UTS Institute for Sustainable Futures

Climate Framework to Improve the Resilience of Sanitation Technologies

How-to Guide | September 2023

Authors

Jeremy Kohlitz | Ian Cunningham | Juliet Willetts

Citation

UTS-ISF, 2023. ClimateFIRST: Climate Framework to Improve the Resilience of Sanitation Technologies: How-to Guide. Prepared by University of Technology Sydney, Institute for Sustainable Futures for the Bill and Melinda Gates Foundation. Authors: Jeremy Kohlitz, Ian Cunningham and Juliet Willetts.

About the authors

The University of Technology Sydney – Institute for Sustainable Futures (UTS-ISF) conducts applied research to support water and sanitation policy and practice in Asia and the Pacific. UTS-ISF provide partners with technical expertise including climate change; planning, governance and decision-making; gender equality and inclusion; public health and water resources; monitoring; and policy and practice advice.

Acknowledgments

The authors would like to thank Freya Mills, Pierre Mukheibir, Nuhu Amin, Jay Faletta and Jess MacArthur for their contributions to this work, as well as University of South Florida, Ankur Scientific, Georgia Institute of Technology, Cranfield University and iDE. Input and guidance from Brian Arbogast, Jan-Willem Rosenboom and Alyse Schrecongost and funding support from the Bill and Melinda Gates Foundation are also gratefully acknowledged.

Institute for Sustainable Futures

University of Technology Sydney
PO Box 123 Broadway, NSW, 2007
www.isf.uts.edu.au

Disclaimer

The authors have used all due care and skill to ensure the material is accurate as at the date of this report. ISF and the authors do not accept any responsibility for any loss that may arise by anyone relying upon its contents.

ClimateFIRST was funded by the Bill and Melinda Gates Foundation.

Cover photo: All Seasons Upgrade. Credit: Kim Heng Lay, iDE   Graphic design and layout by Jo Yuen: www.joyuendesign.com.au

Introduction

The Climate Framework to Improve the Resilience of Sanitation Technologies (ClimateFIRST) aims to support the global sanitation sector to develop sanitation technologies that can better accommodate the effects of increasingly extreme and volatile climates.

ClimateFIRST is used to:

- Identify the potential impact of climate hazards on a sanitation technology.
- Determine how the climate resilience of a sanitation technology can be strengthened through design.
- Score the overall climate resilience of the sanitation technology.

ClimateFIRST is relevant for sanitation technology designers, research and development personnel, and professionals working to implement sanitation technologies, primarily in low- and middle-income countries. ClimateFIRST is intended to be used for decentralised technologies for the containment and/or treatment of human waste.

Photo: UTS

Background

Climate change is dramatically altering physical climate conditions that directly affect sanitation technologies in urban and rural contexts. Consequently, the climate is increasingly likely to drive the failure of sanitation technologies and increase public health risks through the release of faecal pathogens, nutrients and other pollutants into the environment.

The risks that climate hazards cause failures to sanitation technologies can be reduced through improved design of sanitation technologies. The University of Technology Sydney – Institute for Sustainable Futures (UTS-ISF) developed ClimateFIRST to provide guidance on assessing how these failures might occur and how design features can reduce the risks of failure in a given sanitation technology. The design features featured in ClimateFIRST are based on a literature review of the latest thinking in resilient technological design across sanitation and other sectors, and the opinions of sanitation experts. This work was supported by the Bill and Melinda Gates Foundation.

Resilient sanitation technology design is just one component of **climate-resilient sanitation service delivery systems** — institutional, governance, service, financial, and social aspects are also critical for resilience. As such, ClimateFIRST is not a complete guide to developing climate-resilient sanitation. Instead, it should be considered as a resource focused on technologies, and to be used as part of wider shift towards resilient sanitation for all.

Through use of ClimateFIRST, sanitation designers and implementers will be better equipped to deploy sanitation options that can perform essential functions despite worsening climate hazards.

