
Wastewater gone viral
Pandemic signals from the sewer

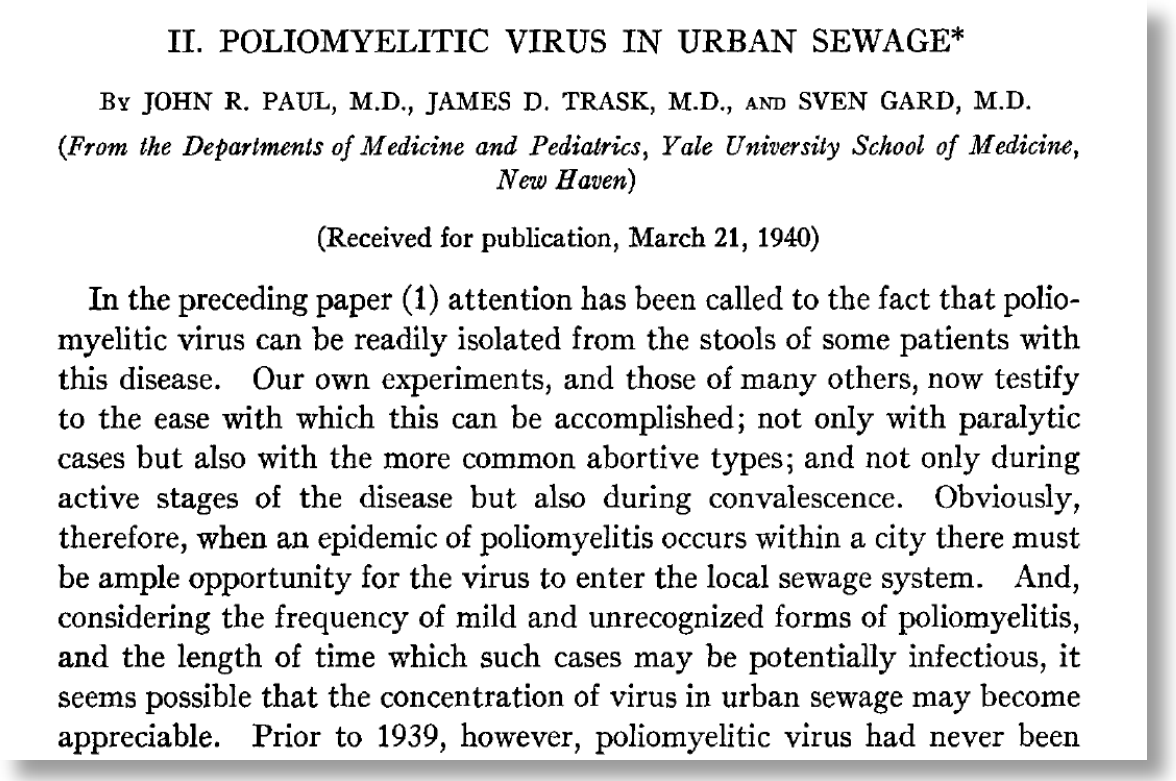
Viruses monitoring of sewage

1940 Charleston, Detroit, Buffalo
Poliovirus epidemic

Rationale:
transmission via water?

Method:
inoculation of Rhesus monkeys

Outcome:
Infectious poliovirus in wastewater during outbreak



II. POLIOMYELITIC VIRUS IN URBAN SEWAGE*

By JOHN R. PAUL, M.D., JAMES D. TRASK, M.D., and SVEN GARD, M.D.

(*From the Departments of Medicine and Pediatrics, Yale University School of Medicine, New Haven*)

(Received for publication, March 21, 1940)

In the preceding paper (1) attention has been called to the fact that poliomyelitic virus can be readily isolated from the stools of some patients with this disease. Our own experiments, and those of many others, now testify to the ease with which this can be accomplished; not only with paralytic cases but also with the more common abortive types; and not only during active stages of the disease but also during convalescence. Obviously, therefore, when an epidemic of poliomyelitis occurs within a city there must be ample opportunity for the virus to enter the local sewage system. And, considering the frequency of mild and unrecognized forms of poliomyelitis, and the length of time which such cases may be potentially infectious, it seems possible that the concentration of virus in urban sewage may become appreciable. Prior to 1939, however, poliomyelitic virus had never been

Journal of Experimental Medicine

Sewage surveillance of polio

1992 Netherlands Poliovirus epidemic

Rationale:

Surveillance of poliovirus circulation in at-risk communities

Method:

Virus isolation and cell culture

Outcome:

Early circulation of outbreak virus (retrospectively)

Epidemiol. Infect. (1995), **114**, 481–491

Isolation of epidemic poliovirus from sewage during the 1992–3 type 3 outbreak in the Netherlands

H. G. A. M. VAN DER AVOORT, J. H. J. REIMERINK, A. RAS, M. N. MULDERS AND A. M. VAN LOON

Laboratory of Virology, National Institute for Public Health and Environmental Protection, P.O. Box 1, 3720 BA Bilthoven, the Netherlands

(*Accepted 6 January 1995*)

SUMMARY

To examine the extent of wild poliovirus circulation during the 1992–3 epidemic in the Netherlands caused by poliovirus type 3, 269 samples from sewage pipelines at 120 locations were examined for the presence of poliovirus. The epidemic virus strain was found in 23 samples, all from locations inside the risk area which contained communities that refuse vaccination for religious reasons. By sewage investigation, the wildtype virus was shown to be present in the early phase of the epidemic at two locations, one week before patients were reported from that area. The wild type 3 poliovirus was also detected retrospectively in a river water sample collected for other reasons three weeks before notification of the first poliomyelitis case, at a site a few kilometres upstream the home village of this patient. Oral poliovirus vaccine (OPV) virus was found at 28 locations inside or at the border of the risk area. Trivalent OPV was offered to unvaccinated or incompletely-vaccinated persons living in this region as part of the measures to control the epidemic.

Sewage surveillance of polio: added value

Wilkinson et al, 2022

Early warning before cases of paralysis occur

9 countries

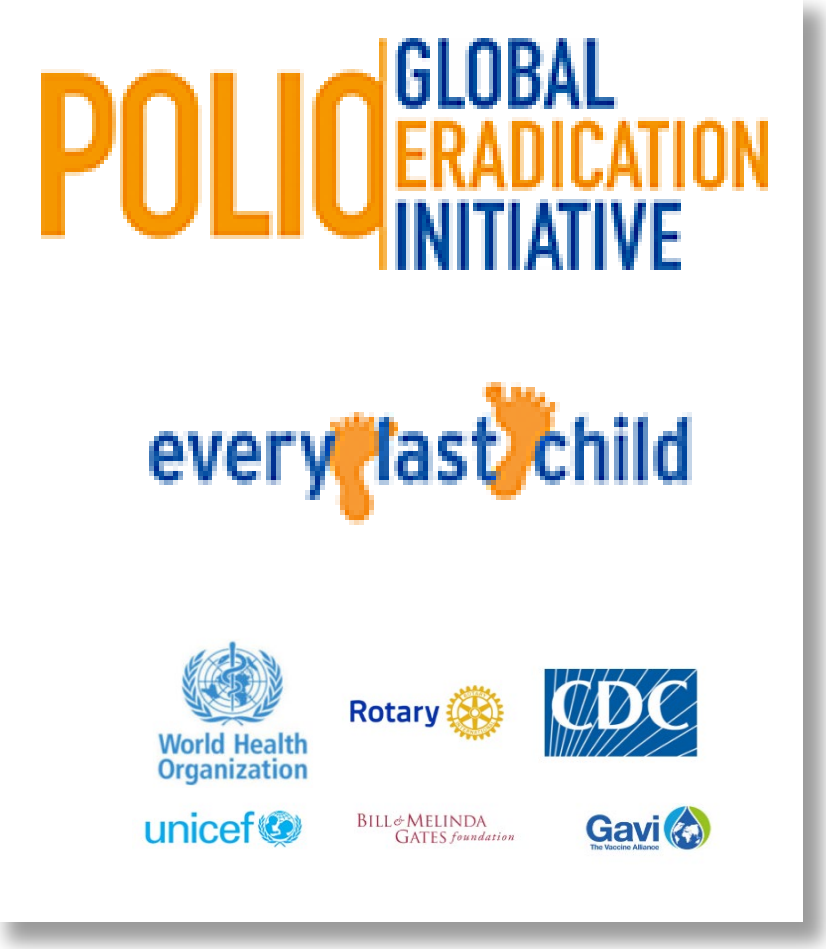
Monitor trend

Increase in 1, decline in 2 countries

Confirm absence

‘Variants of concern’

27 detected in 32 countries



Water virology pandemic response 1

Can SARS-CoV-2 be transmitted via water?

Are workers, recreational waters, drinking water safe?

Amoy Gardens, Hong Kong, 2003

Health risk to workers?

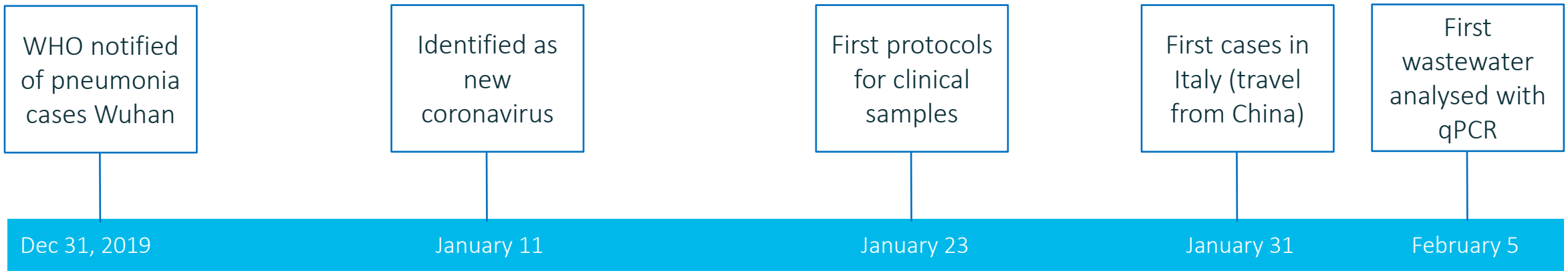
- No epidemiological signals
- No case reports
- In stool:
  - high RNA concentrations
  - but few reports of infectious virus
  - rapid inactivation in intestine
- In wastewater:
  - no reports of infectious virus
  - virus is not robust in wastewater

- Standard personal protection (to protect against other viruses)

Photo credit: Broadbent

Photo credit: Jurisam

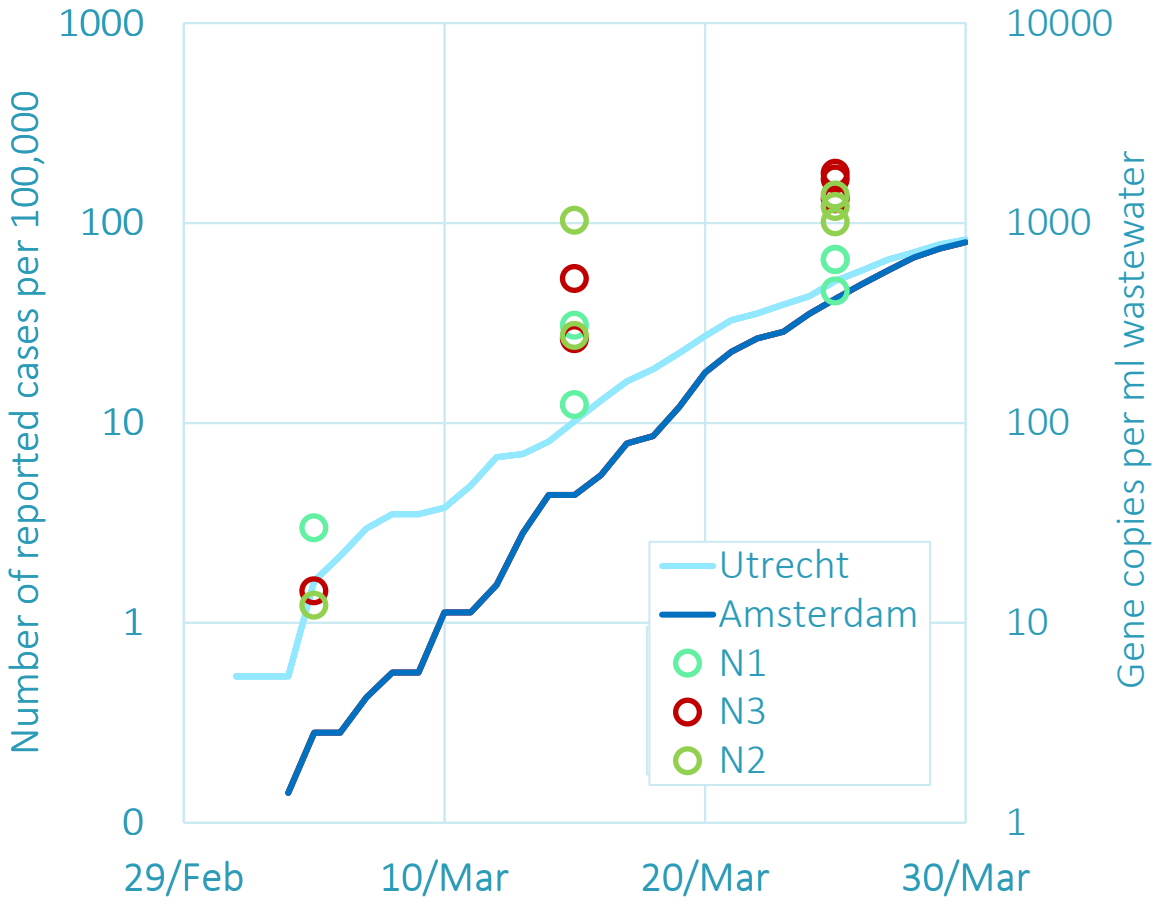
Water virology pandemic response 2



Virus test: science at warp speed

Sewage surveillance at WWTP in the Netherlands

- Clear increase in reported cases coincides with increase in concentration in wastewater
- Two other WWTP: virus detected in wastewater 6 days before first reported case
- National surveillance (RIVM)



Medema et al, 2021, EST Letters

Erasmus MC

Miranda de Graaf, Marion Koopmans, Evelien de Schepper, Ray Izquierdo Lara, Claudia Schapendonk, Patrick Bindels, Johan van der Lei, Margreet Vos

RIJNMOND GEZOND DATA BASE

GGD Rotterdam-Rijnmond

Ewout Fanoy

Rijksinstituut voor Volksgezondheid en Milieu
Ministerie van Volksgezondheid, Welzijn en Sport

Eelco Franz, Roan Pijnacker, Christian Carrizosa Balmont

KWR

Goffe Elsinga, Leo Heijnen, Frederic Been, Gertjan Medema

stowa

Bert Palsma, Imke Leenen

Royal HaskoningDHV
Enhancing Society Together

Stefanie Stubbé, Emma Weisbord

PARTNERS4URBANWATER
onderzoek & advies

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waterschap Hollandse Delta

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Hoogheemraadschap van Schieland en de Krimpenerwaard

Nick Ivens

waternet

Marco Dignum, Alex Veltman, Alice Fermont, Jan Peter van der Hoek

Hoogheemraadschap De Stichtse Rijnlanden

Mark Stevens

NL Health~Holland
SHARED CHALLENGES, SMART SOLUTIONS

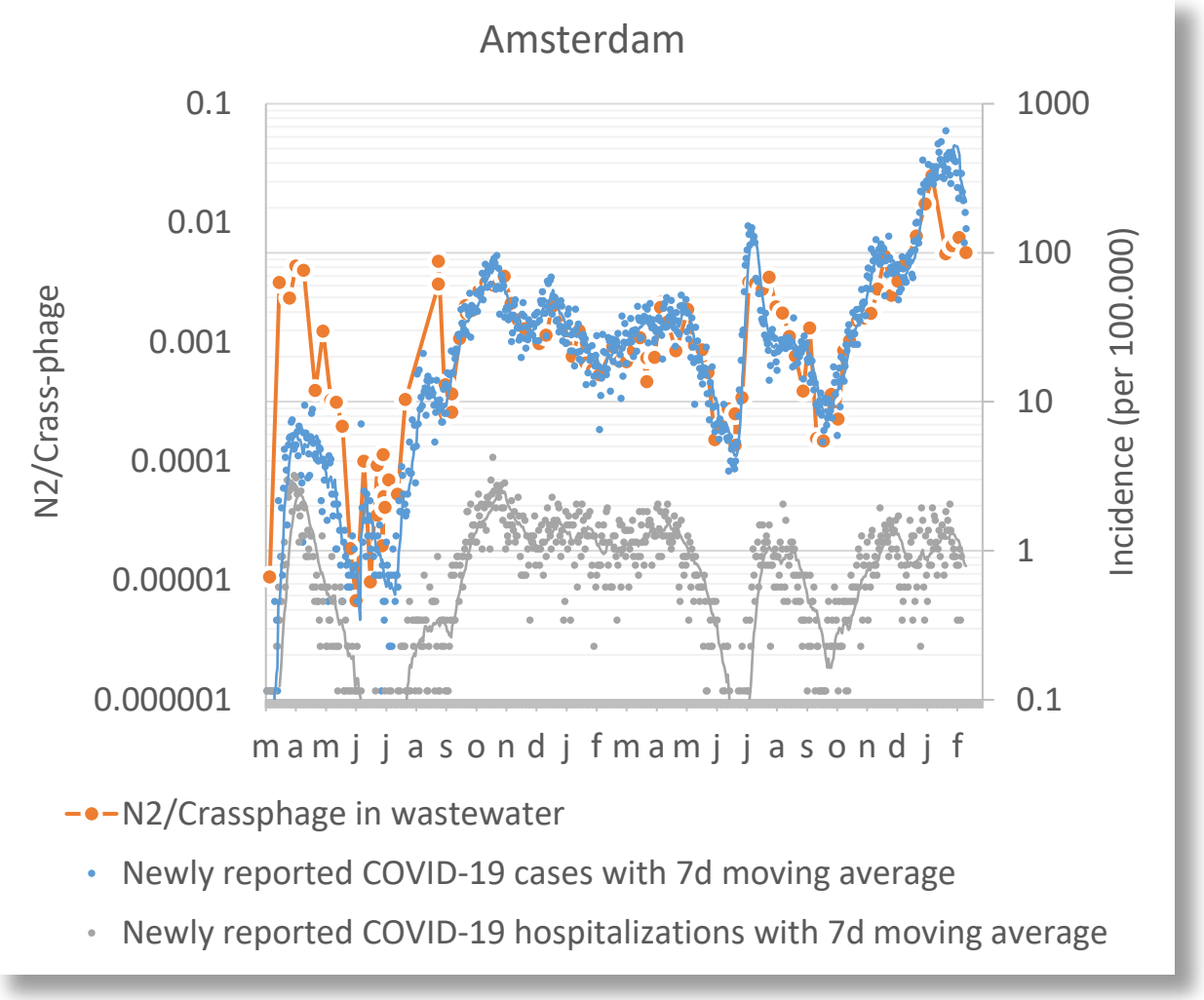
TOPSECTOR WATER & MARITIEM

Objective surveillance of SARS-CoV-2

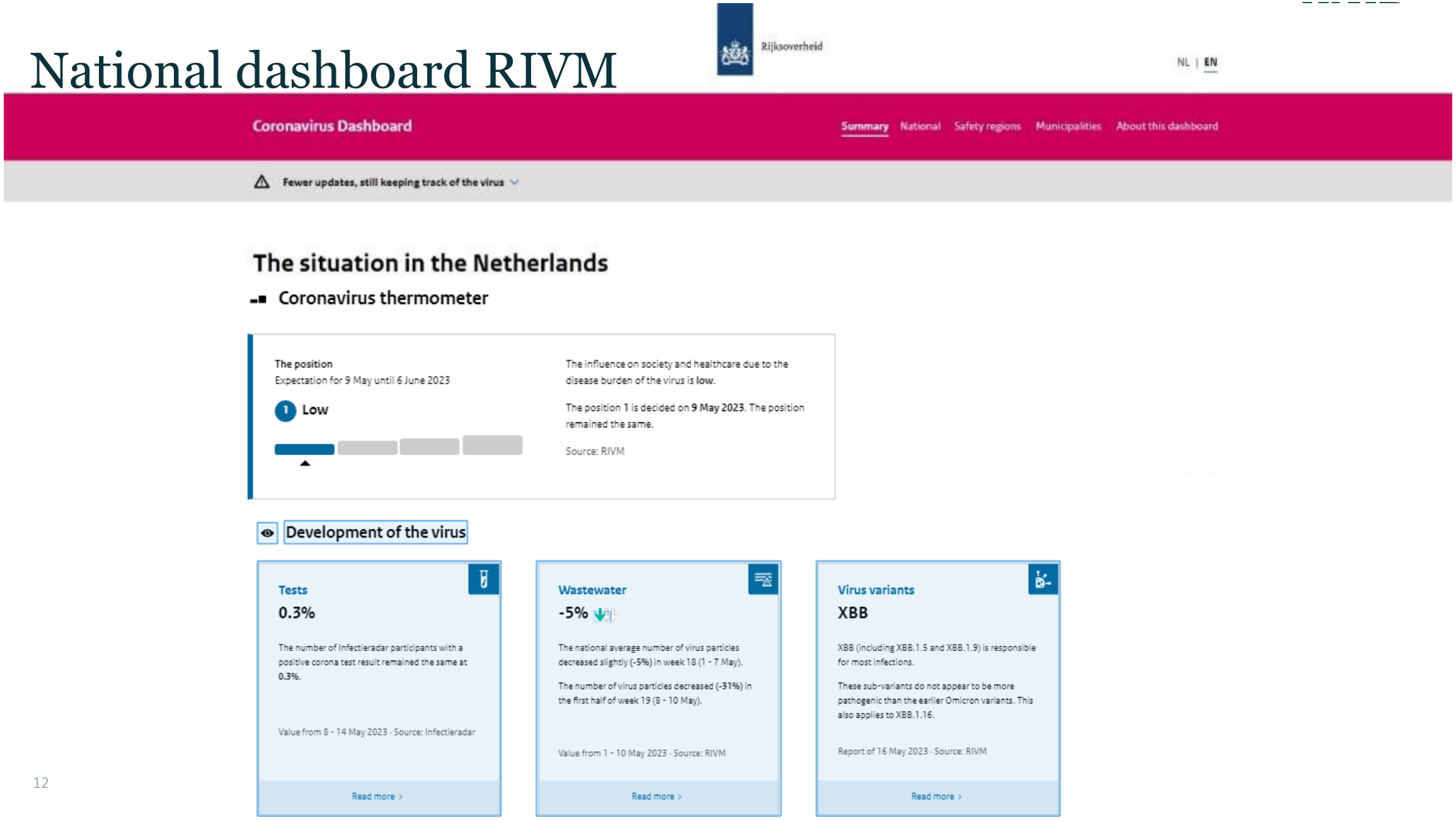
Objective indicator of SARS-CoV-2 circulation, independent of human testing

everybody is going to the toilet, not everybody is going to get tested

- test availability
- testing strategy
- testing willingness
- asymptomatic ‘cases’



