

PROJECT RICLIC – WARM

**Regional Impact of CLImatic Change in Lombardy WAter Resources:
Modelling and applications.**

MANAGING ALPINE FUTURE

INNSBRUCK, OCTOBER 17, 2007

Water scarcity risk in an alpine area: analysis of water allocation within climate change scenarios

P. Giacomelli, A. Rossetti, M. Brambilla, V. Carboni

DEPAAA – Agriculture, Food and Environmental Economics and Policy Dept.

University of Milano (UNIMI)

FINAL GOALS

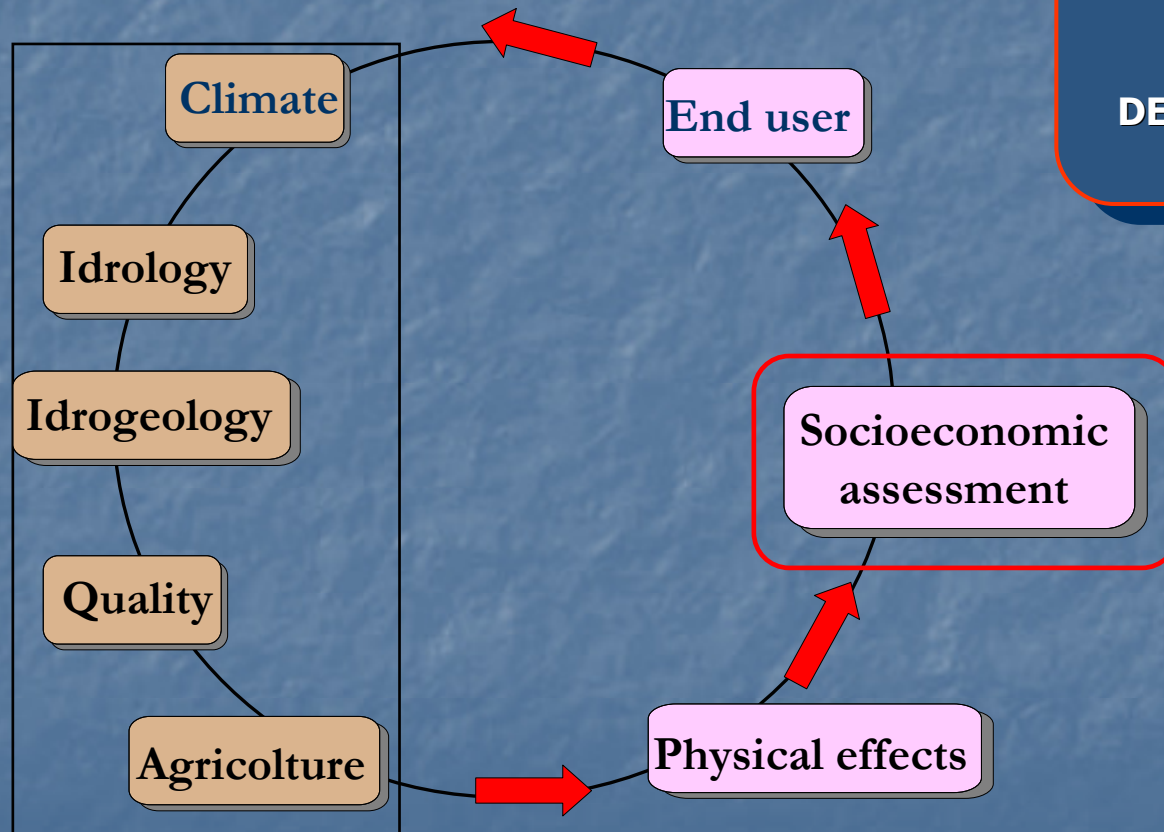
DEVELOP A SCIENTIFIC METHODOLOGY TO ASSESS CLIMATIC IMPACTS ON WATER RESOURCES AND PROVIDE A SUPPORT TO DECISION-MAKING PROCESSES ON WATER MANAGEMENT



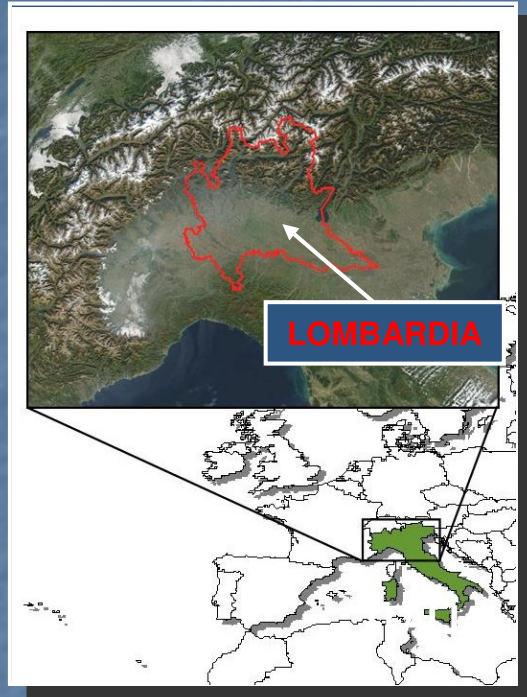
RICLIC-WARM project frame

WP8 DAMAGES AND RISK EVALUATION

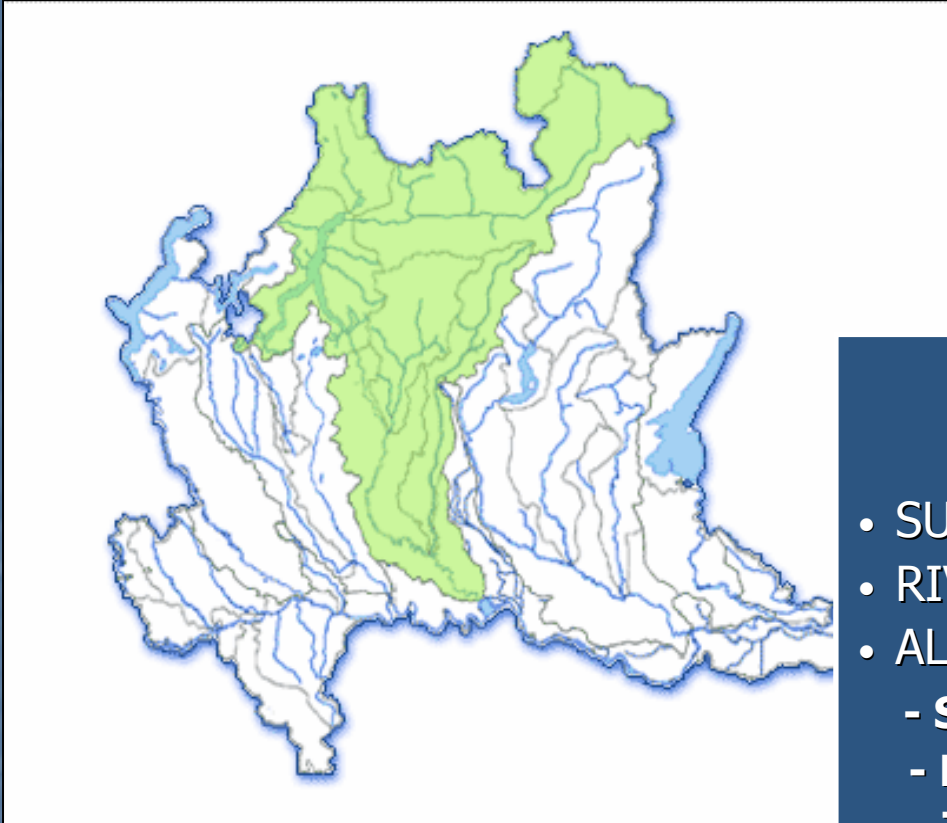
Prof. Paolo Giacomelli
DEPAAA - University of Milano



