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modelEAU

Integrated Control with Weather Forecast

Workshop on integrated, real time control of sewer-wastewater treatment systems: State-of-the-art

OUTLINE

- Why RTC
- RTC approaches using weather forecast
- Required rain data for RTC
- Weather forecasting approaches
- Weather forecasting performance
- RTC applications with weather forecast
  - Lorette River (Quebec City)
  - Montreal (Canada) sewer system
  - Louisville (Kentucky, USA)
- Conclusions

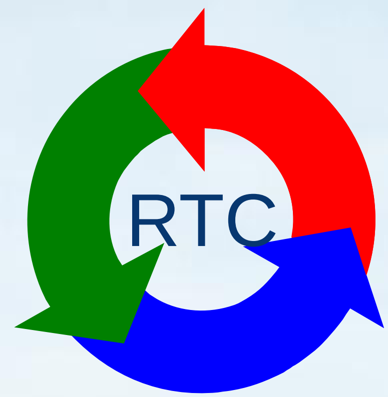
Why real-time control?

Wet weather

- Minimize CSOs
- WWTP performance improvement
- Receiving waters quality improvement

Critical events

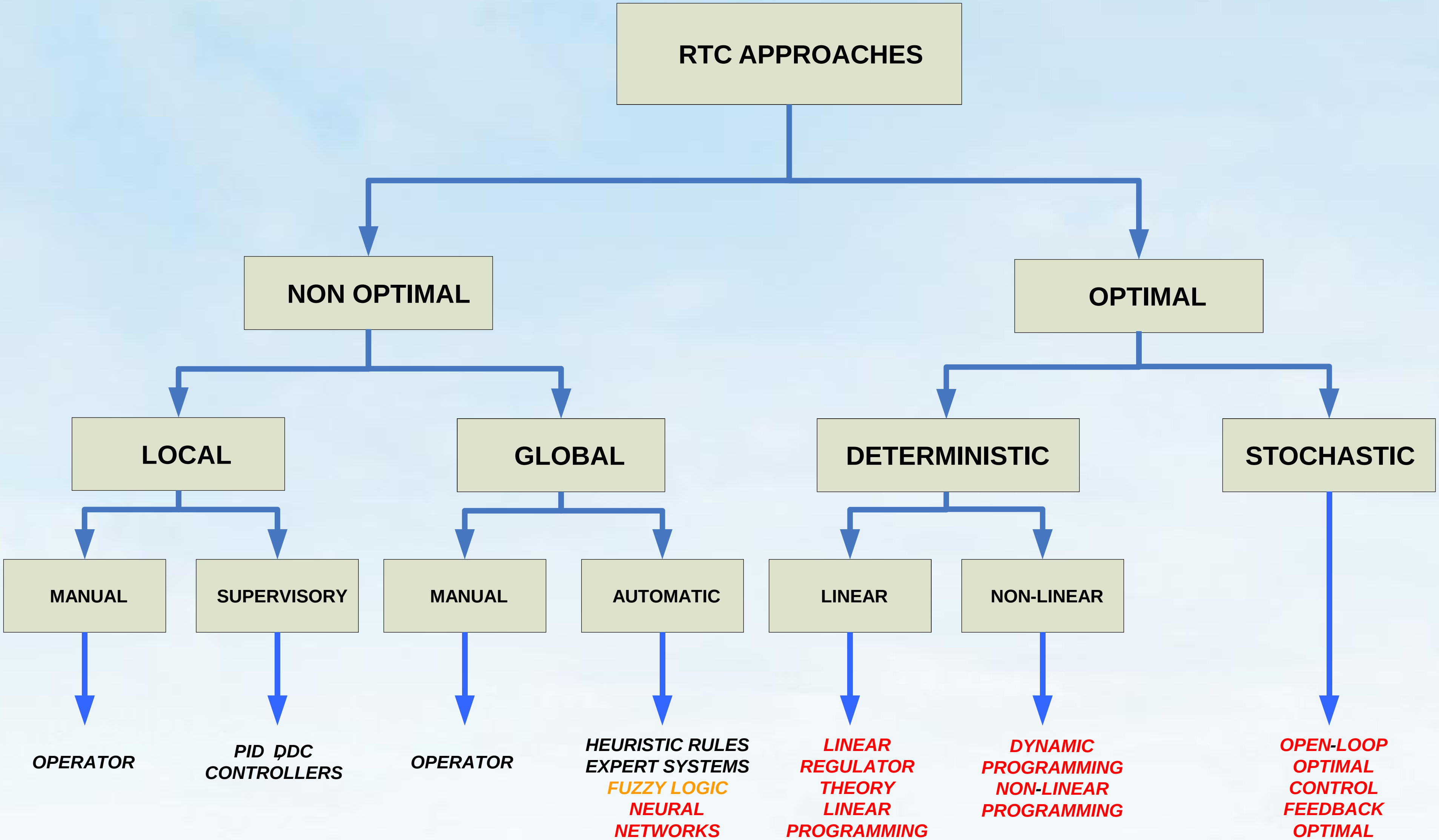
- Reduce flooding



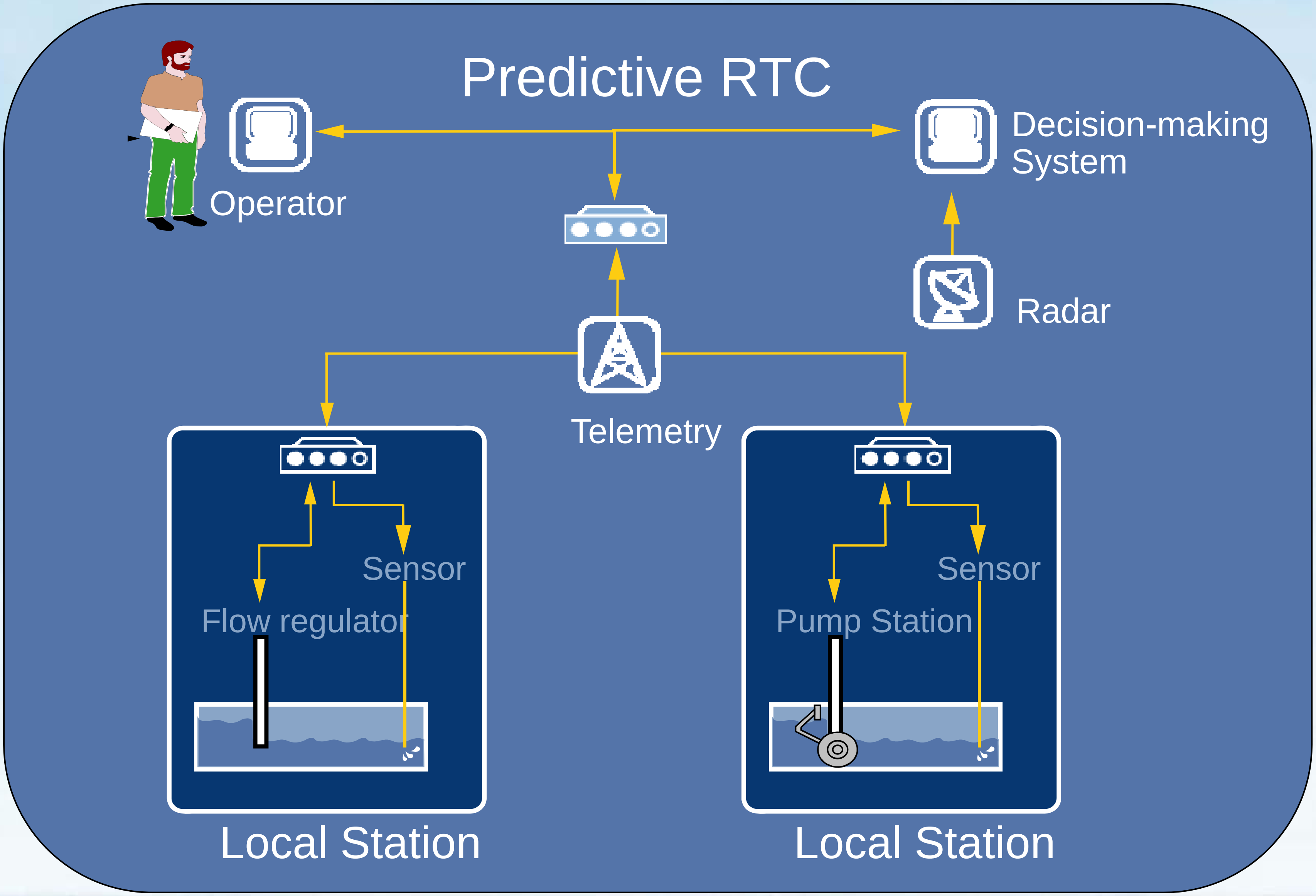
Partial system unavailability

- Adaptable management during equipment failure, shut-downs

RTC approaches using weather forecast



Architecture of a RTC system with radar weather forecast



Required rain data for RTC

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- **Louisville, Kentucky**
  - **Watershed length = 24 Km**
  - **Average Storm radii = 6 Km**
  - **5% margin of error = 24 rain gauges (1 rain gauge / 6 Km^2)**

Runoff Margin of Error	Ratio of Watershed Length to Effective Storm Radii			
	1	2	4	10
	Number of Rain Gauges			
5%	4	7	24	46
10%	2	4	10	14
15%	1	2	5	7

- **USEPA (1976)**

Required rain data for RTC

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- **Spatial resolution for RTC requires radar images**

Task	Rainfall record period	Rain Gauge	Temporal resolution (min)	Spatial resolution
Design, sizing, pre-planning	Some events	Same region	≤ 15	1 gauge per sub-catchment
