Climate-driven QMRA model: Case study for Ålesund water supply

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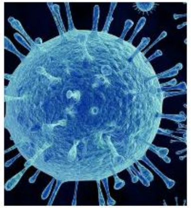
Introduction

- Extreme weather events due to climate change are likely to increase in the 21st century (IPCC, 2014)*

- Extremes of rainfall, flooding, temperature, etc are linked to **surface water** quality, waterborne diseases

- Mitigating potential effects on drinking water supply systems necessitate identifying key risks, such as microbial contamination of water

E. coli



Norovirus

Giardia

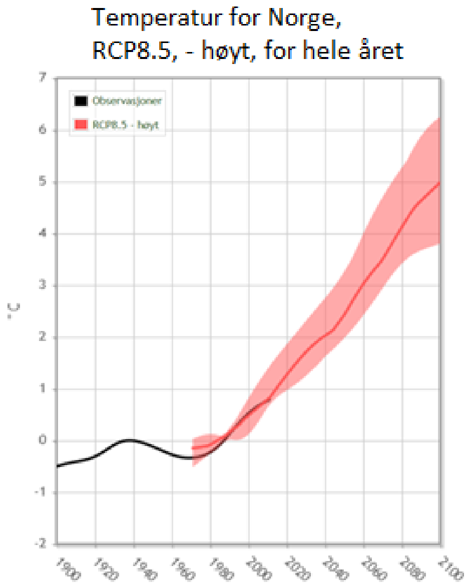
Flooding in Buskerud, west of Oslo

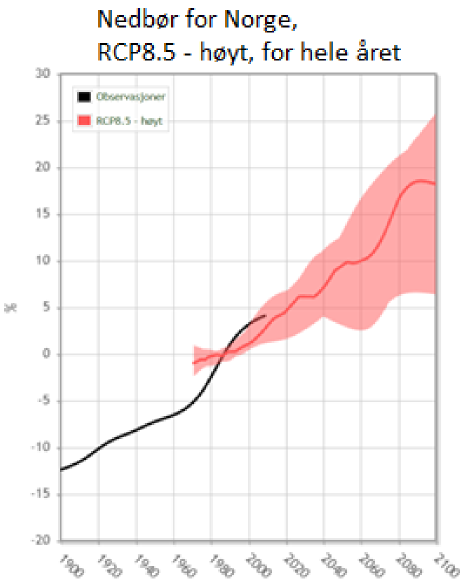
* IPCC, 2014: Climate Change 2014: Synthesis Report. IPCC, Geneva, Switzerland, 151 pp.

Projections of temperature and precipitation in Norway

- **Temperature**: Increase by 2.3 ºC to 4.6 ºC by 2100

- **Precipitation**: Increase by 5% to 30% with major seasonal variations, increased torrential rains (Ministry of the Environment ,2010)*





* Ministry of the Environment (2010). Adapting to a changing clime. Norway's vulnerability and the need to adapt to the impact of climate change. Official Norwegian Reports NOU 2010: 10

Research Objectives

Aim: To evaluate the potential consequences of current climate projections on the risks of pathogen infection from treated water consumption in the Ålesund WTP

Research Questions:

