during summer and prolonged rainfalls during autumn. The later results in the autumn high-water. Still neither travel time of the flood signal may be distinguished not there is an immediate response of the precipitation signal in the discharge time-series.


Aiviekste discharge. Dry Year.
Discharge
250.00
200.00
150.00
100.00
50.00
0.00
25
20
15
10
5
0
AivHES
AivLub
W
01.Jūl.76
31.Jūl.76
30.Aug.76
30.Sep.76
30.Okt.76
30.Nov.76
30.Dec.76
29.Jan.77
01.Mar.77
31.Mar.77
01.Mai.77
31.Mai.77
30.Jūn.77
Time


Aiviekste discharge. Wet Year.
Discharge
300.00
250.00
200.00
150.00
100.00
50.00
0.00
35
30
25
20
15
10
5
0
01.Jūl.78
31.Jūl.78
30.Aug.78
30.Sep.78
30.Okt.78
30.Nov.78
30.Dec.78
29.Jan.79
01.Mar.79
31.Mar.79
01.Mai.79
31.Mai.79
30.Jūn.79
Time
AivHES
AivLub
W



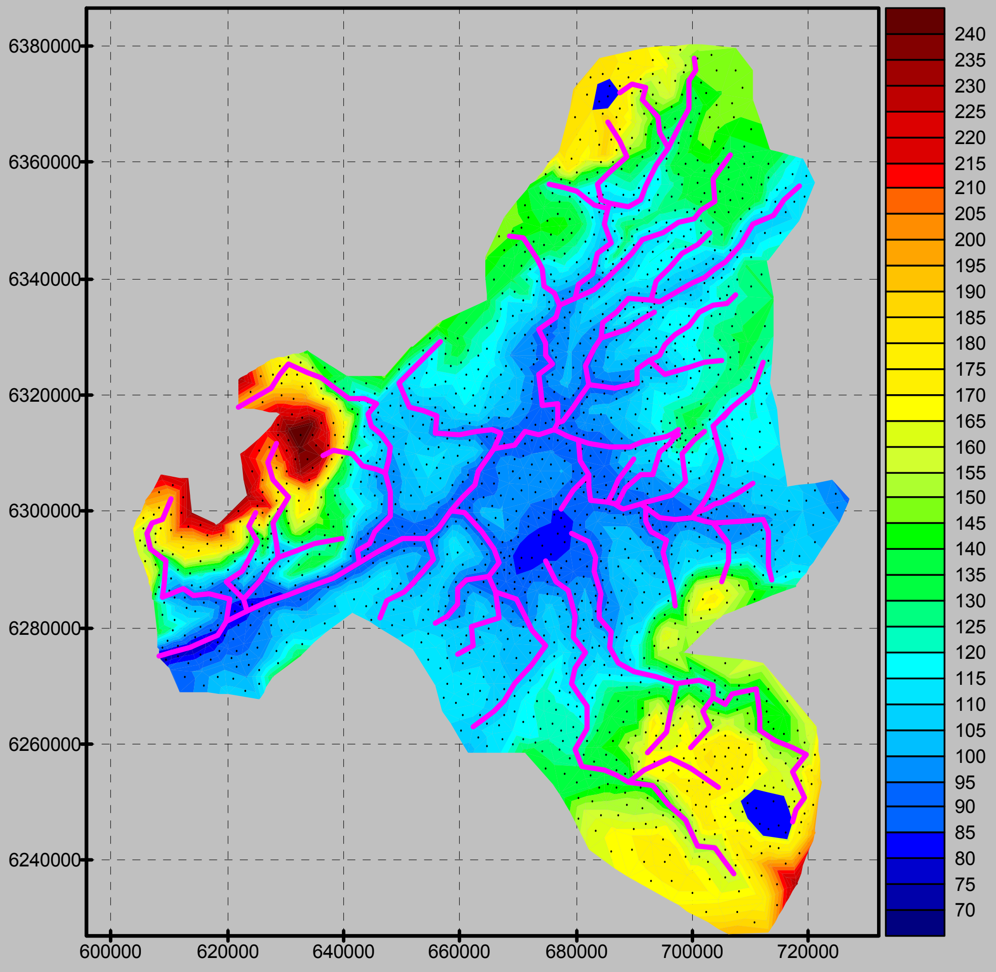
Kuja and Rēzekne discharge. Average Year.