Evaluation proof refined planning	Several events	Within catchment	≤ 5	≤ 1 km^2/gauge
RTC operation	On-line	Within catchment	≤ 5	≤ 1 km^2/gauge

- **Schilling (1991)**

Weather Forecasting Approaches

Approach	Method	Advantage	Drawback
Heuristic	Null forecast	Very easy to implement	Underestimate future rainfall intensities
	Constant forecast	Very easy to implement	Underestimate rainfall during increasing intensities Overestimate rainfall intensities during decreasing intensities
Statistical	ARMA model	Model well known in hydrology Mimic the correlation structure of homogeneous rainfalls	Assumes a stationary process Needs a large set of data for calibration
	Neural Network	Do not rely on a "a priori" knowledge of the rainfall process	Black box model No existing methods for defining the structure of the neural network
	K-Nearest Neighbours	Non parametric method Asymptotical optimality among historical data	Needs a large set of historical data No existing method for selecting the number of nearest neighbours
Phenomenological	Radar images propagation methods	Performing approach based on meteorological forecasting model Many providers	Often limited to a 1-hour prediction Annual fees Needs on-line calibration with rain gauges
	Rain gauge propagation methods	Performing approach Non stationary model	Complex theory Require a large number of rain gauges over a large territory

Weather Forecasting Performance Statistical Approach

- Sieve Watershed in Italy
  - 850 km^2, 12 rain gauges, 4 years of rainfall data

Approach	Correlation coefficient		
	1 h forecasting horizon	2 h forecasting horizon	3 h forecasting horizon
ARMA	0,744	0,472	0,283
K-Nearest Neighbour	0,709	0,493	0,336
Neural Network	0,689	0,511	0,407