1. What are the likely effects on runoff and discharge of microbial organisms in the water source catchment?

2. What are the likely effects at the raw water intake depth?

3. What are the public health risks associated with climate induced events in the water supply system?

4. Are the barriers in the water supply system enough for possible changes in the source water quality in the future?

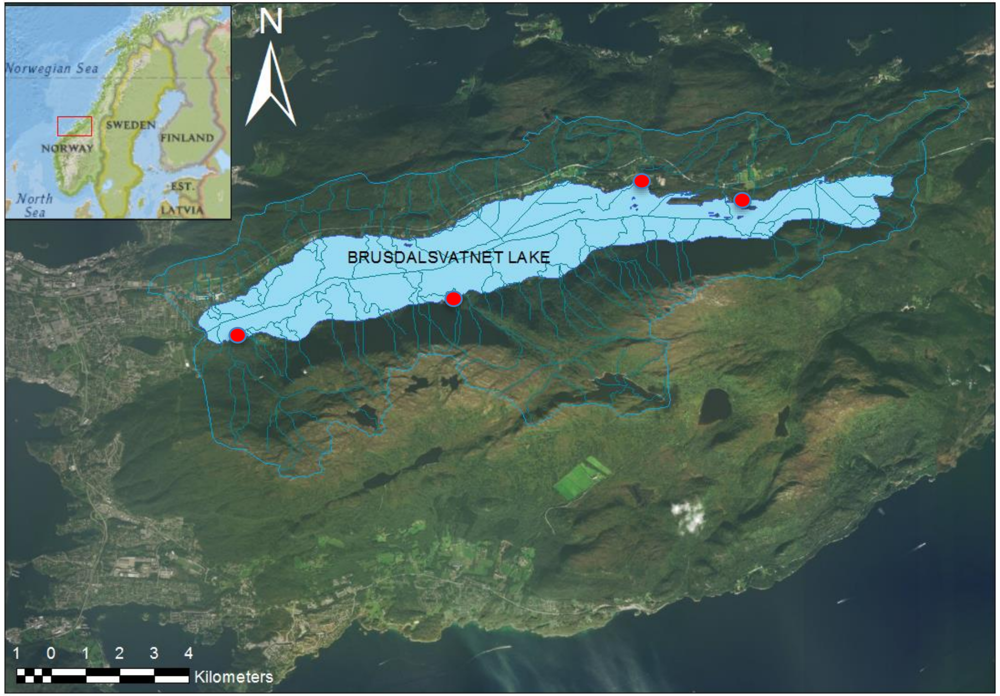
5. What level of corrective actions is needed?

Methods

Study location

- Surface area: 7.3 Km^2
- Catchment size: 30 Km^2
- Residence time: *ca*. 8 years
- Mixing periods: mainly spring & autumn seasons
- Major *E. coli* discharge points so far?
  - Slettebakk stream
  - Brusdalen stream
  - Arsetelva
  - Vasstrandelva
- Tributaries: *ca*. 200

Brusdalsvatnet Lake

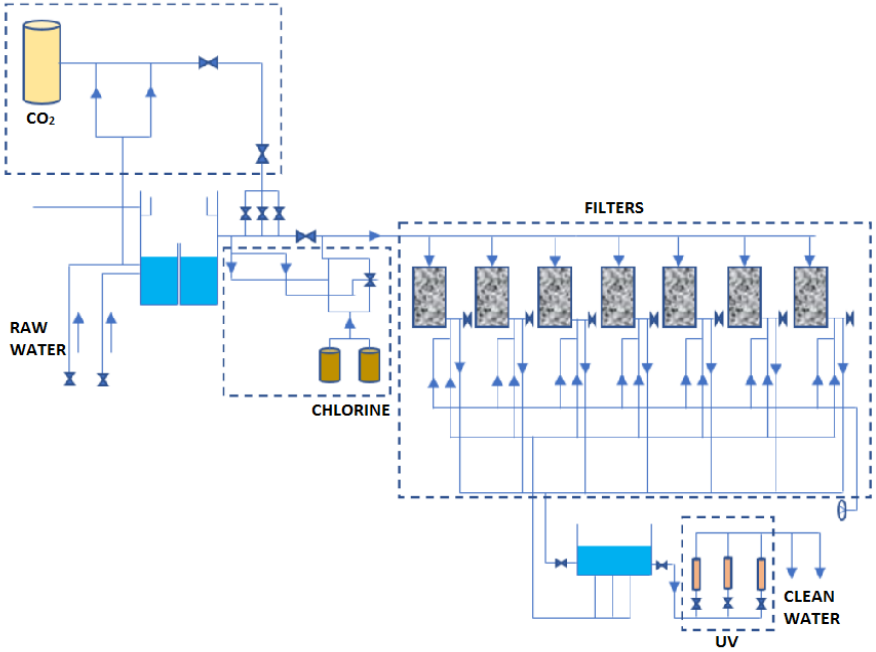


Water treatment

- Main steps:
  - Chlorine
  - 1 media filter (marmor)
  - UV

- Production capacity:
  - Draws ca. 55,000 m^3 of raw water daily
  - Produces ca 1334 m^3/h
  - Average population connected : ca. 50,000