Calibration strategy

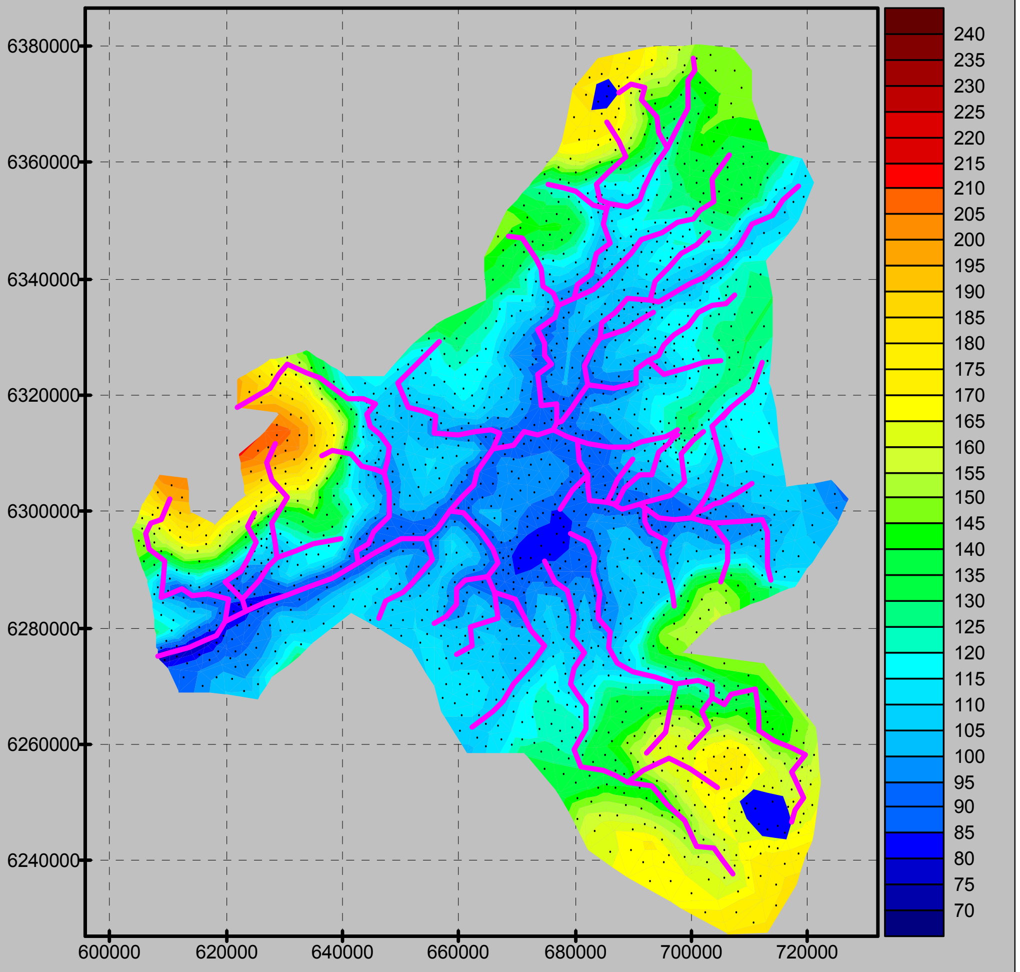
- Calibration goal achieved by changing model parameters – groundwater parameters and land-use dependent surface water run-off, evaporation, melting and infiltration parameters

- Each three year model calibraton run is preceded by 90 year run for stabilising the grounwater level in quasi-periodic state (to avoid "initialization" effects)