- Toth et al. (2000)

Weather Forecasting Performance
Phenomenological Approach

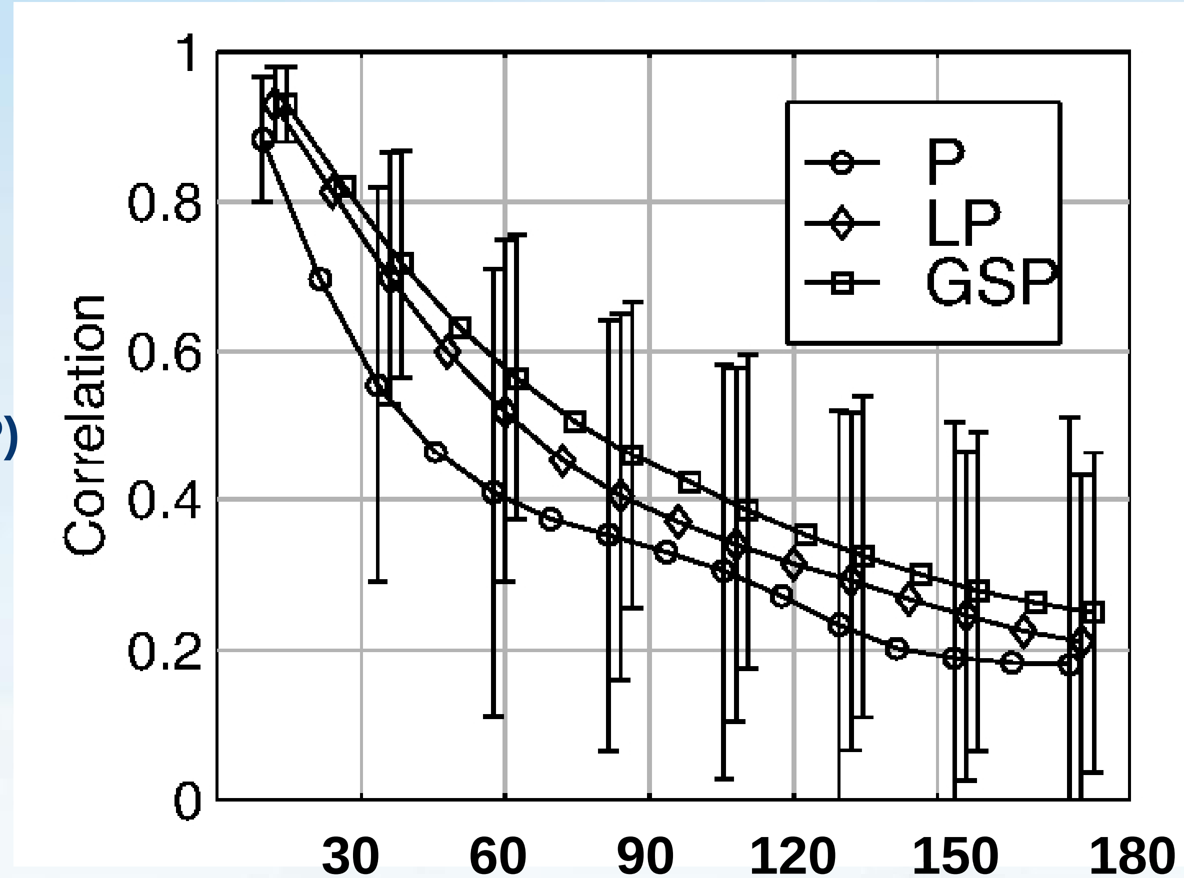
- **Tulsa, Oklahoma**
  - **1024 km^2, WSR-88D radar, 2 years of rainfall data**

3 forecasting methods

Eulerian persistance (P)

Lagrangian persistance (LP)

General statistical procedure (GSP)



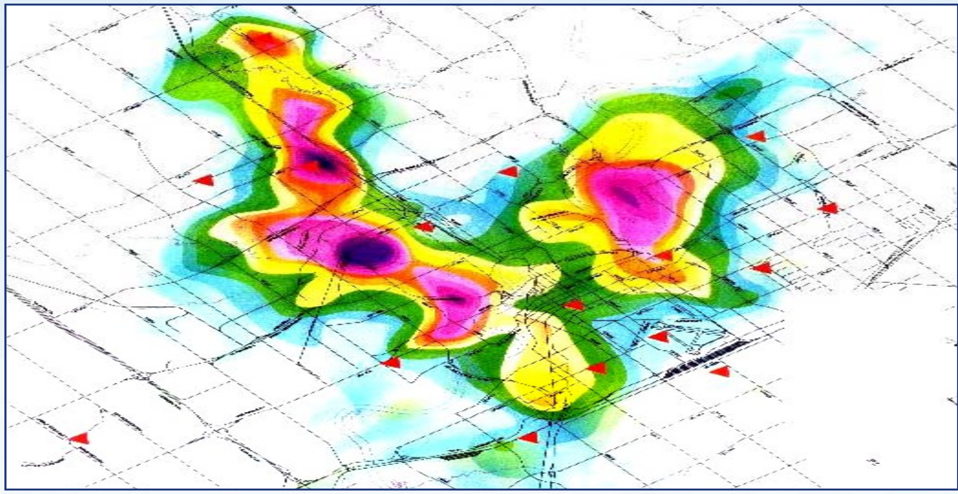
30 60 90 120 150 180

Time (minutes)

- **Grecu and Krajewski (2000)**

Do I need weather forecast for my RTC application?