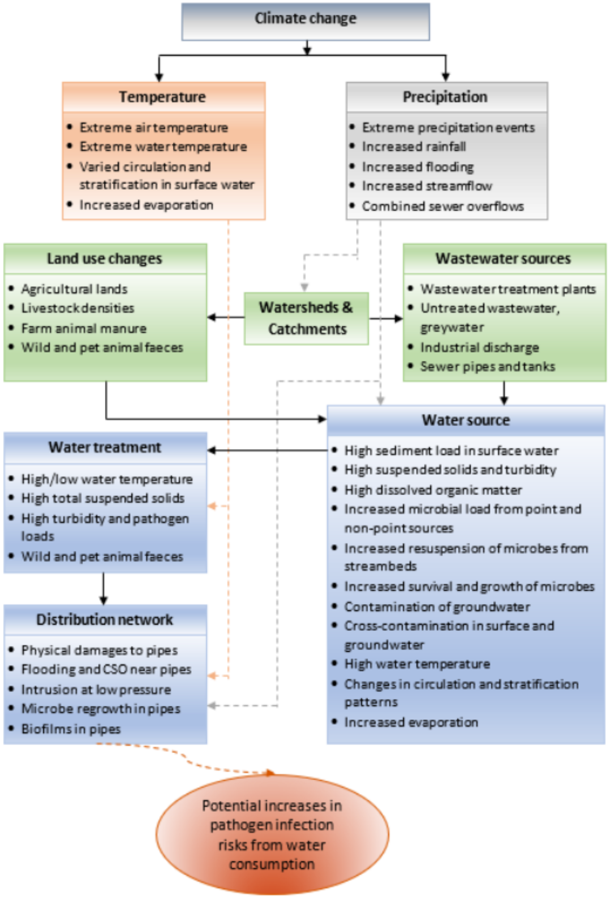
Treatment steps



Modelling approaches

- ❑ Catchment : Distributed hydrological model
- ❑ Lake :
  - Hydrodynamic modelling
  - Artificial Intelligence modelling
- ❑ Treatment : Process models
- ❑ Pathogen Infection Risks : QMRA modelling

Conceptual framework

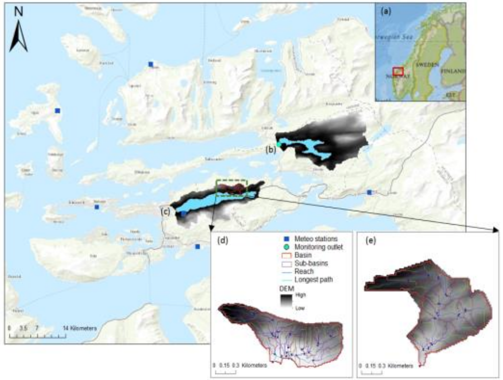


Hydrological modelling

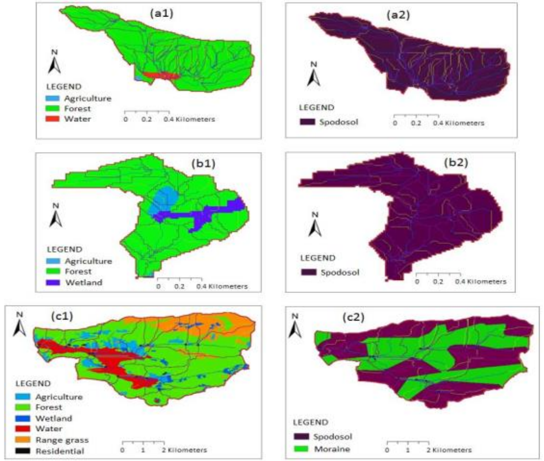
- ❑ Model Applied:
  Soil and Water Assessment Tool (SWAT)
  - Distributed hydrological and water quality model

- ❑ Major Inputs:
  - Daily precipitation and air temperature (seven years data)
  - Precipitation and air temperature projections for 2045 & 2075 for Møre og Romsdal (RCP8.5 scenario)
  - Flow measurements (seven years data)
  - *E. coli* concentrations in streams from sampling (2017)

