Evidence of Wider Environmental Transmission of SARS-CoV-2

Evidence summary for SAGE (12th June 2020)

Assessing risk of transmission through outdoor air, water, outdoor surfaces, and food.

Based on available evidence up to 10th June including expert opinion of the group, consideration of transmission of other viruses, and literature (often non-peer-reviewed) on SARS-CoV-2.

Statement on uncertainty

A number of significant evidence gaps hamper assessment of transmission risk of SARS-CoV-2 through environmental pathways. While various studies have detected viral RNA signatures from environmental samples (from air, water, treated effluents and sewage and surfaces) using RT-PCR, infectivity has not been assessed in most cases. Very few studies have investigated the presence of infective virus using culture techniques. In addition, the infective dose of SARS-CoV-2 is still uncertain. Assessments of risk and uncertainty therefore draw heavily on expert judgement and knowledge of other pathogens throughout this document. The level of risk of catching SARS-CoV-2 from the environment is highly dependent on the levels of infective SARS-CoV-2 circulating in the population and its geographical spread.

Key conclusions

Note: Risk levels are expressed at a population level not an individual level (see paragraph 8 below), using the FSA qualitative risk scale (see paragraph 9 below).

- The highest risk of outdoor transmission is through aerosols and droplets when people are in prolonged close, face-to-face contact within 2m. This is likely to be lower than indoor settings but remains a risk especially in crowded areas, e.g.at major sporting events, festivals and public gatherings. This risk has already been considered by the Environmental Modelling Group and has not been considered further here**.**
- Beyond 2m, risk is likely to progressively decrease. By 10m, risk of outdoor aerosol or droplet person-to-person transmission is **Very Low with medium uncertainty**.
- Based on current epidemiological evidence, the risk of long-range (>10m) aerosol or droplet person-to-person transmission outdoors is **Negligible with low uncertainty,** due largely to dispersion effects**.**
- The risk of acquiring virus from infrequently touched outdoor surfaces is **Very Low to Negligible with medium uncertainty**, particularly if surfaces are exposed to sunshine on a daily basis.
- Surfaces that are frequent touch points such as outer shop door handles, cash machines, outside shutters, door knockers and door bells are likely to be slightly higher risk, i.e. **Low with medium uncertainty**.
- Recent modelling of the solar inactivation of SARS-CoV-2 on surfaces indicates that the virus could remain infectious for long time periods when light levels are low. Modelling survival time in direct midday sunlight at the latitude of London showed that the time for 90% infectivity reduction is likely to be around 30 minutes in mid-summer but extended to 300 minutes in mid-winter (Sagripanti and Lytle 2020). The virucidal effect of UV may be halved on a cloudy day or in the shade (Ben-David and Sagripanti 2010; 2013). In practice, this means that the risk of outdoor fomite transmission (and reaerosolisation) could be elevated under UK winter conditions (December-March).
- Public toilets represent a potential SARS-CoV-2 exposure point for a number of reasons. Primary amongst these is that they contain many touch surfaces which could be contaminated with infective nasopharyngeal fluids or faecal material and to which many people are exposed in a short time period. Toilets also represent the point at which the amount of infectious virus might be greatest in waste water. Aerosol, faecal/ocular, and

faecal/oral transmission risks have been hypothesised based on virus presence and evidence exists based on previous SARS-CoV outbreaks. In addition, toilets may be a contact hub point in the community where transmission can occur between users through face-to-face droplet transmission, in the toilet building itself, and in proximity. Thorough and frequent cleaning is likely to reduce risk, although this can be challenging in some remote public toilets. Toilet users, cleaning staff and plumbers may also be exposed to contaminated surfaces or sewage. The level of risk is **Medium with high uncertainty.**

- Once wastewater is treated, effluent discharged to receiving waters will contain very little coronavirus (few studies have detected virus in wastewater treatment effluents), and the risk of this being a route of infection is **Negligible with medium uncertainty**. The same risk would apply to sewage sludge applied to land and municipal solid waste: by law all biosolids (intended for application to crop-growing land) are treated and the thermophilic process will rapidly inactivate coronavirus. The level of risk is **Negligible with medium uncertainty.** Episodically, risks from sewage may be raised to **Low or Very Low with medium uncertainty** based on heavy rainfall and the triggering of combined sewage overflows, which lead to higher sewage loading of receiving waters. Pollution monitoring is therefore important.
- Recreational use of waters, particularly fresh waters many of which are not designated bathing waters (e.g. rivers, lakes and canals) presents a theoretical risk, but there is no evidence of coronavirus transmission by this route. The level of risk is **Very Low to Negligible with medium uncertainty.** Episodically, risk may be raised to **Low or Very Low with high uncertainty** based on heavy rainfall associated with the operation of combined sewage overflows discharging untreated sewage into receiving waters. Pollution monitoring is therefore important.
- Airborne droplet transmission between bathers in close proximity (<2m) is likely to be a more significant risk than from waste water sources. Waterborne transmission between bathers beyond 2m is **Negligible Risk with medium uncertainty**.
- Risk of infection from mains-supplied drinking water is **Negligible with low uncertainty**. Risks from private water supplies may locally be **very low to low with high uncertainty**, due primarily to contamination from septic tanks.
- The probability of exposure of UK consumers to SARS-CoV-2 via food is **Very Low with high uncertainty**. The uncertainty associated with this estimate is high as there is still no evidence to confirm or refute the hypothesis that people can be infected by ingesting SARS-CoV-2 in food.

Key variables to be taken into account when developing risk assessments

- Environmental factors that may elevate the likelihood of virus remaining infectious include:
  - Colder temperatures (e.g. cold weather, refrigeration).
  - Absence of sunlight.
  - High rainfall could either increase risk (triggering combined sewage overflows and speeding up transition time in the sewerage network) or reduce it (increasing dilution).
  - Turbidity: the virus may be protected by organic material aggregates in wastewater, though subsequent treatment would probably reduce the risk of its penetration through to effluent.
  - Particulate matter in the atmosphere could either increase risk (shielding virus particles from UV light) or decrease it (exposure to heavy metals or other chemicals).
  - Humidity.
- Robust systems are in place in the UK's food, water and waste systems to protect staff and the public from harmful pathogens. Any breakdown of these systems caused by equipment shortages, staff shortages or additional pressures may increase the risk levels reported here.

- Weather conditions may also affect the behaviour of the public and their potential exposure to infection. This could include congregation of people in popular outdoor sites (e.g. beaches, beauty spots), bathing in rivers and the sea, retreat to indoors spaces due to unexpected rain, and the degree to which people adhere to social distancing.

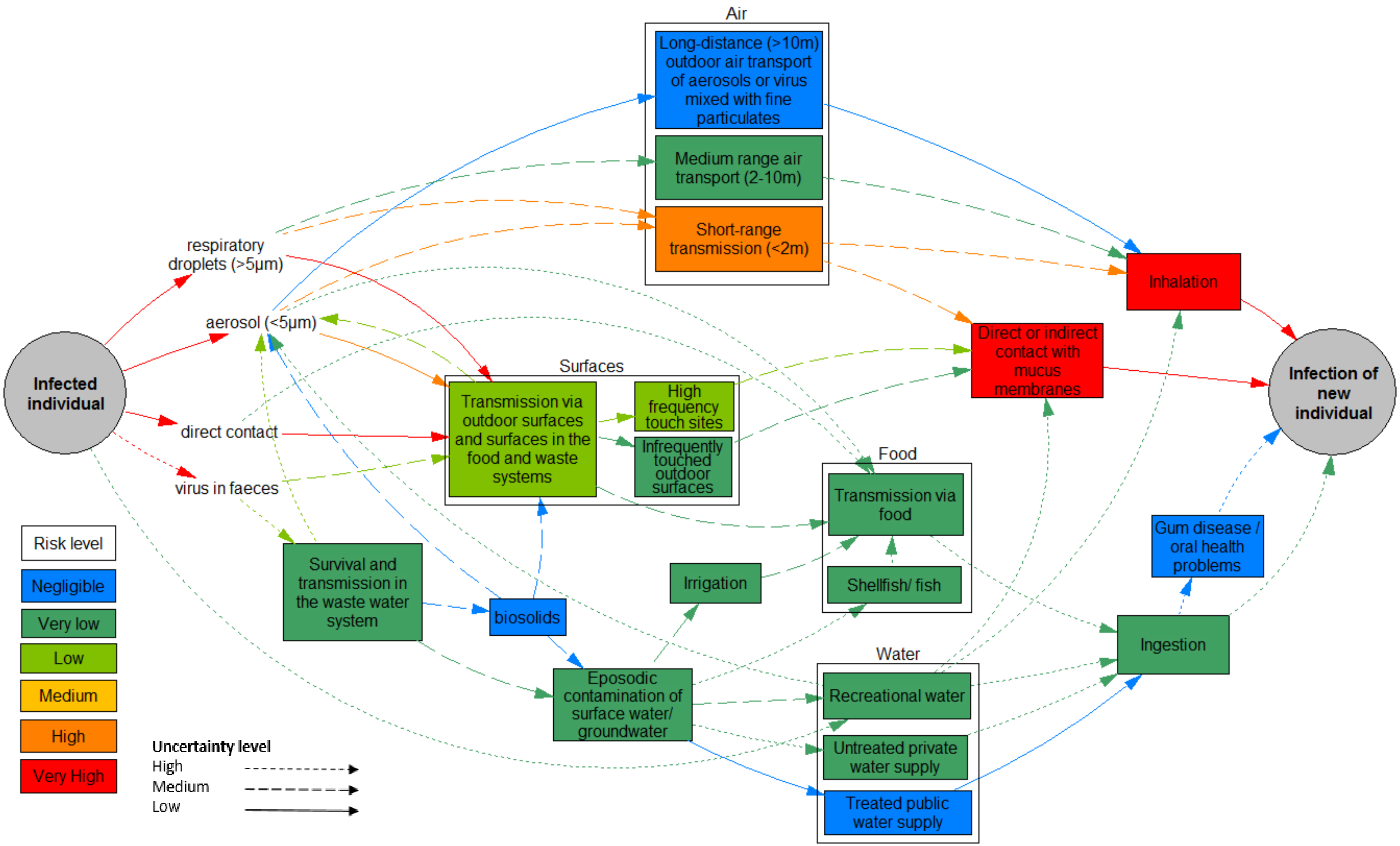

Figure 1. Overview of pathways of transmission considered, colour coded by assessed risk level. Solid line = low uncertainty, dashed line = medium, dotted line = high uncertainty. The risk of short-range airborne transmission has not been directly assessed in this report. The relatively high risk of this pathway shown here is based on previous work by the SAGE Environmental Modelling Group.