- RTC performance versus weather forecast depends on several parameters:
  - Quality of weather forecasts
  - RTC approach implemented
    - optimal versus non-optimal
    - control objectives
  - Sewer network architecture
    - location of RTC sites
  - Sub-catchments response time
  - The number and distribution of rain gauges



RTC application with weather forecast

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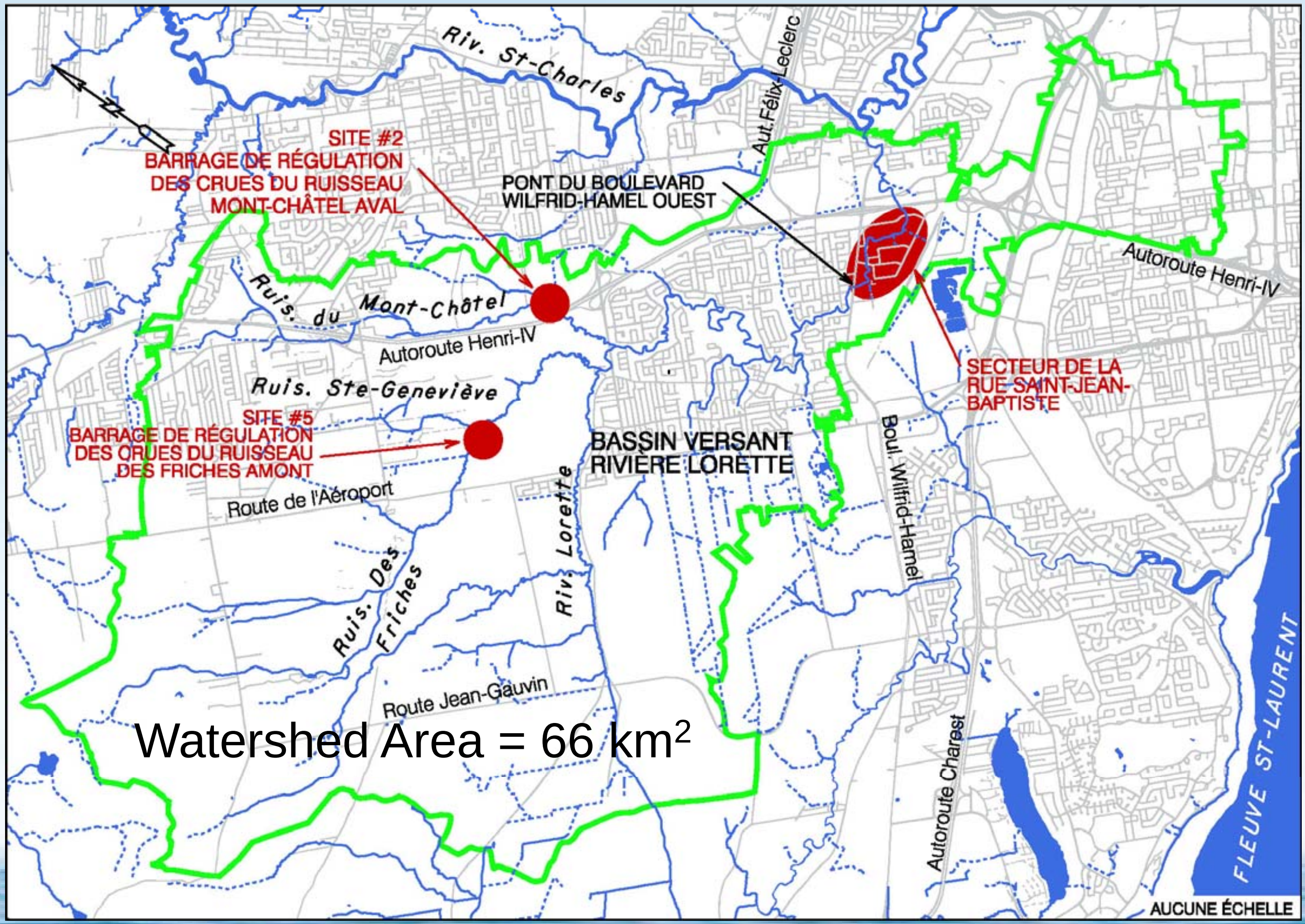
- **Lorette River (Quebec City)**
  - **Control Sites : Des Friches dam, Mont-Châtel dam**
  - **Control Objective: Flood Control in St-Jean-Baptist Area (max flow 80 m³/s)**



RTC application with weather forecast

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- **Accurate weather forecast is crucial for the flood control**
  - **During flooding, 17,5 m^3/s out of the 80 m^3/s flow rate estimated for optimal control (Des Friches & Mont-Châtel) come from weather forecasts**

Inflow to Hamel Bridge	Traveling time between inflows and Hamel Bridge	Data source used by the optimiser to compute the optimal set points		% of the total flow at Hamel Bridge
		Des Friches Dam	Mont Châtel Dam	
Des Friches Dam	1h45	Flowmeter	Flowmeter	21%
Mont-Châtel Dam	1h30	Rain gauge	Flowmeter	18%
Airport	1h45	Flowmeter	Flowmeter	31%
Notre Dame	1h45	Rain gauge	Rain Gauge	9%
Sainte-Geneviève	>2h00	Rain Gauge	Rain Gauge	2%
Other inflows	<1h00	Weather forecast	Weather forecast	22%