Flow regionalization



Land use characteristics

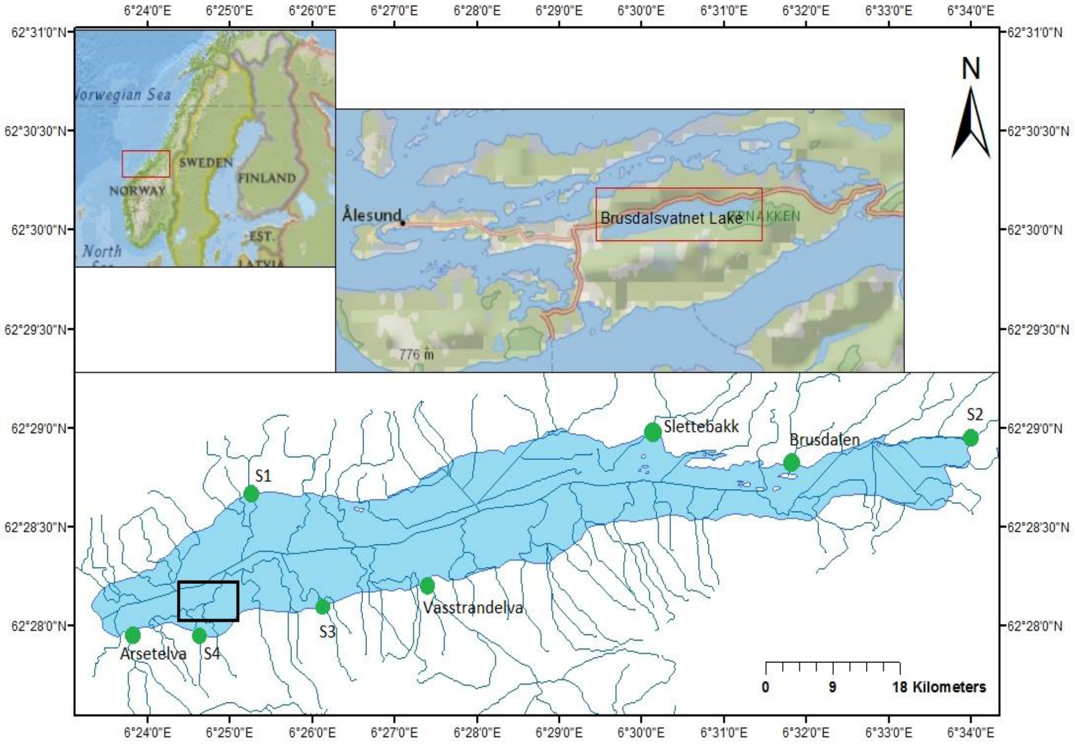


Hydrodynamic and water quality modelling

- Model applied:
  GEMSS software

- Main input data:
  - Meteorological:
    - air temperature
    - pressure
    - cloud cover
    - wind speed
    - wind direction
    - relative humidity
  - Flow
    - Measured in – 2017
    - Predicted – 2045 & 2075
  - *E. coli*:
    - Measured – 2017
    - Predicted – 2045 & 2075

E. Coli discharge points

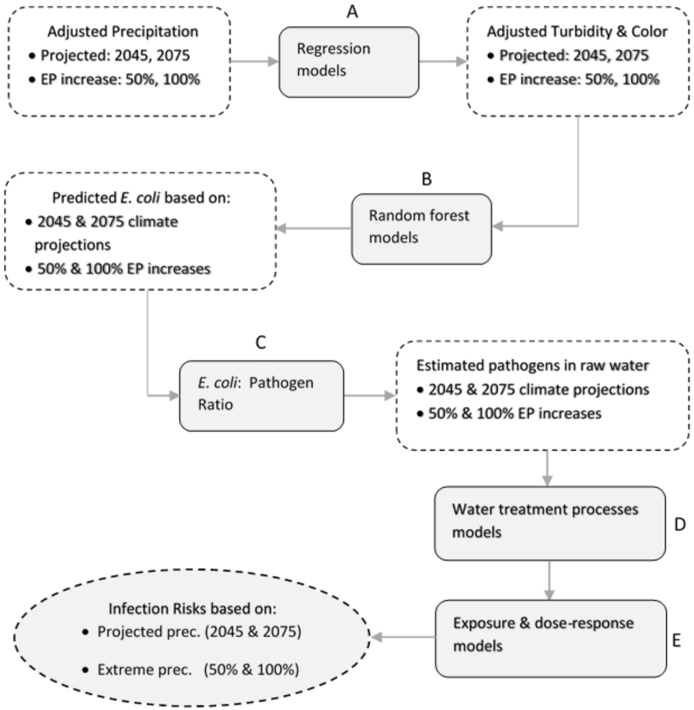


QMRA

- Modelling steps
  - Regression – Prediction of turbidity and color
  - AI (Random Forest) – Prediction of *E. coli*
  - Process models – Barrier efficiency
  - QMRA models – Infection risk calculation

- Inputs
  - Turbidity & color in raw water (2009-2015)
  - *E. coli* in raw water (2009-2015)
  - Precipitation (2009-2015)
  - Projections of precipitation for Møre og Romsdal (2045 & 2075)