About this guide

This guide provides how-to instructions and supplementary material to users of ClimateFIRST. ClimateFIRST itself is an Excel-based tool accompanies this guide. A video version of this guide can be found online.

Carrying out an assessment with ClimateFIRST comprises five steps. This guide describes how to carry out each step and provides tips and examples. It also describes how inputs into ClimateFIRST are summarised and provides more detailed information on climate hazards and resilience design features.

The assessment process is comprised of five steps:

1. **Scoping:** The assessment team describes the sanitation technology, chooses which components of a sanitation technology are included or excluded in the assessment, and identifies the geographical location in which the sanitation technology is being assessed.
2. **Hazardous events and trends:** The team identifies the hazardous events and trends (HETs), such as flooding or drought, that are relevant to the sanitation technology's location and describe the HETs' characteristics for that location.
3. **Hazards:** The team assesses the impact of relevant climate hazards (e.g. force of flood waters) that may be associated with the HETs indicated in Step 2 on the sanitation technology.
4. **Design features:** The team assesses the extent to which the sanitation technology's design features can help the system avoid, reduce or offset the negative impacts of the hazards identified in Step 3, and considers how the design features could be added to the sanitation technology.
5. **Overall resilience:** The team gives the sanitation technology an overall resilience score against each HET based on their judgements stemming from the previous steps.

ClimateFIRST then provides a summary of the inputs provided by the assessment team across four tabs.

The following sections cover recommended preparations before beginning the assessment, each of the five steps of the assessment process, and interpretation of the summary outputs.

There are two versions of ClimateFIRST: A full version and a lite version. The lite version focuses only on floods and droughts and assesses a smaller range of design features. The lite version is intended for users who do not have time to complete the full version or wish to do a less detailed assessment. This guide covers the full version, but the instructions are applicable to the lite version as well.

Preparation for the assessment

There are many different dimensions to consider when assessing the resilience of a sanitation technology. Consequently, **a thorough assessment may require a full day** to complete the steps and allow for discussion amongst the assessment team members.

Teams should complete the following preparation prior to carrying out the assessment to make the process efficient.

Preparing for the assessment

The lead for the assessment process should familiarise themselves with ClimateFIRST. They should be confident to lead others through the process and have allocated sufficient time for the group to derive benefit from doing the assessment together.

Assembling the assessment team

Effective assessments and justifiable decisions require a diversity of perspectives. Assessment teams should be comprised of multiple people who are familiar with the design and operation of the sanitation technology. This may include sanitation engineers, designers, research and development personnel, operators or technicians. It could also include commercialisation partners.

Gathering reference materials

In addition to this guidance document, teams should collate relevant drawings, schematics or photos of the sanitation technology being assessed to use as references during assessment deliberations. Teams should also have knowledge of, or access to, historical and predicted climate information for the location/context in which the sanitation technology is being assessed. The climate information should indicate which hazards events and trends (HETs) are, or will likely be, of concern in the chosen locations (see Step 2 of the assessment process).