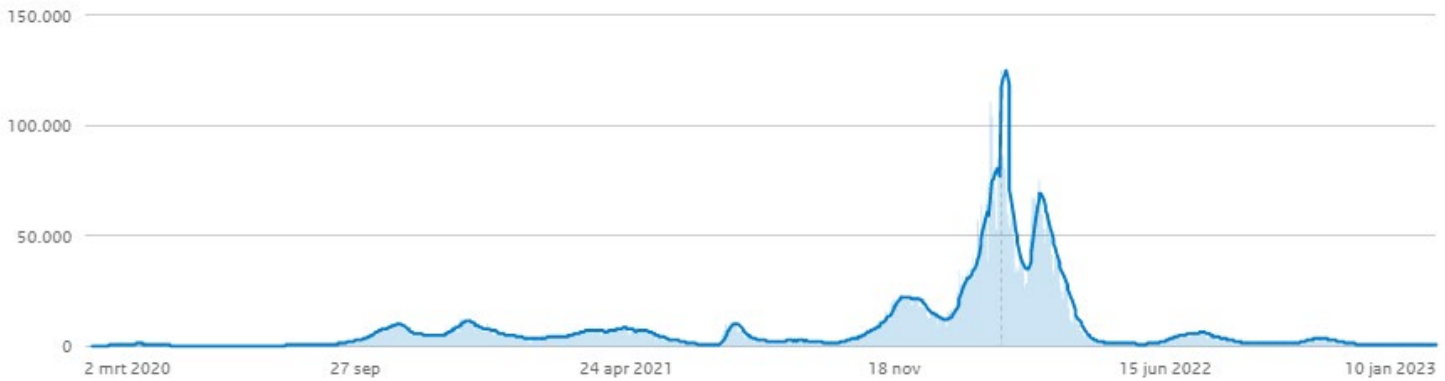
National dashboard RIVM



National data (dashboard RIVM)

Hospitalizations

SARS-CoV-2 load wastewater

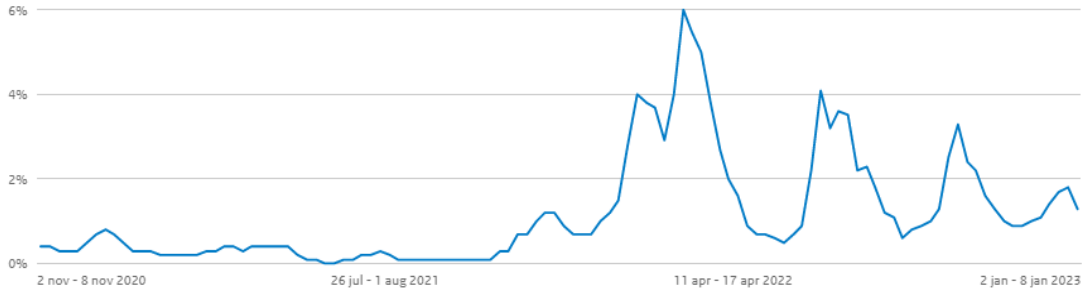


Positive tests

Nationale data (dashboard RIVM)

Hospitalizations

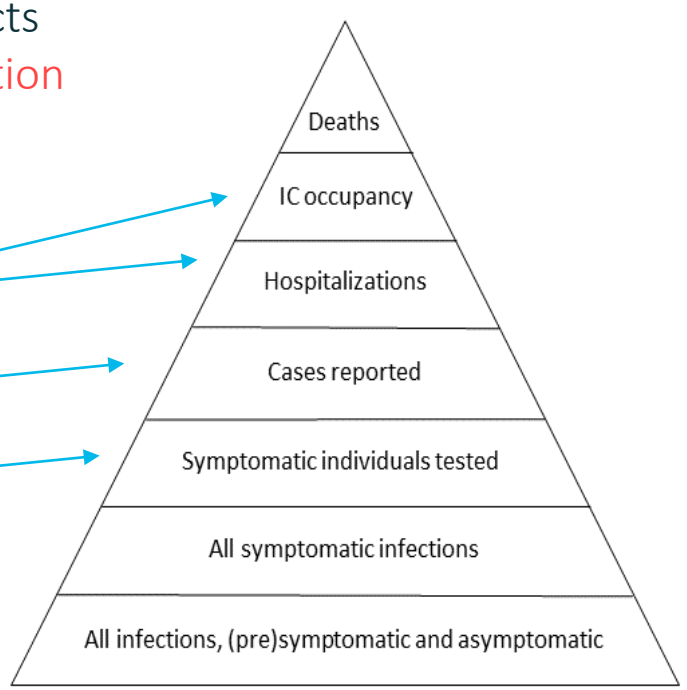
SARS-CoV-2 load wastewater

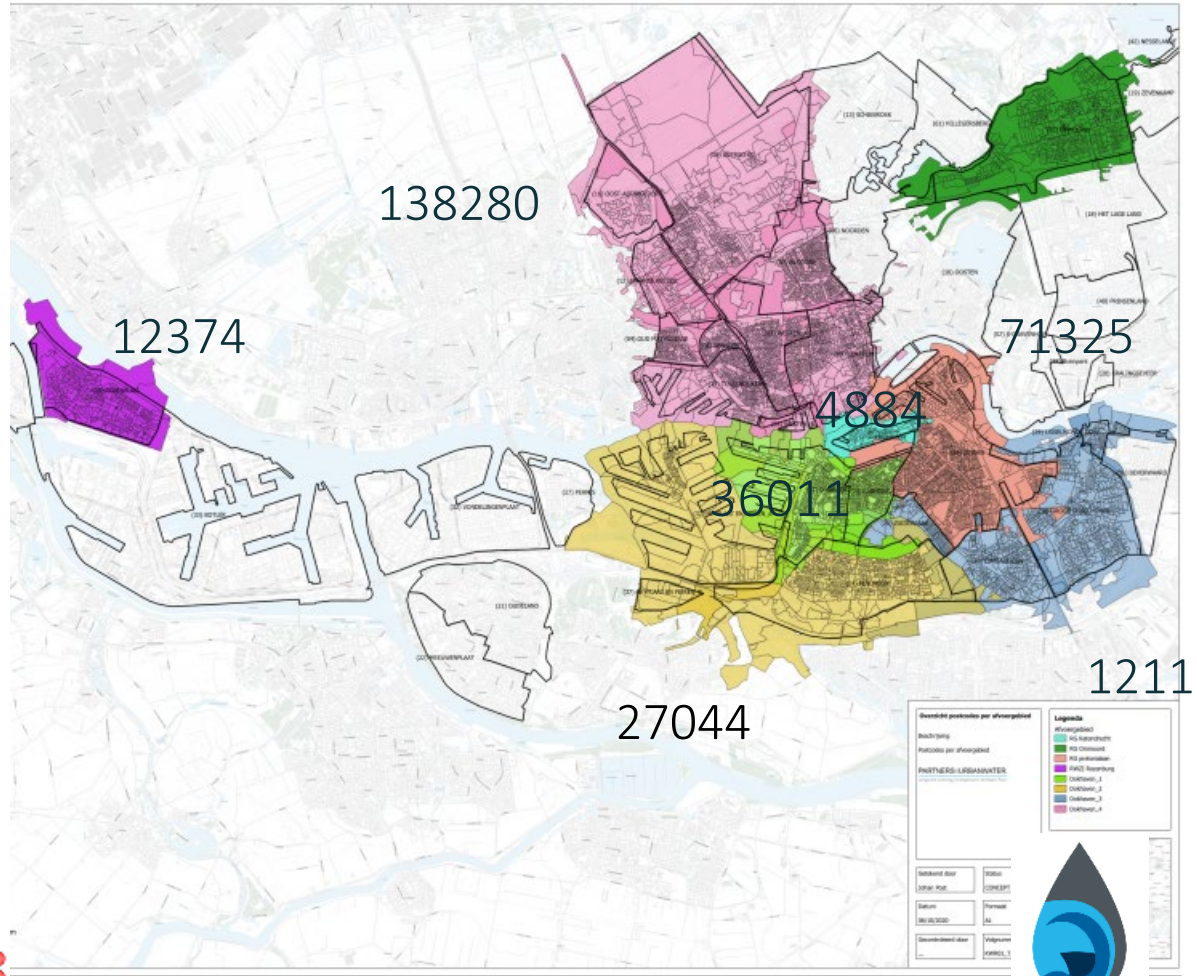


Population study (self reported positive tests) Infectieradar

Use case: understand COVID-19 dynamics: the infectious disease surveillance pyramid

High resolution surveillance:
- Time: 3/week
- Space: city districts
- Matched population

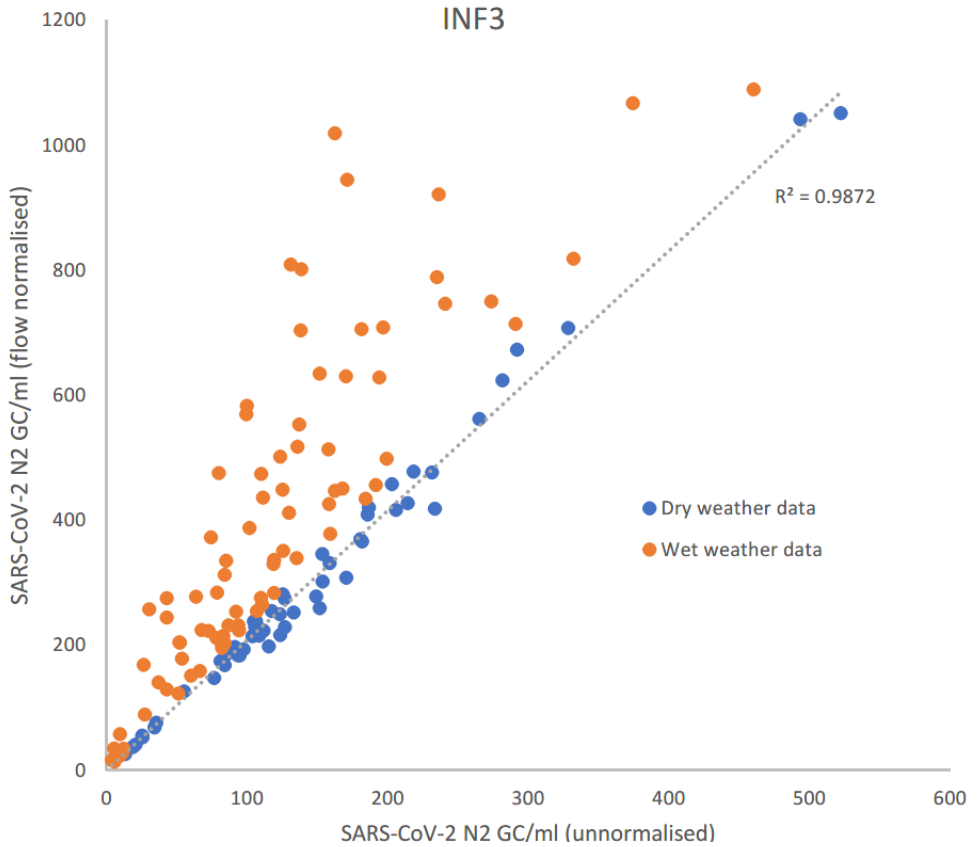




Rain dilutes SARS-Cov-2 signal

Wet weather Rotterdam district 3
Lower SARS-CoV-2 concentration
Up to factor ~3 to 4

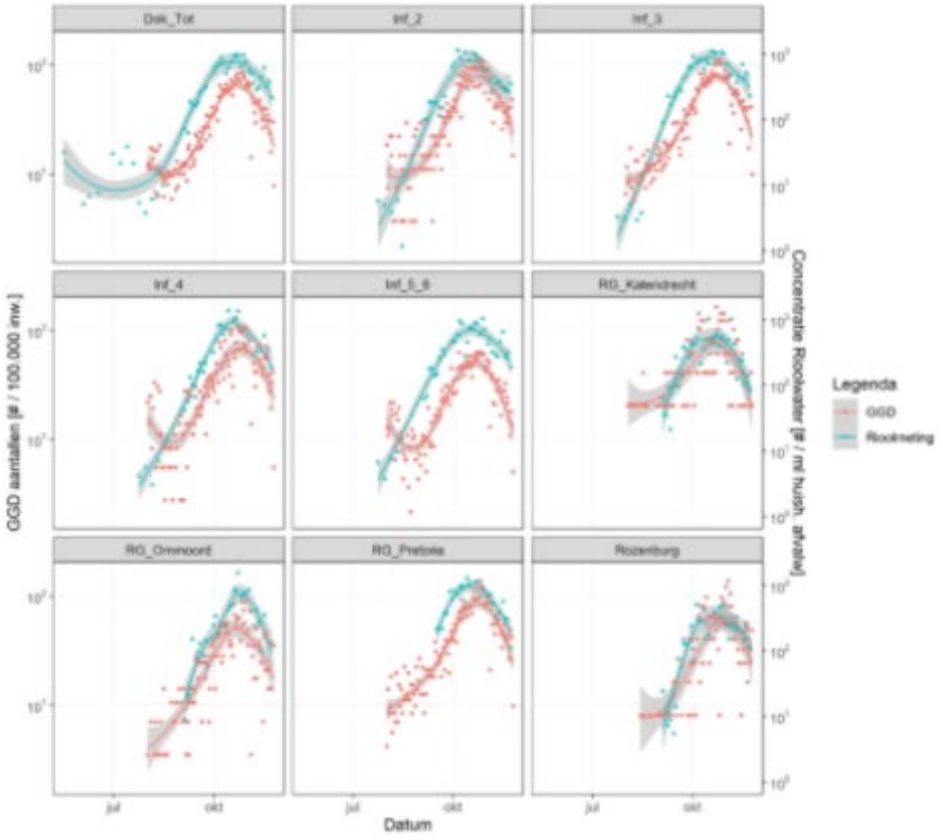
Normalisation of SARS-CoV-2 concentration with domestic wastewater flow (inhabitants * 120 l pppd), checked with conductivity and CrAssphage



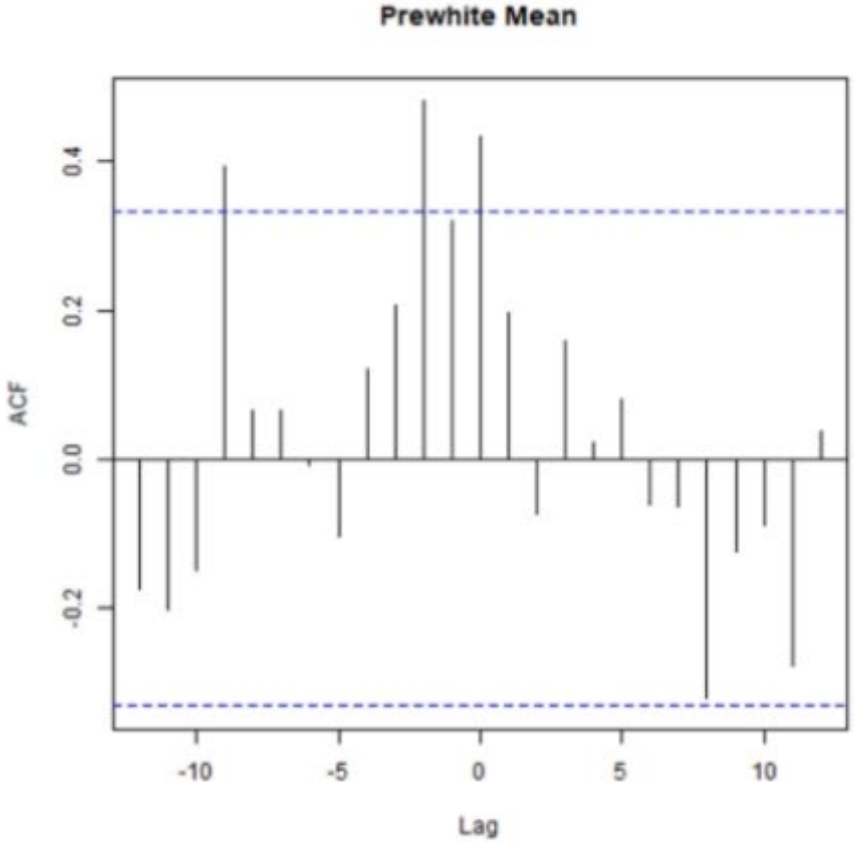
Comparing sewage and clinical surveillance
Second wave (sep – dec 2020)

KWR

Trends in clinical (red) and sewer (blue) data

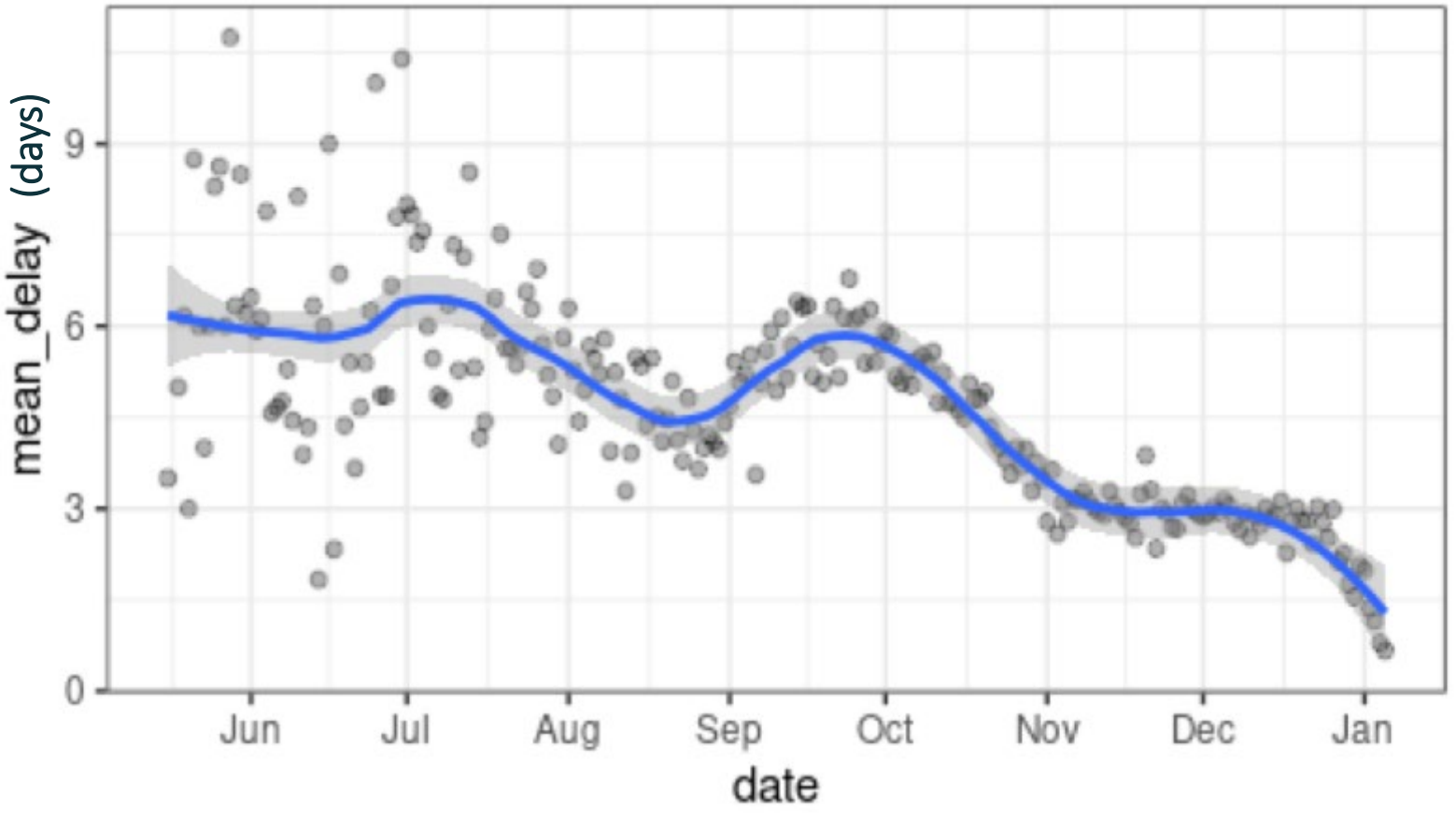


Autocorrelation between clinical and sewer data

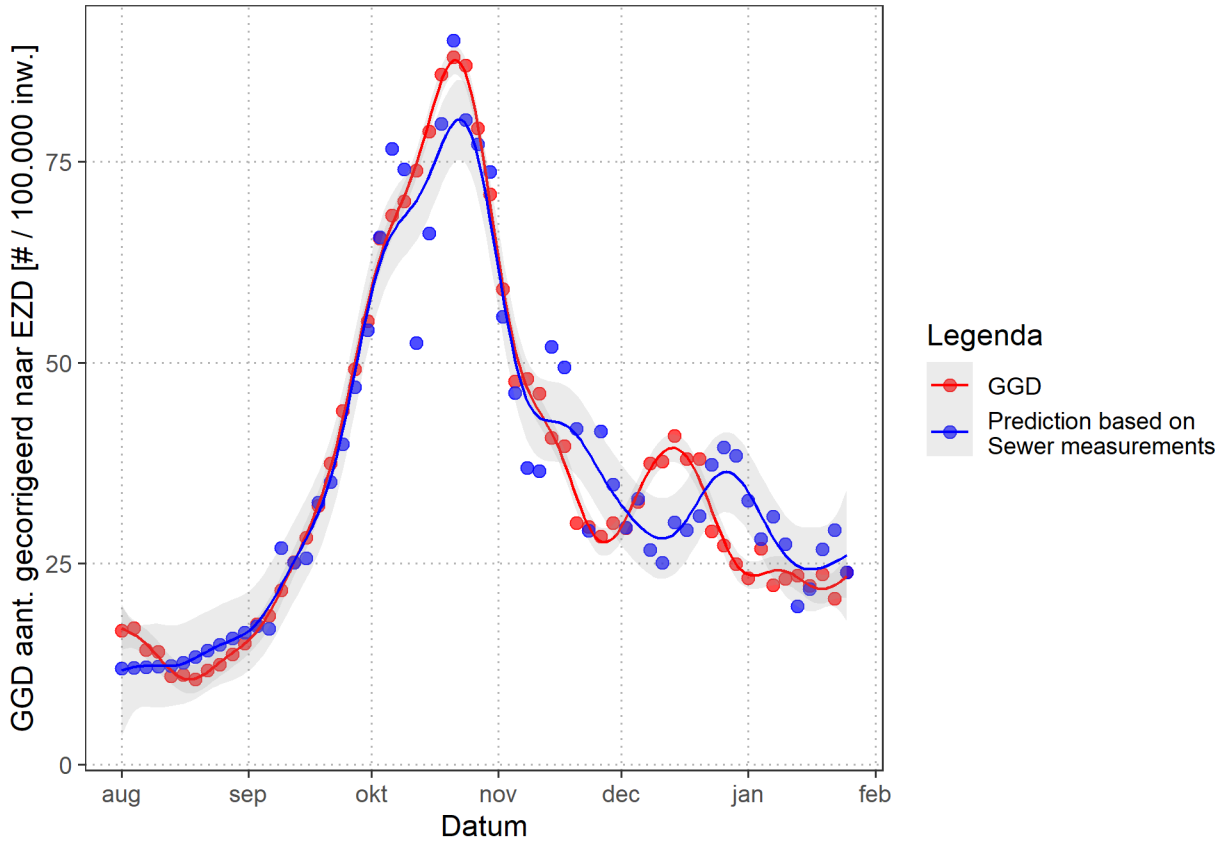


Highest correlation with 0 / -2 (= sewers are 6 days ahead)