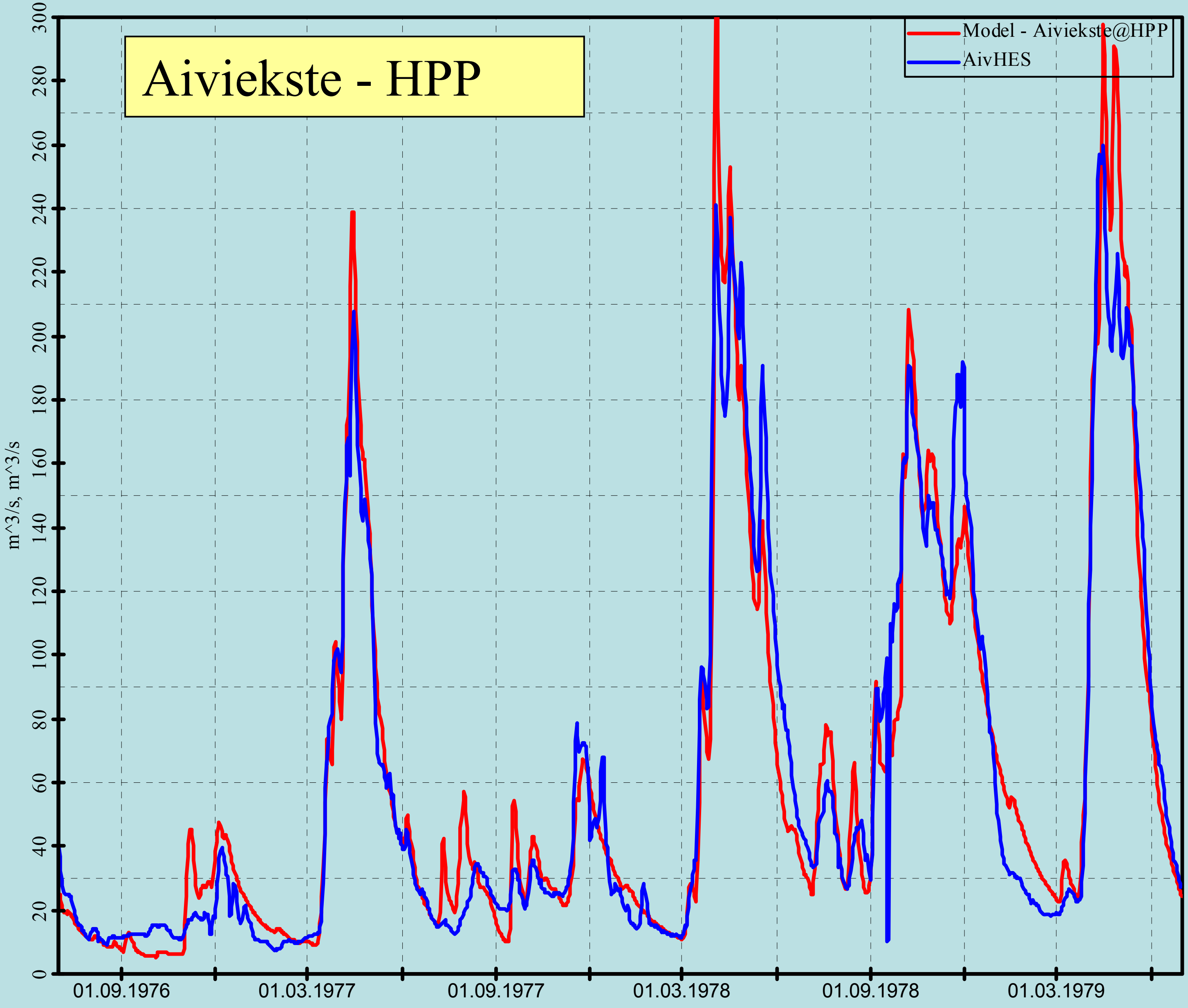
Surface level



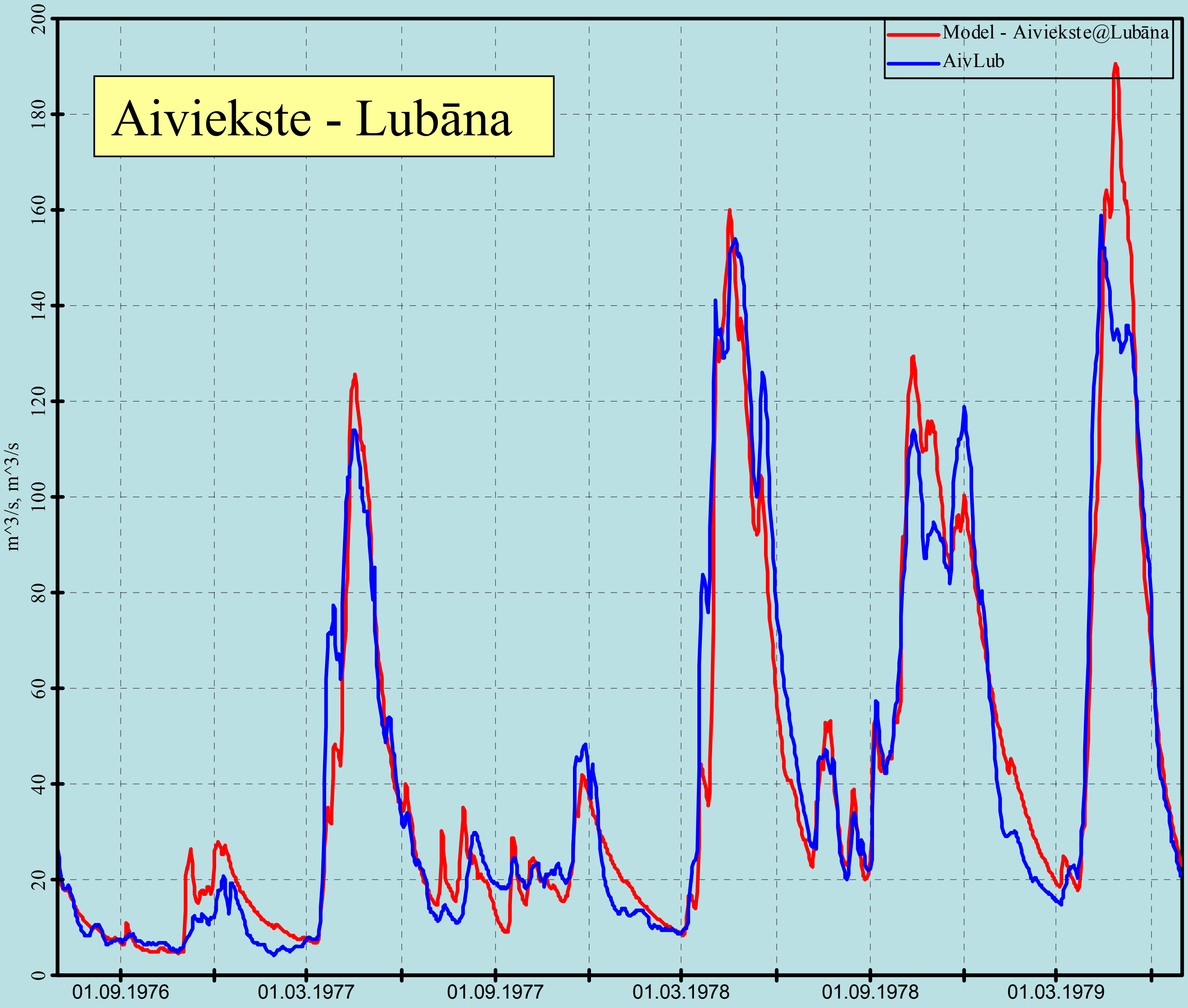
Typical groundwater level



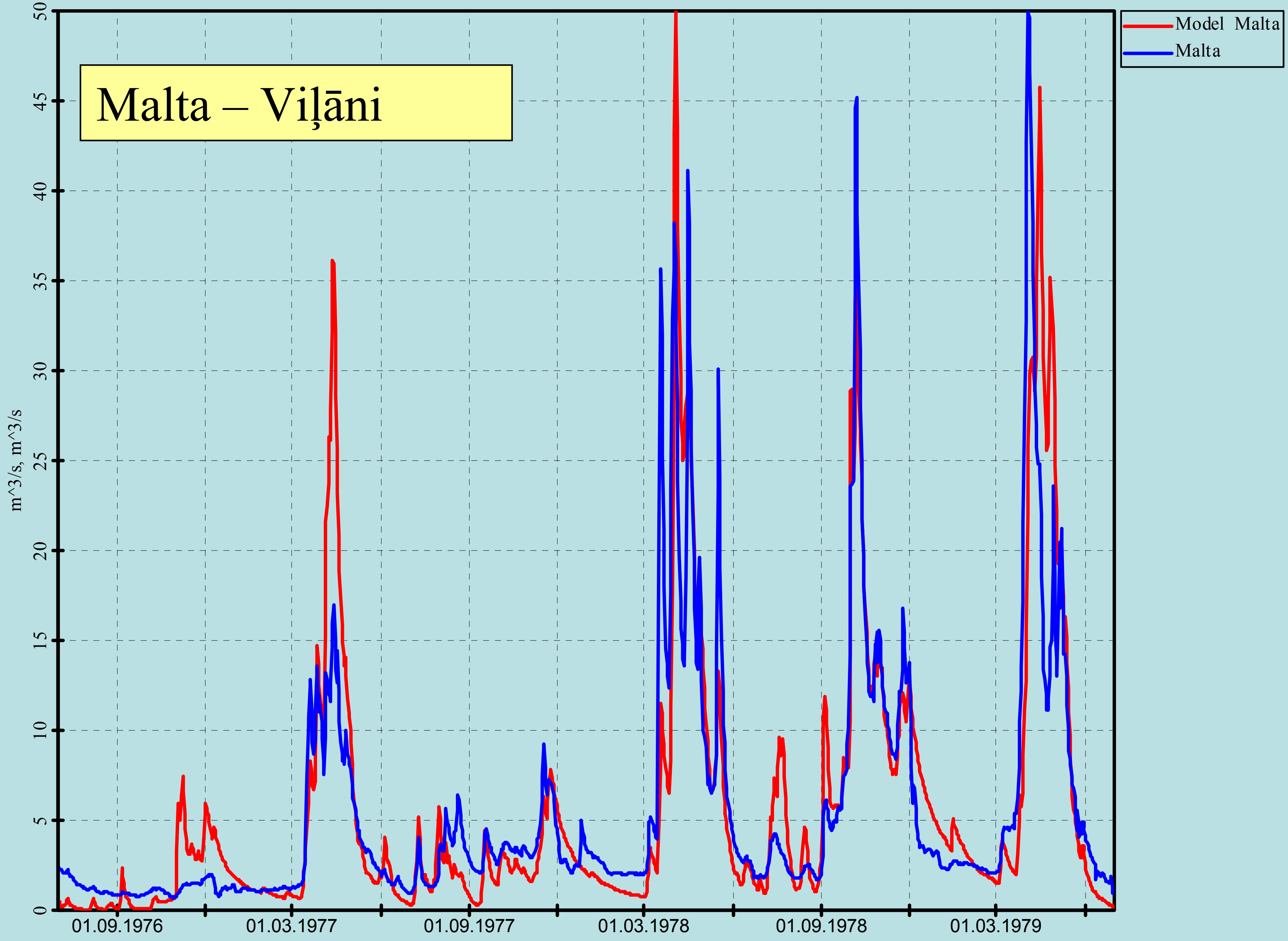