Scope of this Paper

1. This report focuses on the potential transmission routes of the SARS-CoV-2 virus in:
   - **Outdoor air**: short (<2m), medium (2-10m) and long range (>10m) transmission, including potential interactions with fine particulate matter
   - **Water and sewage** beyond the built environment:
     - Waste water/sewage systems (including aerosol generation)
     - Wider water transmission in surface waters, groundwater, recreational waters and private water supplies.
   - **Surfaces**
     - In the outdoor environment.
     - In the food and waste sectors.
     - Including animals as fomites i.e. mobile surfaces.
   - **Food**
     - Via products of animal origins (meat, dairy, eggs) from infected livestock.
     - From contamination in the food chain.

   The report does not consider transmission pathways via animal hosts which have been assessed in other formats by SAGE.

2. Transmission pathways assessed by this group are summarised in figure 1.

3. For each of these pathways, the report critically assesses current evidence to identify potential sources of pollution, transmission pathways and exposure points where people may come into contact with the virus.

4. The aim is to provide the scientific evidence for environmental virus transmission to enable decision making and risk management controls in sectors, and to support sectorial analysis.

5. A full assessment of pathways in specific sectors (e.g. waste-water, waste and recycling) or high contact areas (e.g. children's play areas, outdoor café furniture and parking machines) is beyond the scope of this report. However, evidence summarised in this report can be used to inform further risk analysis, especially where multiple transmission routes are involved. We have provided an example in Box 2 (on public toilets) of how the information in the report can be used to inform a more detailed risk assessment for particular settings.

6. Several factors identified in this report may amplify risk in specific sectors (e.g. cold temperature and air handling in abattoirs and slaughter houses).

Types of evidence considered.

7. Much of the evidence available on the detection of SARS-CoV-2 in water, air and on surfaces is from RT-PCR analysis. This shows the presence of SARS-CoV-2 RNA rather than the presence of intact and infectious virus. Assays that have cultured SARS-CoV-2 virus from environmental samples, thus demonstrating infectivity, have been rare. The group has therefore drawn on evidence from surrogate viruses, epidemiological evidence where available, and expert opinion in assessing the likelihood of infection.

Assessment of risk:

8. The report uses the qualitative scale for the frequency of occurrence of risks developed by the Food Standards Agency (Table 1). We have applied this to assess risk at a population level rather than at an individual level. For example, in figure 1, short-range aerosol

transmission from face to face contact is shown as very high. At a population level, these events will almost certainly occur. At an individual level, the risk of becoming infected through close contact with someone with Covid-19 is lower.

9. The exposure to SARS-CoV-2 and potential risk from environmental pathways will depend on the levels of SARS-CoV-2 circulating in the population and its geographical spread.

Box 1. A qualitative scale for the frequency of occurrence of risks (Food Standards Agency 2006[1])

Frequency category	Interpretation
Negligible	So rare that it does not merit to be considered
Very Low	Very rare but cannot be excluded
Low	Rare but does occur
Medium	Occurs regularly
High	Occurs very often
Very High	Events occur almost certainly

Uncertainty category	Interpretation
Low	There are solid and complete data available; strong evidence is provided in multiple references; authors report similar conclusions
Medium	There are some but no complete data available; evidence is provided in a small number or references; authors report conclusions that vary from one another
High	There are scarce or no data available; evidence is not provided in references but rather in unpublished reports or based on observations or personal communication; authors report conclusions that vary considerably between them; may be based heavily on expert opinion

[1] https://science-counil.food.gov.uk/sites/default/files/fsasciencecouncilwg2riskuncertaintyfinrep.pdf

1. Air and the risk of transmission of SARS-CoV-2 when people are outside

Is infectious virus present in ambient air?

10. While the transmission of SARS-CoV-2 via human respiratory droplets and direct contact is clear, there is no evidence for aerosol transmission occurring when individuals are > 2 m apart. It is currently not considered as a transmission route in guidance from the Centers of Disease Control and Prevention (CDC) [1], PHE/NHS or the WHO [2,3].

11. The transmission ranges of droplets and aerosols containing the virus are determined by their size and environmental conditions. A droplet 100 µm in diameter sediments 1 m in ~3 s, while a 10 µm droplet sediments in ~300 s. Thus, a large droplet can be carried only a little further by wind than it would otherwise travel from an exhaled jet, but still settles on surfaces within a few metres from an infected person. However, a 10 µm particle at wind speeds of 10 km/h could be carried many hundreds of metres before sedimenting or impacting on surfaces. Indeed, respirable particles (<5 µm diameter) could be carried a considerable distance, but will be significantly diluted from source. Even at source, particle concentrations in the respirable size range are expected to be as low as 1 per cm^{-3} from a cough or sneeze.

12. Most investigations of SARS-CoV-2 in air depend on detecting viral RNA in the sample, which cannot determine if the virus is infectious or not. To date, more than 10 studies have looked for RNA signatures of the virus using air samplers/filters but only one attempt was made to isolate infectious virus and it was unsuccessful [4]. Of these studies three detected virus in outside air. Liu et al, 2020 detected virus in crowded areas outside two Wuhan hospitals [5] and Setti and colleagues reported virus on particulate matter collected on filters in Bergamo in Northern Italy [6]. Liu et al. [5] stated "*outside the hospitals, we found the majority of the sites have undetectable or very low concentrations of SARS-CoV-2 aerosol (below 3 copies m^{-3}), except for one crowd gathering site about 1 m to the entrance of a department store with customers frequently passing through, and the other site next to Renmin Hospital where the public including outpatients passed by. While both sites were outside the building, it is possible that infected carriers of SARS-CoV-2 in the crowd may have contributed as the source of virus-laden aerosol during the sampling period*". The results reinforce the importance of avoiding crowded gatherings. The levels found by Setti et al. were very low (< 0.1 copy per cubic metre). In neither case is it known if the virus was infectious.

13. A study by Zhang detected SARS-CoV-2 RNA in aerosols (285-1130 copies/m^3) in hospital locations close to departments receiving COVID-19 patients or in wastewater treatment sectors [7]. Qian et al. [8] identified 318 outbreaks of COVID-19 in China involving 1,245 infected individuals in 120 cities. Only 1 outbreak was identified to have occurred outside and was between two people having a conversation.

How long does the virus remain infectious in ambient air?

14. Comparing survival of pathogens in the laboratory with survival outdoors suggests outdoor air is more toxic to pathogens under the same conditions of relative humidity and temperature than indoor air. This is attributed to a likely "open air factor", including UV light – pollutant concentrations, and oxidants (particularly correlated with ozone), but also may relate to the 'hostile' environment on particulate matter (PM) which can contain metal and organic components.

15. Two studies have measured survival indoors in a laboratory at only 1 intermediate relative humidity (~60 %) and temperature [9,10]. They suggested that the virus remains infectious for between 2 and >16 hours. For bacteriophages and influenza, indications are that survival is improved at low and high RH, but is lower at an intermediate RH. It has been proposed that this is connected with the cumulative dose the virus is exposed to at high solute concentrations in droplets [11]. Whether a similar non-monotonic behaviour is the case for SARS-CoV-2 is unknown. Laboratory studies show that infection risk decreases with increasing temperature [12]. Importantly, one unpublished study [12b] has suggested that there is no loss of infectivity for SARS-CoV-2 in <1 hour, but simulated sunlight (most likely the UV component) can lead to rapid loss of infectivity in <5 min at RHs between 20 and 70 %.

16. The US Department of Homeland Security have recently developed an aerosol decay model for SARS-CoV-2. This indicates that the rate of viral decay is accelerated by increases in UV exposure, temperature and relative humidity. On a dull day (UV index of 3-4 and air temperature of 10°C) decay is likely to be c.5% per minute compared to c. 30%/min on a hot sunny day (UV index 10; 30°C) (USDHS, 2020). This is similar to the conclusions of the Sagripanti and Lytle 2020 modelling paper. However, this finding does not affect our overall assessment of risk as dispersal is likely to be a more significant factor in reducing exposure than decay rate.