Modelling framework



Results

Flow and *E. coli* in the future

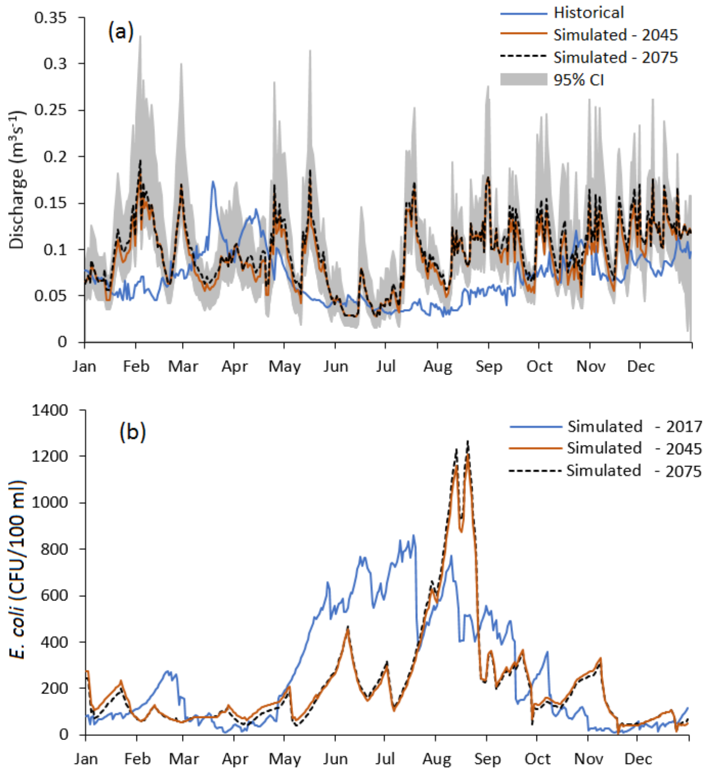
Stream flow?

- ❑ Stream flow in catchment may increase in the future
- ❑ Pattern and timing of peak flow may shift in the future e.g.,
  - Spring → Winter
- ❑ Higher stream flow in late summer

***E. coli* concentration?**

- ❑ Lower peak concentration in spring & summer
- ❑ Higher concentration at the onset of autumn

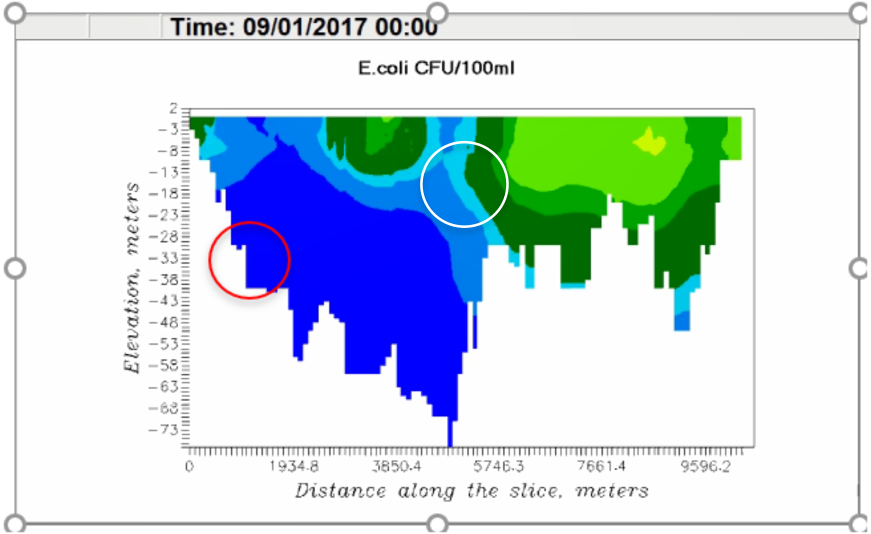
Predictions for 2045 & 2075



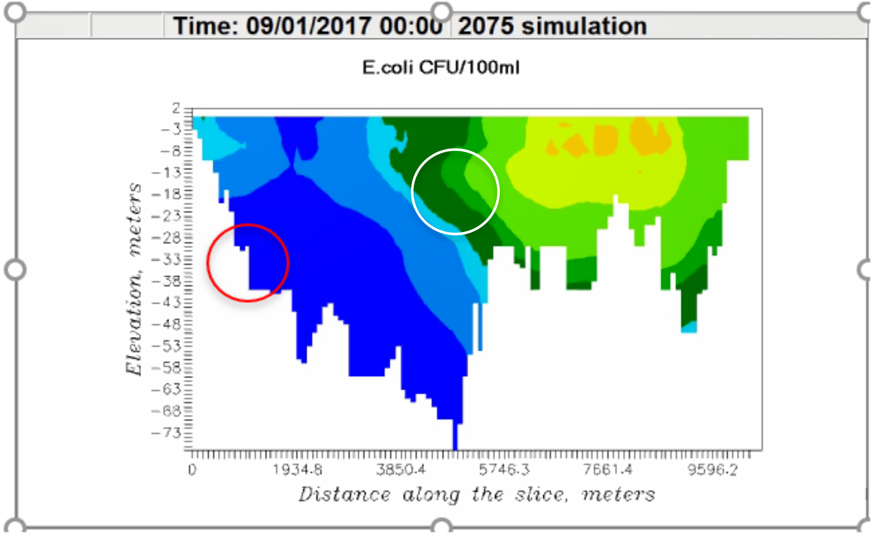
(a). Stream flow, (b) *E. coli* concentration in Slettebakk