Study area



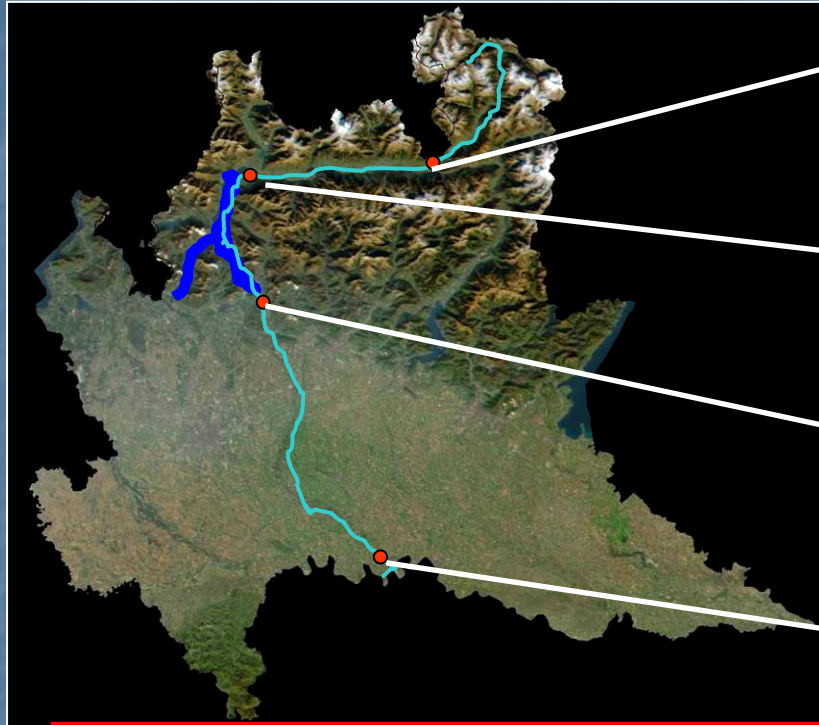
Adda River Basin



• *Main characteristics*

- SURFACE DRAINED: 7.979 km²
- RIVER LENGTH: 313 km
- ALTITUDE RANGE:
 - Sources of Adda: 2.237 m asl
 - Mean Lake Como elevation: 198 m asl
 - Join with Po river: 36 m asl
- RIVER BASIN SURFACE: 38% of Lombardy

Adda River Basin



TIRANO (441 m asl)
Year average discharge : 26,75 m³/s

FUENTES (198 m asl)
Year average discharge: 88,0 m³/s

MALGRATE (198 m asl)
Year average discharge: 158,2 m³/s

JOIN WITH PO RIVER (36 m asl)
Year average discharge: 287,72 m³/s

STORAGE CAPACITIES

- LAKE COMO
 - Absolute capacity: 22.500 Mmc
 - Regulation capacity: **254,3 Mmc (37%)**

HYDROELECTRIC RESERVOIRS:

- 56 reservoirs: **419 Mmc (63%)**

Hydroelectric exploitation

Four companies detain the right
of exploitation of Sondrio Province waters:

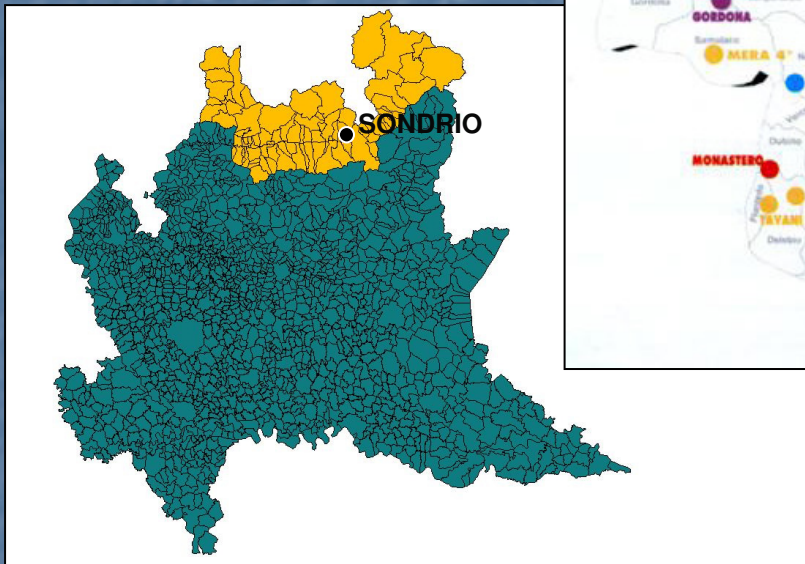
- **EDIPOWER: 8 plants**
- **ENEL: 18 plants**
- **EDISON: 8 plants**
- **A.E.M. MILANO: 7 plants**
- **OTHER: 32 small plants**



Hydroelectric net production (year 2000): **5.886.000 MWh**

- **11,1%** of the national hydroelectric production;
- **45,4%** of the regional hydroelectric production;
- only the 16% of the electricity produced is distributed within Sondrio Province.