What dose is required for infection by airborne transmission?

17. The inhaled dose required for infection (both indoor and outdoor) is a significant unknown [13,14]. Some clinical and epidemiological data have suggested the potential for aerosol transmission. However, it is expected that any viral release outdoors would be rapidly diluted. Precedence for aerosol transmission was observed for Middle Eastern Respiratory Syndrome: the absence of signature of the virus in upper respiratory tract (nose, pharynx, larynx) but development of lower respiratory tract (bronchioles, bronchus, alveoli) infection, supported airborne transmission. A study of SARS-CoV-1 suggested that infections could result from a single virus [15] but animal models need a far higher dose to establish infection. So far 10^6 plaque forming units (pfu) have been used for animal models [16,17] but, anecdotally, 10^4 pfu intranasal may be sufficient challenge.

How do interactions with ambient particulate matter influence the airborne transmission of the virus?

18. Evidence suggests there are increased risk factors associated with development of Covid-19. Pre-existing lung conditions caused by long-term exposure to poor air quality are likely to be a confounding and important factor [18]. Only one study to date has identified RNA from SARS-CoV2 alongside urban PM [6]. However, the impacts of this on infectivity and the mechanism and range of transport are unclear. As stated above, ambient PM contains many oxidants such as metals and organic components which would be a hostile environment for the virus.

19. It seems unlikely on current epidemiological evidence that aerosol and droplet transmission will occur outdoors apart from where people are in close and prolonged contact (<2m) in crowded areas e.g. major sporting events, festivals, public gatherings.

20. The highest risk of outdoor transmission is through aerosols and droplets when people are in prolonged close, face-to-face contact within 2m. This is likely to be lower than indoor settings but remains a risk especially in crowded areas, e.g.at major sporting events,

festivals and public gatherings. This risk has already been considered by the Environmental Modelling Group and has not been considered further here**.**

21. Beyond 2m, risk is likely to progressively decrease. By 10m, risk of outdoor aerosol or droplet person-to-person transmission is **Very Low with medium uncertainty**.

22. Based on current epidemiological evidence, the risk of long-range (>10m) aerosol or droplet person-to-person transmission outdoors is **Negligible with low uncertainty.**

2. Water and the risk of transmission of SARS-CoV-2 via water/waste water

23. This section provides an overall view of the potential risk of transmission of SARS-CoV-2 through wastewater, risks associated with wastewater processing, and the risks of recreational use of waters that might be impacted by treated or untreated wastewater.

24. Since little is known of the behaviour and fate of SARS-CoV-2 in the wider environment, it is necessary to draw on information available on SARS-CoV-1, SARS-MERS and, to a lesser extent, other coronaviruses of human and animal origin. Reference also is made to other, non-corona, viruses that are commonly associated with wastewater and faecal-oral transmission.

Underlying principles that guided analysis in this section

- In addition to multiplying in the respiratory tract, SARS-CoV-2 has also been shown to multiply in the gastrointestinal and urinary tracts.
- SARS-CoV-2 can be shed at moderately high levels in urine (ca. 10^2 genome copies (GC)/ml) and faeces (ca. 10^4-10^6 GC/ml).
- The rate of shedding of infectious virus in faeces and urine is still uncertain.
- Current evidence suggests that high shedding rates are largely associated with cases expressing high levels of infection and exhibiting strong symptoms of COVID-19 (i.e. diarrhoea).
- Faecal shedding rates of SARS-CoV-2 in mildly symptomatic cases appear to be much lower and shorter in duration. Consequently, these pose a lesser risk for disease transmission via the urine/faecal-oral route.
- Shedding in faeces may occur in both the pre-symptomatic and post-symptomatic phase in COVID-19 cases, albeit at much lower levels (Wu et al., 2020).
- To become a substantive risk in the wider aquatic environment, infectious SARS-CoV-2 must be present in sufficient numbers to constitute an infectious dose. The infectious dose is still not known, but in this analysis we assumed that ca. 10^3 viral particles need to be ingested/inhaled to initiate infection.
- RNA sequences from SARS-CoV-2 can be found in wastewater and water, but this does not mean infectious viral particles are present.
- A small number of studies have shown that SARS-CoV-2 recovered from urine and faecal matter can be infectious *in vitro*. This knowledge is critical for any risk assessment of disease transmission. These studies have been done in both human and animal cell culture. However, many of the infectivity studies have been poorly conducted and not properly validated. Critically, the proportion of infectious particles present in urine and faeces remains unknown. Despite these caveats, it is not impossible that faeces and urine contains infectious virus, which might leave the body and enter the sewerage system.
- In a spectrum of viral ‘robustness’ coronaviruses lie between the classic sensitive enveloped respiratory viruses such as influenza and the non-enveloped enteric agents like norovirus.
- Currently, there are no reported cases world-wide which have shown a direct link between SARS-CoV-2 infection and exposure to sewage, drinking water, recreational water or other wastes.
- In the discussion below we assumed a basic level of sanitation, the wearing of personal protection equipment (where appropriate) and personal hygiene.

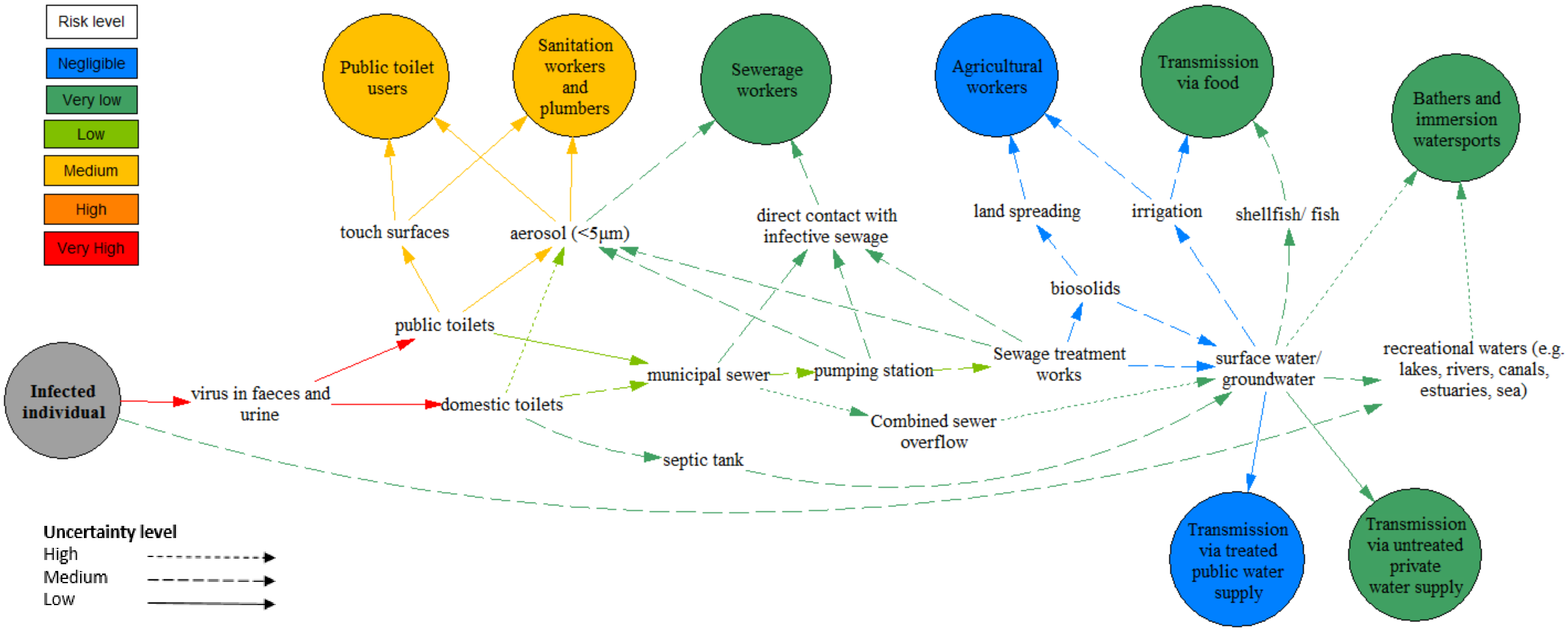

Figure 2: **Possible transmission pathways in water**. Colours represent FSA risk categories (Negligible, very low, low, medium, high, very high). Lines represents uncertainty: Solid line = low uncertainty, dashed line = medium, dotted line = high uncertainty.

Wastewater

25. Public toilets may represent a significant SARS-CoV-2 exposure point. This is because they are an introductory point into the sewage system at which the concentration of potentially infectious virus may be high. However, several other non-water exposure routes are also likely to be significant. The various possible transmission routes in public toilets are explored in Box 2.

26. Aerosol, faecal/ocular, and faecal/oral transmission risks have been hypothesised based on virus presence and existing evidence based on previous SARS-CoV outbreaks. Lodder et al. (2020) and WHO (2020, Page 2) considered that "*There is no evidence that the Covid-19 virus has been transmitted via the sewerage system with or without wastewater treatment*"; and suggested that "*Best practice for protecting the health of workers at sanitation facilities should be followed".*

27. Sewage environments are likely to be quite hostile to SARS-CoV-2 and it is unlikely that any virus will remain infectious for long after shedding. Nevertheless, exposure to sewage within tightly confined spaces might present a minor occupational health risk to operators or sewage workers. However, assuming appropriate PPE is worn, these risks are expected to be **Very Low**.