Photo: UTS

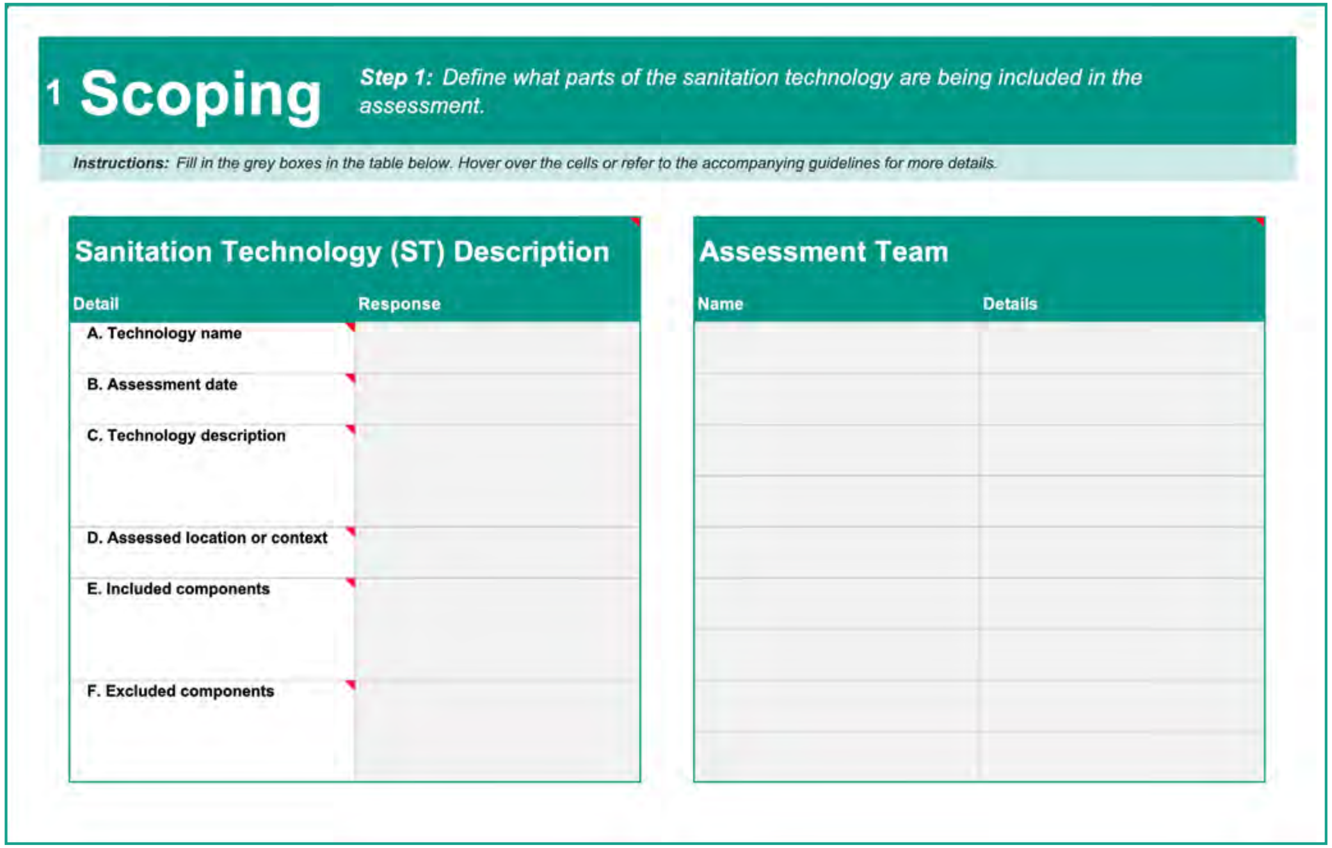
Scoping

The assessment team describes the sanitation technology, chooses which components of an sanitation technology are included or excluded in the assessment, and identifies the geographical location in which the sanitation technology is being assessed.

The assessment team should provide information about the sanitation technology being assessed including its name, the date of the assessment, a brief description of the technology, and names and details (e.g. role, organisation) of the assessment team members.

Implementation location

A location or context in which the sanitation technology is being assessed should be considered. This will help identify the relevant HETs and hazards in subsequent steps and provide a grounded reference point when considering the potential impacts of hazards. The location or context may be a place where the sanitation technology is likely to installed (e.g. rural, coastal Bangladesh).


1 Scoping

Step 1: *Define what parts of the sanitation technology are being included in the assessment.*

Instructions: *Fill in the grey boxes in the table below. Hover over the cells or refer to the accompanying guidelines for more details.*

Sanitation Technology (ST) Description

Detail	Response
A. Technology name	
B. Assessment date	
C. Technology description	
D. Assessed location or context	
E. Included components	
F. Excluded components	

Assessment Team

Name	Details

Setting scope

The team should decide which components of the sanitation technology to include in or exclude from the assessment. For example, if the team wants to focus on assessing a containment technology, they may choose to exclude latrine superstructures from the assessment. The choices made during scoping are important because they will influence design considerations and resilience scores later on. The team may come back to this step later on and modify the scoping choices.