Sondrio Province

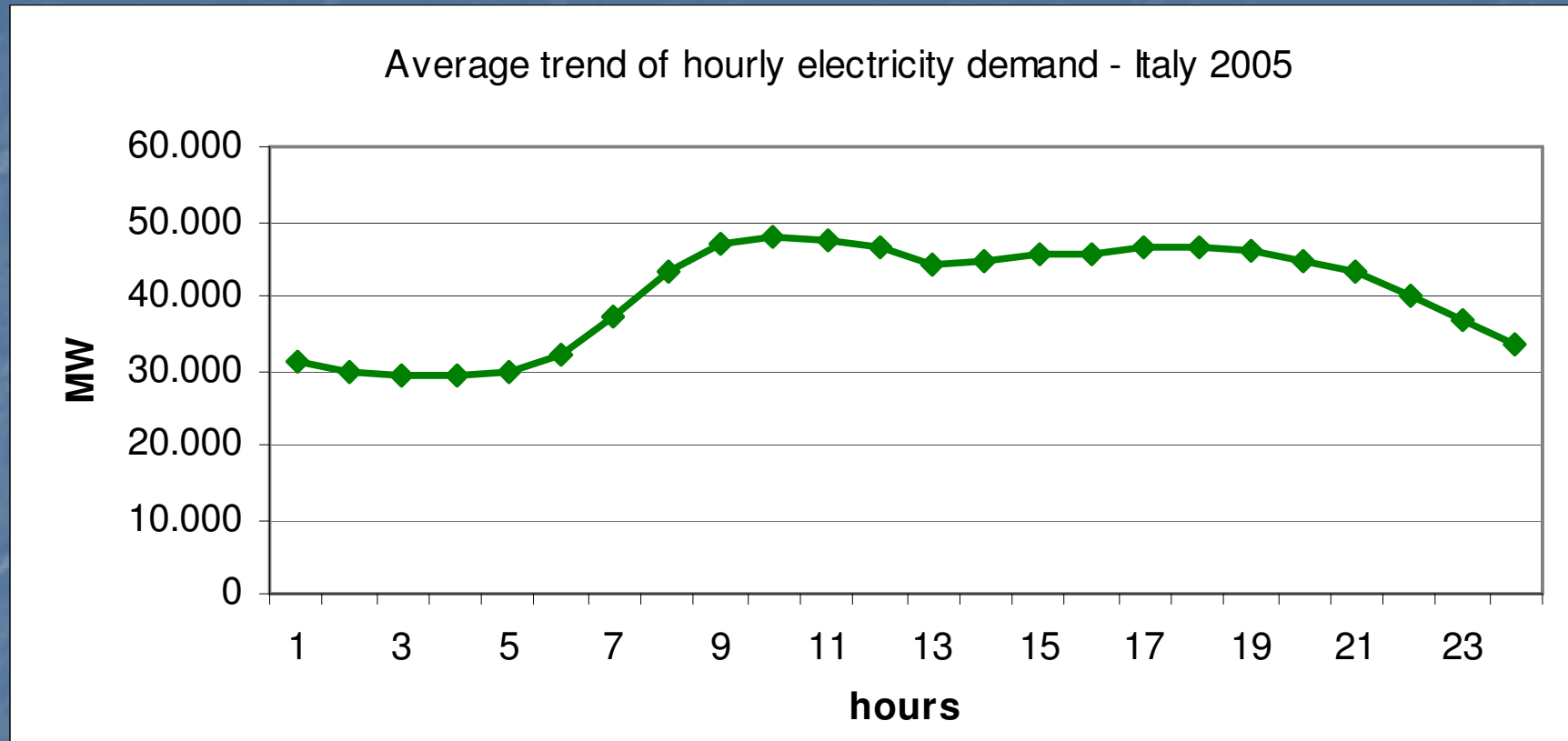


90% of Sondrio Province's area is caught by hydroelectric facilities

	WATER CHANNELS AND PIPES					RESERVOIRS	
	Water plugs	Free	Pressurized	Turbines	Average annual production (1997-2001)	Amount	Overall capacity
	n	Km	Km	n	kWh x 1000	n	mB
OVERALL	303	89,592	296,285	122	5.823.301	56	419.055.000

Source: SONGINI, 2003

Daily electricity demand oscillations



	Agriculture	Industry	Tertiary	Household	Overall
GWh	5.364,4	153.726,8	83.793	66.932	309.816,8
%	1,73%	49,62%	27,05%	21,60%	

HOURS OF THE DAY

DAYS IN THE MONTH

Leggenda: F1 (red), F2 (orange), F3 (yellow), F4 (light yellow).
 F1: Festività, F2: Ponti, F3: Sabati, F4: Domeniche.

CALCOLO ORE FASCE ORARIE
 DELIBERA AEEG N°29205 DEL 29/12/2005

Mese Luglio

Mese	Giorno	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
Luglio	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
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Luglio	26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
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Luglio	29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Luglio	31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

WEEKEND

MONTH OF JULY 2005

Source : TERNA, 2006

	Time band	Wholesale prices (€/MWh)
F1	very high request peak	122,83
F2	high request	73,23
F3	average request	57,91
F4	low request	39,84

HOURS OF THE DAY

DAYS IN THE MONTH

Leggenda: F1 F2 F3 F4
 Festività Pont Sabati Domeniche

CALCOLO ORE FASCE ORARIE
 DELIBERA AEEG N°29205 DEL 29/12/2005

Mese Agosto

Giorno	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
Agosto 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 28	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Agosto 31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

MID-AUGUST
OFF-PEAK
PERIOD

MONTH OF AUGUST 2005

Source : TERNA, 2006

	Time band	Wholesale prices (€/MWh)
F1	very high request peak	122,83
F2	high request	73,23
F3	average request	57,91
F4	low request	39,84

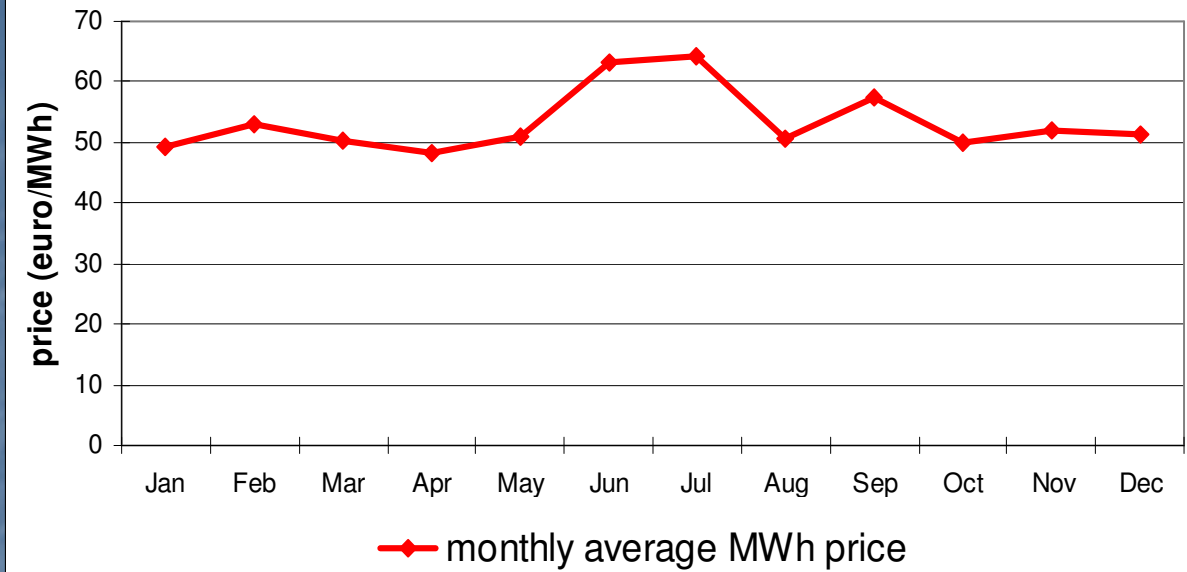
Monthly aggregation of the amount of hours belonging to different time-bands