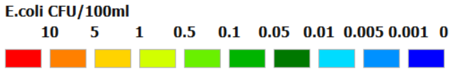
E. coli at intake in the future

Autumn - 2017



Autumn - 2075



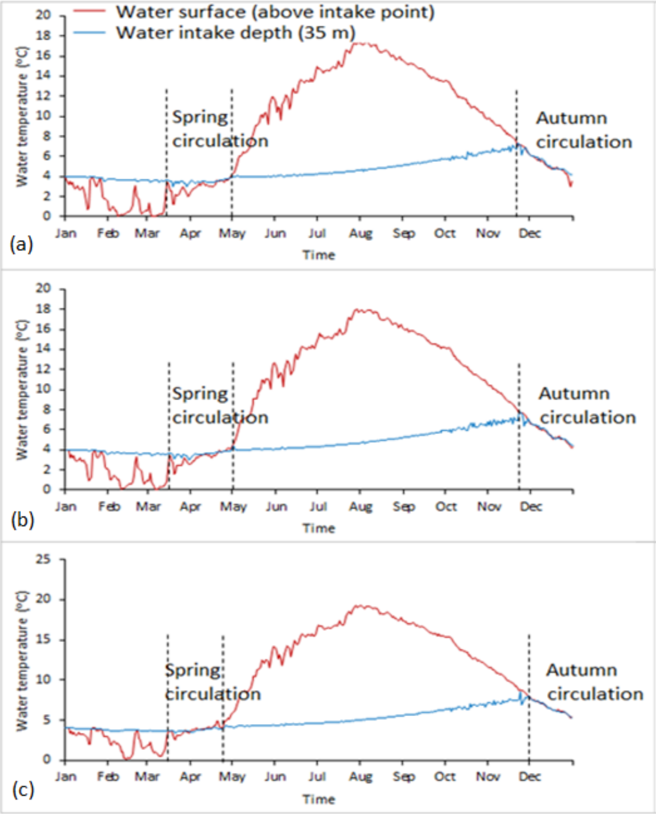


Future circulation in Brusdalsvatnet Lake

Circulation?

- Spring mixing may occur earlier in the future (shifts by ca. 1 week)
- Autumn mixing may occur later in the future (shifts by ca. 1 week)
- Longer summer conditions (e.g. water temperature)

Predictions for 2045 & 2075



(a). 2017, (b). 2045, (c). 2075

Projected water quality

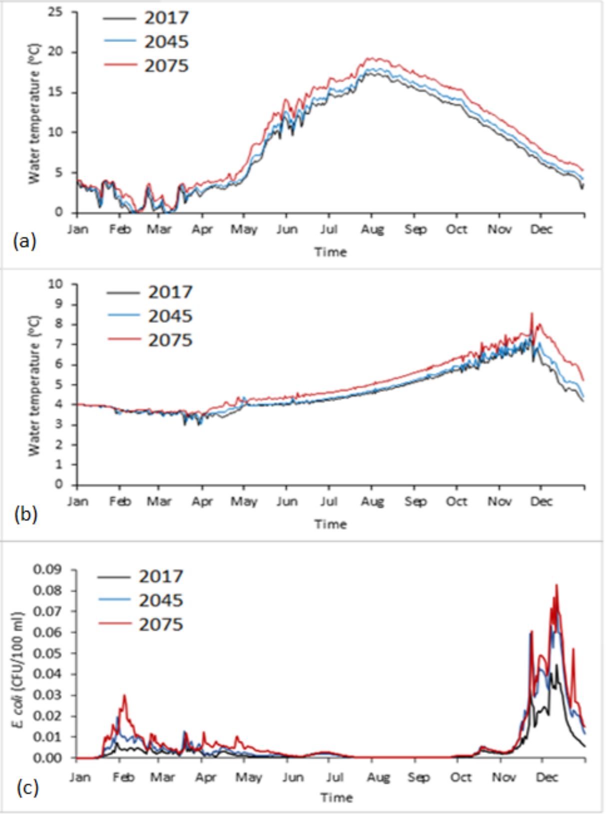
Temperature changes?