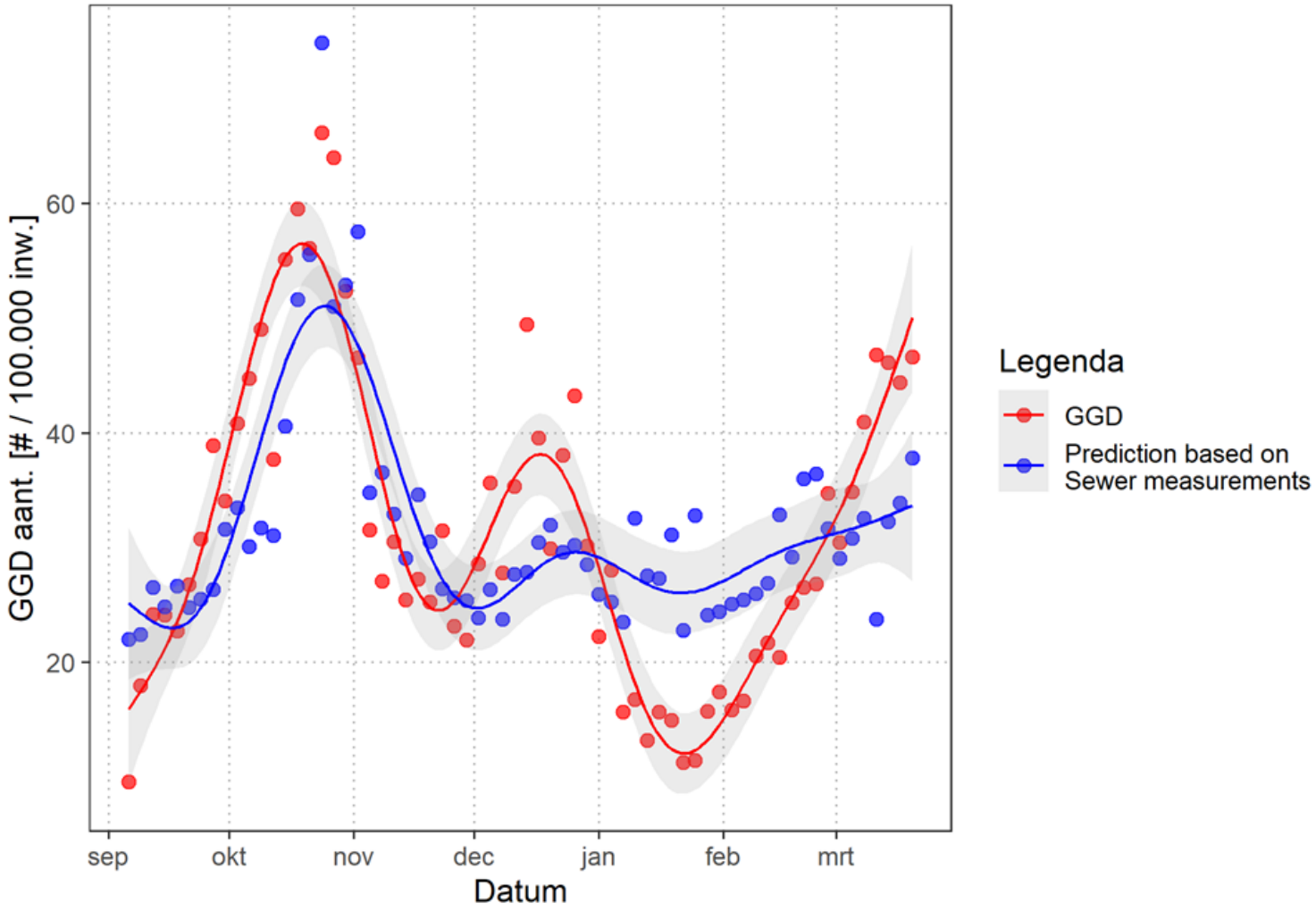
Delay in clinical testing (disease onset vs nose swab)



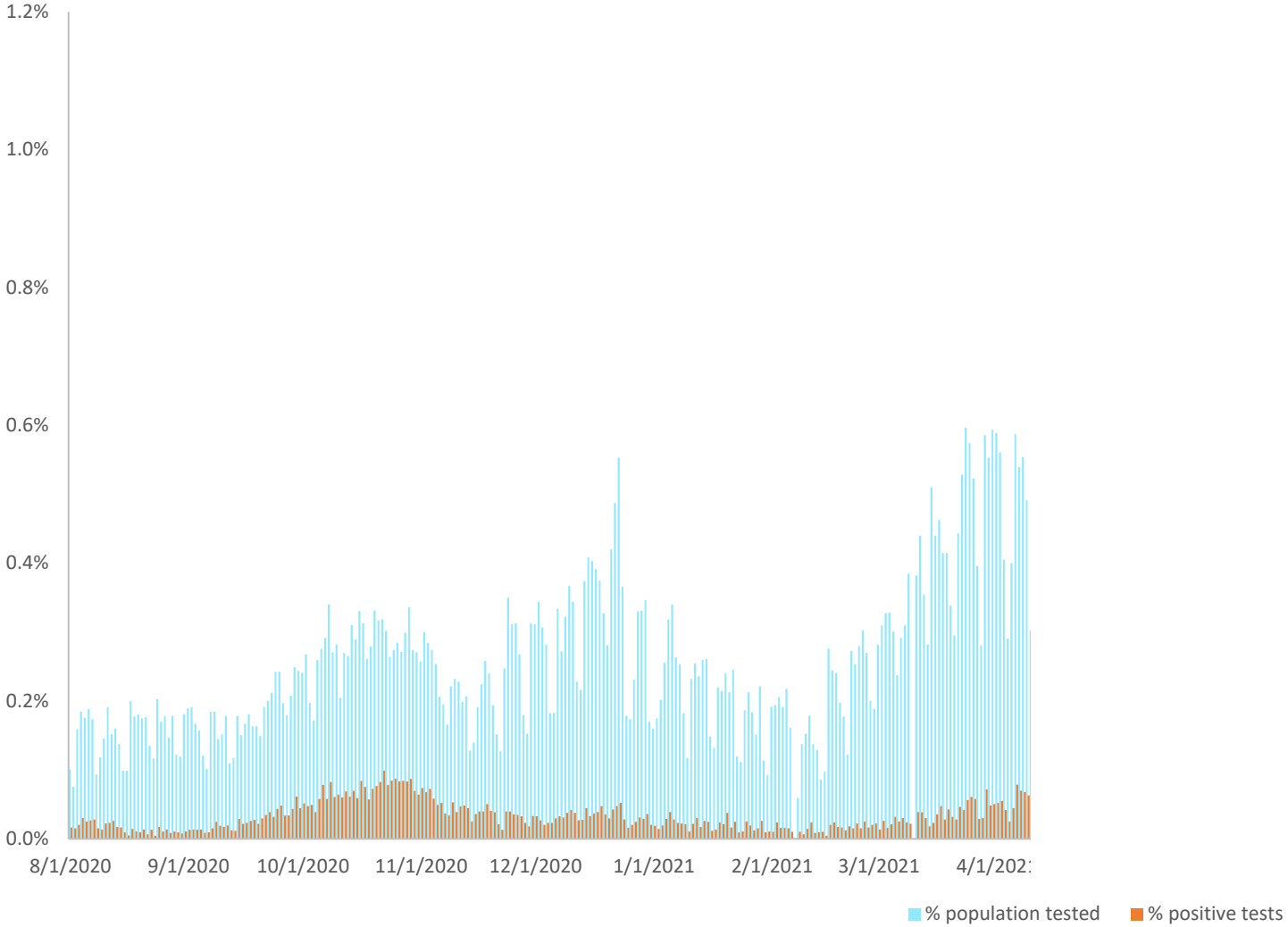
Simple linear regression positive tests onset day vs sewage



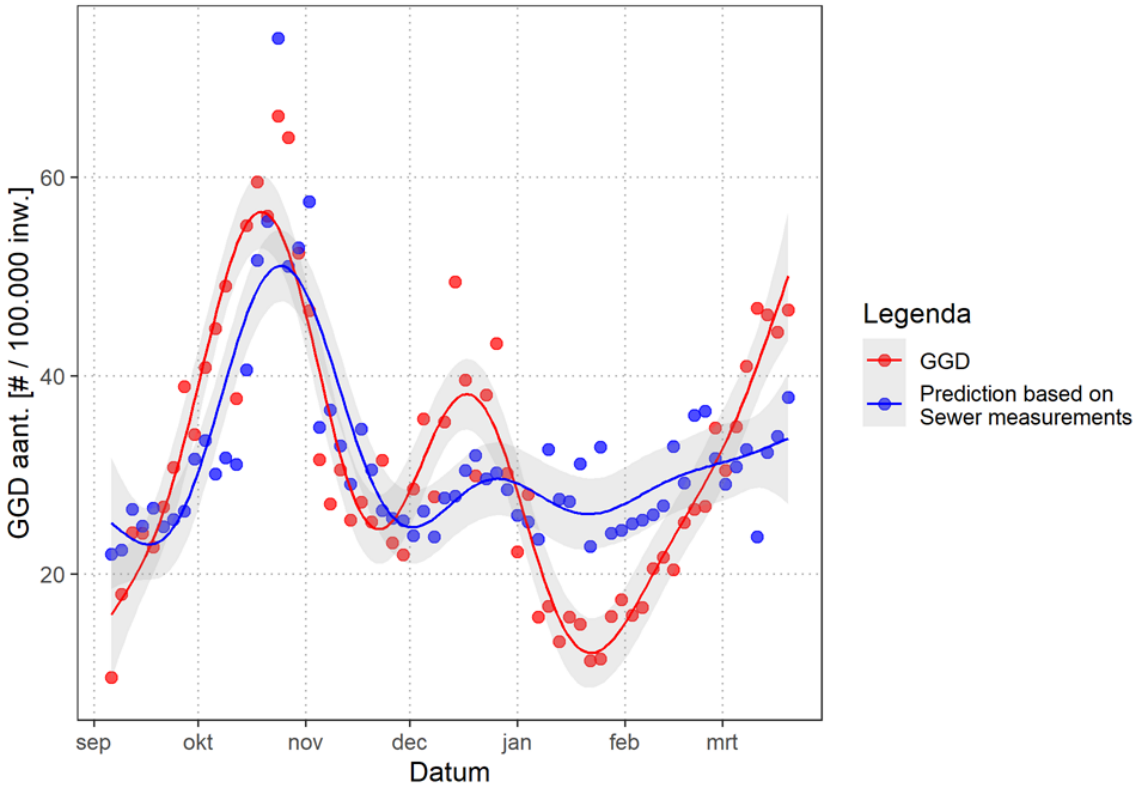
Model started to diverge in Dec 2020

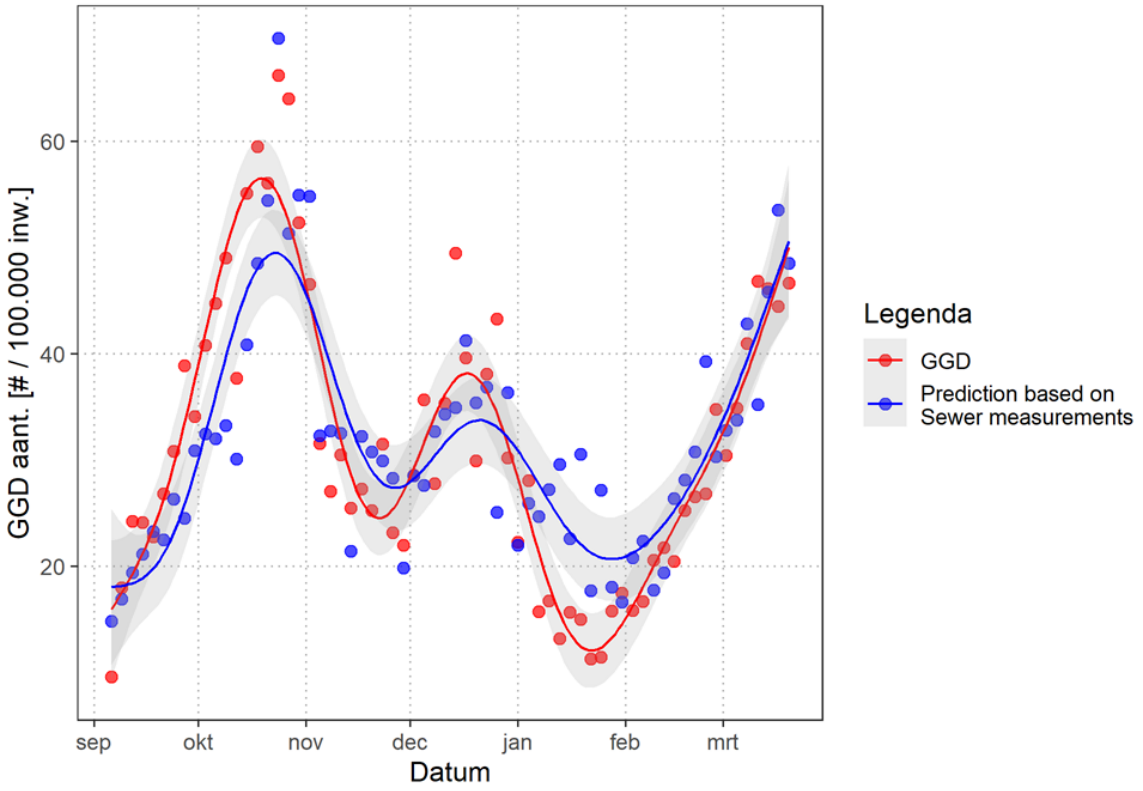


Dynamics in clinical testing (Rotterdam data)

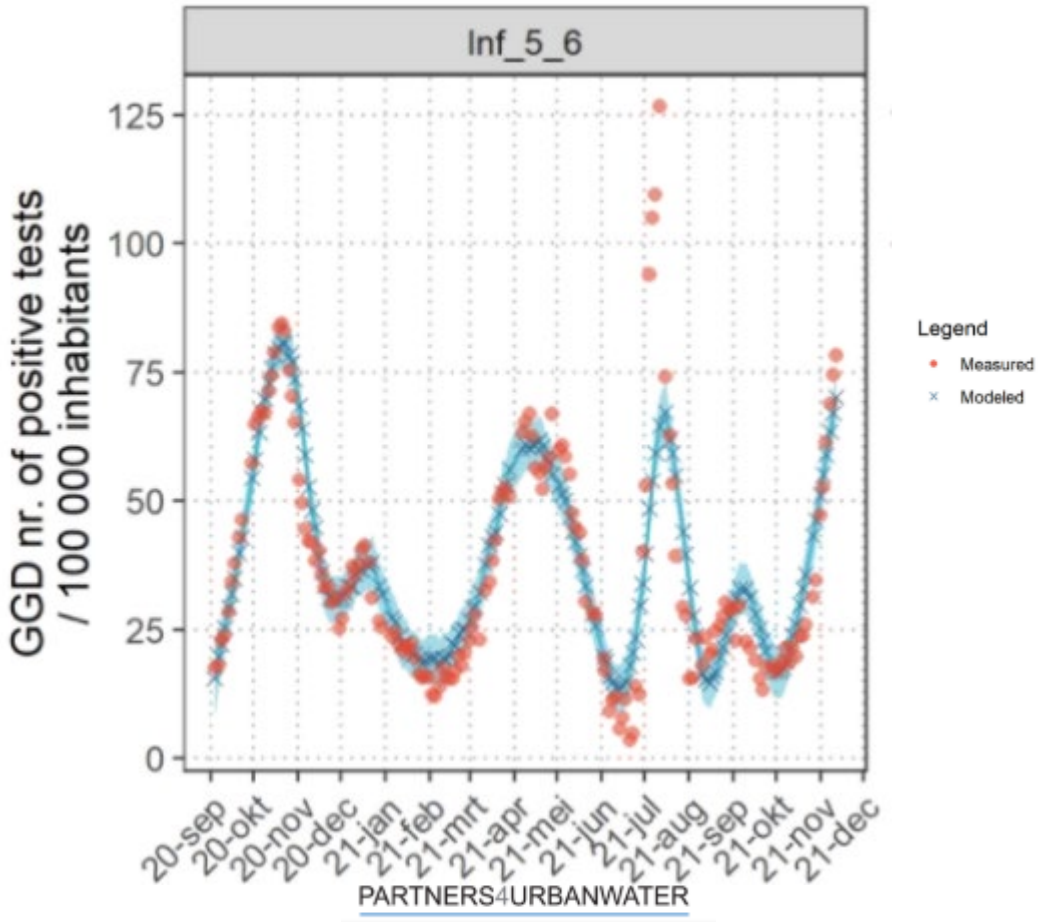


Model improvement: include testing rate as index of testing behaviour





Relation between concentration in wastewater and newly reported cases



Normalisation of wastewater concentration with flow (with EC)

Langeveld et al, 2022, STOTEN

Normalisation of newly reported cases

- For test delay (to symptom onset day)
- For test behaviour (#tests per 100,000)

De Graaf et al, 2023 STOTEN

Wastewater = newly reported cases

- Also with Alpha and Delta
- Also with vaccination
- Except for July 2021 (open nightlife if tested)

Data analysis Rotterdam data

Sewage as objective indicator of virus circulation

Undertesting of humans in certain city areas?