ClimateFIRST works best for small- to medium-scale decentralised containment and treatment technologies. It is not designed for expansive, large-scale sewer systems. The team should focus on a specific sanitation technology design and not a generic technology (e.g. a specific septic tank design instead of septic tanks in general).

In addition to the containment or treatment technology itself, the team may choose to include (or exclude) other components, such as:

- The toilet/squatting pan
- Slab
- Pipes
- Junction boxes
- The toilet superstructure or other superstructures housing sanitation technologies
- Protective barriers (e.g. drainage, dykes, roofs, etc.) constructed specifically for the benefit of the sanitation technology.

ClimateFIRST should not be used to assess:

- The above components in isolation from a containment or treatment technology.
- Human resources such as capacity of service providers and service authorities.
- The institutional, financial or social context of the sanitation technology.
- External supporting infrastructure such as roads, electricity grids, and water supplies not constructed specifically for the sanitation technology (although the dependence of the sanitation technology on these will be considered by the assessment team).
- Technologies used for the construction and repair of sanitation technologies (e.g. excavators, cement mixers etc.) and for the emptying and conveyance of waste (e.g. emptying trucks, gulpers etc.) that are not in-situ.

Photo: UTS

2 Assessment Step

Hazardous events and trends

The team identifies the hazardous events and trends (HETs), such as flooding or drought, that are relevant to the sanitation technology's location and describe the HETs' characteristics for that location.

The assessment team should select the HETs and against which the sanitation technology's resilience will be assessed.

2 Hazardous events & trends

***Step 2:** Indicate what climate related hazardous events or trends are relevant to your assessment.*

***Instructions:** Select hazardous events and trends that are relevant for the climate context in which you are assessing the ST and fill in the grey boxes in the table below. Hover over the cells or refer to the accompanying guidelines for more details.*

Hazardous events & trends (HET)	Is the HET relevant?	HET Characteristics
Flood Fluvial flooding (overflowing of a river or other water body) and pluvial flooding (precipitation intensity exceeds drainage capacity)	☑ Yes	
Changing precipitation patterns Increased variability in seasonal precipitation patterns and inter-annual precipitation	☑ Yes	
High sea level Permanent inundation from sea level rise or temporary seawater intrusion/coastal flooding due to sea level rise, storm surge, high tide or wave setup	☑ Yes	
Fire weather Weather conditions (temperature, soil moisture, humidity, and wind) that trigger and sustain fires	☑ Yes	
Severe wind High wind velocity due to thunderstorms, wind gusts, tornados, or cyclones	☑ Yes	
Droughts Episodic combination of low rainfall and runoff deficit, and evaporation that leads to dry soil (i.e. hydrological drought)	☑ Yes	
Changing air temperature Increased variability in diurnal and seasonal air temperature	☑ Yes	
Extreme heat Episodic high surface air temperature events that are potentially exacerbated by humidity	☑ Yes	

Hazardous events and trends continued

ClimateFIRST contains eight HETs for use in this assessment:

Floods: Fluvial flooding (overflowing of a river or other water body) and pluvial flooding (precipitation intensity exceeds drainage capacity)

Changing precipitation patterns: Increased variability in seasonal precipitation patterns and inter-annual precipitation

High sea level: Permanent coastal inundation from sea level rise or temporary seawater intrusion/coastal flooding due to sea level rise, storm surge, high tide or wave setup.

Fire weather: Weather conditions (temperature, soil moisture, humidity and wind) that trigger and sustain fires.

Severe wind: High wind velocity due to thunderstorms, wind gusts, tornadoes or cyclones.

Droughts: Episodic combination of low rainfall and runoff deficit, and evaporation that leads to dry soil (i.e. hydrological drought).

Changing air temperature: Increased variability in diurnal and seasonal air temperature.