28. Relative risks strongly depend on where local COVID-19 hotspots might exist within a community. Sewage from hospitals may possess a high viral load, but usually makes up only a relatively small volume relative to the wider community (typically ranging from about 0.2 to 2% of the total community sewage flow, depending on the size of hospital and community). High levels of disinfectant and surfactants in hospital sewage are also likely to eliminate much of the infectious virus. Even in such locations, most urban sewers are underground and human exposure is very rare, except during storm events when combined sewage overflows are in operation. However, even in this scenario, the probable risk is **Very Low** because SARS-CoV-2 does not appear to retain infectivity after shedding.

29. Current studies at a range of urban centres in the UK indicate that at the peak of infections in the UK, levels of SARS-CoV-2 RNA in untreated wastewater were in the region of 10^4 to 10^5 genome copies per litre (GC/L). This has subsequently fallen to 10^2 GC/L, two months after the lockdown began. Even if all this virus was infectious, the likelihood of ingesting large enough quantities of wastewater to induce infection is extremely low.

30. Lodder et al. (2020) has suggested that the presence of the SARS-CoV-2 particles in wastewater, such as at sewage treatment plants, can be a useful indicator of community infection and can provide a practical sampling tool to indicate this community status. Observations of SARS-Cov-2 presence and persistence in surface waters are further supported by the empirical data from Casanova *et al*. (2009) and Xu *et al*. (2020). However, the risk to operators at treatment plants is still **Very low** if proper use is made of PPE. Even though this is highly probable, the lack of specific evidence for SARS-CoV-2 transmission suggests a precautionary approach until safer data on infectivity are available.

31. Water companies report that their STW staff already wore appropriate PPE, as recommended by WHO, before the pandemic and that these practices have continued (based on communications with (United Utilities, Thames Water and Welsh Water). There have been no reports from the water companies that they have seen an increase in staff absence or COVID-19 cases since the start of the pandemic. Further, Professor de Roda Husman of RIVM (pers comm.) advises that *personnel be very careful when working with human waste and wastewater. For sewage workers we already have a risk-based approach in the Netherlands because of Legionella and endotoxins which is also protective for SARS-*

CoV-2. The same level of risk would obtain even when combined sewage overflows (CSOs) are operating, though the uncertainty level would be higher.

32. Once wastewater is treated, effluent discharged to receiving waters will contain very little coronavirus (few studies have detected virus in wastewater treatment effluents), and it is highly unlikely that any that does get released remains infectious, hence the risk from treated wastewater is **Negligible with low uncertainty**. Though outbreak reports for enteric viruses (e.g. norovirus) demonstrate that viruses can survive in effluents, there is no such evidence for SARS-CoV-2.

33. However, survival may be slightly more when: (i) the receiving environment is constrained (limiting dilution); (ii) the treated effluent is not disinfected (e.g. by UV light) and; (iii) hydrological drivers reduce retention time in the plant; i.e. this will be an **episodic risk** which is also highly dependent on level of infection in population. However, other evidence suggests simulated sunlight readily degrades SARS-CoV-2 on surfaces (Ratnesar-Shumate 2020). Overall, the risk of disease transmission under these conditions is **Very low with medium uncertainty**.

34. Similar considerations apply to sewage sludge applied to land and municipal solid waste: by law all biosolids intended for application to crop-growing land are heat treated, which will rapidly inactivate any coronavirus. Overall, the risk of disease transmission via this route is **Negligible with medium uncertainty**.

<u>Recreational Waters</u>

35. Recreational waters include marine, transitional and fresh waters. Water-based activities may be classified as contact (e.g. swimming, surfing, paddle-boarding) or non-contact (e.g. boating, angling) water sports. Some waters are designated as bathing waters under the European Bathing Water Directive (2006) and their microbial quality monitored for specific faecal indicator bacterial content.

36. All these waters present a theoretical risk supported by outbreak reports for other diseases worldwide and health-based standards (e.g. WHO, 2003: EU 2006), but there is no evidence of coronavirus transmission by this route. This may change as exposure increases through the northern hemisphere summer holiday season and as more evidence is accrued.

37. In part, the risk is dependent on level of sewage treatment prior to release via long sea outfalls (LSOs) and on whether untreated sewage is discharged with the treated effluents via the LSO or urban surface water drains, and levels of coronavirus infection in the community. Such designated bathing waters in the UK are generally associated with a higher level of wastewater treatment (including UV) relative to non-LSO discharges.

38. There is no current evidence of infectious virus in open waters. The likelihood of infectious SARS-CoV-2 penetrating this far is very small, largely because infectious virus in sewage sources is **Very low to Negligible with medium uncertainty**. Further dilution in surface waters will make concentrations even lower.

39. Therefore, although contact water sports are usually associated with ingestion an average of 32mL/hour, Dufour et al 2017), the risk of waterborne infection is likely to be **Negligible with high uncertainty**.

40. Controls in place for robust enteric viruses in swimming pools (e.g. chlorination) are likely to be effective against SARS-CoV-2.

41. Given the low amounts of infectious virus that are likely to pass into recreational waters through the faecal/accidents or shedding , and the effect of dilution, person to person transmission via inhalation <2m apart is likely to be a more significant risk to swimmers, beachgoers and watersports enthusiasts than infection from waterborne routes. Although waterborne transmission is Negligible, taking account of possible person-to-person spread, aerosols generated by swimmers/people engaging in water sports, ingested spit carried in recreational water, and episodic events of high viral load, transmission risk is considered **Very Low to Low with high uncertainty** on a precautionary basis. Waterborne transmission between bathers beyond 2m is **Negligible Risk with medium uncertainty**.

<u>Other environments</u>

42. *Shellfish:* Consumption of shellfish grown in polluted waters is a well-documented route of transmission for enteric viruses (e.g. norovirus), but no information exists on whether bivalve molluscs concentrate coronaviruses in the same way, nor whether the virus would survive. Adherence to existing regulations governing harvesting and treatment of shellfish for human consumption should ensure coronavirus was not a risk. This is supported by the recent FSA assessment (FSA 2020b) The risk of infection is **Very Low with high uncertainty**.

43. *Water abstraction for drinking water treatment:* SARS-CoV-2 is inactivated by oxidising disinfectants including chlorine and ozone, therefore properly functioning conventional drinking water treatment would eliminate any risk of infection, which would thus be **Negligible with low uncertainty**. Water consumers using private water supplies may be at greater risk from microbial pollution, particularly due to leaching of contaminated water from septic tanks. However, the likelihood of infectious SARS-CoV-2 contaminating these supplies at appreciable levels is **Low to Very low with high uncertainty.**

44. *Water abstraction for irrigation of food crops*: There is a potential to contaminate crops but is highly unlikely to be at infectious dose levels. It is highly dependent on levels of infection in the community and the level of water treatment prior to abstraction. The risk is likely to be **Very Low with medium uncertainty**.

45. *Burial sites*: The risk of SARS-CoV-2 release from the burial of individuals who have died from COVID-19 was assumed to be **Negligible**. The main route of contamination would be through groundwater contamination and subsequent abstraction. There is no recent evidence that viruses have been transmitted by this route in the UK.

46. *Landfill sites, anaerobic digestion facilities*: It is likely that the levels of SARS-CoV-2 contamination on waste materials entering waste handling facilities will be negligible. There is no recent evidence that viruses have been transmitted by this route in the UK.

<u>Box2: Case study on public toilets</u>

47. Public toilets have been highlighted as a particular case in which water, airborne and surface transmission routes may all be significant. They are at the point in the sewage system at which loads of infective virus from faeces and urine are likely to be at their highest. Aerosol, faecal/ocular, and faecal/oral transmission risks have been hypothesised based on virus presence and evidence from previous SARS outbreaks (Patel 2020, McDermott 2020, Meng 2020, Liu 2020). They may also be a contact hub point where community transmission can occur between users through face-to-face droplet transmission or fomite transmission via high frequency touch sites. In this respect they are similar to other high throughput, enclosed spaces (e.g. buses and trains) (figure 2).

48. Potential routes include:
   (i) Surface splashes of urine or faeces directly onto toilet seats or other fomites followed by touching the surface and transferring to mucus membranes.
   (ii) Aerosolisation of faecal material during flushing and inhalation by anyone nearby (public toilets frequently do not have lids to reduce pathogen spread). There is limited evidence available on this risk.
   (iii) Aerosolisation of contaminated sewage from incorrectly installed plumbing.
   (iv) Direct contact or inhalation of aerosols by plumbers or sanitation workers. While sewage workers usually wear respirators and other personal protective equipment, the same is not usually true for sanitary plumbers or cleaners of public toilets.
   (v) Fomite transmission via touch surfaces contaminated with infective faecal material or nasopharyngeal fluids if cleaning is not frequent and thorough.

49. It is worth noting that most studies of SARS-CoV-2 in toilets have been conducted in healthcare environments, which have higher frequency and more thorough cleaning regimens than public toilets (e.g. Chia et al 2020). There is very little sampling data or epidemiological data on transmission from public toilets as they have been closed during the lock-down.