RTC application with weather forecast

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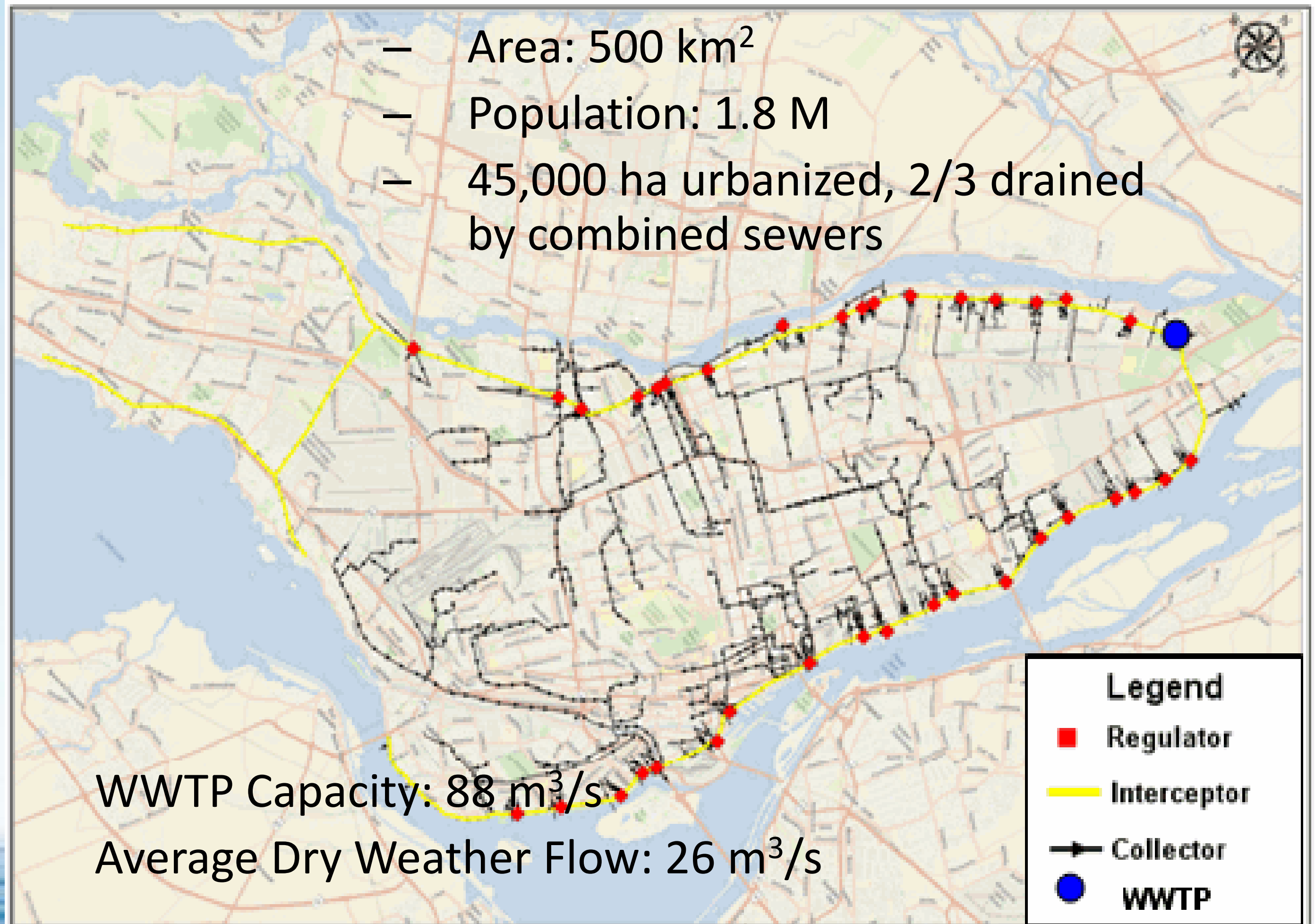
- **Montréal**
  - **RTC Sites : 39 located along the Southern and the Northern Interceptors**
  - **Control Objective: CSO minimisation**

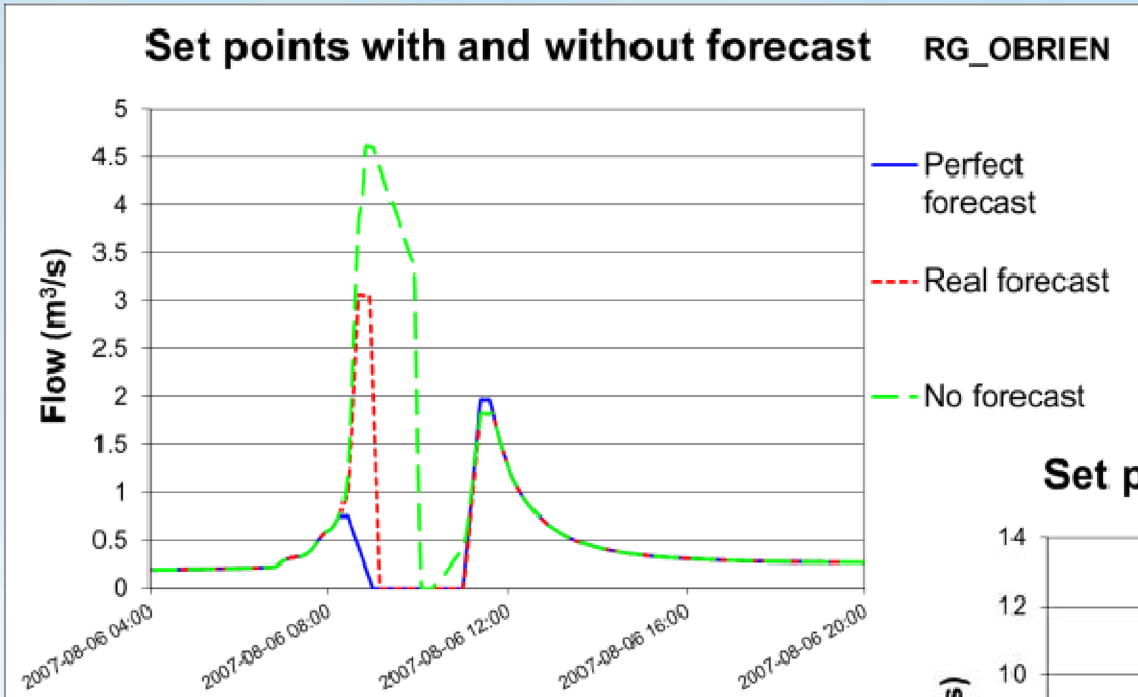
Weather Forecast:

- Environment Canada
- McGill radar
- 1 pixel/km^2
- updates every 5 minutes
- 2-hour horizon



RTC application with weather forecast

- Upstream RTC actions are highly sensitive to weather forecast

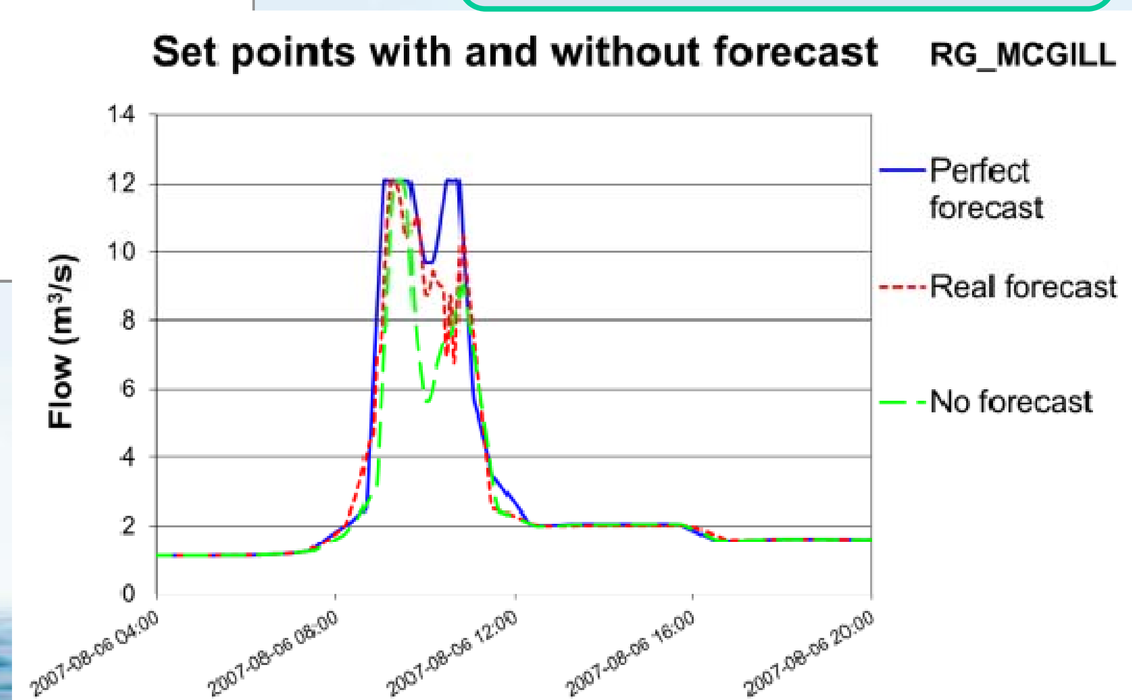


Nash = 0.69 (perfect forecast)
Nash = 0.73 (real forecast)

High sensitivity

Very high sensitivity

Nash = -10.75 (perfect forecast)
Nash = -2.69 (real forecast)