Calibration results

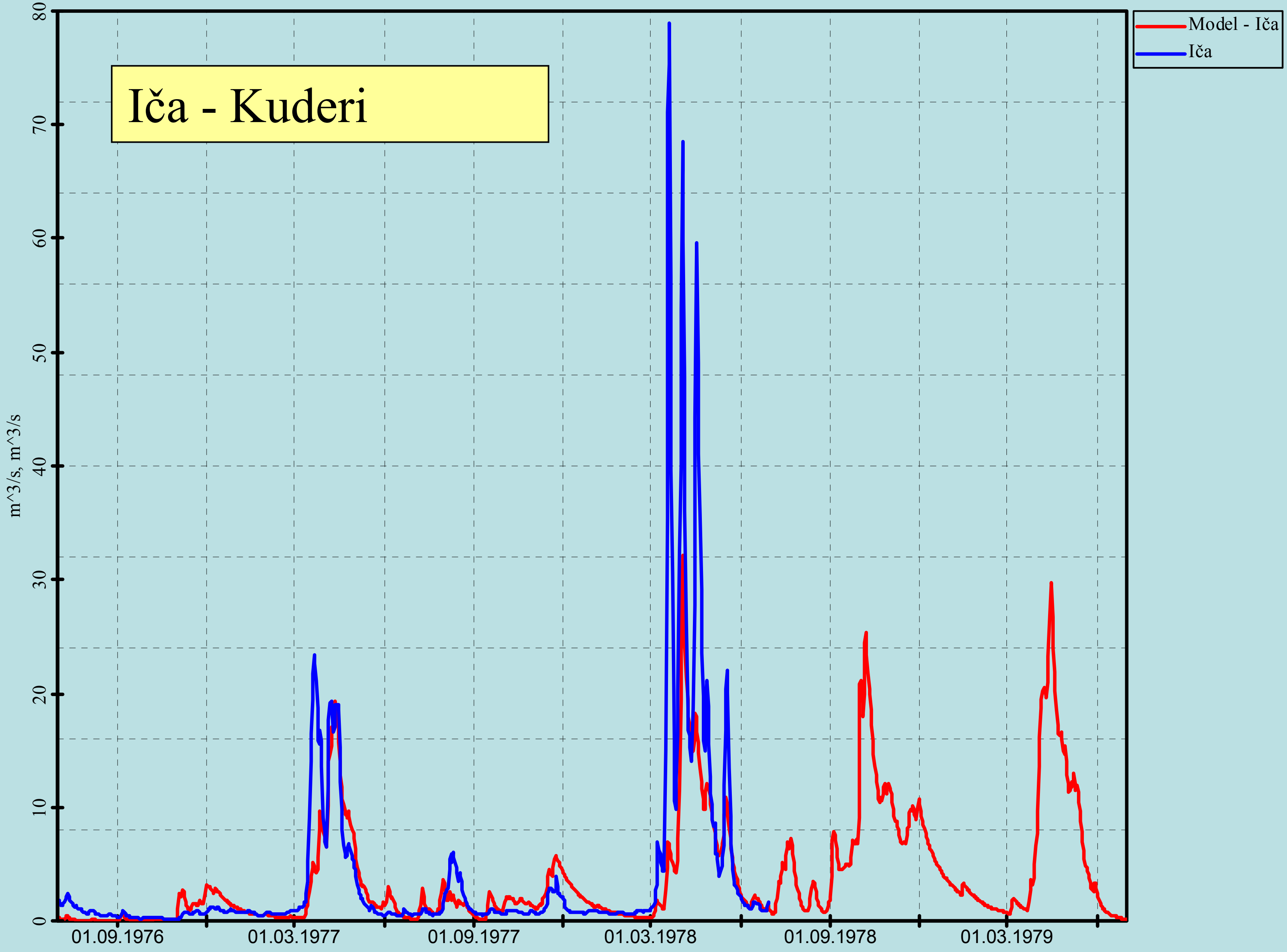


Aiviekste - Lubāna

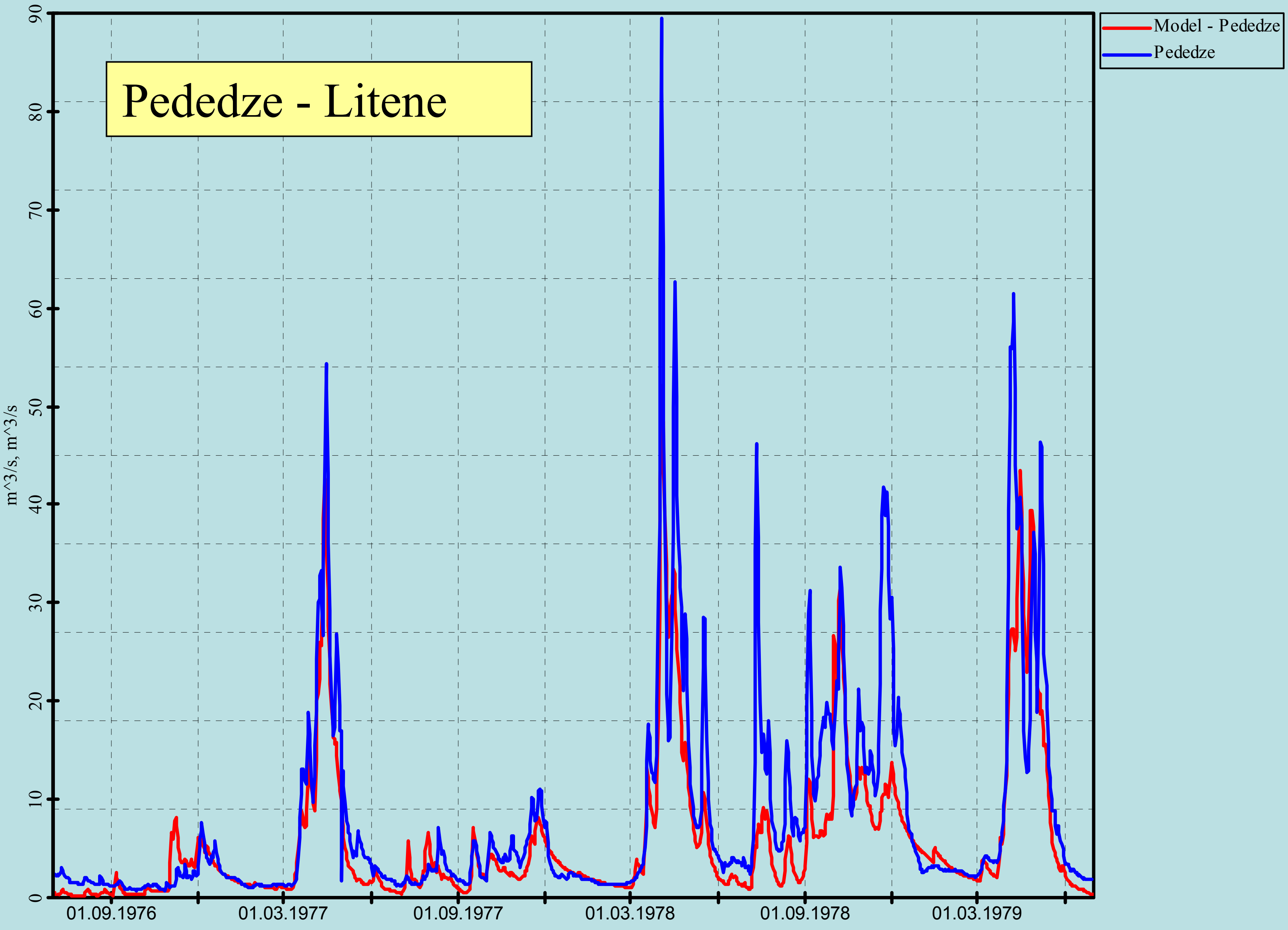


Malta – Viļāni




Iča - Kuderi
Model - Iča
Iča
m^3/s, m^3/s
0
10
20
30
40
50
60
70
80
01.09.1976
01.03.1977
01.09.1977
01.03.1978
01.09.1978
01.03.1979