MONTH	overall monthly hours for each time-band			
	F1	F2	F3	F4
Jan	0	192	32	520
Feb	0	240	40	392
Mar	0	147	161	436
Apr	0	60	220	440
May	0	176	132	436
Jun	133	160	25	402
Jul	147	168	21	408
Aug	40	117	41	546
Sep	60	178	94	388
Oct	0	147	147	450
Nov	16	155	123	426
Dec	50	100	60	534

Wholesale prices (€/MWh)	
F1	122,83
F2	73,23
F3	57,91
F4	39,84

- Main on-peak months:
JUNE, JULY, SEPTEMBER
- Main off-peak months:
JANUARY, APRIL, AUGUST

Monthly average MWh price

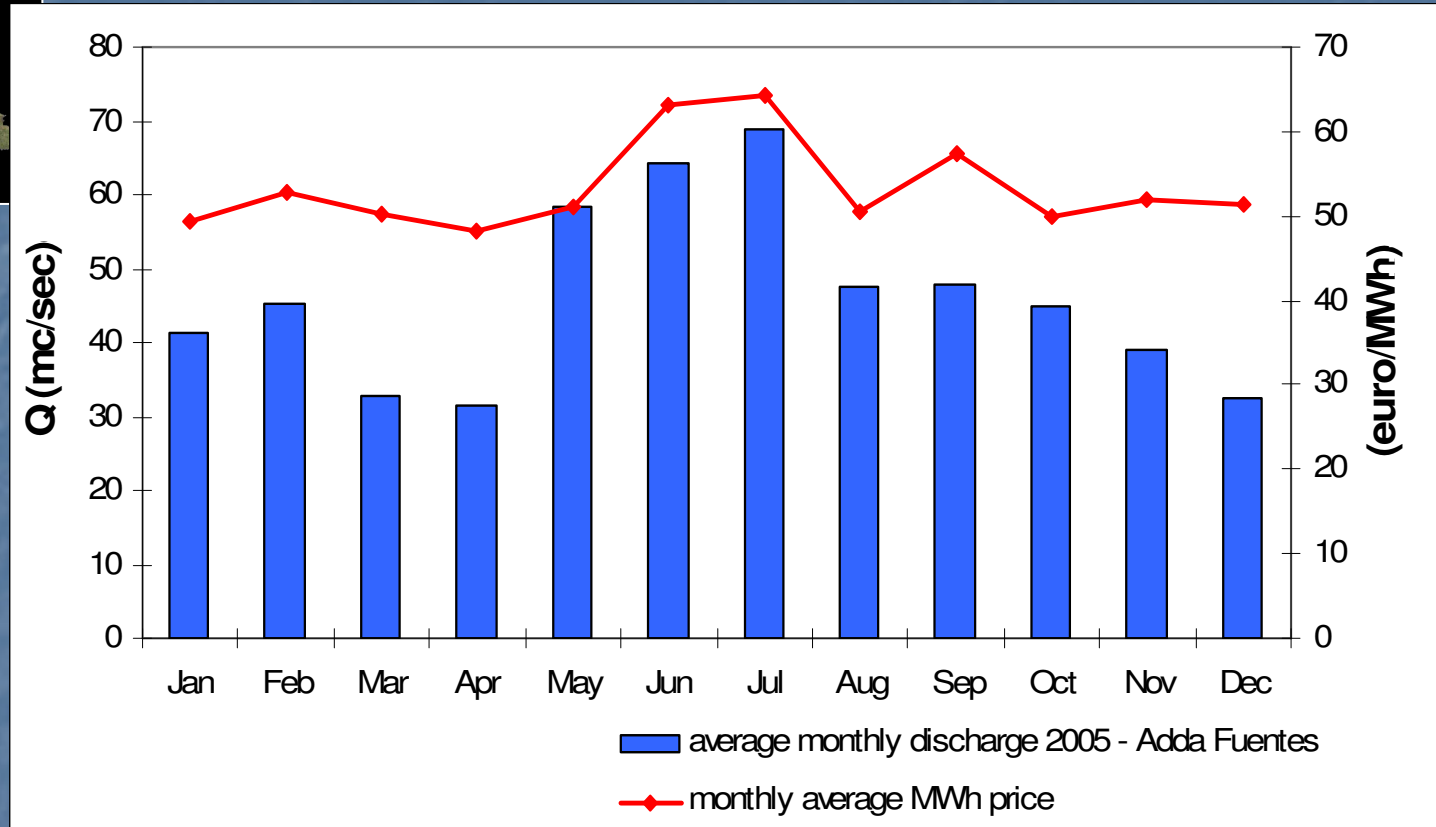
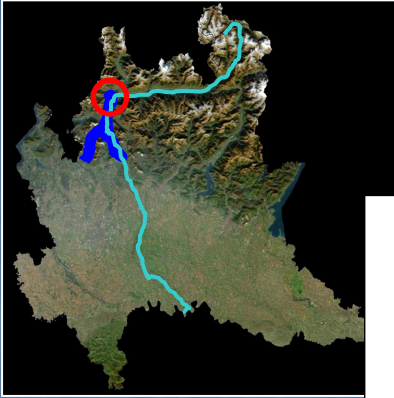


Source : TERNA, 2006

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average MWh price (euro)	49	53	50	48	51	63	64	51	57	50	52	51