Extreme heat: Episodic high surface air temperature events potentially exacerbated by humidity.

These HETs have been shortlisted by the creators of ClimateFIRST as most relevant for sanitation from a broader list provided by the Intergovernmental Panel on Climate Change (page 12-12).

The assessment team should select HETs from this list that are relevant to the location of the sanitation technology. For example, if the sanitation technology is being assessed with reference to landlocked country, the "high sea level" HET may not be relevant and can be deselected. If the sanitation technology is still in design phase, or if it has been deployed in multiple environments, the team may choose to assess the sanitation technology against all HETs rather than focusing on location-specific examples.

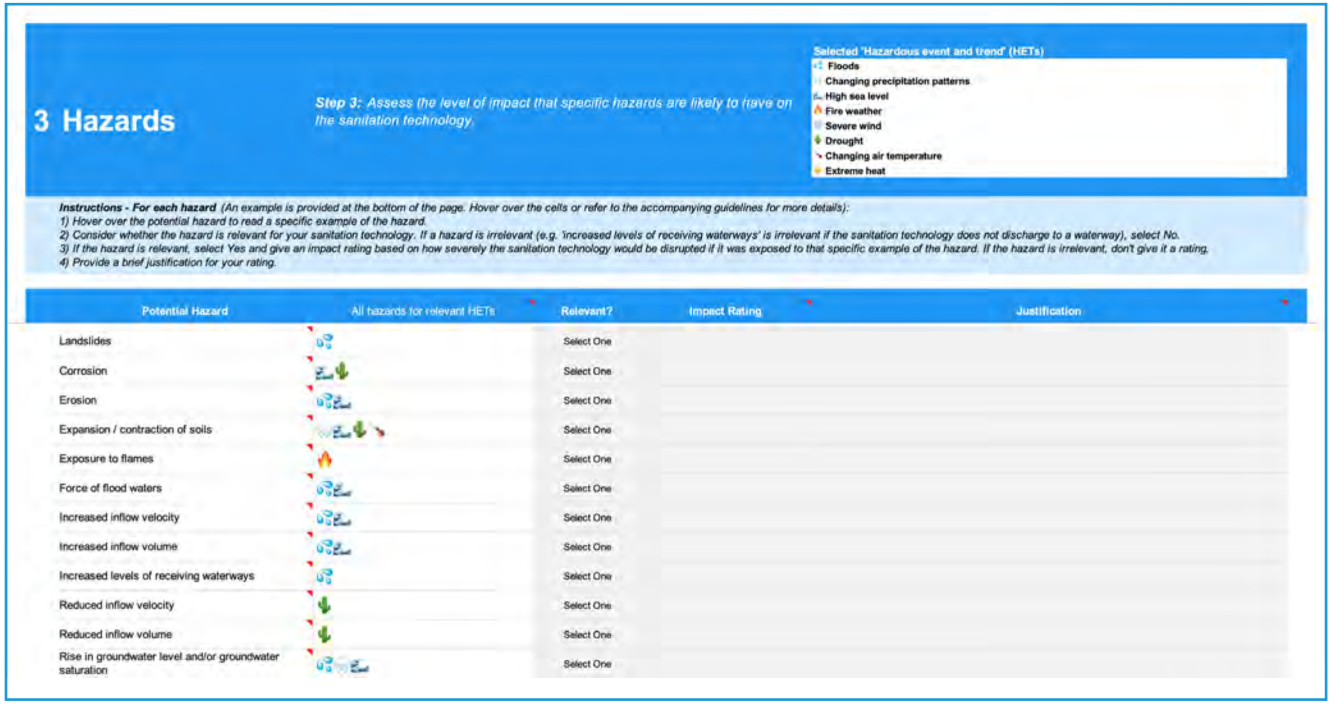
In choosing relevant HETs, the team should consider historical and current climate trends and future climate predictions (e.g. see the World Bank Climate Change Knowledge Portal or the IPCC Interactive Atlas). These trends and predictions may be described briefly in the 'HET Characteristics' column.