Pededze - Litene



Result of calibration,

measured and calculated average discharges for the calibration period

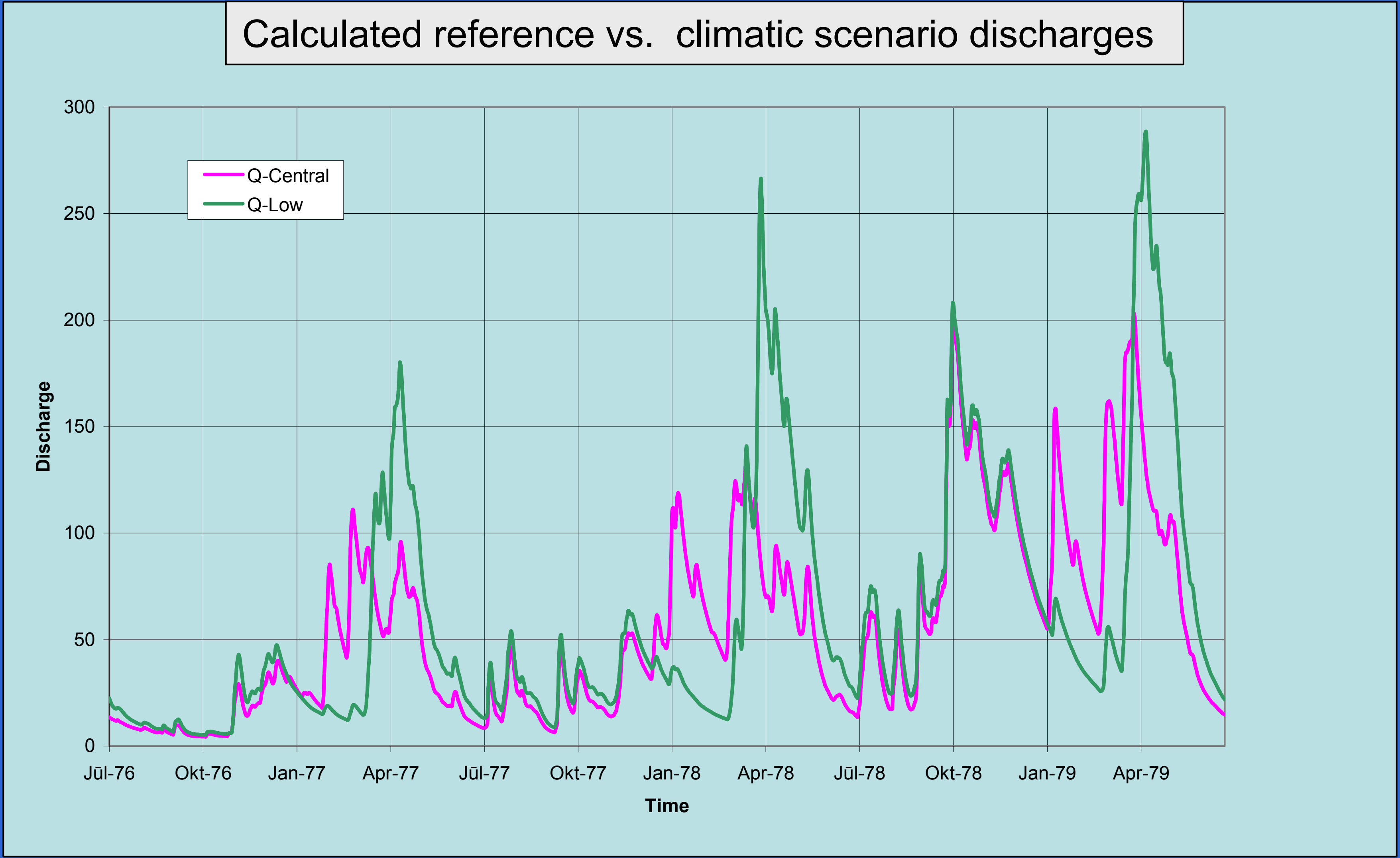
	Stacija	Novērots m^3/s	Aprēķināts m^3/s
1	Kuja, Aizkuja	2.64	1.82
2	Pededze, Litene	8.29	5.86
3	Ičа, Kuderi	4.07	2.76
4	Malta, Viļāni	5.71	5.77
5	Rēzekne, Griškāni	3.30	2.48
6	Aiviekste, Lubāna	43.19	43.25
7	Aiviekste, HES	61.73	62.60

Impact of climate change to Aiviekste run-off

- Three climate change scenarious considered: “low”, “central”, “high”
- Climate change scenario gives seasonal change of precipitation and temperature
- The same three (normal, dry, wet) years calculated as in calibration