Season	Temperature at intake point	
	Predicted change Factor from 2017	
	2045	2075
Winter	0.68	0.89
Spring	0.37	0.43
Summer	1.03	1.21
Autumn	1.21	1.34

E. coli changes?

Season	E. coli concentration at intake	
	Predicted change Factor from 2017	
	2045	2075
Winter	0.92	1.30
Spring	2.30	2.71
Summer	0.05	0.07
Autumn	2.63	2.91

Predictions for 2045 & 2075

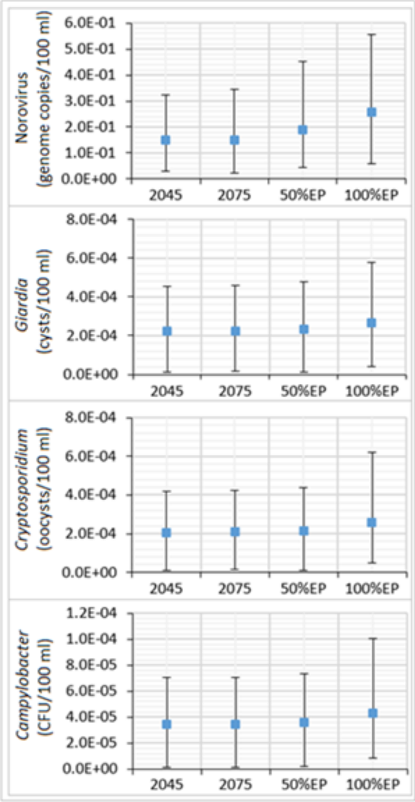


(a). Surface & (b). intake temperature, (c). intake *E. coli*

QMRA

- Predicted microbial organisms in raw water:
  - Higher average concentrations under extreme precipitation scenarios
  - Higher concentration of Norovirus compared to other pathogens

Pathogen concentrations under climate scenarios



Barrier efficiency

- Comparison with Norsk standards:
  Virus : 5 log
  Giardia : 3 log
  Cryptosporidium : 3 log
  Campylobacter : 5 log

- Filters and UV in the WTP indicate acceptable barrier efficiencies

- Chlorination show very low barrier effect

Calculated log removal

Pathogen	Log removal (π) mean (min, max)			
	Rapid sand filtration	Chlorination	UV	Total
Norovirus	0.09 (0.06, 0.19)	0.0099(0.0094,0.011)	3.234 (3.095, 3.366)	3.335 (3.164, 3.574)
Giardia	0.174 (0.099, 0.332)	0.00039 (0.00036, 0.00042)	3.646 (3.489, 3.792)	3.819 (3.589, 4.125)
Cryptosporidium	0.253 (0.151, 0.504)	0.00039 (0.00037, 0.00042)	3.646 (3.489, 3.792)	3.898 (3.642, 4.296)
Campylobacter	0.932 (0.566, 1.887)	0.039 (0.037, 0.0415)	3.646 (3.489, 3.792)	4.617 (4.094, 5.722)

Pathogen Infection Risks (IR)

- Current median IR are within acceptable limits of 1/10000 (WHO)
- Under current projections of precipitation,
  - median IR may be low in the future
  - Confidence limits suggest otherwise
- Extreme precipitation events could lead to increases in IR
- Virus and protozoa may be the main drivers of IR

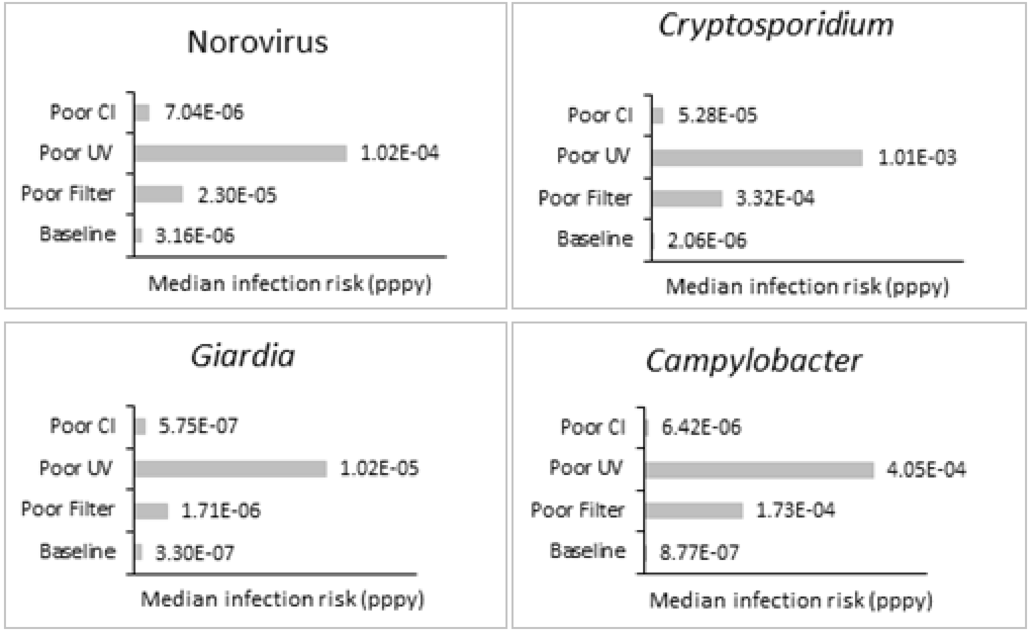
Pathogen Infection Risks (pppy)