In the '**HET Characteristics column**', the team can write brief notes about the present and projected nature of the HET in the geographic area in which they are doing the assessment.

It should be noted that a major challenge in designing for climate resilience is the problem of uncertainty. Uncertainty arises from limited knowledge about how climate change will influence HETs in local areas in the future and how society and nature will respond. Dealing with uncertainty is largely a matter of management and governance when it comes to sanitation technologies, rather than the physical design of sanitation technology.

Hazards

The team assesses the impact of relevant climate hazards (e.g. force of flood waters) that may be associated with the HETs indicated in Step 2 on the sanitation technology.



3 Hazards

Step 3: Assess the level of impact that specific hazards are likely to have on the sanitation technology.

Selected 'Hazardous event and trend' (HETs)
- Floods
- Changing precipitation patterns
- High sea level
- Fire weather
- Severe wind
- Drought
- Changing air temperature
- Extreme heat

Instructions - For each hazard *(An example is provided at the bottom of the page. Hover over the cells or refer to the accompanying guidelines for more details):*
1) Hover over the potential hazard to read a specific example of the hazard.
2) Consider whether the hazard is relevant for your sanitation technology. If a hazard is irrelevant (e.g. 'increased levels of receiving waterways' is irrelevant if the sanitation technology does not discharge to a waterway), select No.
3) If the hazard is relevant, select Yes and give an impact rating based on how severely the sanitation technology would be disrupted if it was exposed to that specific example of the hazard. If the hazard is irrelevant, don't give it a rating.
4) Provide a brief justification for your rating.

Potential Hazard	All hazards for relevant HETs	Relevant?	Impact Rating	Justification
Landslides		Select One		
Corrosion		Select One		
Erosion		Select One		
Expansion / contraction of soils		Select One		
Exposure to flames		Select One		
Force of flood waters		Select One		
Increased inflow velocity		Select One		
Increased inflow volume		Select One		
Increased levels of receiving waterways		Select One		
Reduced inflow velocity		Select One		
Reduced inflow volume		Select One		
Rise in groundwater level and/or groundwater saturation		Select One		

Reviewing the hazards

Hazards are occurrences that may cause damage to the sanitation technology or its ability to function and provide a service. They can lead to consequences for public health or the environment.

Based on the HETs identified in Step 2, ClimateFIRST will output an amalgamated list of potential hazards (a complete list of the hazards is shown in Annex 1). Many hazards are relevant to more than one HET. By clicking on the cell "All hazards for relevant HETs", users can filter the hazards by HET.

A specific example of each potential hazard can be seen by hovering the mouse over the cell. For each potential hazard, the assessment team should:

1. Refer to the specific example of the hazard and decide if it is relevant to the sanitation technology or not. For example, the hazard 'increased levels of receiving waterways' is irrelevant if the sanitation technology does not discharge to a waterway. In the '**Relevant?**' column, used the dropdown menu to indicate if the hazard is relevant or not.

2. If the hazard is relevant, give an '**impact rating**' to indicate how severely the sanitation technology would be affected if it was exposed to the specific example of the hazard. (Low = Little or no impact on the sanitation technology; Moderate = Moderate impact causing reduced performance; High = High impact likely causing a failure of the sanitation technology).