50. The level of risk to toilet users, cleaning staff and sanitation engineers is considered to be between **Low** (rare but does occur) and **Medium** (occurs regularly) with **low uncertainty**

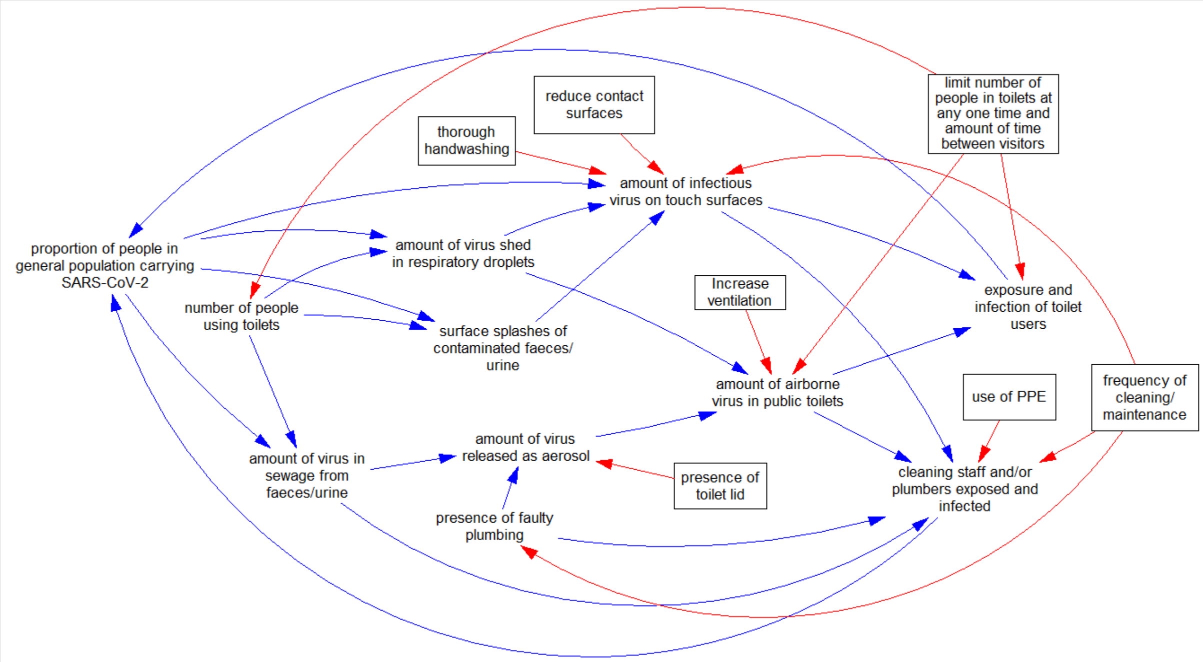

Figure 3. Influence diagram showing factors affecting infection risks in public toilets. Blue arrows show an effect increase and, red arrows decrease. Boxes show potential intervention points.

Notes on potential risk mitigation in public toilets illustrated in Figure 3.

i. Increase ventilation: The ability to implement this may vary between toilets. Some public toilets are mechanically ventilated and others rely on natural sources (open windows).

ii. ‘Thorough handwashing’ by users: This depends on available sink; provision of clean water; soap (liquid not bar); clean towels, preferably disposable; or bottle of alcohol gel.

iii. ‘Limiting number of people in toilets at any one time and time period between users’ may reduce droplet transmission by allowing infectious droplets to settle, though is unlikely to affect aerosol transmission.
iv. ‘Frequency of cleaning/maintenance’: Cleaning and decontamination is critical; but while the methods and consumables remain fairly standard, the frequency required depends upon people-traffic.
v. Maintenance is also critical, given the implications from a blocked or leaking toilet.
vi. Toilet design needs to ensure that all segments of the population (including for example, physically disabled people, blind, mentally impaired and children) are able to follow good hygiene practices.
vii. Given the likely virucidal effect of UV light, it might be useful to encourage ingress of sunlight into toilet facilities.

3. Surfaces and the risk of transmission of SARS-CoV-2 via surfaces in the outside environment

51. This paper includes material from other papers developed by the Environment and Modelling Group (EMG).

52. In a paper from the EMG based on evidence from 26 April 2020, it was noted that "*Recent work suggests differences in surface survival depending on the material (based on a single paper: van Doremalen et al., 2020) with SARS-CoV-2 surviving longest (up to 72 hours) on plastic and stainless steel, with a significant reduction in infectious titre over this timescale, followed by cardboard (infective up to 24 hours) and copper (infective less than 4 hours).*" Evidence, albeit from in vitro study, for varying longevity of SARS-CoV-2 on surfaces. (**Medium uncertainty**).

53. Chin et al (2020) reported on the temperature dependence of SARS-CoV-2 survival in virus transport media. They noted that the virus is highly stable at 4°C (0.7 log-unit reduction in 14 days) but at 70°C the time for virus inactivation was only 5 min. They also examined decay on surfaces including paper, tissue paper, wood, cloth, glass, banknotes, stainless steel, mask material at 22°C and RH (relative humidity) of approximately 65%. The authors note that no infectious virus could be detected from treated wood and cloth on day 2. The authors caution that the method used to recover virus "does not necessarily reflect the potential to pick up the virus from casual contact." Inoculated objects retrieved at desired time-points were soaked with 200 µL of transport medium for 30 mins to elute the virus; so not analogous with fingertip transfer. They also found the virus to be susceptible to disinfectants. (**Medium uncertainty**)

54. In a preliminary study, not yet peer-reviewed (Pastorino et al, 2020), SARS-CoV-2 stability was enhanced when present with bovine serum albumin, used to mimic the protein content within the body fluids of the respiratory system. Virus was still detected at the end of the 96 h experiment for the three surfaces included in the study (glass, aluminium and plastic). This may indicate that some laboratory studies underestimate surface survival. Evidence accumulating for surface survival, particularly if shielded by organic soil. Another in vitro study. (**Medium uncertainty**)

55. The US Department of Homeland Security (DHS) (2020a) has leveraged laboratory findings to develop a predictive model and calculator to estimate the natural decay of SARS-CoV-2 under a range of temperatures (21.1°C – 35°C) and RH (20% - 60%). At present it applies to the decay of the virus in simulated saliva on stainless steel and ABS (acrylonitrile butadiene styrene) plastic surfaces. It is anticipated that the calculator will be extended to include nitrile surfaces. At present, neither the calculator, nor supporting documentation, refer to scientific papers. (**Medium uncertainty**)

56. US Department for Homeland Security (2020b) outlines preliminary results from DHS funded work at the National Biodefense Analysis and Countermeasures Center (NBACC). Key points are quoted below:

    1. **Solar radiation rapidly reduces virus stability on outdoor surfaces.** Testing of virus decay in droplets of simulated saliva on a stainless steel surface was conducted at several different intensities of artificial sunlight. Sunlight intensity ranged from darkness to "full" sunlight, which is equivalent to the intensity and composition of unobstructed sunlight at noon at ground level in the Mid-Atlantic Region on the first day of summer. The amount of time it takes for infectious virus to be reduced by half (half-life) in a droplet of simulated saliva on stainless steel at full solar intensity was approximately 2 minutes at room temperature.

Operational Relevance: This data suggests that outdoor surfaces exposed to direct sunlight are at lower risk for virus transmission. (**Medium uncertainty**)

2. **Higher humidity may reduce virus survival.** When in saliva droplets, the virus is most stable at lower humidity.
Operational Relevance: This indicates that the virus is more likely to be stable and persist in areas of lower humidity. Increasing humidity levels may speed virus decay.

3. **The virus dies faster at higher temperatures.** The virus is less stable in saliva droplets on surfaces than in culture media and dies faster in saliva droplets at higher temperatures.
Operational Relevance: Increased temperatures may help kill the virus and reduce transmission. (**Low uncertainty**)

4. **Bleach & Isopropyl Alcohol (IPA) are effective decontamination solutions.** Diluted bleach (1 cup in 1 gallon water) was effective in reducing virus infectivity at least >99.9% in saliva droplets after 5 minutes on a stainless-steel surface. 70% IPA killed > 99.9% virus in a wet droplet of saliva and >98.1%virus was inactivated on stainless steel after just 30 seconds.
Operational Relevance: Reinforces the effectiveness of these EPA recommended disinfectants for use by DHS and other entities to clean and disinfect facilities. (**Low uncertainty**)

5. **Virus stability in saliva is not dependent on droplet size.** There is no statistical difference in half-life as a function of droplet size in saliva.
Operational Relevance: Surface stability data is applicable to a broad range of droplets generated by infected individuals (e.g., talking, coughing, medical procedures)." (**Medium uncertainty**)

57. The persistence of SARS-CoV-1 has been studied more extensively than that of SARS-CoV-2. Kampf et al (2020) reviewed reported persistence on metal, wood, paper, glass, plastic and a disposable gown. Values depended on starting inoculum (viral titre) and viral strain but were typically 4-5 days. The highest value reported was 6-9 days on plastic for a higher starting inoculum. Another in vitro study performed by experienced team (**Medium uncertainty**)

58. Evidence from sampling on cruise liners may be relevant. Moriarty et al (2020) report that SARS-CoV-2 RNA was identified on a variety of surfaces in cabins of both symptomatic and asymptomatic infected passengers up to 17 days after cabins were vacated on the Diamond Princess but before disinfection procedures had been conducted. (**Medium uncertainty**)

59. Of 601 surfaces cruise ship surfaces sampled by Yamagashi et al, 58 were positive (10%) for RNA. RNA was detected from 2/3 of case cabins but from none of the non-case cabins. Only 1 positive sample was found in a communal area. Toilet floor (39%), pillows (34%), table (24%) and chair arm (12%) were the most positive sampling sites. No infectious virus was isolated. Interestingly higher percentage positive samples were found from cabins inhabited by asymptomatic cases (21%) compared to symptomatic cases (15%). The PCR cycle threshold (Ct) value ranged from 26.2-39.0. RNA was detected up to 17 days post cabin occupation (uncertainty dependent on infectivity of virus as opposed to RNA detection).