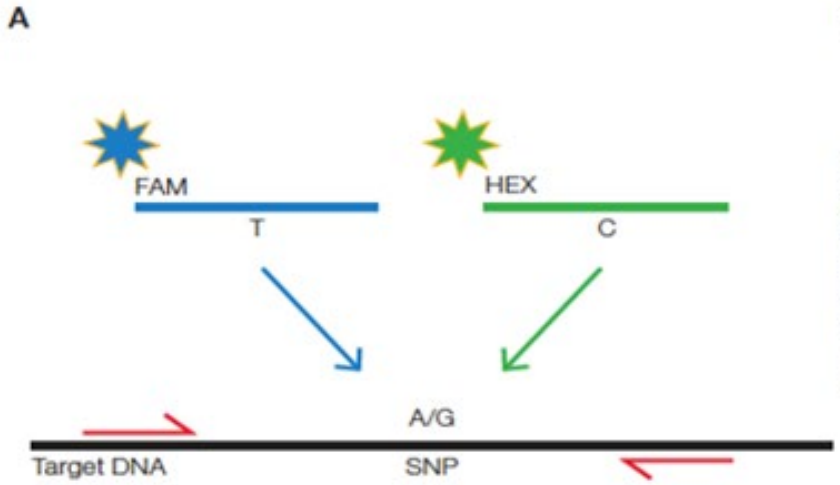
Sewage data used to mobilize testing facilities to city areas with low case number/sewer signal ratio

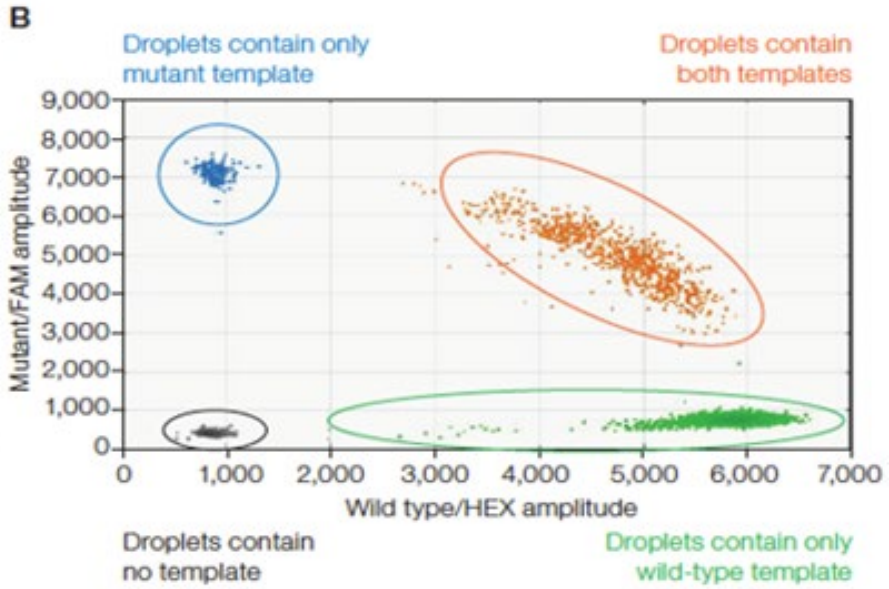
Linking sewage data to human testing data: correct for human testing behaviour via total number of tests

KWR, GGD Rotterdam, Erasmus MC, Partners4UrbanWater, RHDHV, RIVM, Water authorities: Hollandse Delta, Delfland, Schieland & Krimpenerwaard

dd-PCR to detect signature mutations of VoC

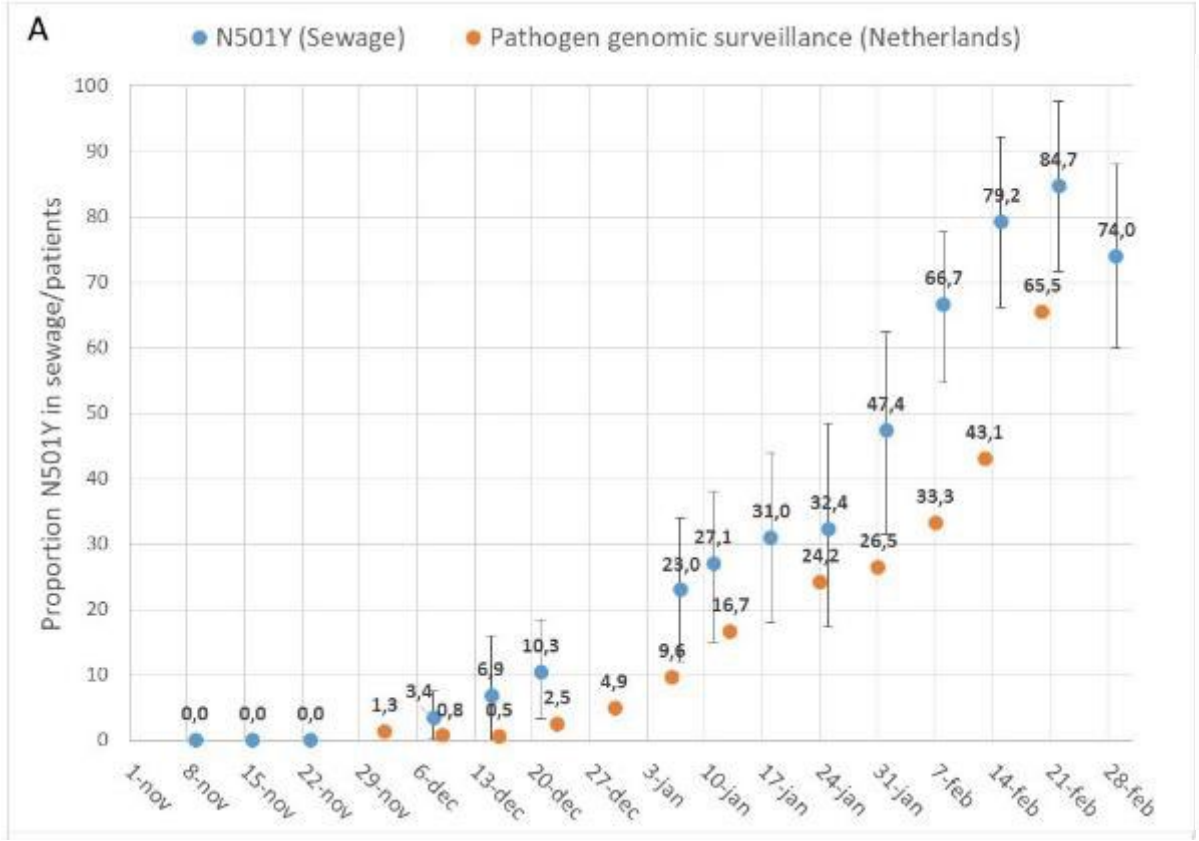
1. Divide wastewater extract in ca 20,000 droplets (each droplet with very few virus-RNA strands)
2. Run PCR in each droplet, using two probes with different colours: one for the wild type and one for the mutant (differ only a SNP)
3. Absolute quantification: count droplets in which the wild type vs in which the mutant (or both
4. Determine relative abundance of wild type and signature mutation in sample



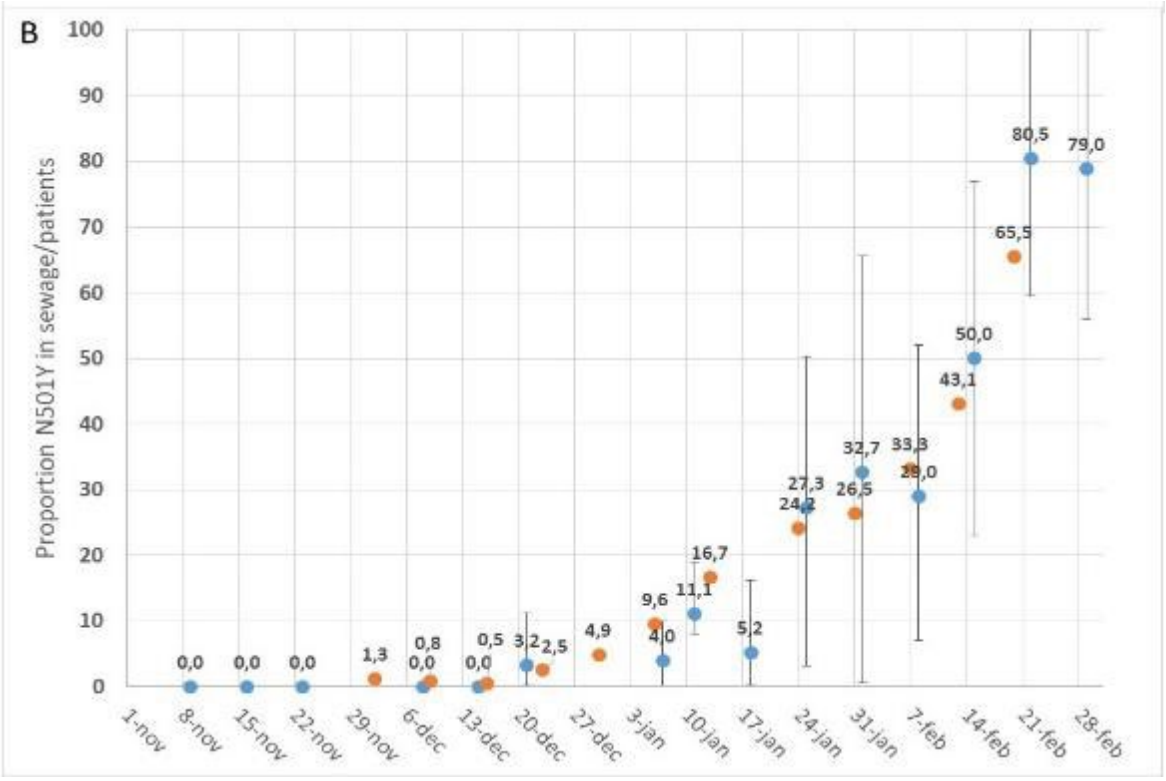


Courtesy of Biorad

Use case: Variant of Concern Alpha introduction N501Y mutation vs 'wild type' by ddPCR (2020/2021)



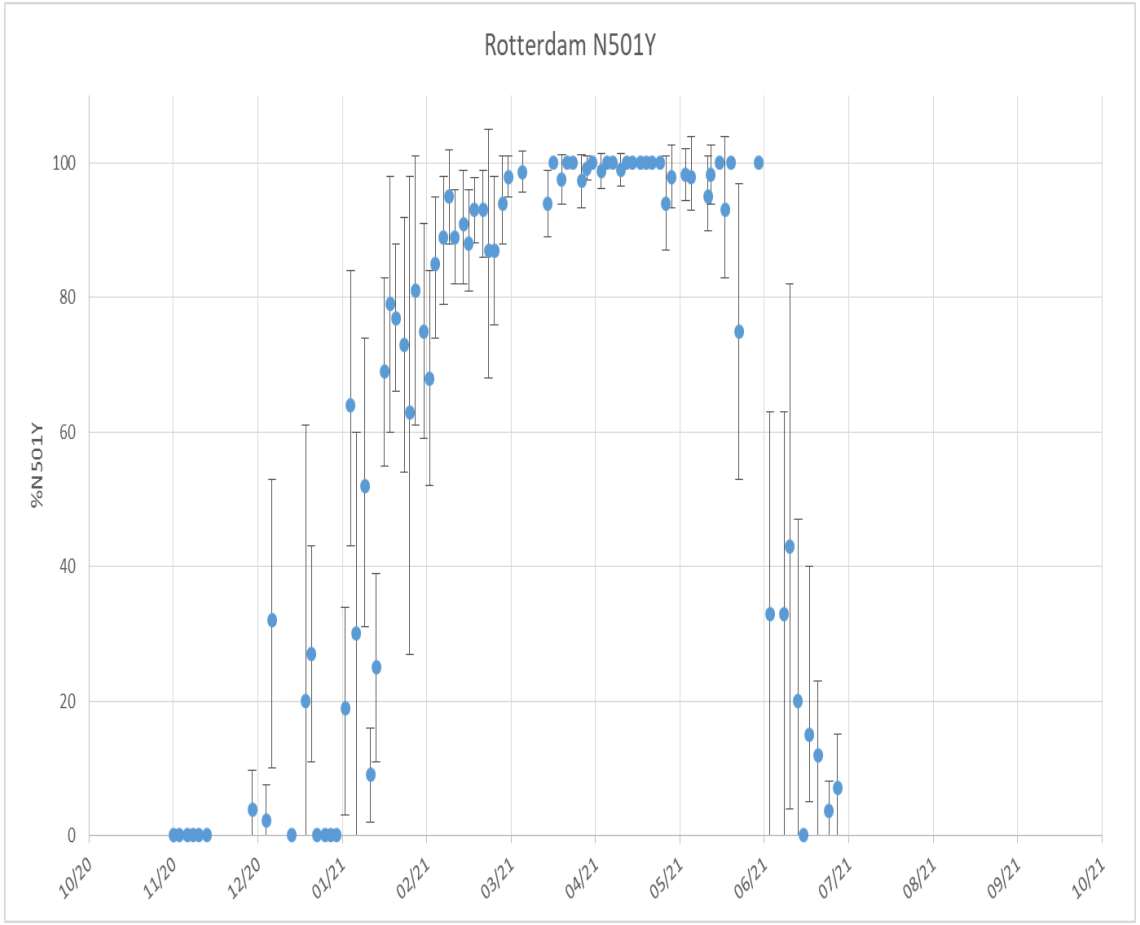
Amsterdam

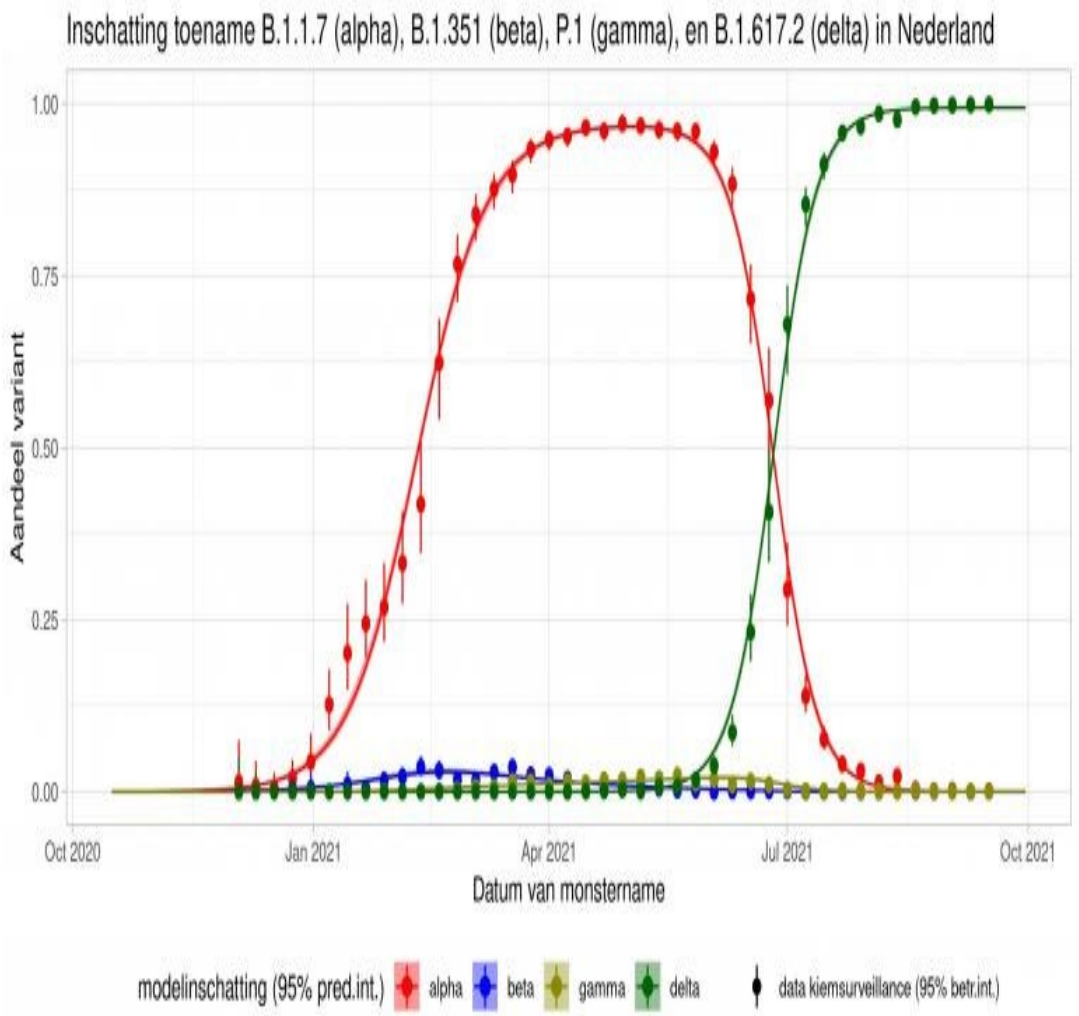


Utrecht

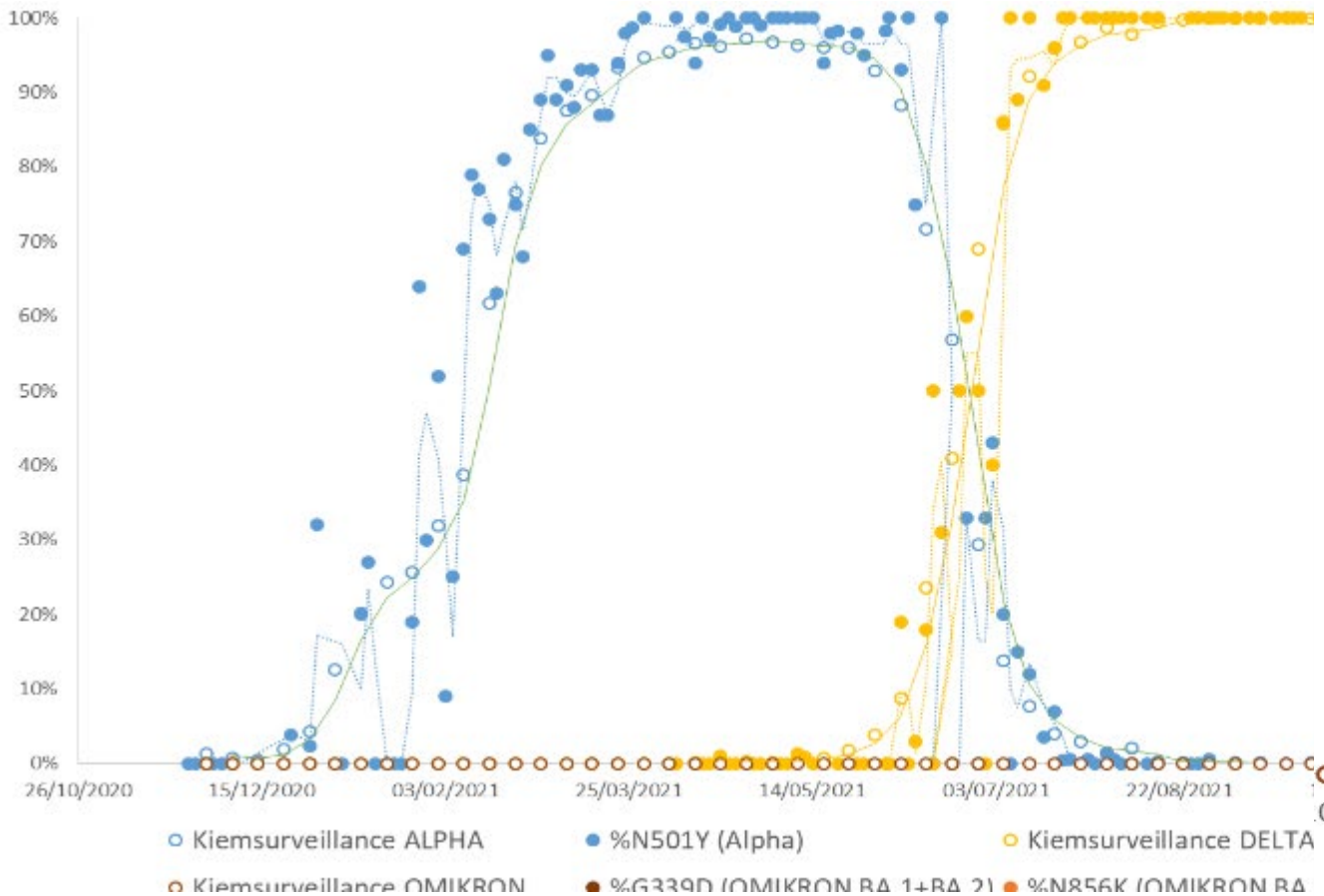
Heijnen et al, 2021, STOTEN

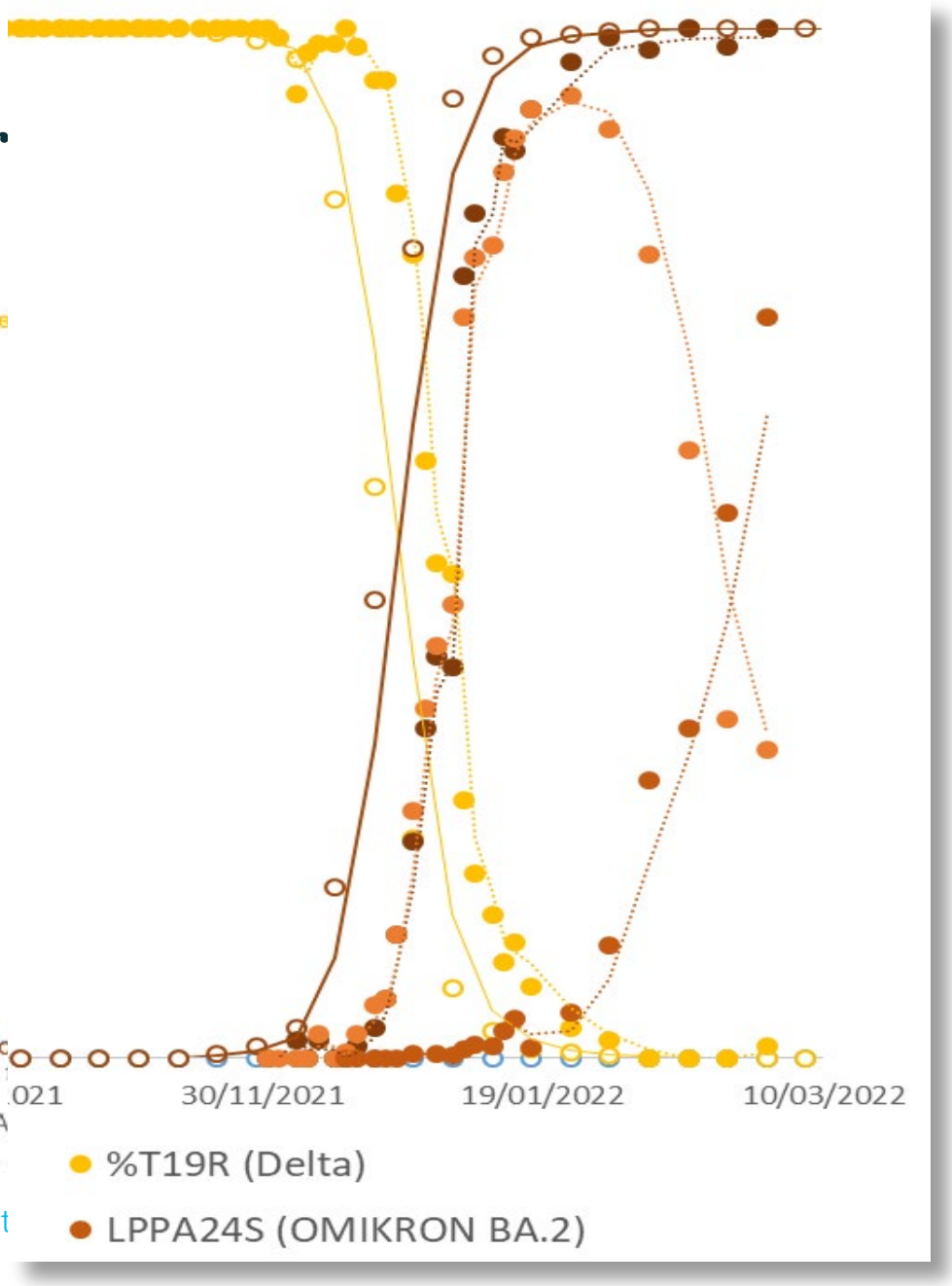
Wastewater surveillance N501Y (alpha) vs Kiemsurveillance (alpha)