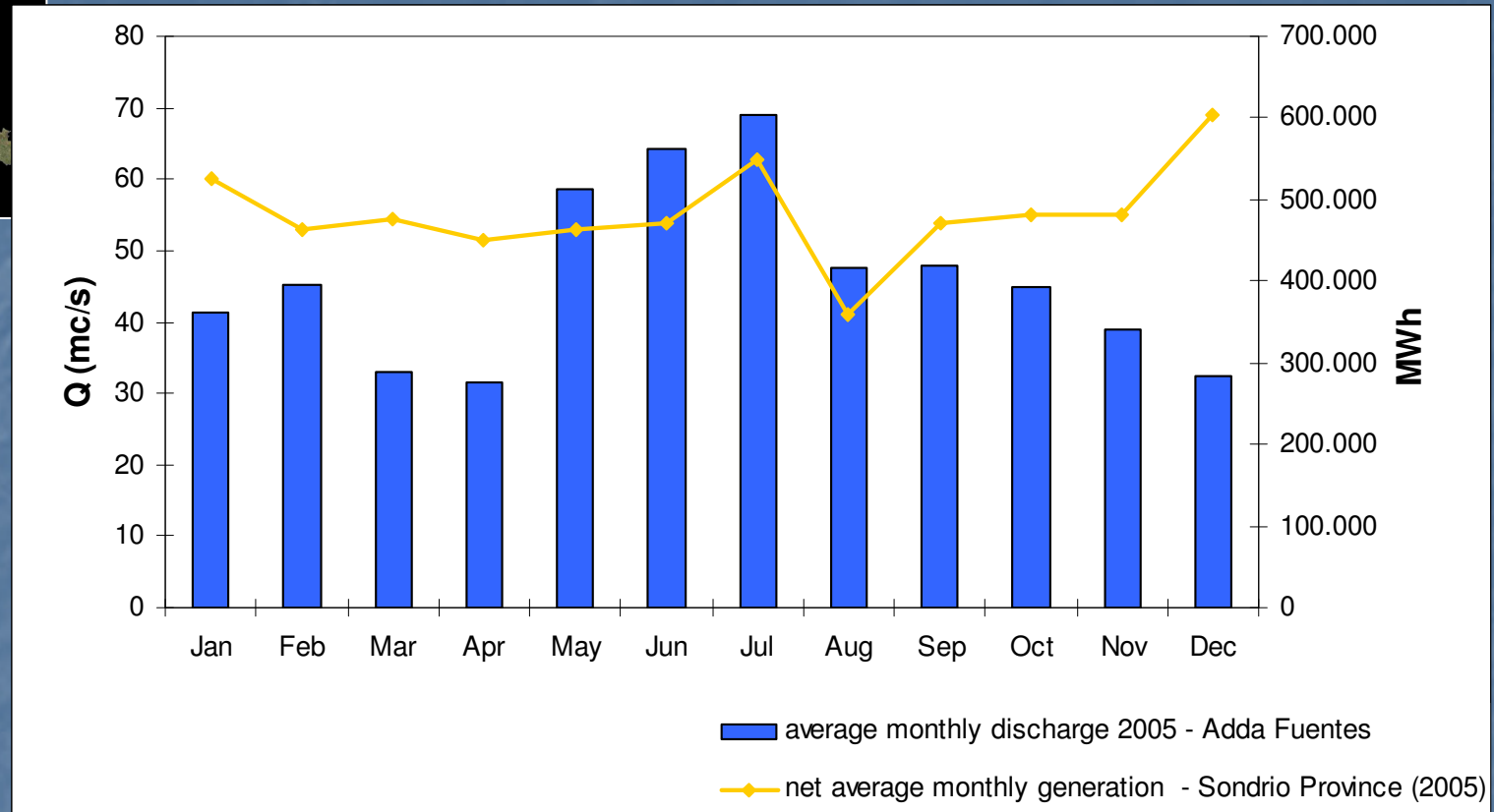
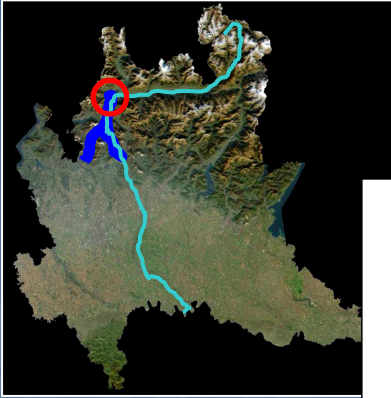
-If we consider the only hydroelectric power, calculated prices are underestimated, since the calculation assume unchanging levels of energy production throughout the year, while the actual generation (and selling) is concentrated in the most profitable hours of the year (on-peak periods).

Year 2005



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly discharges Fuentès (2005)	41,4	45,3	32,9	31,5	58,5	64,2	69,0	47,4	47,9	45,0	38,9	32,4
Monthly average MWh price (euro)	49	52	50	48	50	63	64	50	57	50	51	51

Year 2005



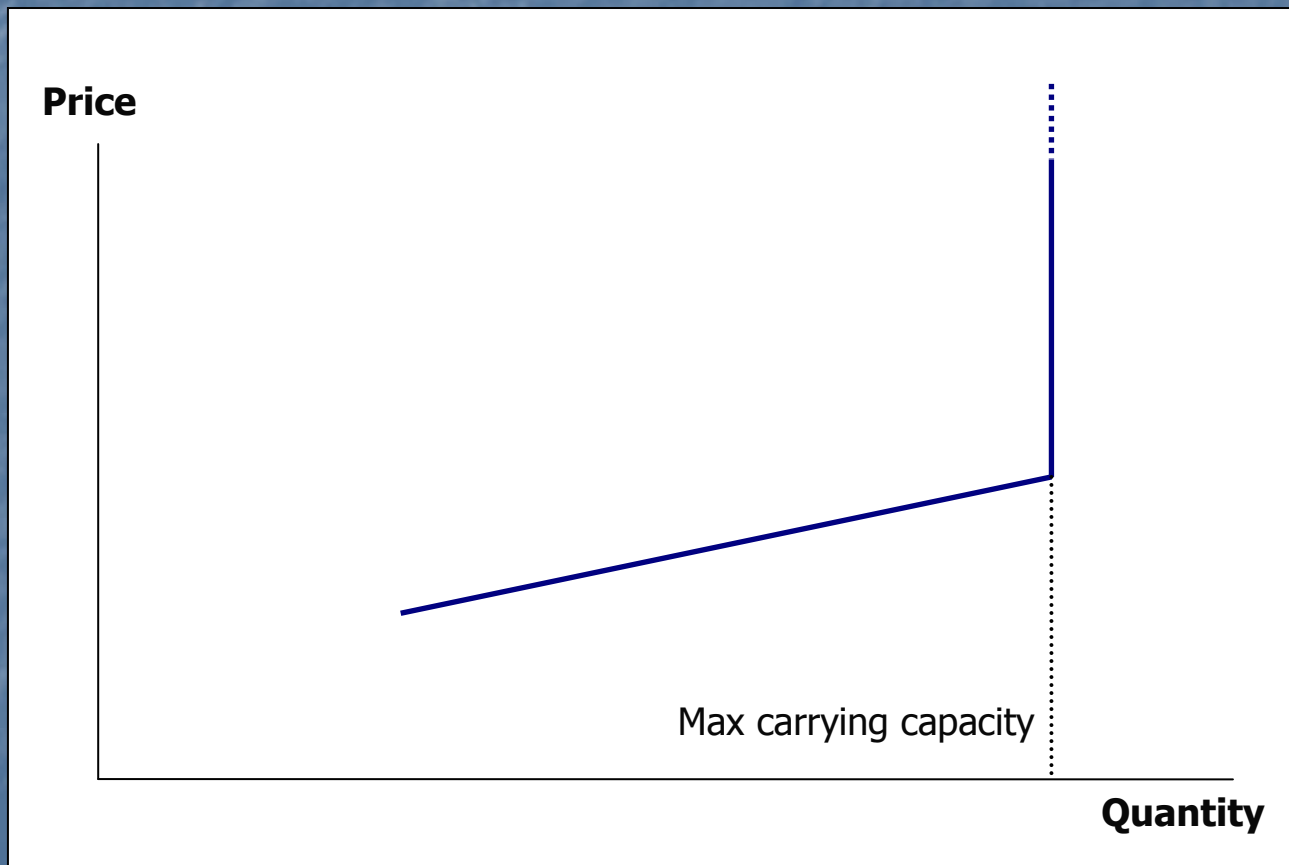
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average monthly discharges Fuentes (2005)	41,4	45,3	32,9	31,5	58,5	64,2	69,0	47,4	47,9	45,0	38,9	32,4
Net average monthly generation Sondrio Province (2005)	526.163	462.905	476.572	449.773	462.303	469.883	549.878	359.832	469.817	481.818	481.151	602.773