60. The only quantification of SARS-CoV-2 surface contamination in from the hospital environment (Zheng Dong (2020) who found levels of up to 1.5×10^5 GC per sample from swabs taken in the hospital environment. Virus was widely distributed on floors, computer

mice, trash cans, and sickbed handrails and was detected in air ≈4 m from patients. These are all hand touch sites; no indication if bathroom surfaces were screened. Virus also found on the soles of shoes of hospital staff, who may transfer it elsewhere when walking out of a SARS-CoV-2 ward.

61. There is no evidence of levels of SARS-CoV-2 in the outside environment bar a paper which detected RNA in soils (205-550 GC/g) and wastewaters (255 to 1.9×10^4 GC/l) in locations close to departments receiving COVID-19 patients or in wastewater treatment sectors (Zhang 2020). (High uncertainty) We require screening studies in the community, targeted sites indoors rather than any outdoor surfaces.

Conclusions on surface transmission

62. Viral survival on surfaces is controlled by a range of environmental factors including temperature, relative humidity (RH), matrix (e.g., bodily fluids) and exposure to light (UV) (Ren et al 2020). (**Low uncertainty**)

63. We can predict that viral survival on surfaces is truncated in areas of high temperature and low humidity, as opposed to areas with low temperature and high humidity. There is uncertainty over areas with high humidity/high temp and low humidity/cool temperatures. There may be benefit in comparing climatic conditions in different countries across the world against virus parameters, controlled for population density and pandemic controls. (**Medium uncertainty**)

64. Virus survival on indoor surfaces may be prolonged according to reports from cruise ships, but RNA demonstration from surfaces is not the same as infectious virus. (**Low to Medium uncertainty**)

65. Very Low possibility that faecal aerosol may be generated by colonised or infected people which contaminates surfaces and air in bathrooms. (**Low to Medium uncertainty**)

66. All usual disinfectants show activity against SARS-CoV-2, especially alcohols and bleach (Low uncertainty) although there are at least two papers showing less activity of quaternary ammonium compounds against virus. Detergents may also be effective (**Medium uncertainty**) due to effect on bilipid envelope.

67. In conclusion, there is no doubt that SARS-CoV-2 can contaminate surfaces in enclosed areas (home, public transport, schools, shops, etc) outside the healthcare environment. Hand touch sites (particularly grab sites) would constitute the highest risk, along with surfaces in bathrooms and public toilets. There is increasing evidence to suggest that the virus survives long enough to be acquired by susceptible people. How often that translates into new infection, we do not know. Demonstrating presence of viral RNA on surfaces is not the same as demonstrating infectious virus, let alone the amount of virus and level of infectivity. **Medium risk with High uncertainty**

68. Should surface contamination be deemed high risk, then cleaning and disinfection of high risk hand touch sites and bathrooms would aid with curtailing spread. Frequency of cleaning would depend on people traffic in the first instance, but also initial inoculum, infective dose (**not yet known**), temperature and humidity. Bleach-based disinfectants rapidly inactivate virus in the absence of organic matter, which tends to inactivate the hypochlorite. Some surfaces may only require attention with detergent based cleaning (**High uncertainty**) but this is worth pursuing from cost, toxicity and environmental damage perspectives.

69. The risk of acquiring virus from outside surfaces is likely to be very low, particularly if surfaces are exposed to sunshine (or even grey light) on a daily basis. The only exceptions may be frequent touch points such as outer shop door handles, cash machines, outside shutters, door knockers, door bells, etc. **(Low risk with Medium uncertainty)**

70. Recent modelling has shown that the time taken for a log^{10} reduction of virus in London in midday sun was 30 minutes at midsummer, 77 minutes in autumn, 173 minutes in spring and 300 minutes in winter (Sagripanti and David Lytle 2020; Ratnesar-Shumate, 2020). The virucidal effect of UV may be halved on a cloudy day or in the shade (Ben-David and Sagripanti 2010; 2013). In practice, this means that the risk of outdoor fomite transmission (and reaerosolisation) could be elevated under UK winter conditions (December-March).

4. Food and the risk of transmission of SARS-CoV-2 via food or food contact material

The text that follows is a summary of the risk assessment conducted by the FSA on the 12th June 2020[2].

71. The FSA overall risk assessment estimates that the probability of exposure of UK consumers to SARS-CoV-2 via food is **Very Low with High uncertainty**. The uncertainty associated with this estimate is high as there is still no evidence to confirm or refute the hypothesis that people can be infected by ingesting SARS-CoV-2 in food (FSA 2020a).

Potential for infection via ingesting virus

72. Food has not currently been identified as a source of infection. The genome of SARS- CoV-2 suggests that it is most closely related to SARS-CoV-1, for which foodborne transmission was also not implicated in any cases of infection. However, this route cannot be ruled out and has not been investigated directly. We therefore make the conservative assumption that such transmission is possible. SARS-CoV-2 requires the presence of the angiotensin-converting enzyme 2 (ACE2) receptor to infect a cell, which is present in various human tissues including oral and nasal mucosa, nasopharynx, stomach, small intestine, and colon (Hamming et al., 2004). Although infection via the oral mucosa may present the most credible route of infection during ingestion of contaminated foodstuffs, because at body temperature the virus is likely to be inactivated rapidly at the pH occurring in the stomach of healthy individuals. Some medications could affect this potential for infection; for example, individuals taking medication that reduce stomach acidity (such as proton pump inhibitors) may have consequences for viral inactivation during digestion.

73. Foodborne exposure to SARS-CoV-2 can occur via two pathways:

    A. via the consumption of foodstuffs of animal origin (primarily meat, eggs, milk, dairy and blood products) from infected animals, or
    B. via the consumption of foodstuffs contaminated by one or more of the following: contaminated products of animal origin, contaminated foods of non-animal origin, contaminated food contact materials, contaminated preparation surfaces, or infected individuals involved in food preparation.

[2] https://www.food.gov.uk/research/research-projects/qualitative-risk-assessment-on-the-risk-of-food-or-food-contact-materials-as-a-transmission-route-for-sars-cov-2

Summary of exposure via infected animals

74. Overall, the likelihood of human exposure to the virus from infected animals (livestock or wildlife) from which meat or products of animal origin are derived is **Negligible with High uncertainty**. More detail on assessment (and supporting evidence) for each of these steps can be found in the full FSA risk assessment (FSA 2020a).

- *The risk from infected eggs, poultry meat and fish and seafood* is assumed to be **Negligible**; the likelihood that meat and blood products, milk and dairy products from other species (including mammals) may be susceptible to the virus is **Negligible to Very Low**.
- *The probability that products consumed in the UK would be derived from infected animals* with sufficient viral titres in edible fractions is **Very Low**.
- *Reduction in viral titre due to processing*: Some food processing methods would be expected to reduce the viral titre; however, due to the diverse range of products available, it is not possible to provide a generalised probability covering all products. Heating to 70°C for less than five minutes is likely to inactivate the virus if present in food (Chin et al 2020). Heating to temperatures above 65°C for shorter periods is likely to reduce the infectivity of any virus present significantly, although with **greater uncertainty**.
- *Proportion of infectious virus surviving transportation to the UK*: survival of virus present in products stored or transported under chilled or frozen conditions is likely to be variable but in some cases, for instance chilled or frozen food, the virus may survive for a period of weeks so no substantial reduction is assumed in this assessment.

Summary of exposure via contaminated foodstuffs

75. Overall the likelihood of exposure to SARS-CoV-2 via contaminated food products produced both domestically and internationally (imports) is **Very Low with high uncertainty**. Although the likelihood in some steps is **Negligible**, due to the high volumes of food and food contact materials and packaging produced both domestically and internationally (excluding illegal imports) a conservative estimate of **Very Low** is assigned.

76. The risk pathway estimated the probability of consumption of cross-contaminated foods considering both products of animal origin and foods not of animal origin. More detail on assessment (and supporting evidence) for each of these steps can be found in the full FSA risk assessment (FSA 2020a).

- *Consumer exposure via the prevalence of infection in human handlers producing commercial food (UK or in importing countries)*: The prevalence of infection in people involved in food harvesting, preparation and processing in the UK or in other parts of the world is considered to be is **very low**;
- *Consumer exposure via the frequency of close contact of infected food handlers and the degree to which hygienic food preparation methods mitigate this exposure*: On the assumption that good food hygiene practices are adhered to, the probability of cross contamination in either domestic or international production, if a worker is contaminated, is **Very Low**. It is possible that transmission may be more likely in certain food production environments, for example those with low air temperature, and as a result uncertainty exists in this estimation.
- *Reduction in viral titre due to processing*: Some food processing methods would reduce the viral titre; however, due to large range of products available both through international import and domestic production, it is not possible to state a generalised probability for all

products. Heating to 70ºC for less than five minutes is likely to inactivate the virus if present in food (Chin et al. 2020). Heating to temperatures above 65ºC for shorter periods is likely to reduce the infectivity of any virus present significantly, although with **greater uncertainty**.