New variants in clinical vs sewage sur

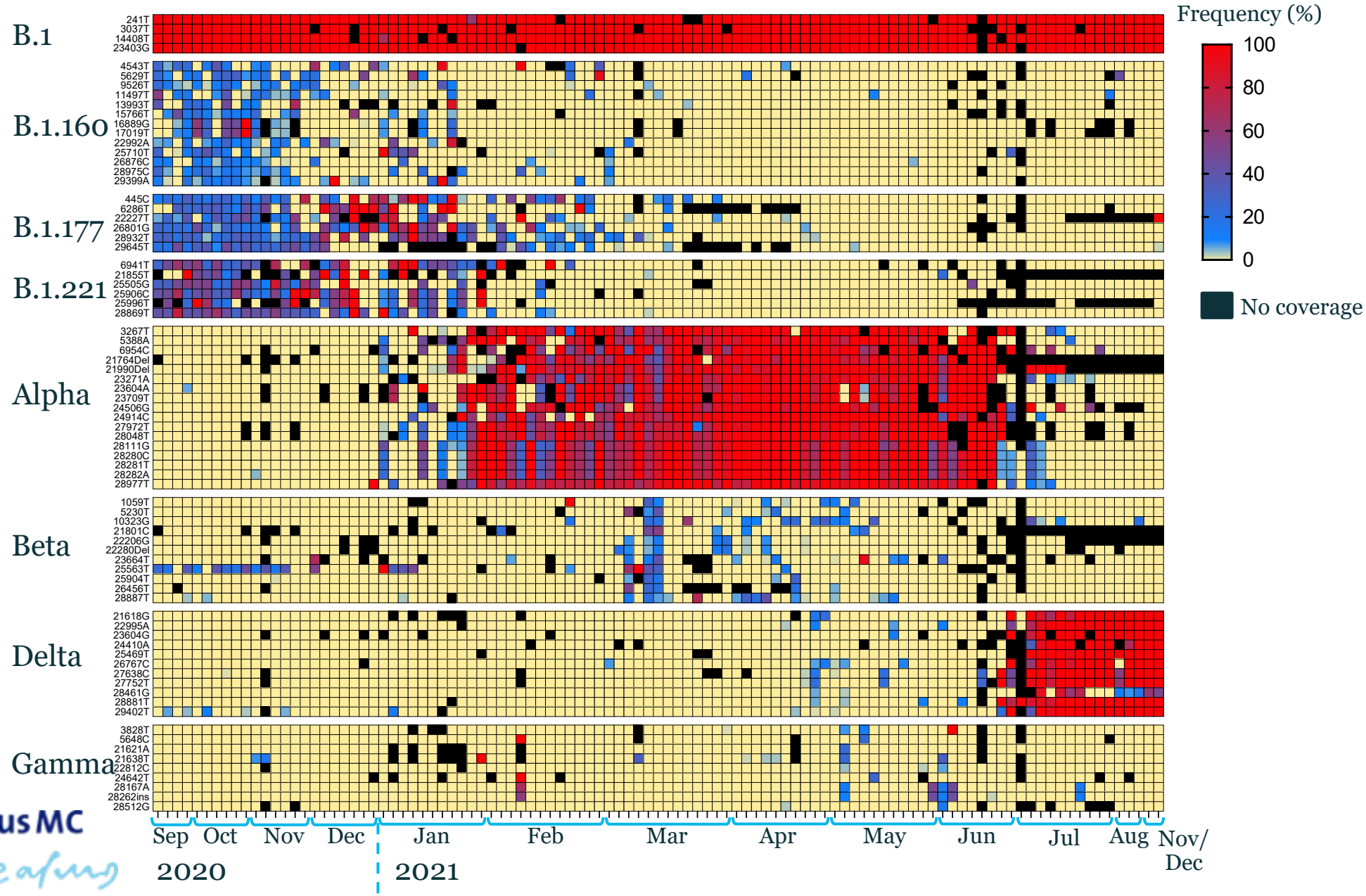




Kiemsurveillance national data RIVM; ddPCR data Rotterdam; new variant

SARS-CoV-2 VoC mutations over time in Rotterdam sewage (NGS)

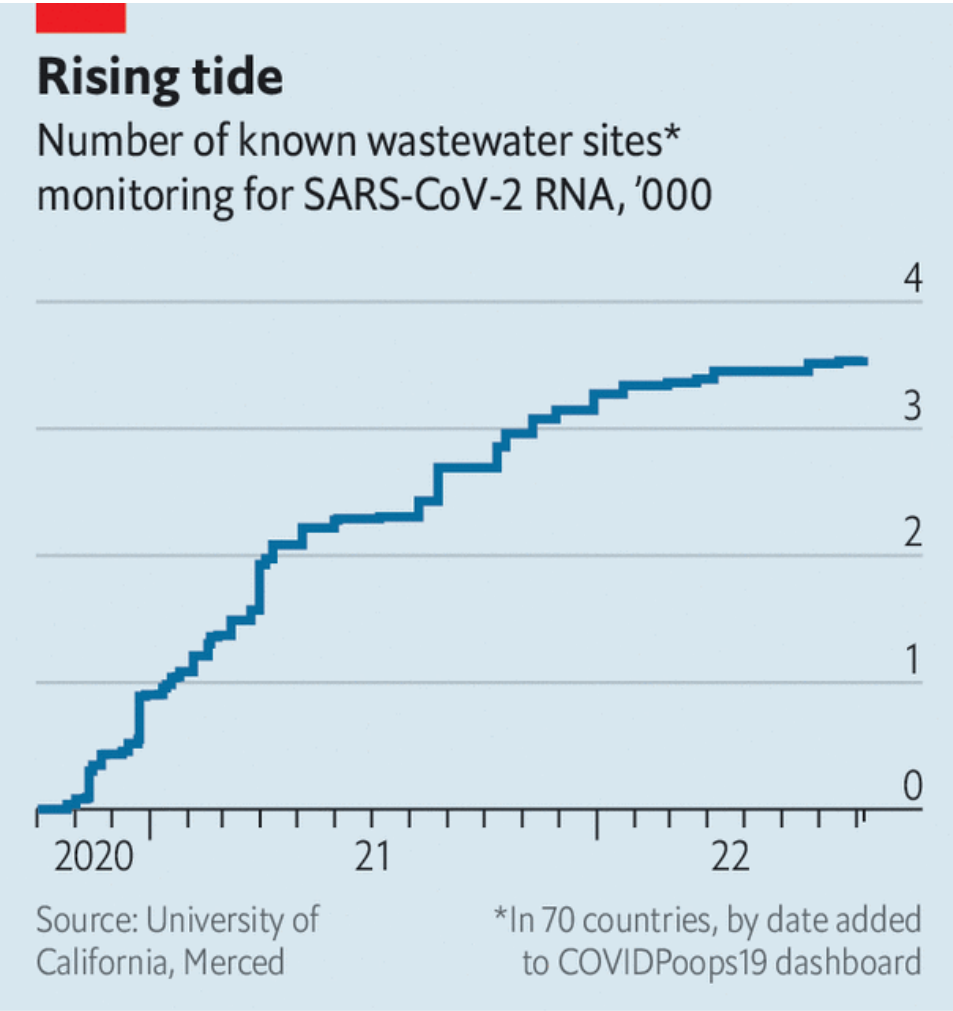
Izquierdo et al, submitted



Where there's muck, there's data

"We've done a decade's worth of science in the first year"

Doug Manuel (epidemiologist at the University of Ottawa)



The Economist

https://sphere.waterpathogens.org/

WASTEWATER SPHERE

Wastewater SARS Public Health Environmental REsponse

The WSPHERE global data center and public health use cases

WASTEWATER SPHERE

GLOBAL MAP | DATA | USE CASES | ABOUT | CONTRIBUTE

Welcome to the W-SPHERE Map

W-SPHERE serves as a global center for data and public health use cases on SARS-CoV-2 in wastewater, and is not designed to take the place of the local dashboards. Please use the links provided to the local data/dashboard to view the most up to date local information.

Datasets (with # of sites)

Category

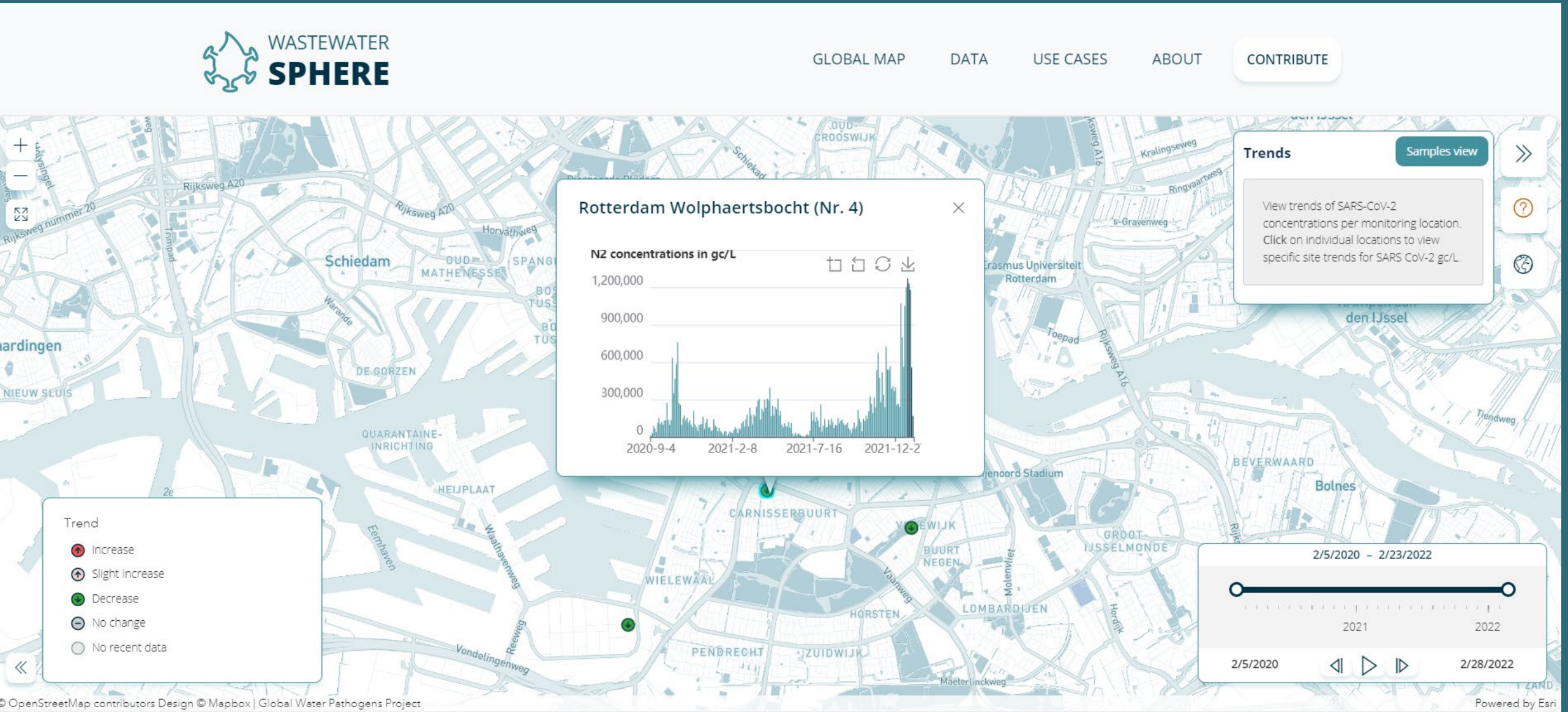
- Data Dashboards included in W-SPHERE (standardized)
- Data Dashboard included in W-SPHERE (not standardized)
- Future Data Dashboards to be included

Partners:

PATH | MICHIGAN STATE UNIVERSITY | KWR | UNIVERSITY OF CALIFORNIA MERCED | ENTHIC

W-SPHERE is being developed as part of a larger wastewater surveillance project led by PATH and is funded by the Bill & Melinda Gates Foundation and the Global Innovation Fund.

View trends and data (for quantitative datasets)



Open access data center

CA - Ottawa - ROPEC

Ottawa Public Health

Wastewater samples are from the Robert O. Pickard Environmental Centre (ROPEC) which collects and treats wastewater from ~91.6% of Ottawa's population. 2,846 km of sanitary sewers, 108 km of combined sewers, 71 wastewater pumping stations,...

2x csv 1x geojson

National

LU - country data - LIST

Environmental Microbiology and Biotechnology research group

This dataset presents the results of national-wide wastewater monitoring efforts in Luxembourg through the sampling of 13 different WWTP across the country from March 2020.

2x csv 1x geojson

National

SI - country data - NIB

NIB - National institute of biology

Wastewater influent samples from slovenian WWTPs.

Scale

- Regional (10)
- National (8)
- Building (1)
- Urban (4)

System Setting

- non-sewered (4)
- treatment facility (13)
- sewered (9)

Data Sources

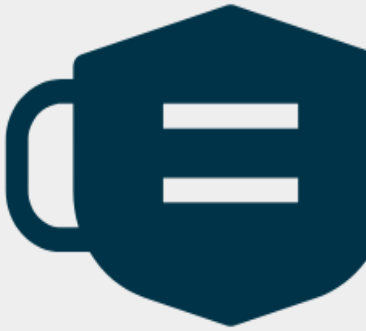
- Scottish Environmental Protection Agency (1)
- KWR Water Research Institute (1)
- Ohio Department of Health (1)
- Ottawa Public Health (1)

Public health use cases

Use cases

Have your wastewater data been used to underpin public health actions?

Our goal is to help health authorities understand the added value of wastewater surveillance, by showcasing good examples of how wastewater data have been used to support public health actions in different settings (national, regional, local, building-level surveillance; high and low resource settings; sewered and non-sewered settings).



Published use cases

South Africa sewage surveillance use case ZA - Water Research Comission	Ghana sewage surveillance use case GH - Greater Accra	Canadian sewage surveillance use case CA - Windsor
Switzerland sewage surveillance use case CH - Eawag	Dutch sewage surveillance use case NL - Rotterdam KWR	Catalan Surveillance Network of SARS-CoV-2 in Sewage ES - Catalonia ICRA

Public health use case Victoria (Australia)

Victoria Australia

Early warning

Adjunct outbreak response

Wastewater surveillance of SARS-CoV-2 (2021)

Aug 12: Positive sample in Shepparton, no reported cases

State and local Health Dept notified: public notification and expanded wastewater surveillance

Aug 19: 4 more positive wastewater samples

Further press coverage, expanded clinical testing services

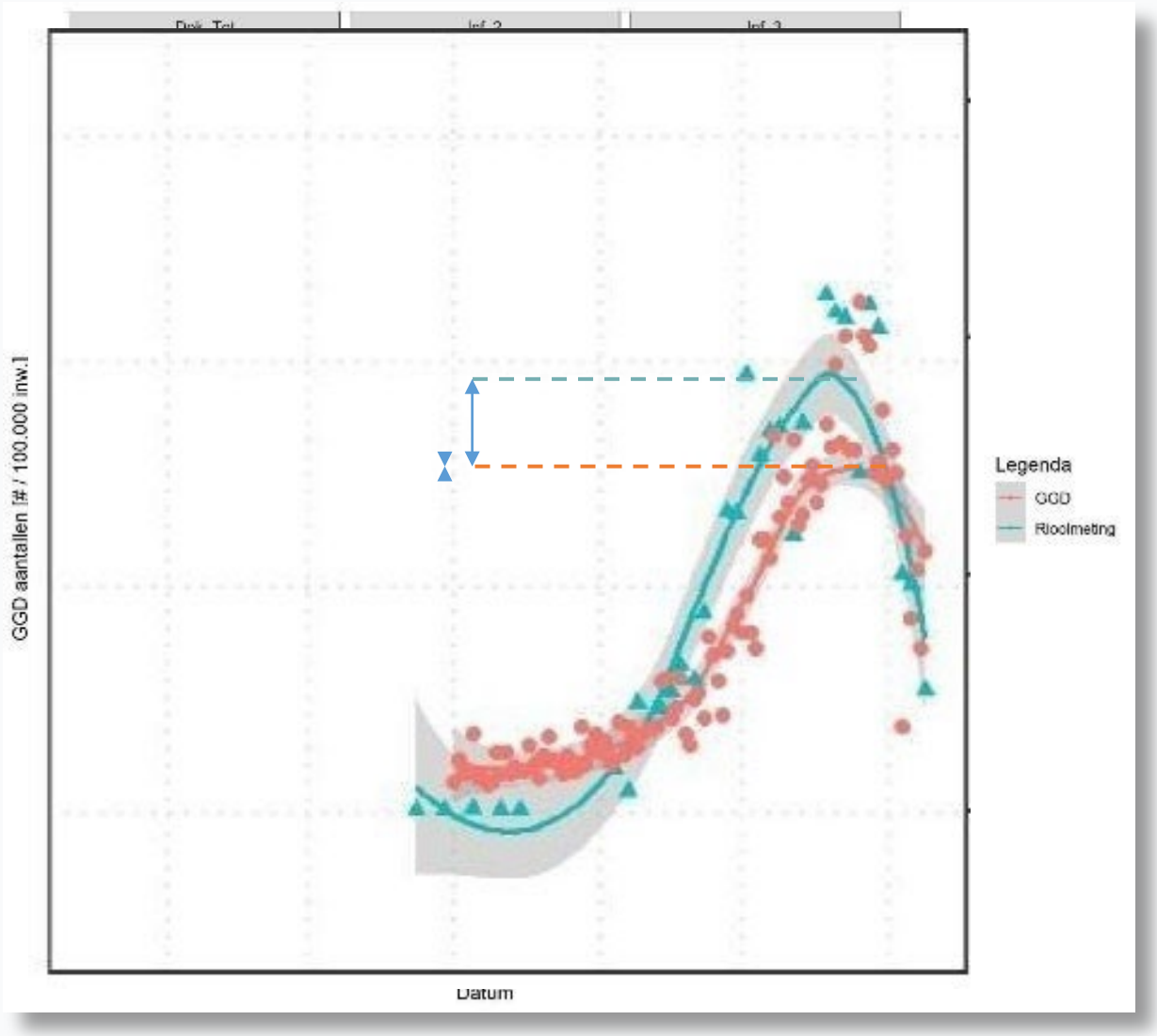
Aug 20: first case reported

Lockdown, expand wastewater testing to towns in region and localised surveillance at facilities with large vulnerable populations

Public health use case Rotterdam (NL)

Undertesting of humans in certain city areas

Sewage data used to mobilize testing facilities to city areas with low case number/sewer signal ratio



Public health use case Rotterdam (NL)

Undertesting of humans in certain city areas

Sewage data used to mobilize testing facilities to city areas with low case number/sewer signal ratio

Public health use case Switzerland

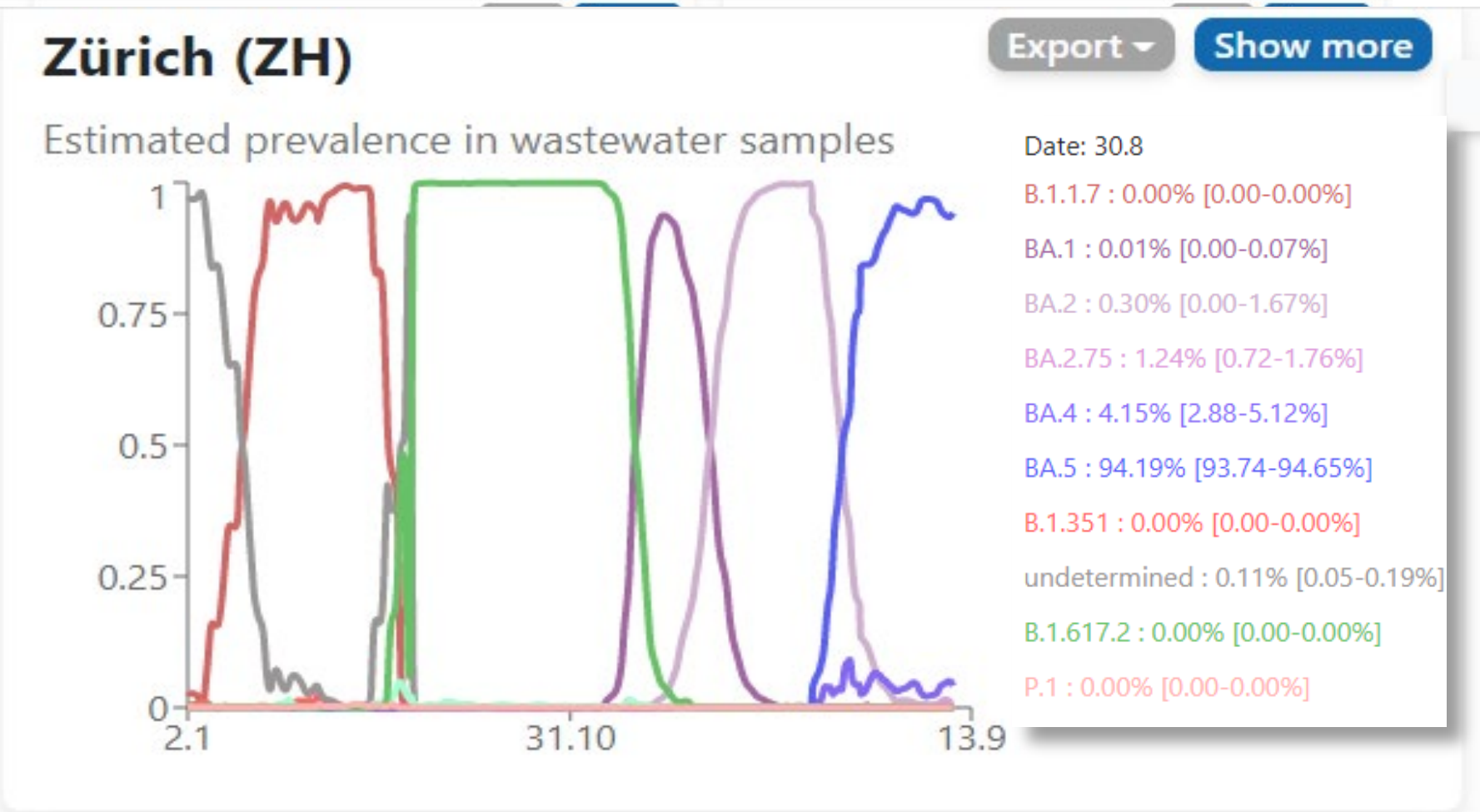
Swiss sewage surveillance use case

Overview of wastewater monitor... | Dashboards | Key information | Timeline | Health actions | Added value of sewage surveill... | Success factors | Limiting factors | Stakeholder participation | Relevant web links →

Switzerland

Comprehensive and early detection of VoC at high resolution

ETH Zürich, EAWAG, EPFL



Public health use case South Africa

Public health use case South Africa

South Africa sewage surveillance use case

Overview | Key information | Health actions | Added value of sewage surveill... | Success factors | Limiting factors | Stakeholder participation | Relevant web links and publica...