RTC application with weather forecast

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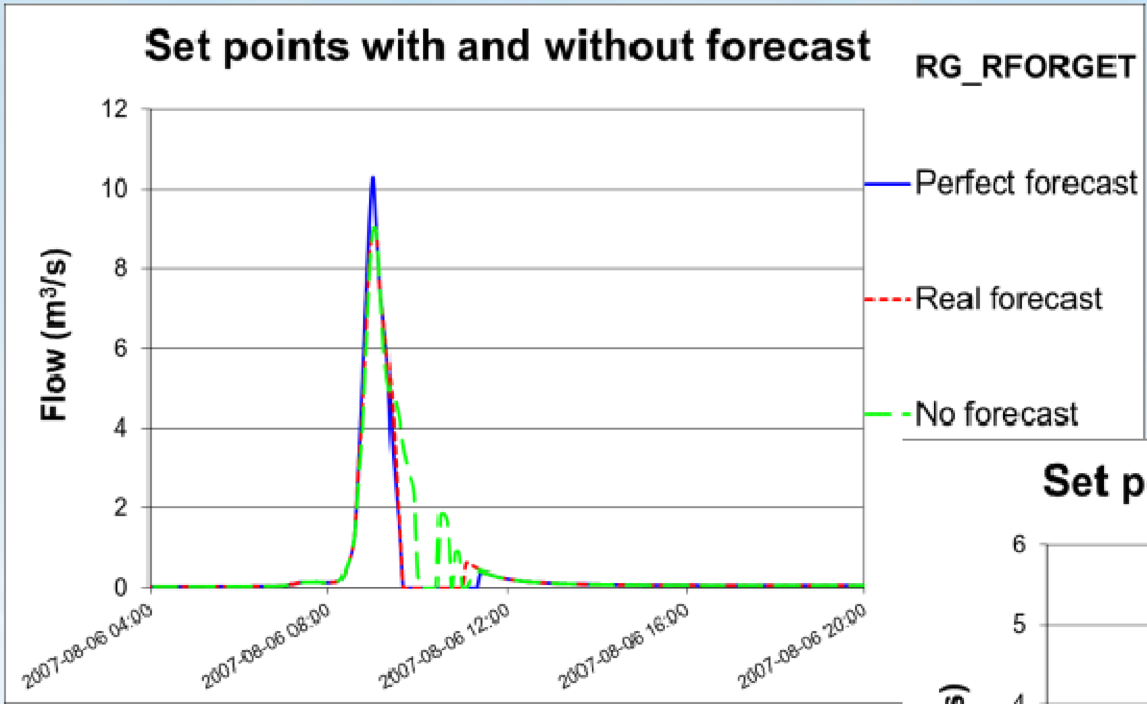
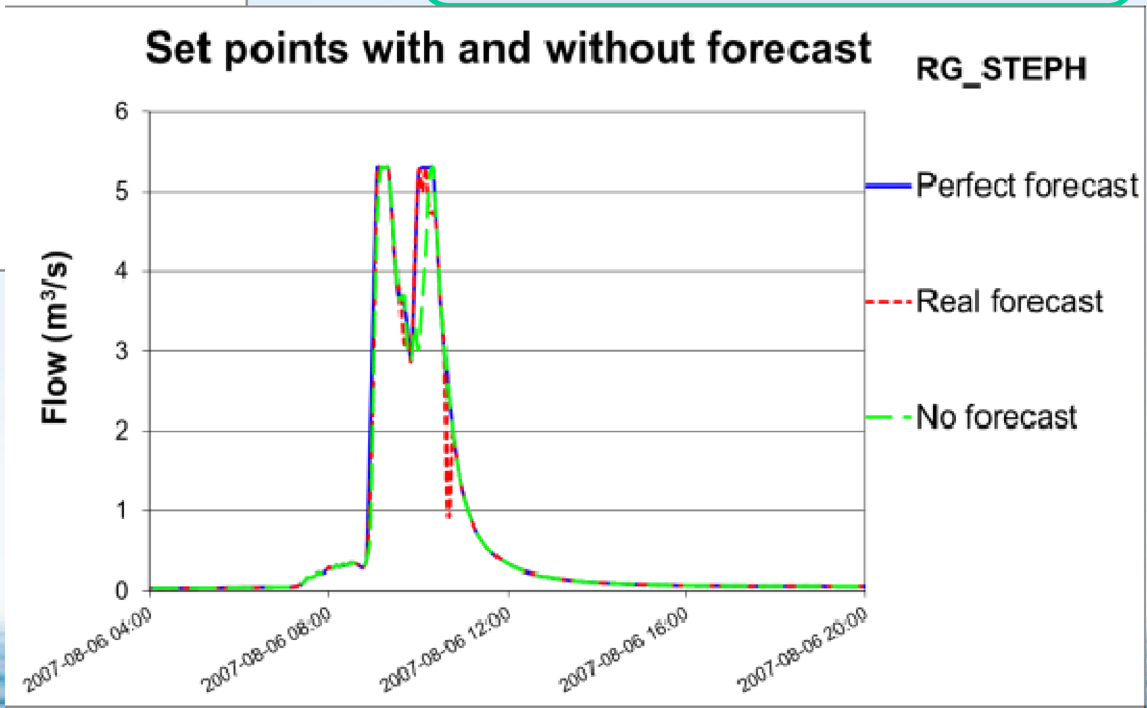
- Downstream RTC actions are less sensitive to weather forecast



Nash = 0.97 (perfect forecast)
Nash = 0.97 (real forecast)

Very low sensitivity



Low sensitivity

Nash = 0.88 (perfect forecast)
Nash = 0.89 (real forecast)