(a) Projected precipitation	Historical			Predicted-2045			Predicted-2075		
	5%CI	Median	95%CI	5%CI	Median	95%CI	5%CI	Median	95%CI
Norovirus	6.8E-08	3.2E-06	9.8E-04	2.4E-07	2.5E-05	2.5E-03	2.6E-05	2.7E-04	2.7E-03
Giardia	1.1E-10	3.7E-07	8.0E-06	2.0E-07	2.0E-05	2.1E-04	2.4E-07	2.7E-05	2.9E-04
Cryptosporidium	8.0E-09	2.1E-06	6.3E-05	8.5E-06	8.4E-05	1.6E-04	8.9E-06	8.7E-06	1.8E-03
Campylobacter	3.7E-09	8.8E-07	4.5E-06	6.6E-07	1.4E-06	3.9E-05	4.8E-07	4.8E-06	4.8E-05
(b) Extreme precipitation	Historical			50% EP increase			100% EP increase		
	5%CI	Median	95%CI	5%CI	Median	95%CI	5%CI	Median	95%CI
Ålesund WTP									
Norovirus	6.8E-08	3.2E-06	9.8E-04	2.7E-05	3.3E-04	3.5E-03	4.1E-05	5.4E-04	7.2E-03
Giardia	1.1E-10	3.7E-07	8.0E-06	3.2E-06	3.3E-04	3.4E-04	5.4E-07	8.6E-04	1.4E-03
Cryptosporidium	8.0E-09	2.1E-06	6.3E-05	2.0E-06	2.3E-04	2.6E-03	4.7E-06	7.5E-04	7.1E-03
Campylobacter	3.7E-09	8.8E-07	4.5E-06	3.3E-06	3.3E-06	3.7E-06	7.1E-06	1.3E-05	3.0E-04

Water treatment scenarios

- Poor disinfection performance increases the infection risks
- Poor performance of chlorine showed the least effect on IR
- The WTP requires optimally operated UV to achieve tolerable infection risks in future

Effect of poor treatment performance



Implications of results

- Patterns of microbial discharge into the Lake may change in the future

- Earlier spring and later spring circulations should be expected in the Lake in the future

- Due to higher intensity of future circulation,
  - Increases in water temperature in autumn seasons should be expected
  - Higher concentrations of microbial pathogens should be expected in late summer, autumn and winter in the future

Implications of results

- The current treatment processes in the Ålesund WTP may be challenged in the future
- Norovirus and *Cryptosporidium* are the key drivers of infection risks in the WTP, and may be high by 2075
- Occurrence of extreme precipitation events in the future could lead to substantial increases in the pathogen infection risks
- Without optimally operated UV systems, the risks of infection of all the pathogens will be high in the future

Recommended corrective actions

- Potential non-point sources of microbial discharge into the Lake should be investigated

- Source water protection is highly essential to reduction in pathogen infection risks in the future during extreme precipitation events

- Presently, treatment steps optimization is required
  - The chlorine step in the WTP should be reconfigured or upgraded
  - Ensuring optimal performance of the UV step is highly recommended

- Potential risks in storage and distribution systems should be assessed to complete the chain.

Acknowledgement

- ❑ Norwegian Meteorological Institute (MET)
- ❑ Norwegian Water Resources and Energy Directorate (NVE)
- ❑ Norwegian Institute for Bioeconomy (NIBIO)
- ❑ Norwegian Geological Survey (NGU)
- ❑ Ålesund Kommune

TUSEN TAKK !