Identifying the appropriate sampling area

Through trial-and-error, it was decided that the **run-off and streams nearby settlements** were the most appropriate sampling points and that **passive sampling** overcame the challenges of routine sampling in non-sewered settlements.

Public health use case South Africa

South Africa sewage surveillance use case

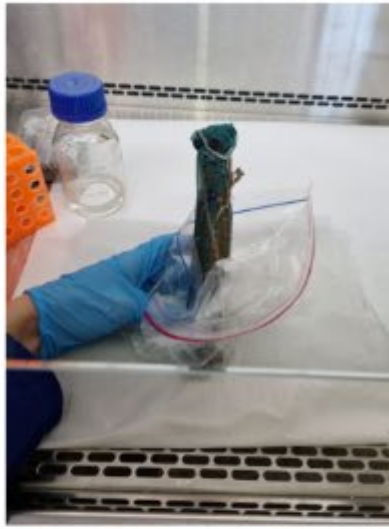
Overview | Key information | Health actions | Added value of sewage surveill... | Success factors | Limiting factors | Stakeholder participation | Relevant web links and publica...

Passive sampling

Passive sampling devices were placed for 24 h in the selected areas.

They were selected because of:

1. Low yield during high dilution periods
2. Easy and cheap sample transfer
3. Fast sample processing



Added value for pandemic response

- Early warning
- Objective, independent of human test behaviour
- Efficient: one sample for a population sample
- Low cost
- Versatile: city, city area, building, on-demand, non-sewered
- Feasible for emergence of Variants-of-Concern
- qPCR platform expendable

International experience (EU and beyond)

Collecting data from wastewater to support public health response

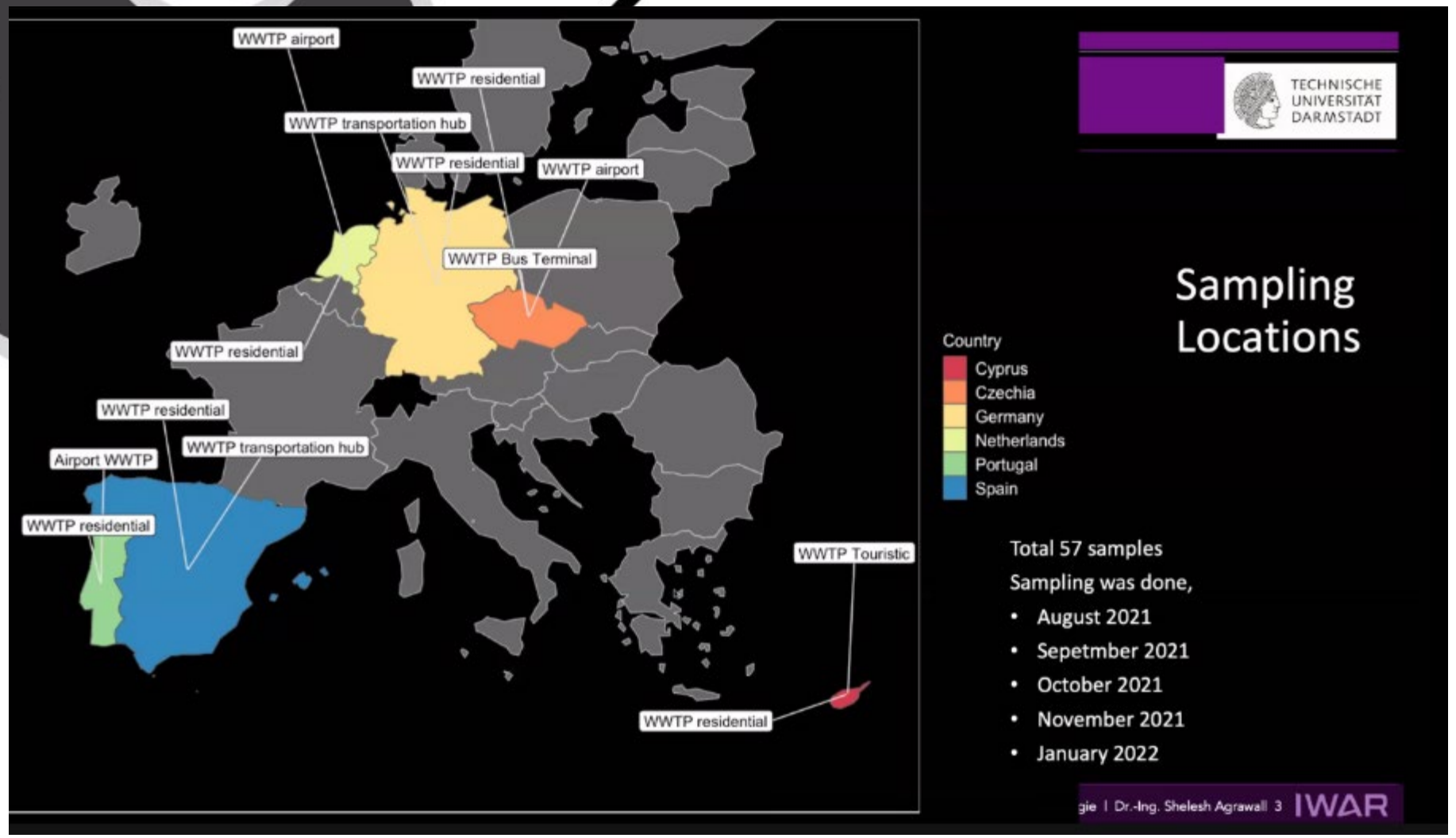
- Atypical for health sector (why do we want sewage data?)
- Atypical for water sector (why do we collect health data?)
- Atypical for academia (surveillance is not research)

Successful implementation of (actionable) sewage surveillance

- Public health institutions that bridge health and environment (see Netherlands, Finland, Hungary) or are ‘early adopters’ (US-CDC, Victoria Dept of Health)
- Local level Public Health agency
- Public health is driver, water sector pro-active support

Supersites

Does Wastewater surveillance of Supersites reveal different story compared to the city ?



Omicron via air travel

Schiphol & Frankfurt:
2 days before first
on positive
al sample

Sample site	Sample date	27/07/2021	27/07/2021	20/07/2021	21/07/2021	04/08/2021	04/08/2021	02/08/2021	02/08/2021	21/09/2021	21/09/2021	22/09/2021	22/09/2021	27/09/2021	27/09/2021
		Spain - Madrid-Barajas Airport	Spain - Madrid	Portugal - Lisboa	Portugal - Aeroporto Delgado	Germany - Frankfurt Niederrad	Germany - Frankfurt Airport	Cyprus - Vathai Gonia (Nicosia)	Cyprus, Vathia Gonia Nicosia	Spain - Madrid	Spain - Aeropuerto de Barajas	Portugal - Lisboa	Portugal - Aeroporto Delgado	Germany - Frankfurt Airport	Germany - Frankfurt Niederrad
G339D (%)		0	0	0	0	0	0	0	0	0	0	0	0	0	0
N856K (%)		0	0	0	1.1	0	0	0	0	0	8	0	0	0	0
N501Y (%)		30	3.7	0	13	0	0	0	0	0	0	0	0	1.3	0
K417N (%)		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Del69-70 (%)		25	0.9	50	10	0	7	1.7	3.4	0	8	0	0	0	0
LPPA24S (%)															

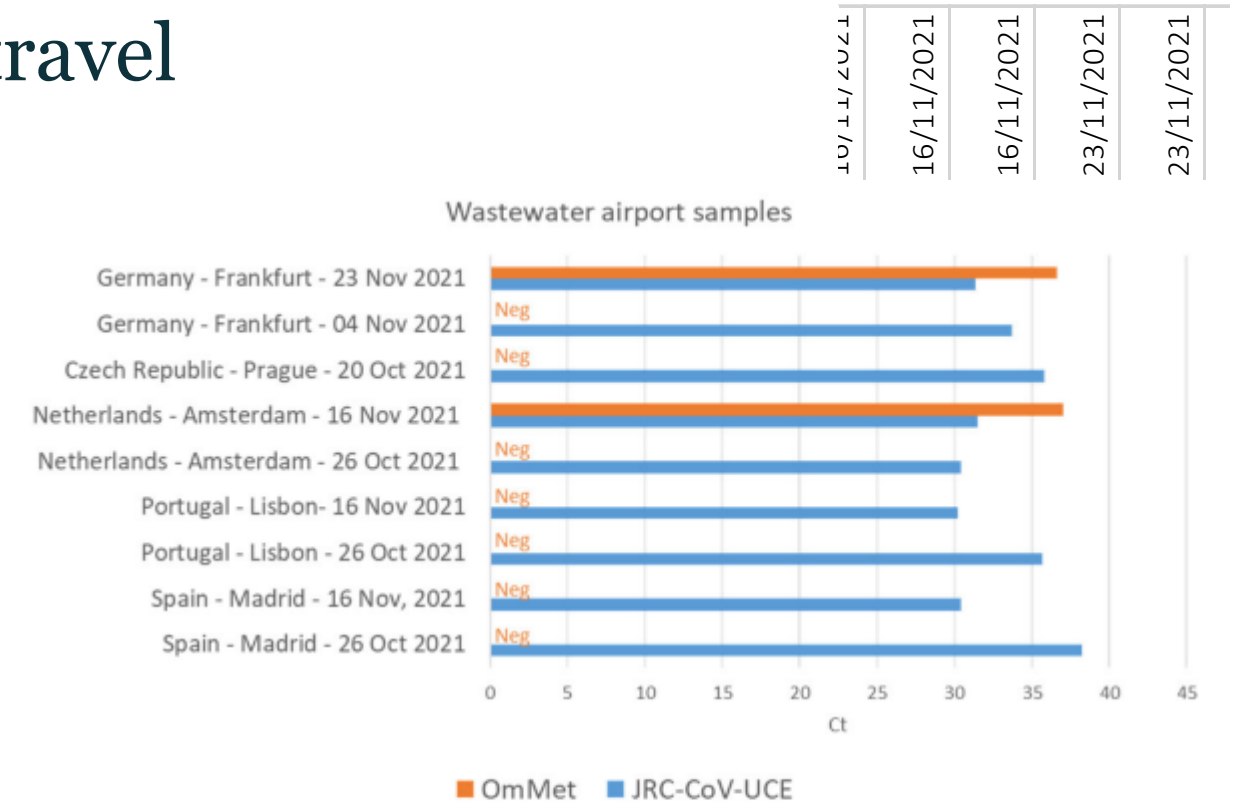


Figure 6. Early detection of Omicron in airport wastewater samples. Samples from the indicated airports were analyzed by RT-PCR with both the JRC-CoV-UCE and the Omicron-specific OmMet [22] assays. SARS-CoV-2 (most likely the Delta variant, which was highly predominant at that time) was identified in all of the samples while Omicron was only detected at lower concentrations (higher Ct numbers) in two samples from airports in Frankfurt and Amsterdam from the middle and end of November 2021. The presence of Omicron was confirmed by genome sequencing [44]. Neg: no detection of Omicron by using the OmMet assay.

26/01/2022	24/01/2022	25/01/2022	09/02/2022	09/02/2022	11/02/2022	09/02/2022	09/02/2022
Germany - Frankfurt Niederrad	Netherlands - Amsterdam	Netherlands - Schiphol	Cyprus, Vathia Gonia Nicosia	Cyprus, Ayia Napa (tourist)	Czech Republic - Prague	Czech Republic - Prague Central Bus Station	Czech Republic - Prague Airport
99.3	99.1	98.7	97.8	95	99.8	100	100
65	66	71	73	80	80	61	75
0	0	0	0	0	0	0	0
98.4	100	98.7	98.1	93	100	100	100
88.2	90	92.2	86	63.5	95.6	88	50
9	12	11.2	10	10	40.4	4.4	2.4

Marchini et al 2023, Viruses

Sewage as an indicator of public health

National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Sewage research is now being used to detect the coronavirus (SARS-CoV-2). This type of monitoring has been used for some time to detect poliovirus and antibiotic-resistant bacteria. RIVM is investigating options for expanding sewage research to include other data that could provide information about public health.

A healthy lifestyle
Oxidative stress*

Personal hygiene and care products
Microplastics, parabens*, UV filters*

Obesity
Biomarkers correlated to BMI

Nutrition
Mycotoxins, vitamins*, isoflavones*

Medication use
Regimen compliance*, insight into over-the-counter medicines*

Non-communicable diseases
Diabetes*, cancer*, allergies*

Use of muscle-building supplements
Anabolic steroids, sequestering agents*, weight-loss supplements*

Drug use
Heroin, cocaine, new party drugs

Forensic research
Drug production

Smoking and drinking
Nicotine, alcohol consumption

Dangerous substances
PFAS, substances of very high concern (SVHC / ZZS), pesticides, flame retardants*, new substances*

Pathogens
SARS-CoV-2, poliovirus, norovirus, antibiotic-resistant bacteria

Poliovirus circulation in London and New York detected via sewage

Extra polio vaccine dose for children in London

News – 9 September 2022

The NHS is inviting children aged 1 to 9 in London to receive a dose of vaccine against. For some children this may be an extra dose on top of their routine vaccinations. In other children it may bring them up to date with their routine vaccinations.

"For every one case of paralytic polio observed, there may be hundreds of others infected. Coupled with the latest wastewater findings, it's clear: polio is a threat to unvaccinated New Yorkers and children today. We must meet this moment by getting ourselves and our children by 2 months old immunized against polio as soon as possible – the protection against this debilitating virus we all need."

Dr. Mary T. Bassett
New York State Health Commissioner

NEW YORK STATE | Department of Health


abc13
TESTING WASTEWATER
FOR MONKEYPOX

Mpox testing of wastewater

Rotterdam Health Service

Could wastewater surveillance be used to

Hepatitis A virus outbreak in Amsterdam school

HAV imported disease in Amsterdam, by travellers to endemic countries

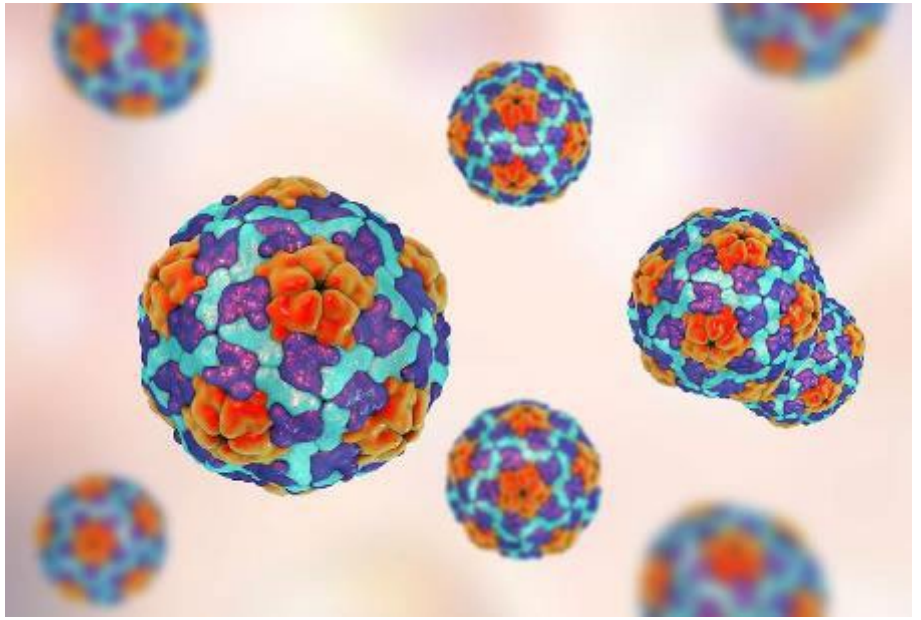
Asymptomatic carriers

Long incubation time

5 cases reported in primary school in Amsterdam

Question: can wastewater surveullance be used to detect if:

- outbreak control measures are effective?
- there is silent circulation of HAV?