Source : TERNA, 2006 and Consorzio dell'Adda, 2006

The controversial role of hydroelectric power production

- The hydroelectric right of exploitation fee does not depend on the actual production, but on the installed capacity (18 €/kW);
- the selling price of hydroelectric energy is not constant but fluctuates both in the short and in the long period;
- the order of priority of water uses (CIVIL, AGRICULTURAL and INDUSTRIAL) is not respected.
- LOW FLOW LIMITS represent the only constraint to hydroelectric company activities;
- *ramp-up* and *ramp-down* constraints are not given;

Supply behaviour deriving from hydroelectricity production



Effects on the environment

Alteration of natural hydrological cycles:

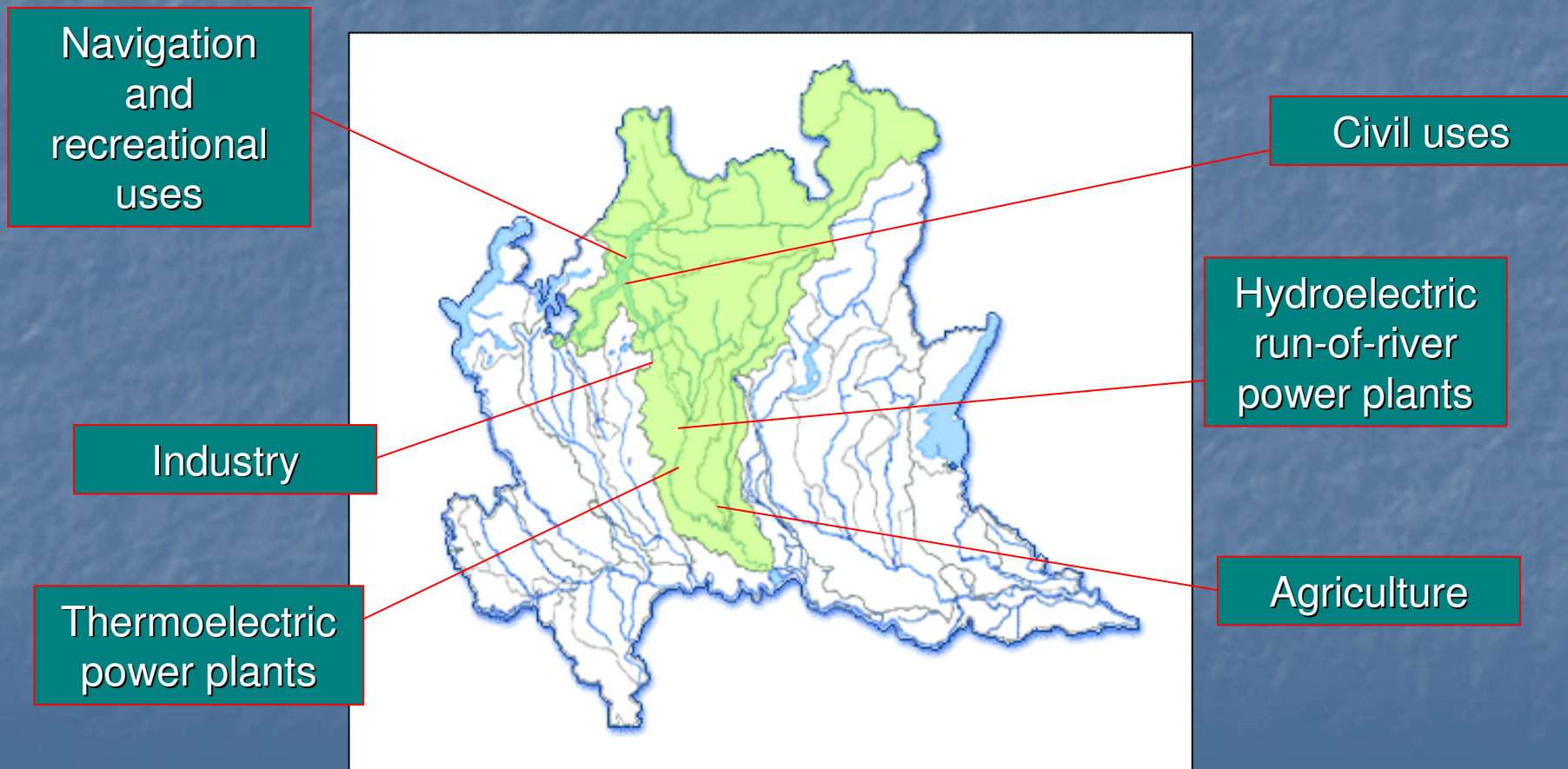
- . day/night variations of discharges;
- . seasonal variations of discharges;
- . ecological effects on the river ecosystems along the watershed (SEDIMENT TRANSPORTATION INHIBITED, EFFECTS ON BIOLOGICAL CYCLES, EFFECTS ON RIVER BANKS EROSION).

Alteration of Lake Como hydrometric levels and quality:

- . ecological problems (FISH REPRODUCTIVE PERIODS);
- . loss of water quality and rise of sanitary consequences.

Effects on the socio-economic system

COMPETITION WITH WATER USERS DOWNSTREAM



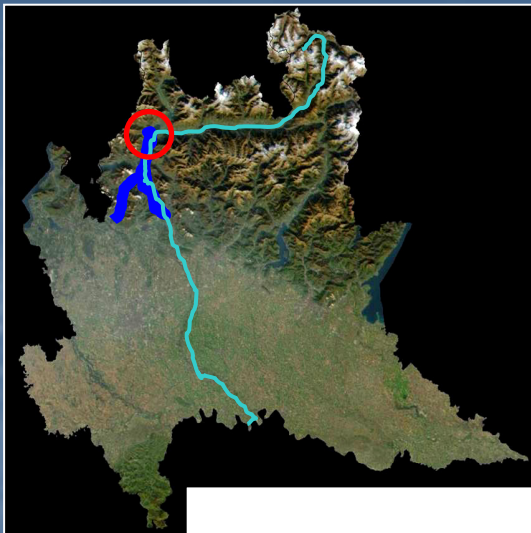
Climate change and socio-economic system