- *Proportion of infectious virus surviving transport to the UK (imported foods only)*: survival of virus present in products stored or transported under chilled or frozen conditions is likely to be variable but in some cases, for instance chilled or frozen food, the virus may survive for a period of weeks so no substantial reduction is assumed in this assessment.
- *Volume of product imported from affected countries to the UK*: the overall volume of food and food contact material and packaging imported into the UK is high, but will vary significantly by region of origin.

Risk Matrix (updated 11/06/2020)

This matrix summarises risks from the pathways considered in the report. The assessment assumes that people are operating within normal parameters. In the case of the water and food sectors, this assumes that workers are following standard operating procedures, following hygiene guidelines and using standard personal protective equipment.

The risk assessment is based on the current status of the Covid-19 pandemic. The assessment uses the Food Standards Agency coding shown in figure 1. The overall score for each pathway represents the consensus of the group.

	Pathway	Probability Category	Uncertainty Category	Comment
Air and the risk of transmission of SARS-CoV-2 when people are outside				
1	Outdoor air within 2m	**HIGH**	**Medium**	Within 2m, the risk of outdoor aerosol or droplet transmission between people in close, face-to-face contact (especially in crowded areas, e.g.major sporting events, festivals and public gatherings) is likely to be similar to the indoor settings already considered by the Environmental Modelling Group, i.e. High with medium uncertainty.
2	Outdoor air > 2m	**VERY LOW**	**Medium**	Beyond 2m, risk is likely to progressively decrease. By 10m, risk of outdoor aerosol or droplet person-to-person transmission is Very Low with medium uncertainty.
3	Outdoor air long-range (>10m)	**NEGLIGIBLE**	**Low**	Based on current epidemiological evidence, the risk of long-range (>10m) aerosol or droplet person-to-person transmission outdoors is Negligible with low uncertainty.
Water and the risk of transmission of SARS-CoV-2 via water/waste water				
4	Public toilets	**MEDIUM**	**Low**	Present pandemic epidemiological evidence proves this pathway. Aerosol, faecal/ocular and faecal/oral transmission risks have been hypothesised from virus presence. Also strong evidence from previous SARS-CoV outbreaks. Relates to toilet users, sanitary engineers and plumbers.
5	Sewerage system carrying untreated effluents	**VERY LOW**	**Medium**	Sewage environments are likely to be quite hostile to SARS-CoV-2 and it is unlikely virus release will remain infective for long after shedding. Nevertheless, exposure to sewage within tightly confined spaces might present a minor occupational health risk to operators or sewage workers. However, assuming appropriate PPE is worn, these risks are expected to be Very Low.

				The virus has been isolated in sewage waters, access to sewerage confined spaces present potential occupational health risks to operatives. Highly dependent on whether there are hotspots of infection in the network. No current evidence of infective virus in sewers.
6	Intermittent discharges of diluted sewage after rainfall and/or SPS failure	**VERY LOW**	**High**	Access to this infrastructure is carefully controlled with staff training and the provision of PPE where necessary. Similar to sewers, no current evidence of infective virus raw sewage. Relative risks strongly depend on where local COVID-19 hotspots might exist within a community. Sewage from hospitals may possess a high viral load, but usually makes up only a relatively small volume relative to the wider community (typically ranging from about 0.2 to 2% of the total community sewage flow, depending on the size of hospital and community). High levels of disinfectant and surfactants in hospital sewage are also likely to eliminate much of the infectious virus. Even under such locations, most urban sewers are underground and human exposure is very rare, except during storm events in combined sewers. However, even in this scenario, the probable risk is Very Low because SARS-CoV-2 does not appear to retain infectivity after shedding.
7	STWs produce both aerosol and faecal oral contact possibilities, e.g. near aeration tanks and sewage sludge disposal to land	**LOW**	**High**	Initial enquiries with UK water suggest no evidence of elevated illness in STW operatives since the start of the pandemic in the UK. But WHO (2020) have recommended PPE for all such workers which may be mitigating risk. Adjacent urban populations may not be so protected however. Highly dependent on level of infection in population.
8	Treated effluent discharges to fresh and marine waters	**NEGLIGIBLE**	**Medium**	Outbreak reports for enteric viruses (norovirus) prove the risk from treated effluents to water users. There is no such empirical evidence for SARS-Cov-2 but may be more likely when: (i) the receiving environment is constrained (limiting dilution); (ii) the treated effluent is not disinfected (e.g. by UV light) and; (iii) hydrological drivers reduce retention time in the plant; i.e. this will be an episodic risk. Highly dependent on level of infection in population. However, other evidence suggests sunlight rapidly degrades virus.
9	Sewage sludge disposal to land	**NEGLIGIBLE**	**Medium**	The SARS-Cov-2 presence would depend on the in-plant process used to treat and thence store the sludge before use, but disposal to agricultural land risks contact with farm workers and food crops. All sludge is treated, sometimes including pasteurisation, and-or aged prior to disposal. Therefore, infective virus is probably very low.
10	Municipal solid waste disposal sites	**VERY LOW**	**Medium**	Risk from contaminated waste theoretically possible but survival of infectious SARS-CoV-2 likely to be extremely low.

	(composting, AD and landfill facilities)			
11	Drinking water treatment works	**VERY LOW**	**Low**	Raw water could produce aerosols impacting on operatives if it was from, say, a contaminated river. However, if source water has none or very low levels of infective virus, exposures are likely very low.
12	Potable domestic water supplies	**NEGLIGIBLE**	**Low**	Public water supplies, general operate in urban areas and are subject to terminal disinfection generally by chlorine which will inactivate SARS-CoV-2. Some rural but not all private water supplies will be subject to disinfection and will present a greater public health risk. Some single dwelling supplies may be open to contamination and have essentially no treatment but for those the likely contamination source would be their own septic tank
13	Sewage, soils and surface waters near hospitals	**LOW**	**High**	Not different than sewers and urban surface waters, except source concentrations of virus might be higher. This could result higher aerosol or droplet carriage but depends on type of hospital and other factors. Highly dependent on level of infection in population. High disinfectant load in sewage.
14	Human burial sites	**NEGLIGIBLE**	**High**	COVID-19 cases may have a high load, but most burials contained and virus unlikely to survive putrefaction process. Risk would be via groundwater route, so unlikely to reach surface.
15	Water abstracted from rivers and used to irrigate food crops	**VERY LOW**	**Medium**	Potential to contaminate crops but likely not at infectious dose levels. Highly dependent on levels of infection in the community.
16	Beach and recreational waters (fresh, transitional and marine)	**LOW/VERY LOW**	**High**	Highly dependent on level of sewage treatment prior to release via long sea outfalls (LSOs) and on whether untreated storm flows are discharged with the treated effluents via the LSO and levels of infection in the community. However, designated bathing waters are regulated in the UK and are generally associated with high level treatment for adjacent sewage discharges. However, like surface waters and sewers, no current evidence of infectious virus in open environments. Potentially greater exposure to faecal/oral and aerosol ingestion during recreational activity.
17	Consumption of potentially contaminated shellfish	**VERY LOW**	**HIGH**	Well documented route of transmission for other human pathogenic viruses, but no information on the concentration rate of SARS-CoV-2 or its survival in shellfish flesh. For non-Grade A growing areas, post-harvest treatment is required. However, the risk control system is based on *E. coli* testing of shellfish flesh.
Surfaces and the risk of transmission of SARS-CoV-2 via surfaces in the outside environment				

18	Infrequently touched outdoor surfaces	**VERY LOW**	**Medium**	The risk of acquiring virus from infrequently touched outdoor surfaces is **Very Low to Negligible with medium uncertainty**, particularly if surfaces are exposed to sunshine on a daily basis. Subject to type of surface, temperature, relative humidity, and matrix (e.g. bodily fluids, organic soil, etc). Refs: 1-5 (Van Doremalen, Chin, Ren, Pastorino, USa)
19	Frequently touched outdoor surfaces	**LOW**	**Medium**	Surfaces that are frequent touch points such as outer shop door handles, cash machines, outside shutters, door knockers and door bells are likely to be slightly higher risk, i.e. **Low with medium uncertainty**
20	Outdoor surface in winter conditions	**MEDIUM**	**High**	Recent modelling of the solar inactivation of SARS-CoV-2 on surfaces indicates that that the virus could remain infectious for long time periods in when light levels are low. Modelling survival time in direct midday sunlight at the latitude of London showed that the time for 90% infectivity reduction is likely to be around 30 minutes in mid-summer but extended to 300 minutes in mid-winter (Sagripanti and David Lytle 2020). The virucidal effect of UV may be halved on a cloudy day or in the shade (Ben-David and Sagripanti 2010; 2013). In practice, this means that the risk of outdoor fomite transmission (and reaerosolisation) could be elevated under UK winter conditions (December-March)
21	Transmission from surfaces exposed to sunlight in summer	**VERY LOW**	**HIGH**	Outdoor surfaces exposed to direct sunlight are likely to present a lower risk for virus transmission. Refs: 6-10 (USb, Ratnesar, Guasp, Eslami, Sagripanti)
22	Transmission from regularly cleaned and disinfected surfaces	**LOW**	**MEDIUM**	Studies showing negative surface screening for virus following bleach-based cleaning in hospitals. Refs: 2,11-13 (Chin,Kampf, Ijaz,Schrank)
23	Surface transmission from toilets	**MEDIUM**	**HIGH**	Mounting evidence for presence of viral contamination in bathrooms. Refs: 14-21 (Ong, Zhang D, Ding, Patel, McDermott, Meng, Liu, Dohla)
24	Surfaces in cruise ships	**MEDIUM**	**Medium**	Viral RNA identified on a variety of surfaces in cabins of both symptomatic and asymptomatic passengers up to 17 days after cabins were vacated but before