Science photo

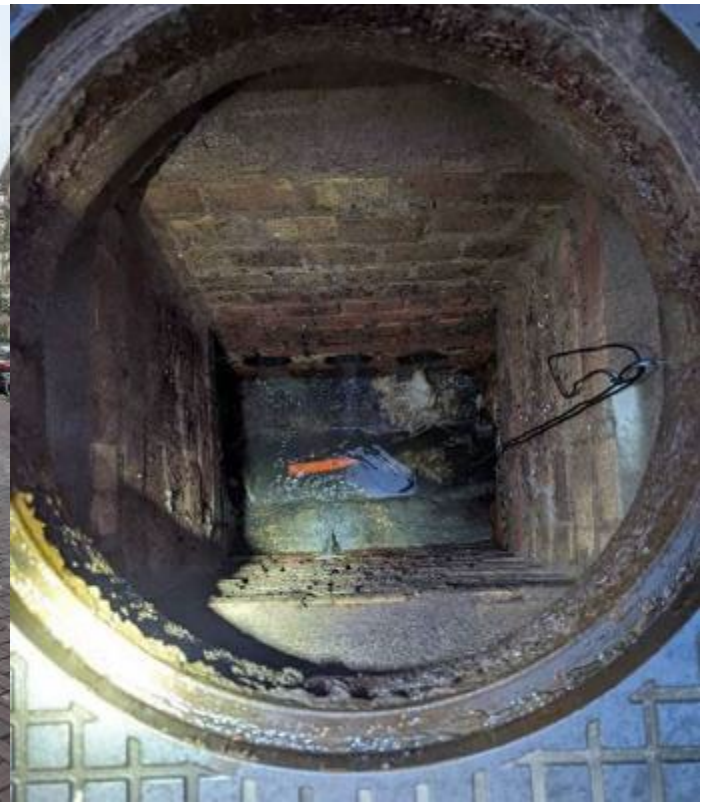
Design

School 2 locations

Most cases at 1 location

Examine local sewer network lay-out

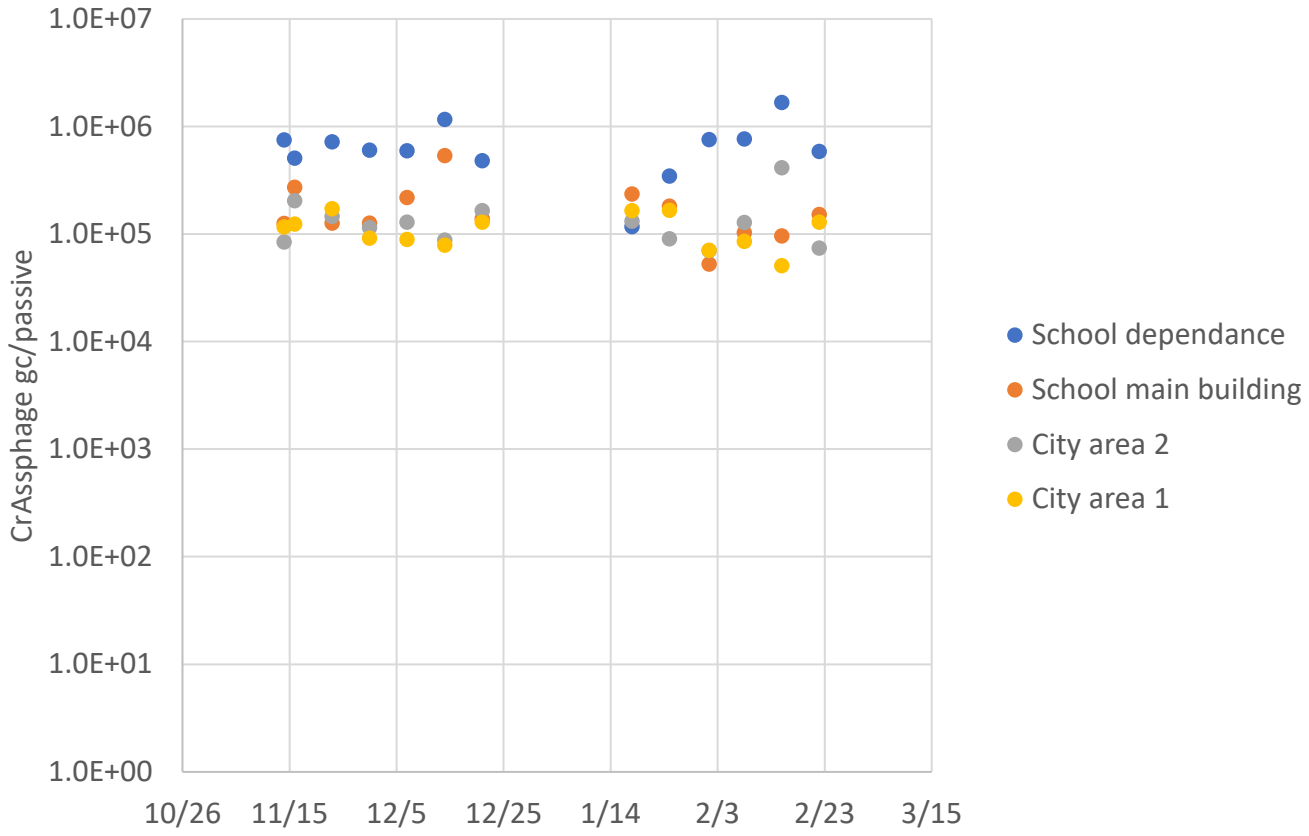
Evaluate sampling sites via manholes



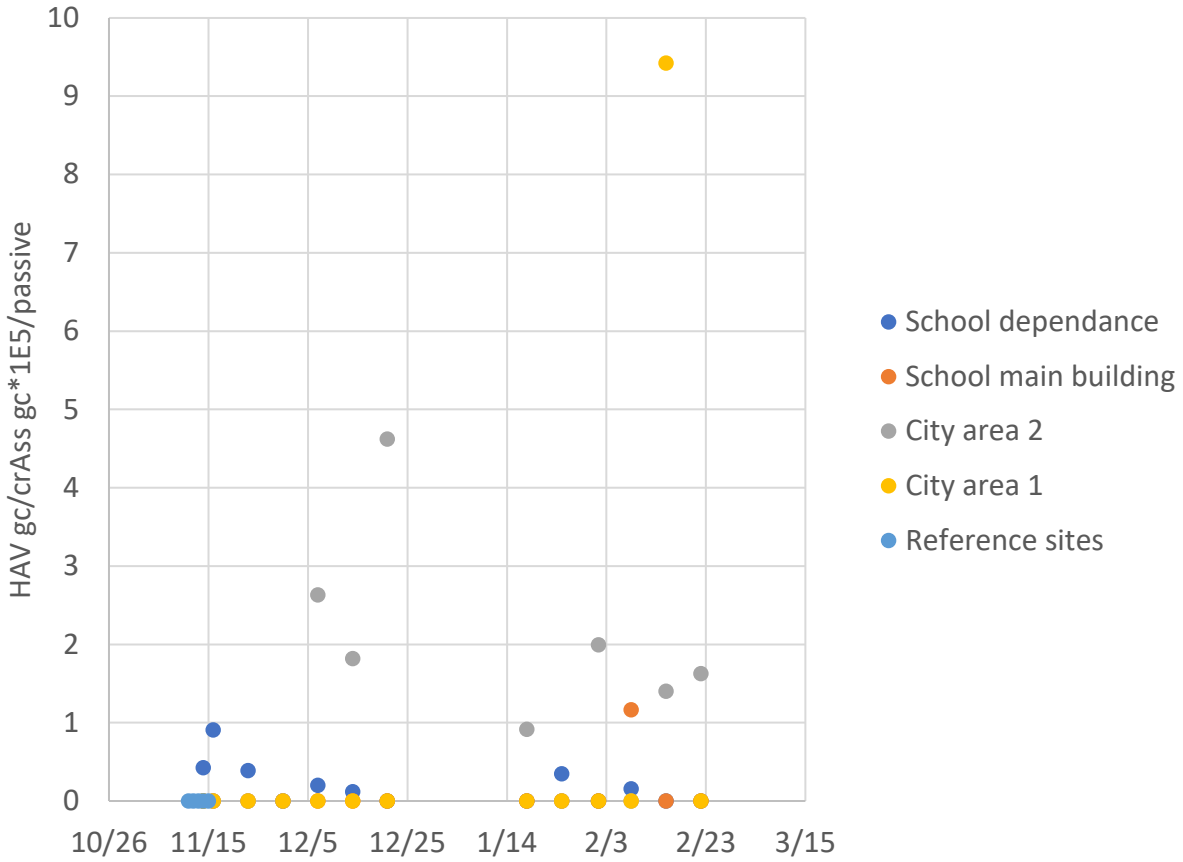
4 sites:
1 sewer draining school building 1
1 sewer draining school building 2
2 in sewer draining city residential areas of school students

Passive samplers 48h-72h, 3/wk

Sampling human fecal material
CrAssphage as normalizer



Sampling for HAV
CrAssphage as normalizer



Sequencing HAV from wastewater and cases

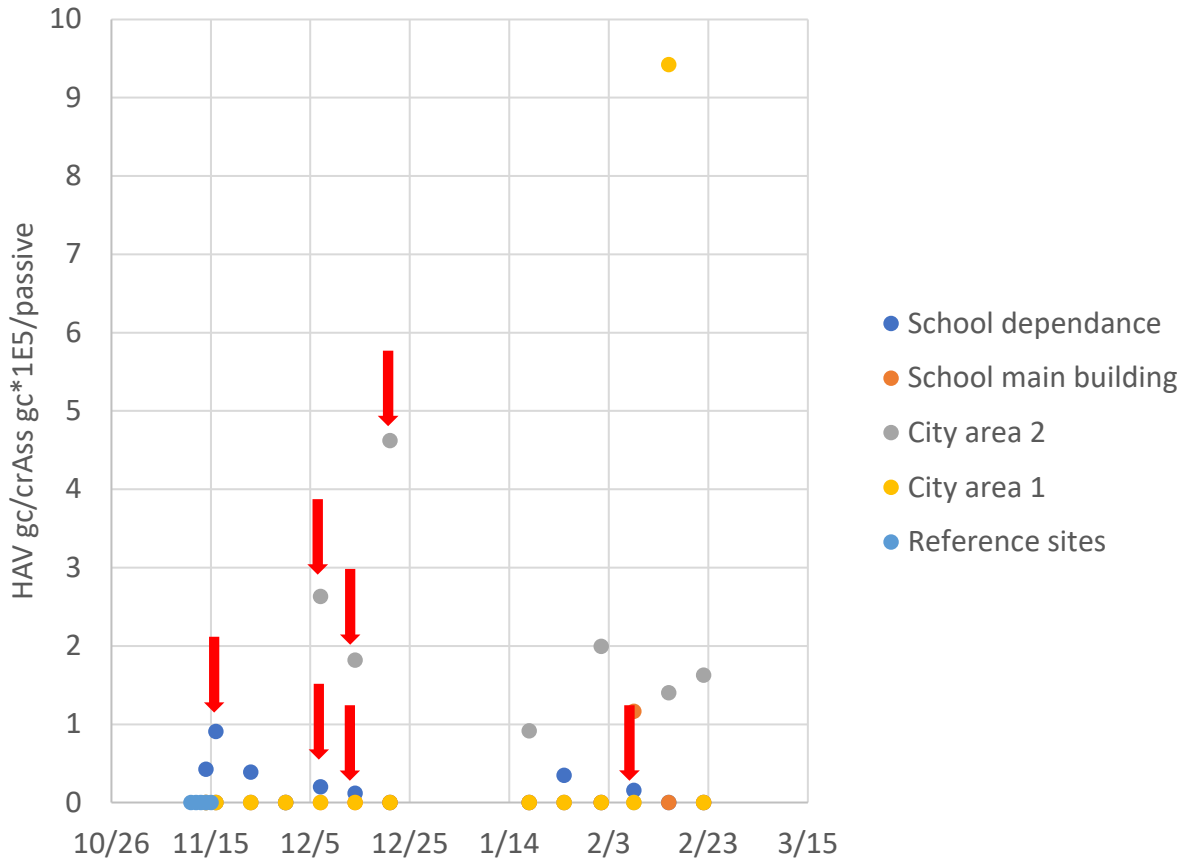
Sanger and Nanopore

Identical strain

- in wastewater samples
- in cases
- IB 22-197
- Somalia

Wastewater surveillance

- confirmed outbreak
- confirmed silent circulation
- supported determination of end
- Found silent circulation of Morocco strain



Human circulation of avian influenza?

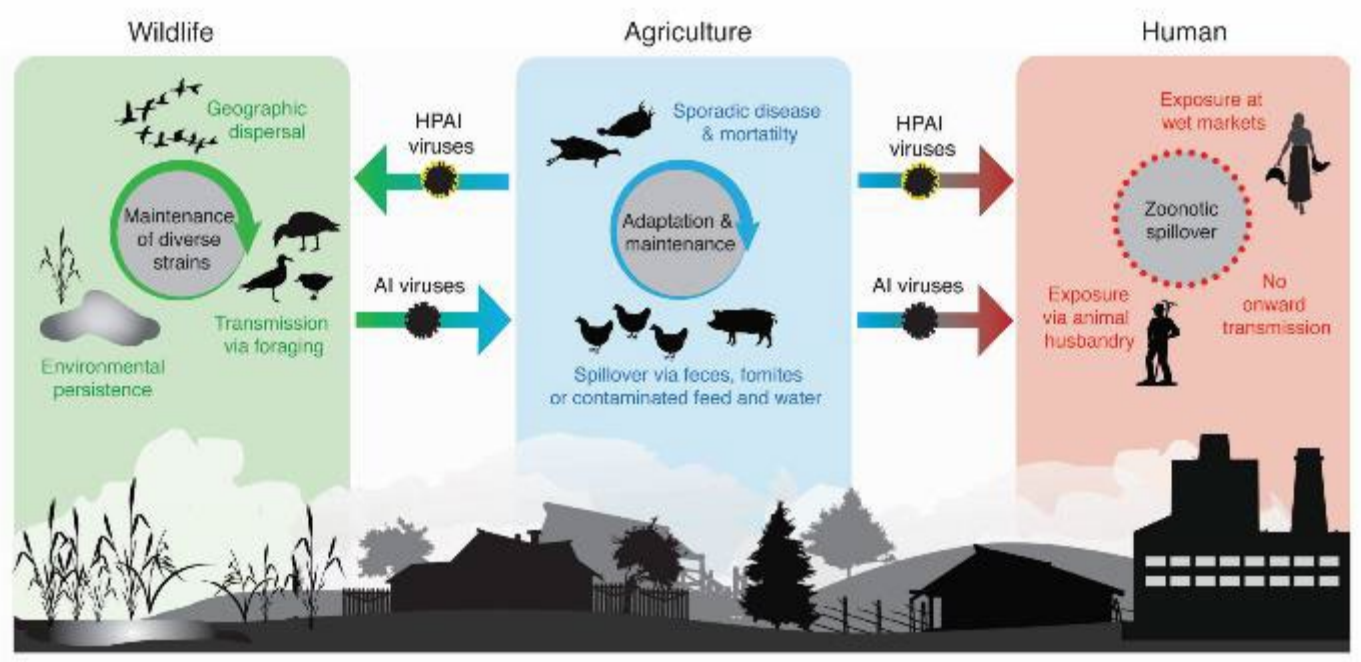
In case of transmission and infection in human(s)

Symptomatic carrier(s)
+
Asymptomatic/mildly symptomatic carriers?

Silent circulation

Wastewater surveillance in affected community

Now: establish proof of concept



Wildlife Management

Scabies in (student) homes

Waste/wash water monitoring as non-invasive surveillance tool

To monitor if control measures are effective

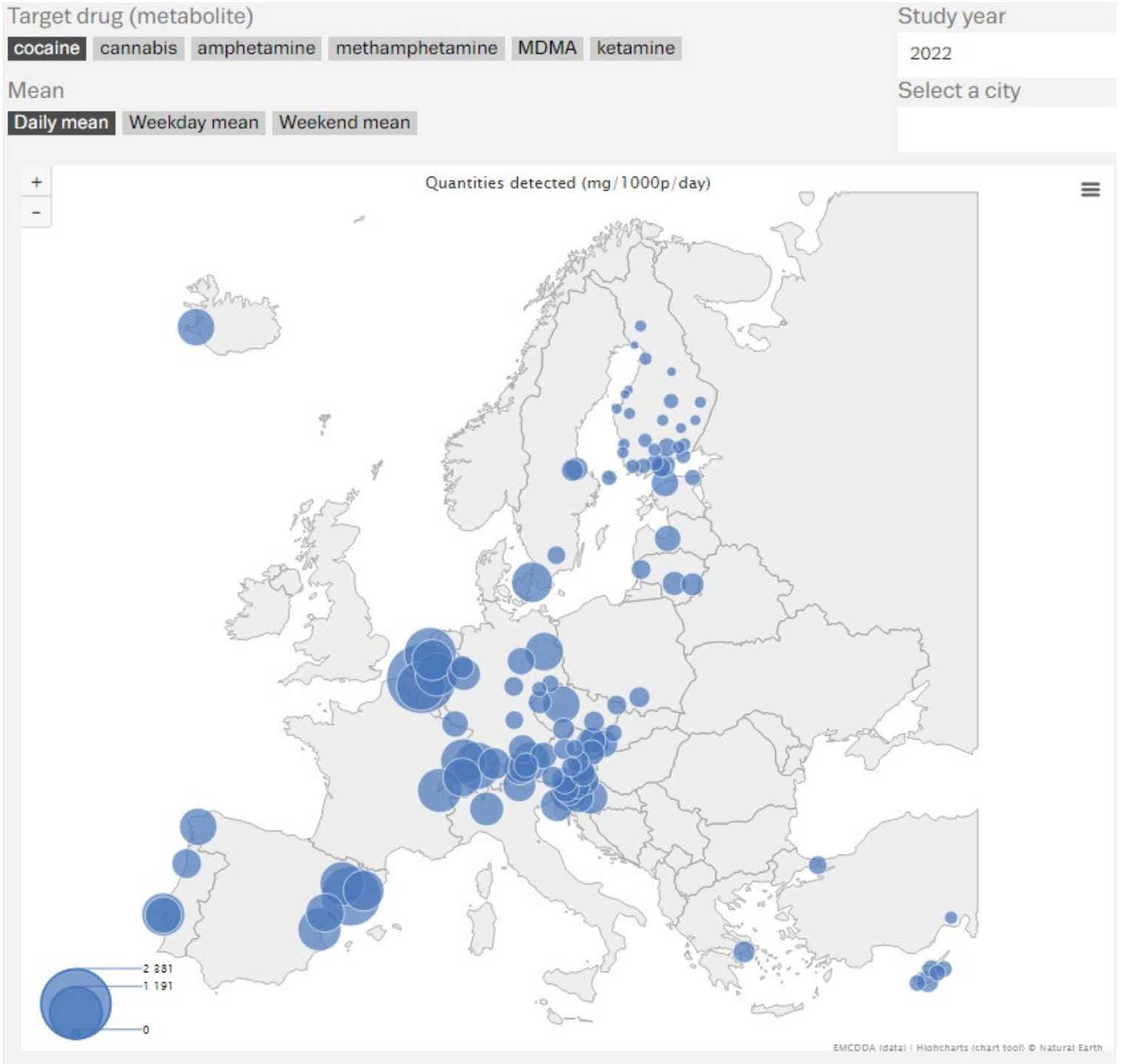
Proof of concept study: bed linnen swaps PCR positive. Will be detectable in wastewater? First test wastewater from laundry

Current location: asylum home for minors

Too sensitive: minors, language barrier, asylum status still unclear

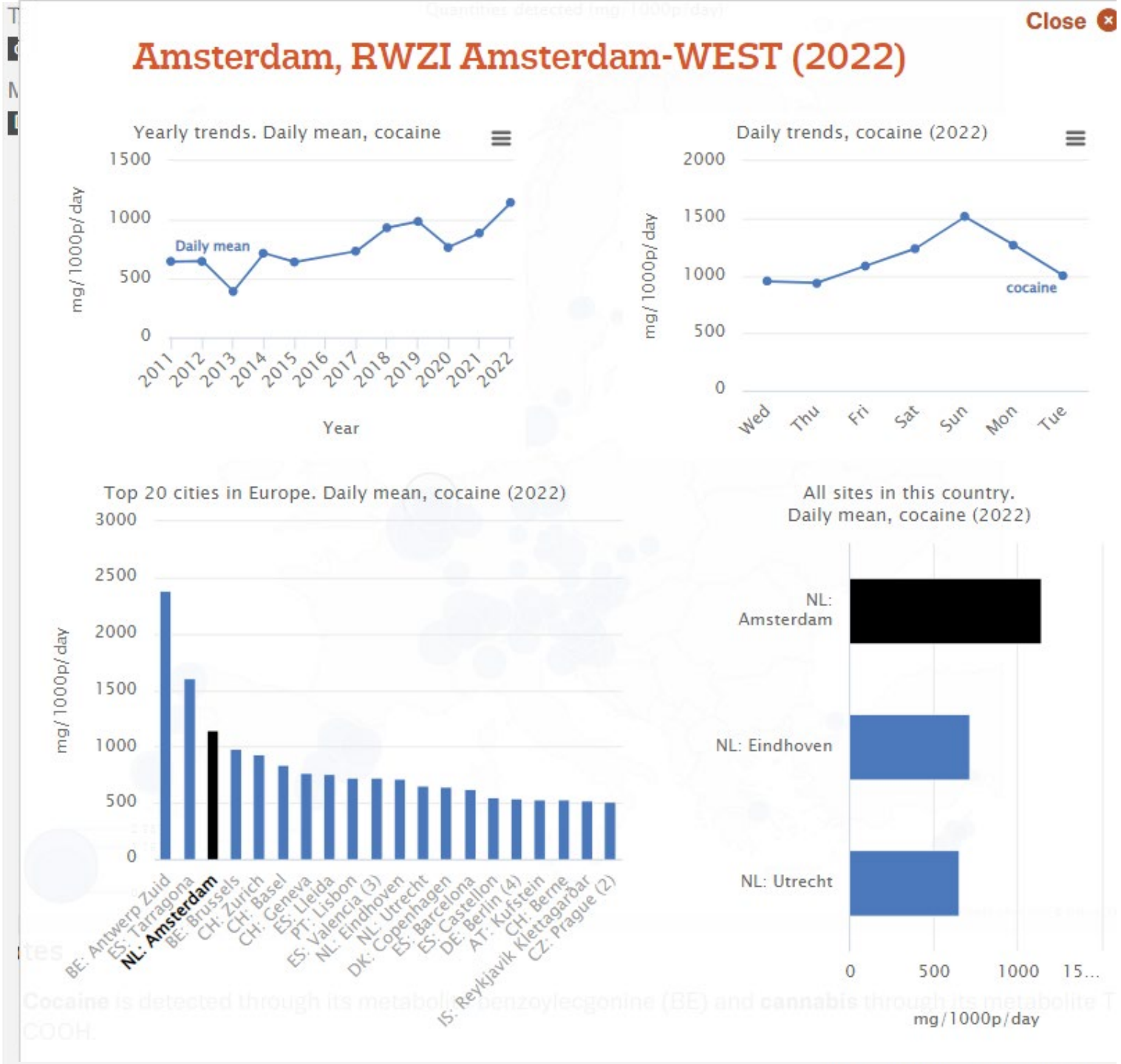
Illicit drugs in sewage

Trends in use (unbiased)



Illicit drugs in sewage

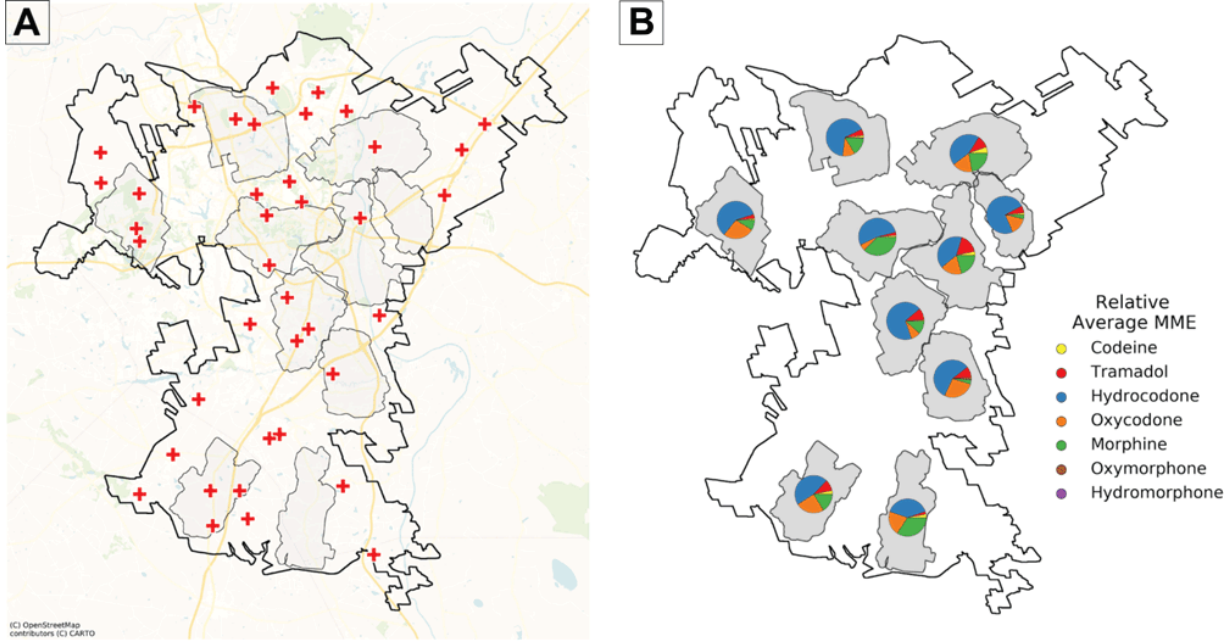
Trends in use (unbiased)