STRONG INTER-CONNECTION BETWEEN NATURAL CYCLES AND HUMAN ACTIVITIES

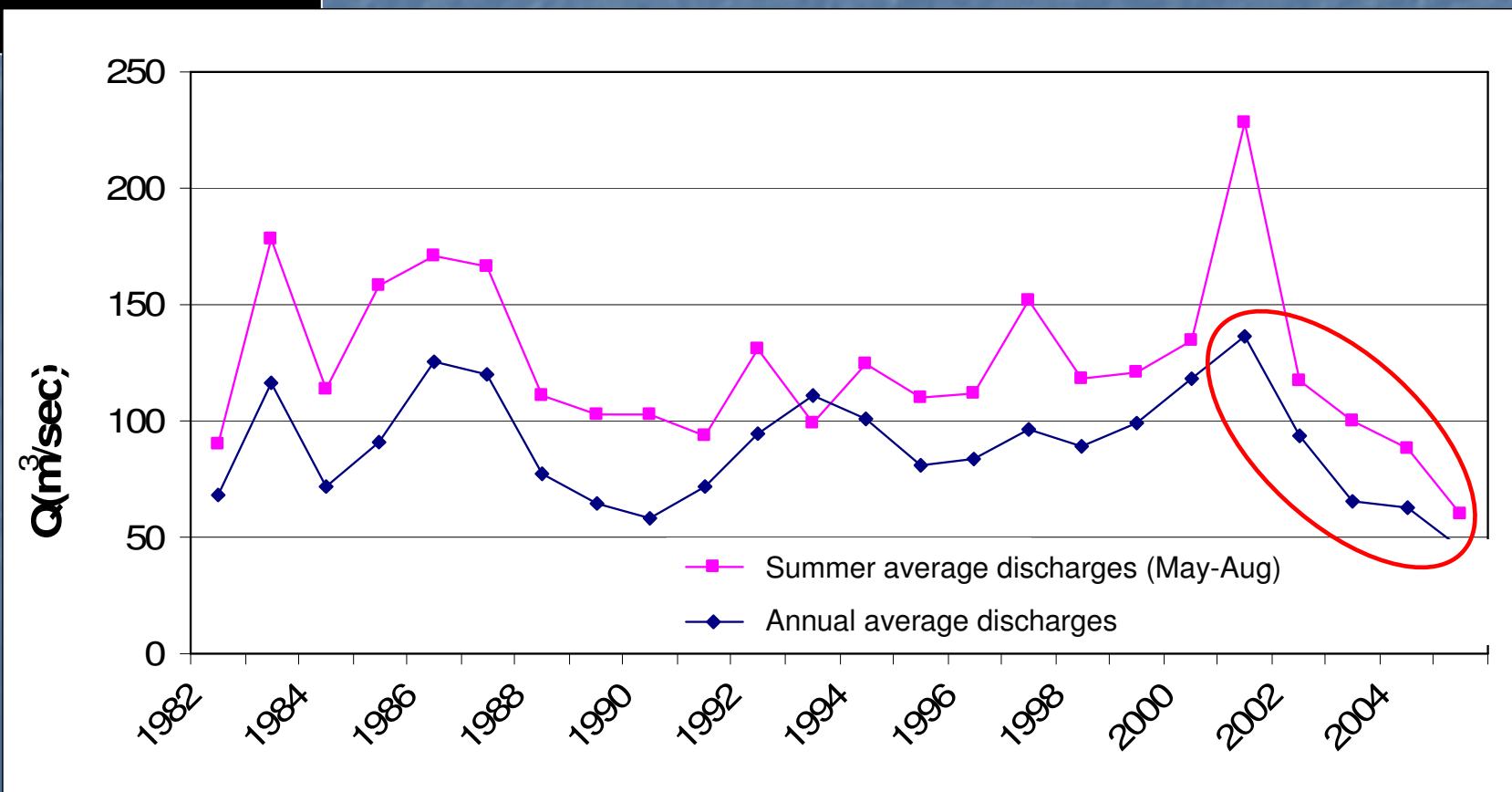
- CLIMATE CHANGE: INFLUENCE ON WATER RESOURCES DISTRIBUTION (STOCKS/FLOWS)
- SOCIO-ECONOMIC SYSTEM: INFLUENCE OF COMPETING WATER USERS ON WATER BALANCES



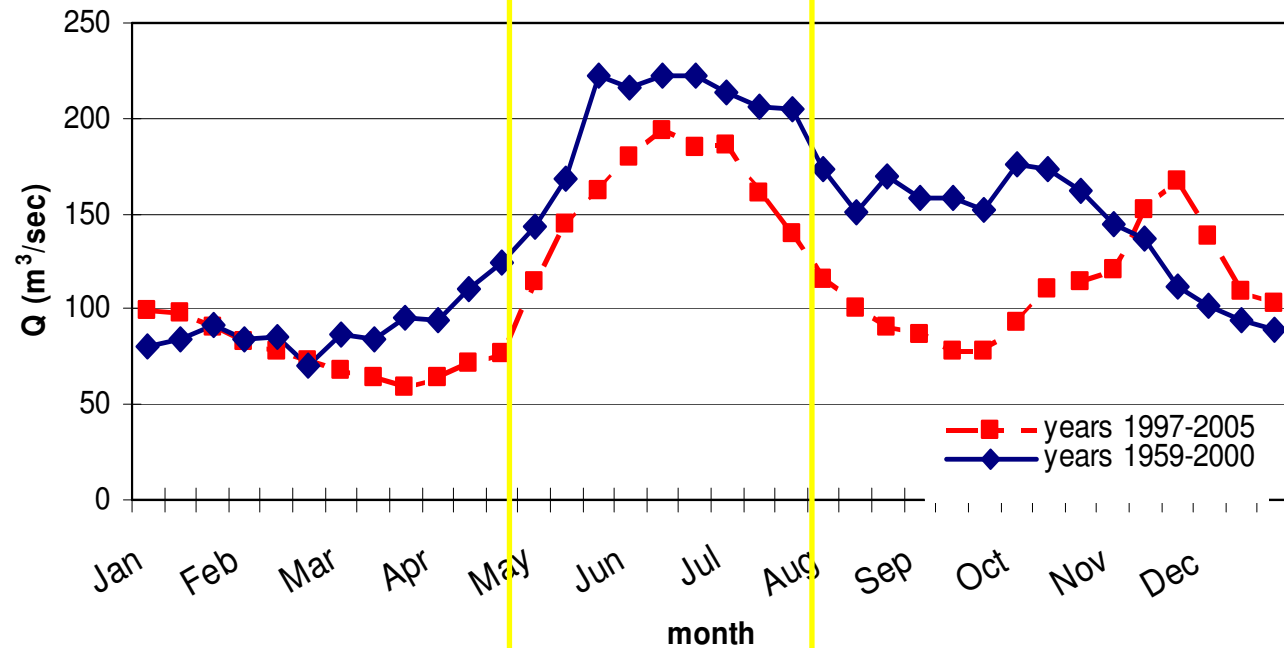
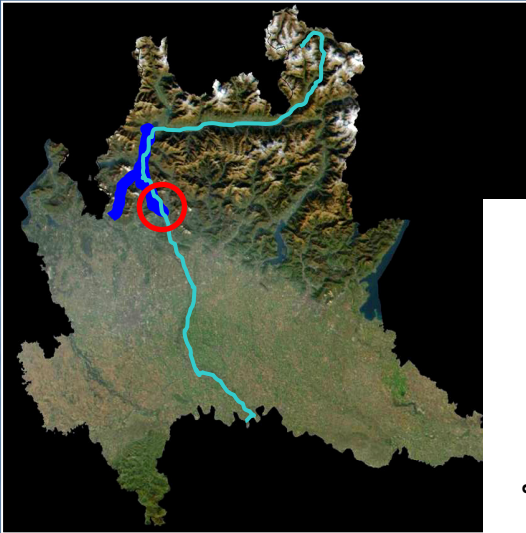
- HIGH STRESS ON WATER RESOURCES UNDER CURRENT CONDITIONS
- HIGH SENSITIVITY OF THE SOCIO-ECONOMIC SYSTEM TO VARIATIONS ON WATER INPUTS