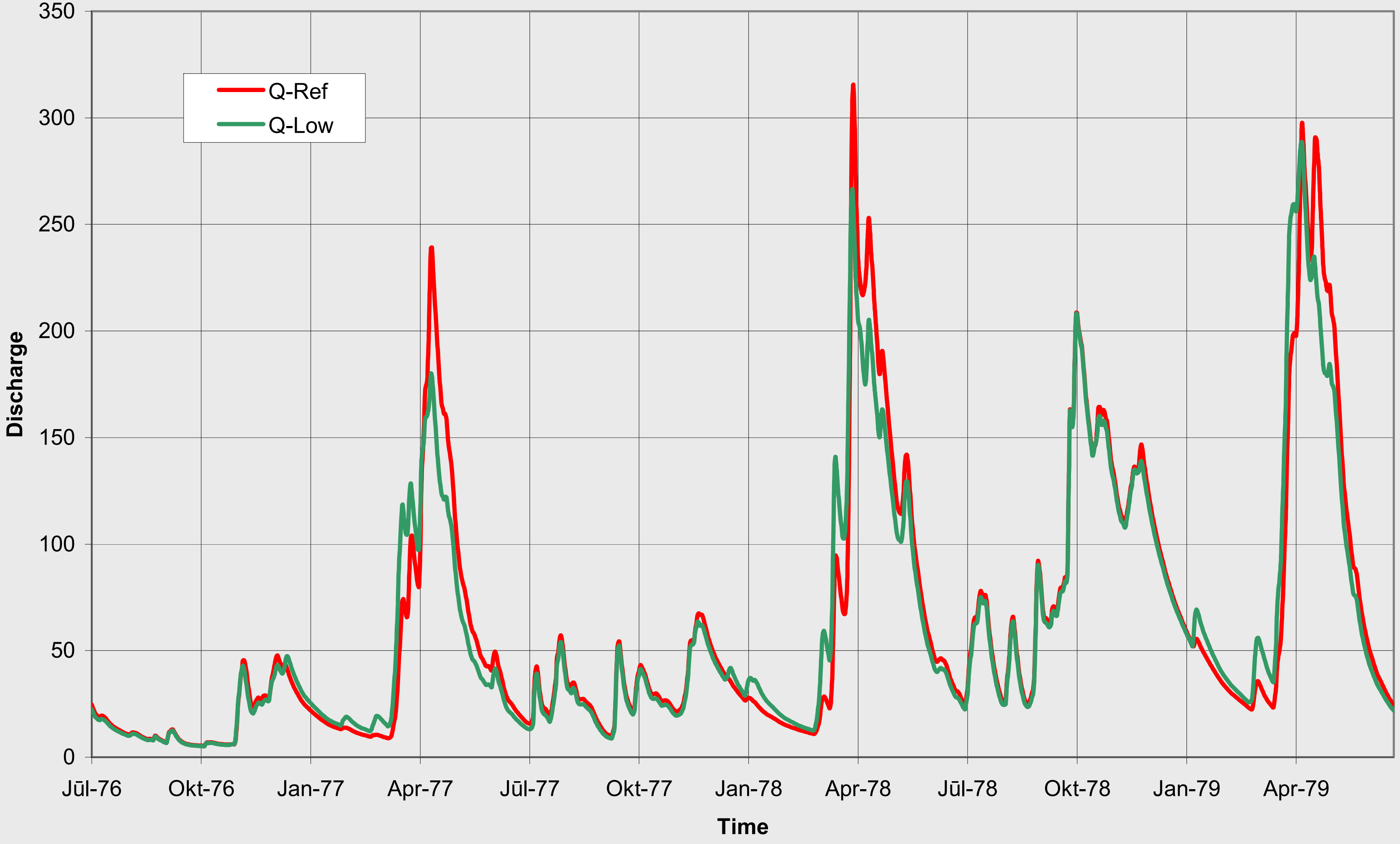
Parameter/scenario	Spring (III-V)	Summer (VI-IX)	Autumn (X-XII)	Winter (I-II)	Year
P / “low”, %	+0.625	+1.25	+1.25	+2.1	+1.25
T / “low”, ºC	+0.5	+0.4	+0.5	+0.65	+0.5
P / “central”, %	+2.5	+5.0	+5.0	+10.0	+5
T / “central”, ºC	+2.0	+1.5	+2.0	+3.0	+2.0
P / “high”, %	+3.75	+7.5	+7.5	+12.5	+7.5
T / “high”, ºC	+3.0	+2.25	+3.0	+3.75	+3.0

Impact of climate change to Aiviekste run-off



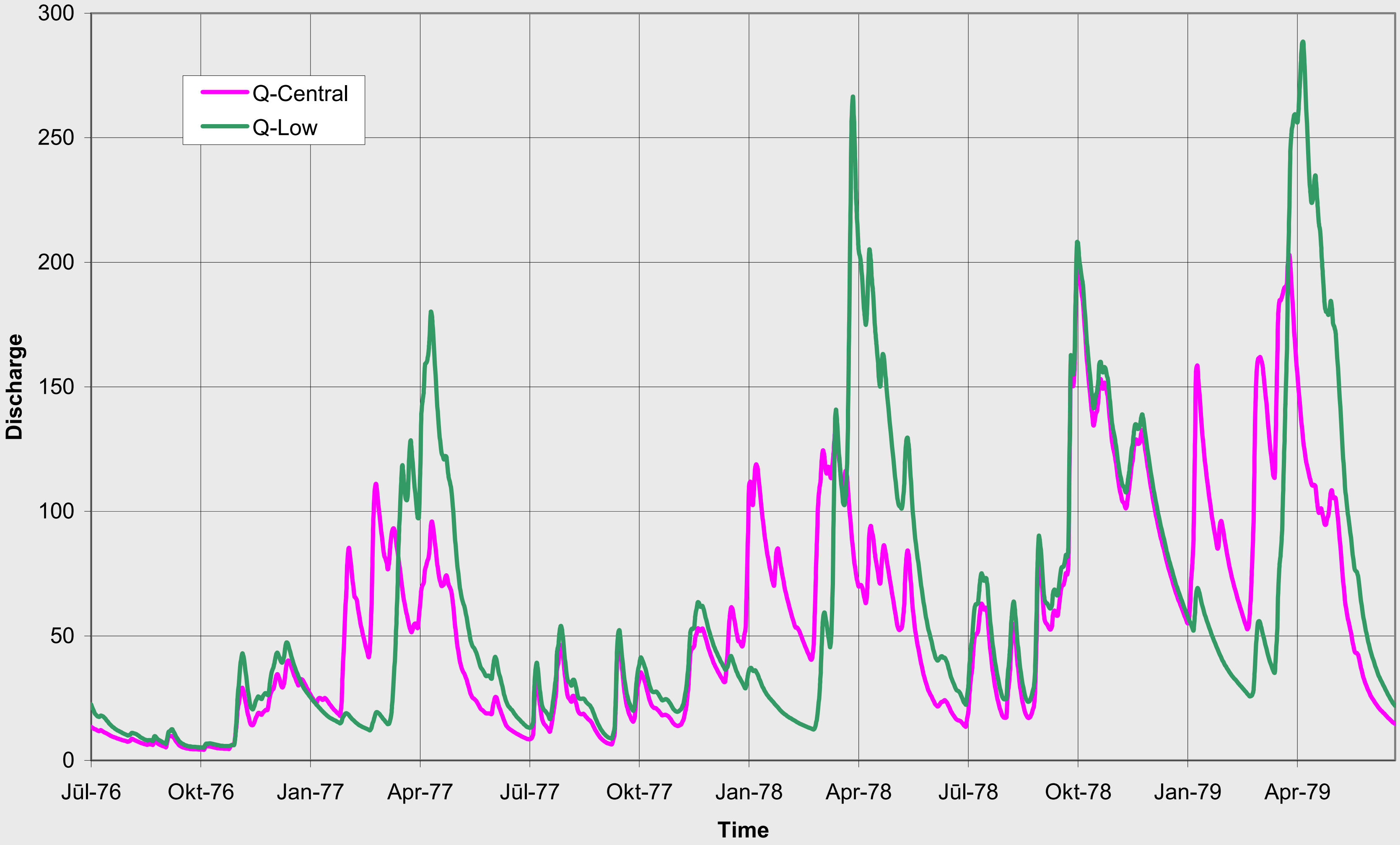
Impact of climate change to Aiviekste run-off