				disinfection procedures; hotspots were toilet floor (39%), pillows (34%), table (24%) and chair arm (12%). Refs: 13,14 (Moriarty, Yamagishi)
Food and the risk of transmission of SARS-CoV-2 via food or food contact material				
25	Consumer exposure via food products from infected animals	**NEGLIGIBLE**	**High**	The uncertainty associated with the estimate is High as there is still no evidence to confirm or refute the hypothesis that people can be infected by ingesting SARS-CoV-2 in food. The High uncertainty reflects that it is extremely challenging to make a meaningful statement about the tissue distribution or titre of virus in (currently theoretical) food animal hosts when we have no suitable animal models.
26	Prevalence of infection in human handlers producing commercial food (UK or in importing countries)	**LOW**	**High**	
27	Consumer exposure via the frequency of close contact of infected food handlers assuming hygienic food preparation methods are used	**VERY LOW TO NEGLIGIBLE**	**High**	

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Research Priorities

Air transmission:

How does the survival of the virus decline with time with change in RH and temperature in outdoor settings in presence of light? How rapid does survival decline on evaporation/exhalation of droplets from the highly humid respiratory tract? A full dependence on environmental conditions is required to understand the likelihood of airborne transmission, as survival is non-monotonic. This will be important to understand seasonal variations in transmission and potential engineering/infrastructure decisions to minimise risk. Current studies use Goldberg drums and Collison nebulisers that can compromise pathogens and have an ill-defined time zero, making short times challenging to study. They also study droplets <5 μm size, less representative of the larger droplets from exhalation events.

What inhaled dose is required and in what size particle? Small respirable size particles may have higher viral load e.g. factor of 8-9 in Influenza A [Milton et al, 2014], but it is unknown how the viral titre depends on droplet size and what dose is required to assess risks.

Milton DK, Fabian MP, Cowling BJ, Grantham ML, McDevitt JJ. Influenza Virus Aerosols in Human Exhaled Breath: Particle Size, Culturability, and Effect of Surgical Masks. PLoS Pathog. 2013;9.

Does particulate matter mix with airborne droplets containing the virus and does this give any synergistic effects, protective or otherwise? What impact does open-air factor have on survival? Atmospheric particulate matter has been linked to the spread of viruses and other contaminants in general. Particulate matter (PM) works as a carrier since it has been noted that viruses might be able to attach or stick to them. However, the role of airborne transmission mixed with PM is still uncertain. In addition, semi-volatile species may partition into virus containing droplets and have a synergistic impact that is un-investigated, in addition to oxidant species such as ozone.

Are their synergistic effects that occur when respiratory droplets contain mixtures of pathogens? For example, if SARS-CoV-2 is mixed with *Streptococcus pneumoniae*, a bacterial species that occurs naturally only in the respiratory tract of humans and is the leading cause of bacterial pneumonia, are their synergistic effects that support airborne transmission? All studies have concentrated on SARS-CoV-2 in aerosol alone.

Food transmission

1. Can people be infected by foodborne exposure to SARS-CoV-2 (or, failing that, other coronaviruses), for example by contaminated food surfaces coming into contact with mucous membranes in the mouth?
2. If (1) is shown to occur, is the risk of infection via food significantly higher for individuals with periodontal disease (and bleeding gums) or other pre-existing conditions or commonly-used medication (for example slower inactivation of virus in the stomach due to the use of antacids or proton pump inhibitors)?
3. Can food animals (pigs, cattle, sheep) become infected? Currently some challenge studies published suggesting low risk, but it would be useful to have a clear idea of what livestock surveillance is currently being conducted, and how we would hear about the results, including negative results. Some evidence that SARS-CoV able to infect pigs.
4. If evidence is obtained supporting (3), what are the titre and survival times of infectious SARS-CoV-2 in edible fractions of products from infected animals? In the absence of data on SARS-CoV-2 or SARS-CoV-1, MERS-CoV and BCoV would be the most relevant (PEDV less so?).

5. Estimation of the rate and extent of contamination of surfaces in proximity to an asymptomatic infected individual (ideally something like “surfaces within 2m will be contaminated with 10^1 infectious viral particles every five minutes” or a dispersion kernel of some sort - I realise this is optimistic)
6. The effectiveness of PPE (cloth face coverings, N95/FFP2 masks) at reducing (5).
7. Information on how air handling and air temperature affect (5) and (6) - I am aware of suggestions that slaughterhouse clusters might be occurring because of the air handling and air temperature in these workplaces.
8. The survival of SARS-CoV-2 on the surfaces of RTE food sold loose (currently primarily fruit, vegetables and baked goods, but ultimately also deli counter foods like olives and cooked meats as those reopen) and the effectiveness of (clearly described methods of) washing and peeling.
9. Heat inactivation times and temperatures to inactivate SARS-CoV-2 in food.
10. What is the risk that vigorous washing of contaminated fresh produce/RTE under a tap will aerosolise virus or contaminate nearby surfaces?
11. What is the risk of aerosolising virus from spraying down/washing contaminated food preparation areas?
12. Any data on the relative potential for jet air dryers, warm air dryers and paper towels to increase environmental contamination.

Water Transmission:

1. What is the infectivity of SARS-CoV-2 in aquatic matrices, especially in wastewater and treated effluent (UV or non-UV treated)? This is a very important issue, having an answer could mean many other questions disappear. We have the great advantage that, unlike with the ‘true’ enteric viruses such as norovirus or rotavirus, coronaviruses will grow in cell culture, so an infectivity assay should be possible. What is the infectivity titre in these matrices? How long does infectious virus survive and persist (not the same) in water? What is the T90 time for infectious virus? What is the relationship between infectious virus levels and genome-copy levels in different matrices?

2. What is the infectivity of SARS-CoV-2 in sewer systems as a function of how long after release as faecal matter? How do oxygen conditions (i.e., the type of sewers) and other environmental factors influence retention of infectivity?

3. How does SARS-CoV-2 as measured by RT-qPCR relate to apparent infectivity? What is the optimal method for preparing samples for RT-qPCR analysis of SARS-CoV-2 in sewage samples? How does the presence of impurities that co-concentrate in sewage impact the reliability of RT-qPCR signals?

4. Does the measured amount of SARS-CoV-2 to sewage and other water relate relative to time from shedding? How fast does signal decline with time? What affects “decay” kinetics?

5. What sources within any community release wastewater with the highest loads of SARS-CoV-2 (e.g., hospitals, clinics, residential, business, industrial etc.) and does the source influence whether one finds infective SARS-CoV-2 in samples?

6. How do the different shedding cycles among symptomatic and asymptomatic patients impact the levels of infectious versus non-infectious virus detected in sewage relative to different sources (impacts how community vs clinical sources might impact exposure risk relative to different locations)? This might be especially important in locations prone to combined sewage overflows.

7. How do different WWTP technologies influence SARS-CoV-2 signal between influent and effluents? Is there any evidence of an infectious virus anywhere in WWTPs?

8. We need to understand virus fate kinetics in real sewers. This can be done by measuring SARS-CoV-2 levels and infectivity is sewage flowing away from higher sources, such as a hospital. If you have flow and concentrations, you can back-model fate kinetics. If you do this in different places and with difference temperatures, one could develop a quantitative model that uses concentrations at source (e.g., faeces) and flow data to predict probable concentrations around a network. This can be done for sewers, but also for any drain system.

9. Risk of infection from public toilets (e.g. aerosol generation).

Surface Transmission

10. The ultimate chain of evidence for surface risk requires genotyping SARS-CoV-2 from surfaces and showing identical genotype between patient virus and surface virus and the timing of each. This has been done for bacterial pathogens in hospitals and serves to confirm the risk to patients from contaminated hand-touch sites.

Expert group on the transmission of SARS-CoV-2 in the wider environment (TWEG)

Chair: Gideon Henderson (Defra, CSA)

Members: Allan Bennett (PHE), Kathryn Callaghan (Defra), Stephanie Dancer (NHS Lanarkshire/Edinburgh Napier University), David Graham (University of Newcastle), Alwyn Hart (Environment Agency), Davey Jones (University of Bangor), Dave Kay (University of Aberystwyth), Miren Iturriza-Gomara (University of Liverpool), Bill Keevil (University of Southampton), Frank Kelly (Imperial College London), Dan McGonigle (Defra), Andrew Morgan (Scottish Government), Cath Noakes (University of Leeds), Jonathan Reid (University of Bristol), Anthony J Wilson (Food Standards Agency), Peter Wyn-Jones (University of Aberystwyth).