RTC application with weather forecast

- **Montréal RTC strategy with weather forecast**

Optimal control → 39 sites

- **Montréal RTC strategy without weather forecast**

High or very high sensitivity → Local control → 18 sites

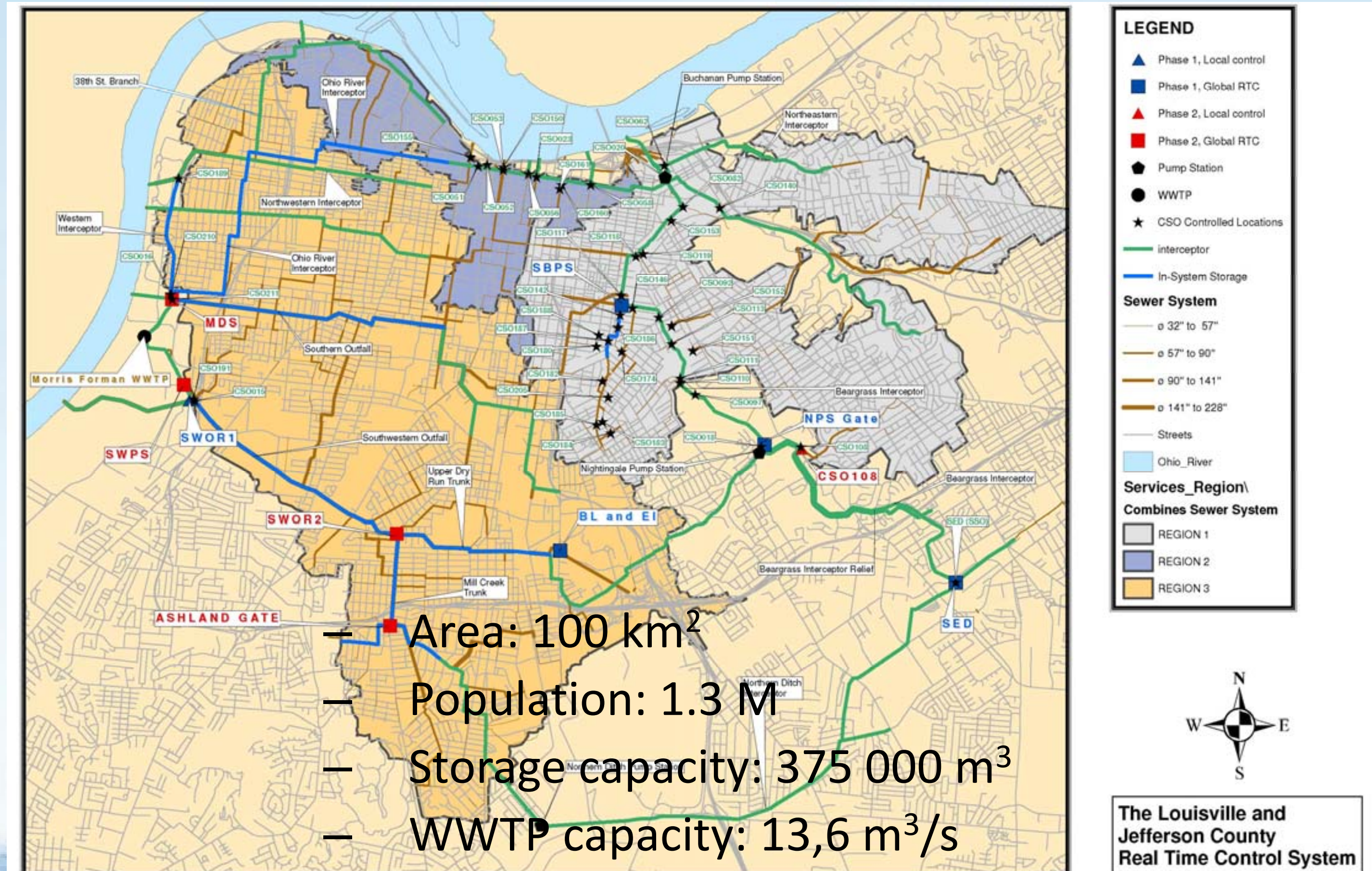
Low or very low sensitivity → Optimal control → 21 sites

RTC application with weather forecast

- **Louisville, Kentucky**
  - **Optimal Control Sites : 8 sites**
  - **Control Objective: CSO minimisation**

Weather Forecast:

- ONERAIN
- Multiple Doppler radar
- 414 pixels
- 1 pixel/km^2
- updates every 5 min
- 2-hour horizon



- Area: 100 km^2
- Population: 1.3 M
- Storage capacity: 375 000 m^3
- WWTP capacity: 13,6 m^3/s

RTC application with weather forecast

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- **RTC sites sensitivity analysis to weather forecast**

RTC sites	Rainfall event		
	August 10, 2006	September 27, 2006	October 19, 2006
SWOR2	Low sensitivity	Low sensitivity	Low sensitivity
SWPS	Low sensitivity	Low sensitivity	Low sensitivity
Ashland	Low sensitivity	Low sensitivity	Low sensitivity
Brady Lake	Low sensitivity	Low sensitivity	Low sensitivity
MDS	Low sensitivity	Low sensitivity	Low sensitivity
SBPS	Very high sensitivity	High sensitivity	Low sensitivity
NPS	Very high sensitivity	Very high sensitivity	Very high sensitivity
SED	Very high sensitivity	Very high sensitivity	Very high sensitivity

RTC application with weather forecast

Site	Objective	Regulator	RTC strategy without weather forecast
SWOR2	Protect against flooding in SWO and minimize CSO	Gate at outlet (2 gates)	Optimal control
SWPS	Protect against flooding in SWO	Sluice gate chamber (3 gates); pump station	Optimal control
Ashland	Protect against flooding in SWO and minimize CSO	Controlled gate	Optimal control
BL	Protect against flooding in SWO and minimize CSO	Gate at outlet of lake (2 gates)	Optimal control
MDS	Minimize CSO and maximize WWTP capacity	MDS controlled gate	Optimal control
SBPS	Protect CSO20	Pumping station	Locally controlled to maintain a constant water depth of 3 ft upstream CSO20
NPS	Maximize use of pumping capacity	NPS gate	Locally controlled to maintain a constant elevation of 447.44 ft in BGIR (below CSO018 weir crest)
SED	Prevent flooding at northern Ditch Pump Station	BGI gate; SEI gate	Fully open; fully closed

RTC application with weather forecast

Site	Objective	Regulator	RTC strategy with weather forecast
SWOR2	Protect against flooding in SWO and minimize CSO	Gate at outlet (2 gates)	Optimal control
SWPS	Protect against flooding in SWO	Sluice gate chamber (3 gates); pump station	Optimal control
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BL	Protect against flooding in SWO and minimize CSO	Gate at outlet of lake (2 gates)	Optimal control
MDS	Minimize CSO and maximize WWTP capacity	MDS controlled gate	Optimal control
SBPS	Protect CSO20	Pumping station	Optimal control
NPS	Maximize use of pumping capacity	NPS gate	Optimal control
SED	Prevent flooding at northern Ditch Pump Station	BGI gate; SEI gate	Optimal control

CONCLUSION

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- Many RTC approaches use weather forecast
  - Optimal and non-optimal approaches
- Several forecasting approaches can be used
  - Heuristic, Statistical, Phenomenological
- Sensitivity of a RTC system to weather forecast
  - Depends on many parameters
  - RTC approach implemented, control objectives, network architecture, location of RTC sites, watershed response time, rain gauge location
- Fallback strategy when loosing weather forecast :
  - Keep the RTC stations that are not sensitive to weather forecast in optimal control
  - Use a local scheme at RTC stations that are highly sensitive to weather forecast

The science of water management,
the art of better living

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