Fuentes (Valtellina outflows) hystorical series: annual and summer average discharges



Lecco-Olginate Floodgate hystorical series (decadic discharges)



Source: Consorzio dell'Adda,
2006

Annual average	Average discharge (m ³ /sec)	Average volume (Mm ³)
Years '59 - '00	140,65	4.435,42
Years '96 - '05	112,40	3.544,23
Water deficit	-28,25	-891,19

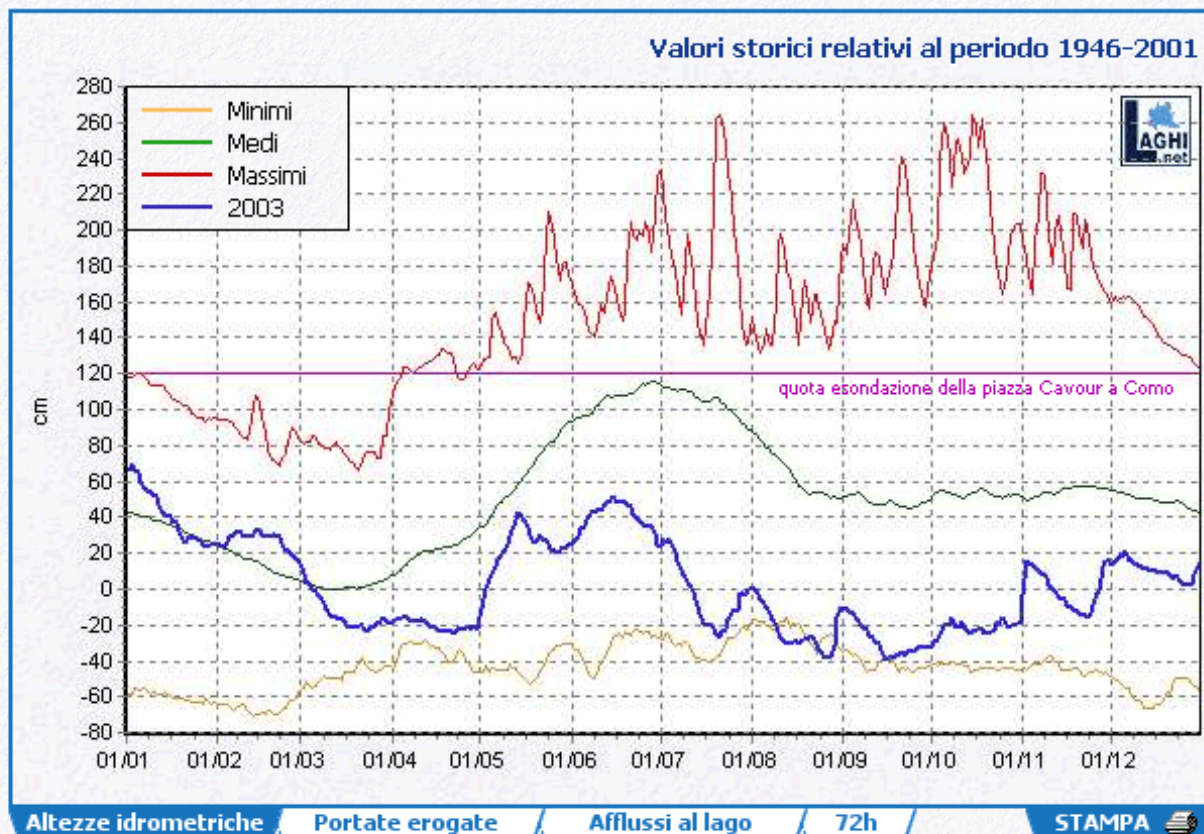
-20,09%

Summer average (May-Aug)	Average discharge (m ³ /sec)	Average volume (Mm ³)
	176,13	2.328,34
	132,10	1.746,28
	-44,03	-582,06

-65,00%

Critical hydrologic conditions observed: year 2003

Lago di Como a Malgrate



Periodo osservazione: 6h

31/12/03 02:00

31/12/03 08:00

tendenza

Altezza idrometrica (cm)	13.5	13.9	→
Portata erogata (m ³ /sec)	77.0	77.2	→
Afflusso al lago (m ³ /sec)	130.7	104.1	↓

Summer 2003 – direct effects observed

- **AGRICULTURE:** crop losses, damage to crop quality;
- **TOURISM:** reduction in recreational uses (e.g.: navigation, bathing) on Lake Como;
- **POWER GENERATION:** change in hydropower potential through the year, altered potential for run-of-river power;
- **PUBLIC WATER SUPPLY:** reduction in availability of summer municipal water, increase of water demand.

CONCLUSIONS

- Hydroelectric activities generate adverse effects on mountain region communities and environment;
- The alteration of river discharges at the local and at the watershed scale occurs according to external dynamics (energy wholesale market/electricity demand). The management of the reservoirs retain/release cycles is carried with the aim of maximizing the company income;
- With water becoming scarcer and susceptible to quantitative variations, the existing allocation problem among different competing users might be exacerbated with increasing potential effects on mountain local communities;
- The right of exploitation fee need to be adapted to a more realistic situation of water resource exploitation.

paolo.giacomelli@unimi.it
rossetti.andrea@unimib.it
marta.brambilla1@unimi.it
valentina.carboni@unimib.it

PROJECT RICLIC – WARM

Regional Impact of CLImatic Change in Lombardy Water
Resources: Modelling and applications

<http://www.riclic.unimib.it/>

ARPA Lombardia (Regional environmental protection agency)

Regione Lombardia

Università degli Studi di Milano - Bicocca

Università degli Studi di Milano

Università degli Studi di Pavia