comparision – reference situation/ “low” scenario



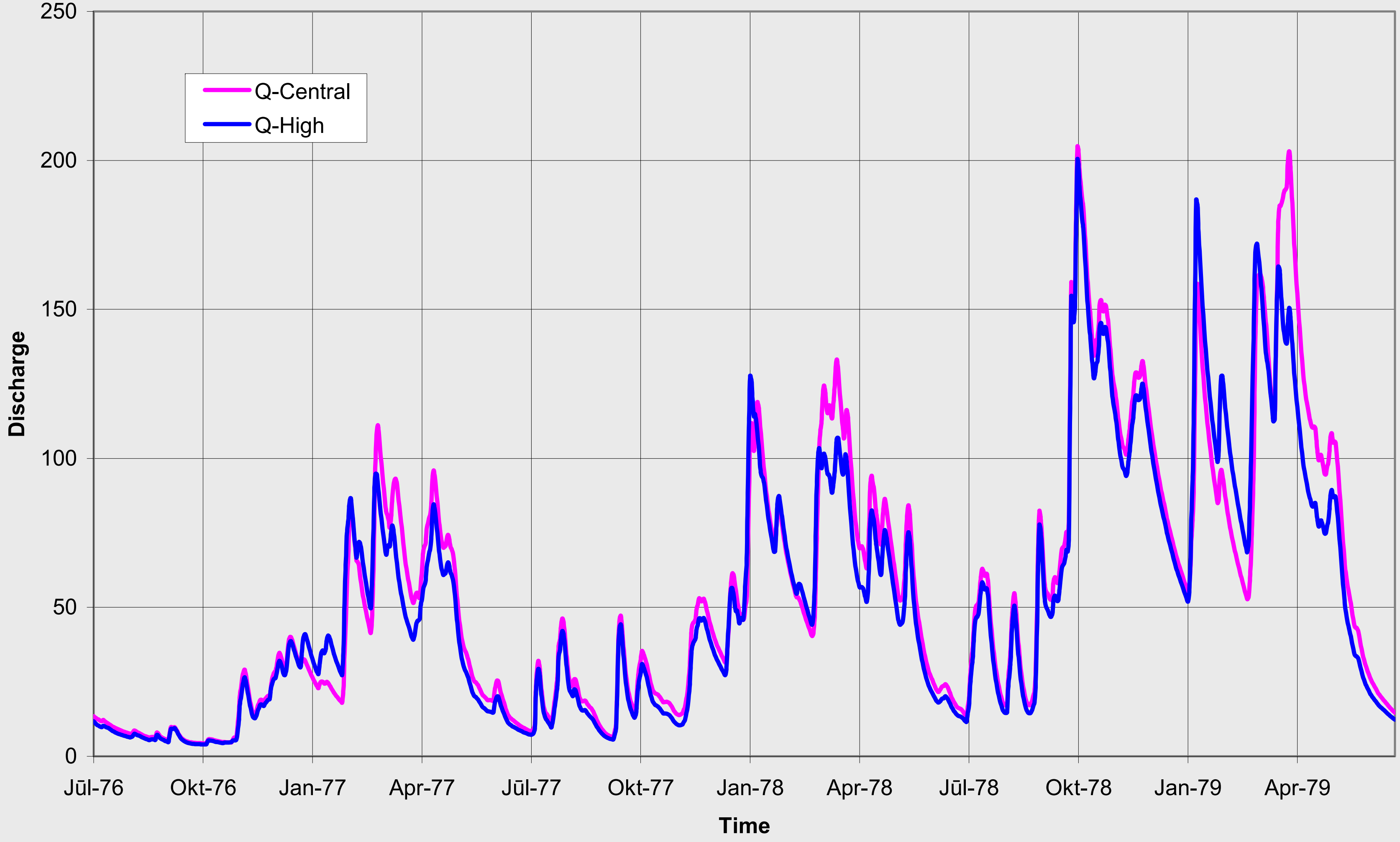
Impact of climate change to Aiviekste run-off

comparision – “low” scenario/ “central” scenario



Impact of climate change to Aiviekste run-off

comparision – “central” scenario/ “high” scenario



Impact of climate change to Aiviekste run-off

Average discharge of Aiviekste (m3/s) for different scenarios

Scenario	Winter I-II	Spring III-V	Summer VI-IX	Autumn X-XII	Year
Reference	24.5	123.3	33.4	65.1	62.6
Observed	17.9	120.5	35.7	65.5	61.7
Low	28.8	119.0	30.8	63.7	61.0
Central	69.0	87.5	23.1	59.2	55.8
High	77.9	74.1	20.3	55.5	52.0

Conclusions

•Spatially and temporary distributed hydrological/hydraulic model is set-up and calibrated for the Aiviekste river basin. Model calculates discharge depending on meteorological forcing parameters (temperature and precipitation).

•Change of river discharge is non-linearly dependent on change of forcing due to climate change.

•Increase of temperature can lead to lower expected river discharge even when the amount of precipitation increases.