Illicit drugs: market size estimation from sewage Amsterdam

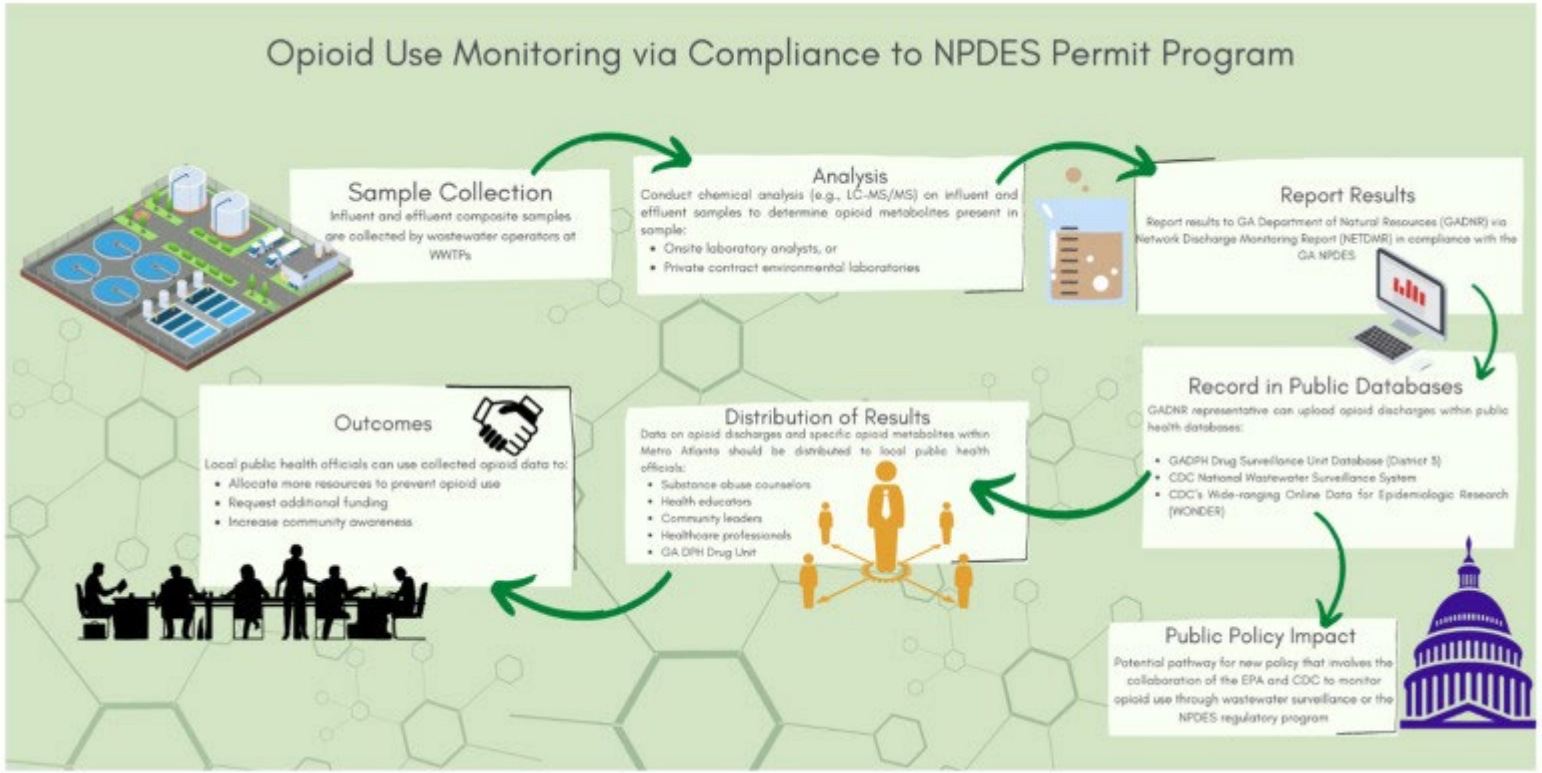
Drug	Weight consumed (/year)	Market size (/year)
Cannabis	1370 kg	€ 84 mln
Cocaine	750 kg	€ 53 mln
MDMA	250 kg	€ 6.5 mln
Amphetamine	170 kg	€ 2.4 mln

Opioids



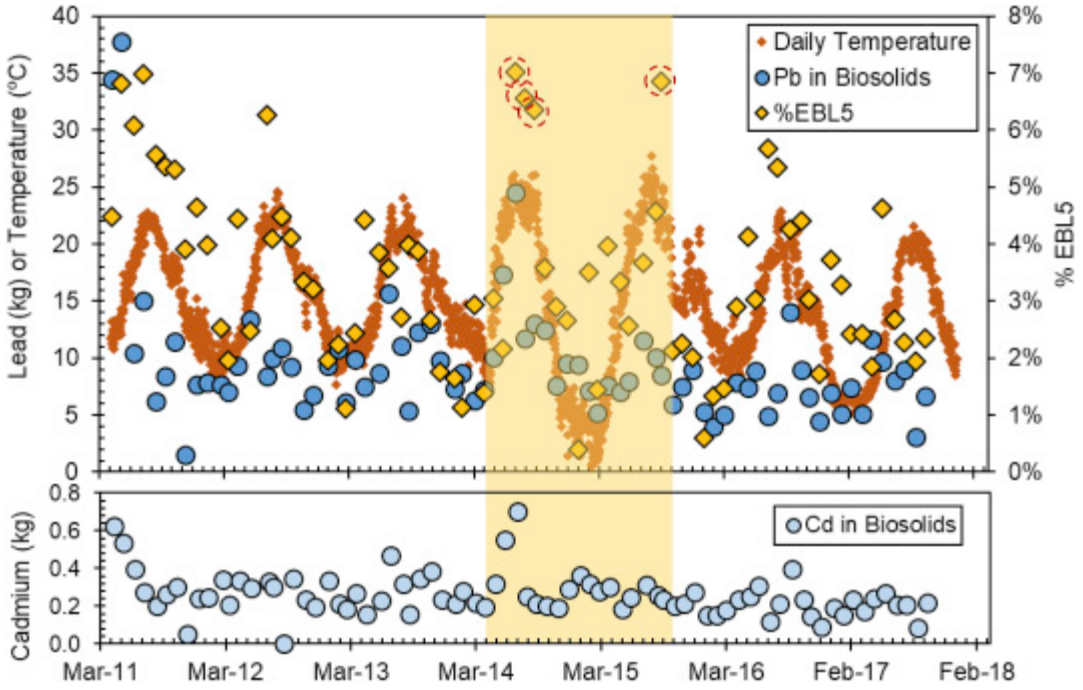
Source: Endo N, et al. Rapid assessment of opioid exposure and treatment in cities through robotic collection and chemical analysis of wastewater. J Med Toxicol 2020;16(2):195-203.

Opioids


Opioid Use Monitoring via Compliance to NPDES Permit Program
Sample Collection
Influent and effluent composite samples are collected by wastewater operators at WWTPs
Analysis
Conduct chemical analysis (e.g., LC-MS/MS) on influent and effluent samples to determine opioid metabolites present in sample:
Onsite laboratory analysts, or
Private contract environmental laboratories
Report Results
Report results to GA Department of Natural Resources (GADNR) via Network Discharge Monitoring Report (NETDMR) in compliance with the GA NPDES
Record in Public Databases
GADNR representative can upload opioid discharges within public health databases:
GADPH Drug Surveillance Unit Database (District 5)
CDC National Wastewater Surveillance System
CDC's Wide-ranging Online Data for Epidemiologic Research (WONDER)
Public Policy Impact
Potential pathway for new policy that involves the collaboration of the EPA and CDC to monitor opioid use through wastewater surveillance or the NPDES regulatory program
Distribution of Results
Data on opioid discharges and specific opioid metabolites within Metro Atlanta should be distributed to local public health officials:
Substance abuse counselors
Health educators
Community leaders
Healthcare professionals
GA DPH Drug Unit
Outcomes
Local public health officials can use collected opioid data to:
Allocate more resources to prevent opioid use
Request additional funding
Increase community awareness

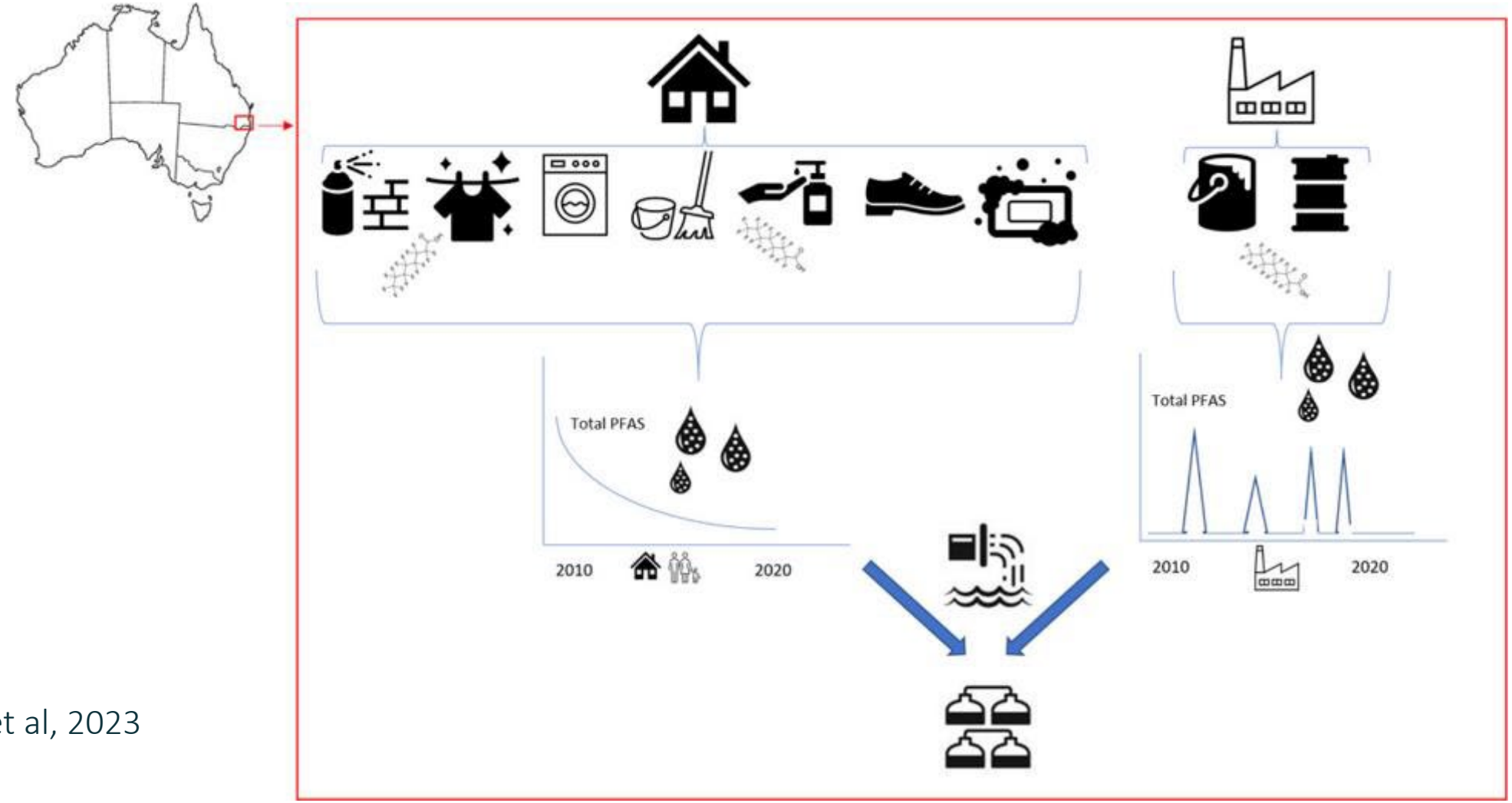
CDC

Lead exposure in Flint



Roy, Tang & Edwards, 2019

PFAS exposure?



Gadden et al, 2023

All set!

Demonstrated added value for public health

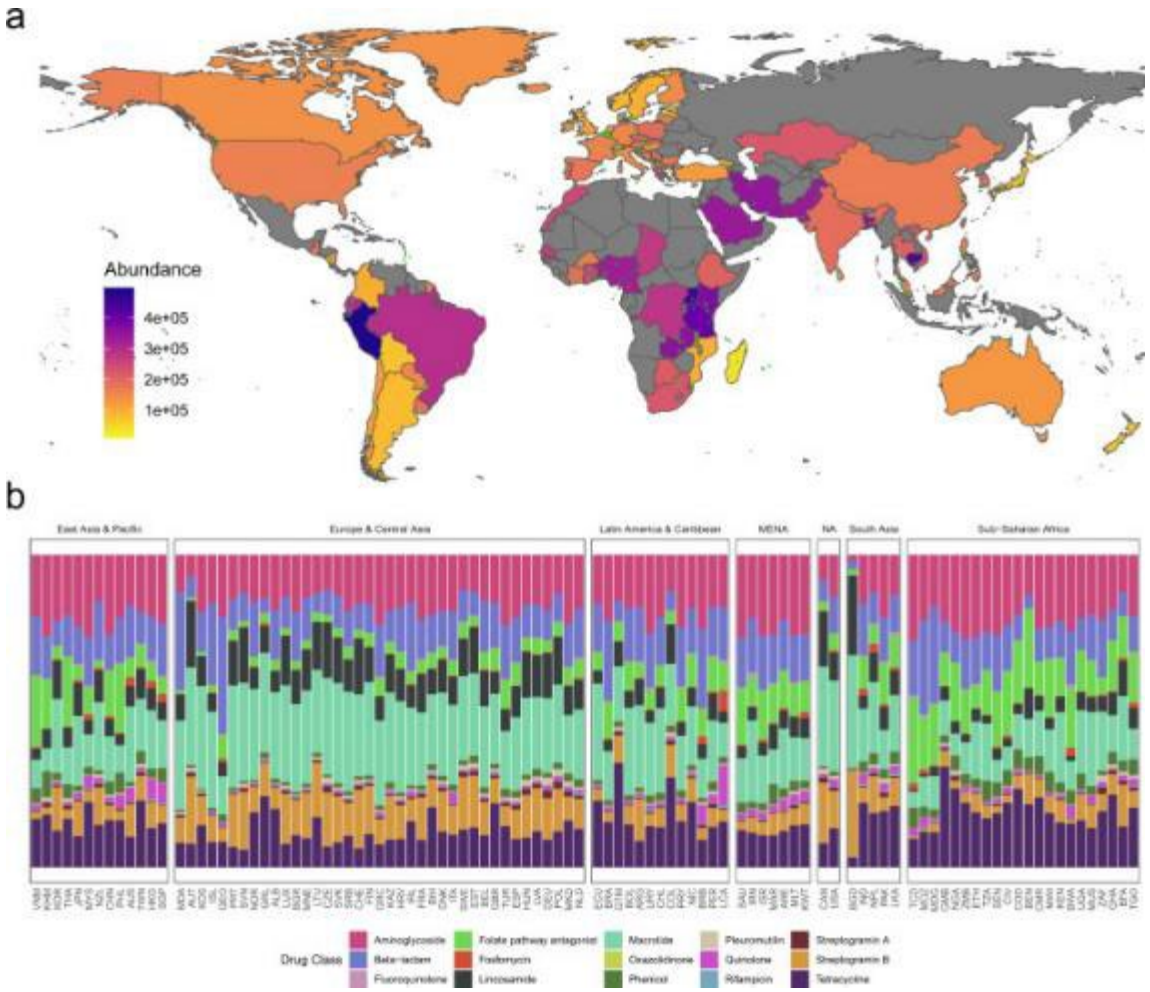
Connections between water and health sector reinforced

Water sector: monitoring infrastructure for operations and water quality

Dissemination of PCR: multi-target platform, environmental testkits

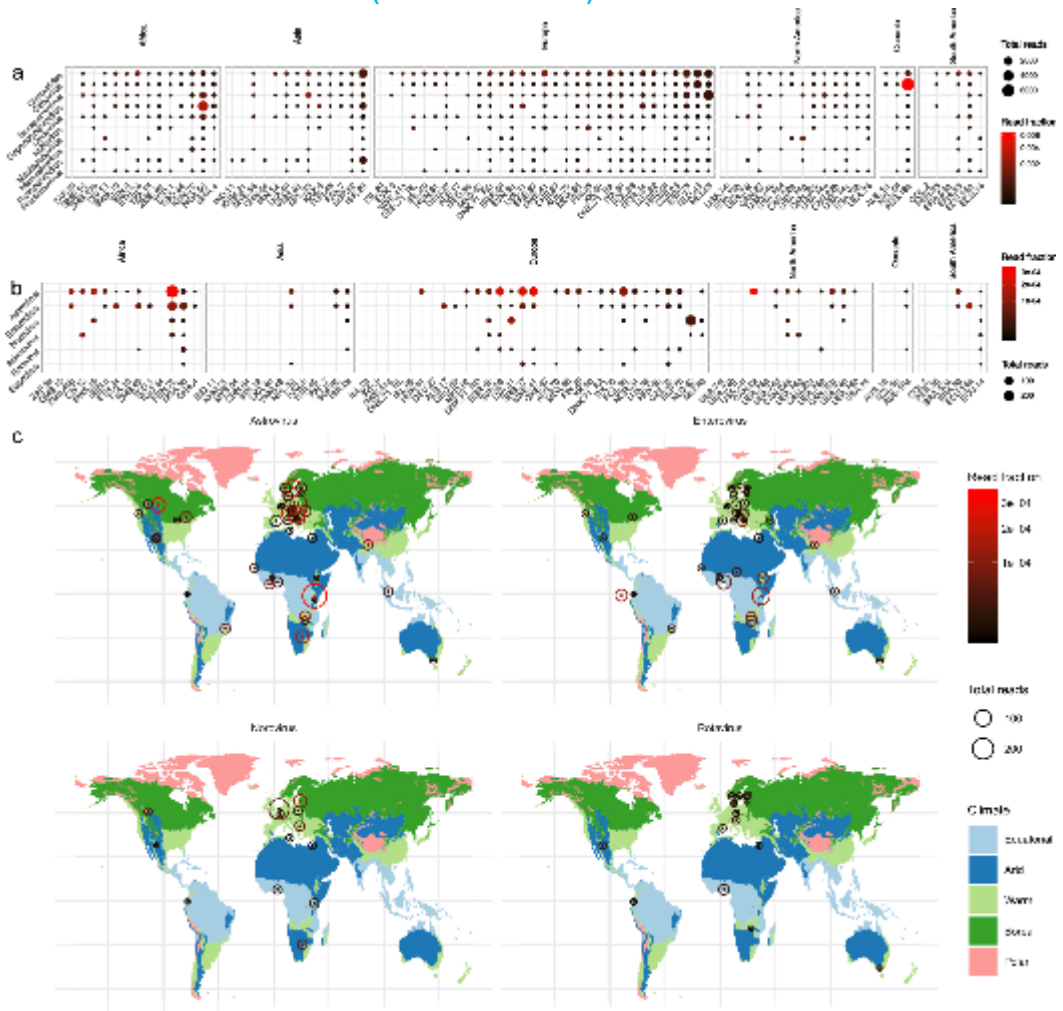
Metagenomic “catch-all” techniques

Global resistome via wastewater



Munk et al, Nat Commun. 2022; 13: 7251

Global (vertebrate) virome via wastewater



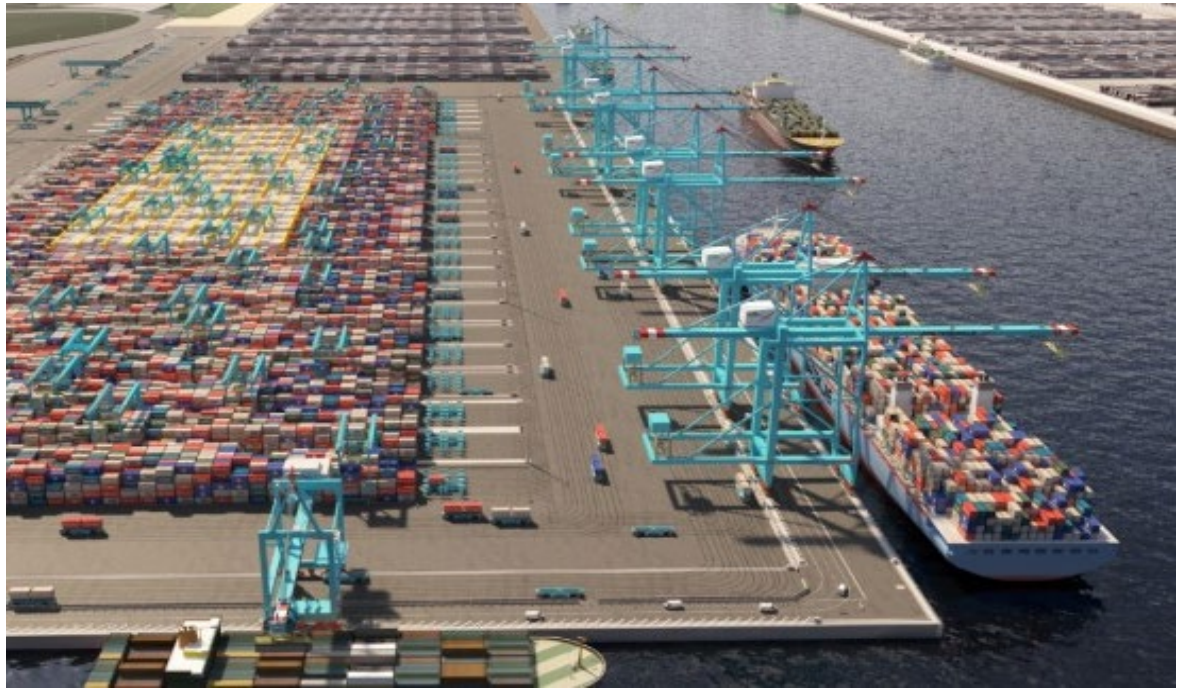
Nieuwenhuijse et al, Sci Rep. 2020; 10(1):13748

Frontrunner INSPECT

International Network Surveillance for Pandemic EmergenCe via Transport hubs

PANDEMIC & DISASTER Preparedness Center (PDPC)

Targeted (d/qPCR) and semi-targeted (*Coronaviridae;* genotype-to-phenotype methods; genotype + antibody capture)



Erasmus MC Zafung | TU Delft Zafung Erasmus Universiteit Rotterdam | Wageningen University & Research | GGD Rotterdam-Rijnmond | KWR | Port of Rotterdam | Schiphol Amsterdam Airport

Global disease surveillance and pandemic sentinel system