3. In the '**Justification**' column, briefly explain the rationale for why that impact rating was given.

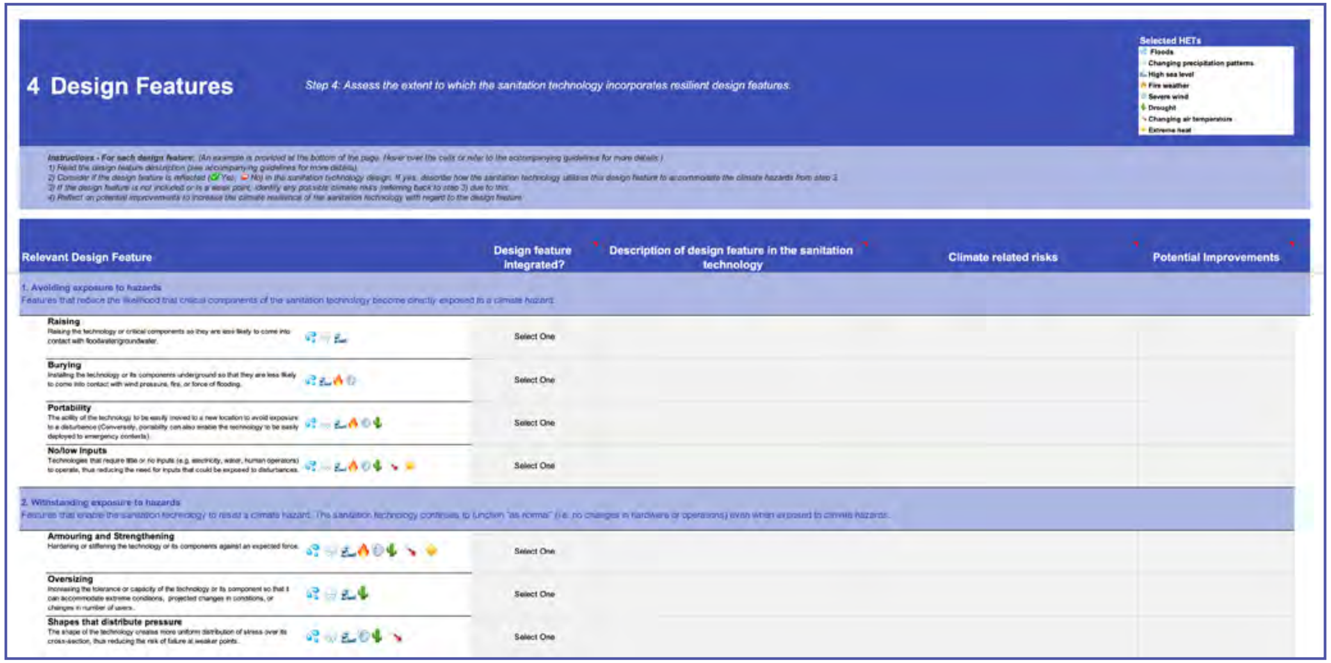
An example of a filled-out row is provided at the bottom of the tab for reference.

Design features

The team assesses the extent to which the sanitation technology's design features can help the system avoid, reduce or offset the negative impacts of the hazards identified in Step 3, and considers how the design features could be added to the sanitation technology.

Resilient design features

Based on the HETs selected in Step 2, ClimateFIRST will suggest up to 25 resilience design features that can be applied to sanitation technologies. Annex 2 lists these design features in full along with examples of how they may be applied to sanitation technologies, examples of how the design features may compromise resilience in other ways, and inputs to consider for implementation of the design feature and O&M.



Design Features continued

These design features are grouped into seven categories*:

1. **Avoiding exposure to hazards:** Design features that reduce the likelihood that critical components and processes of the sanitation technology become directly exposed to a climate hazard.
2. **Withstanding exposure to hazards:** Design features that enable the sanitation technology to continue functioning "as normal" (i.e. no changes in hardware or operations) even when exposed to climate hazards.
3. **Enabling flexibility:** Design features that enable the adaptation or reconfiguration of a sanitation technology's hardware components or that enable changes to a sanitation technology's processes or operations so that the sanitation technology can continue providing services when exposed to climate hazards.
4. **Containing failures:** Design features that enable a sanitation technology to continue providing services (albeit potentially degraded) that meet user needs despite damage caused by climate hazards.
5. **Limiting consequences of complete failure:** Design features that minimise the negative consequences of a sanitation technology failing due to a climate hazard.
6. **Facilitating fast recovery:** Design features that enable the sanitation technology to be quickly rebuilt or restored if it is damaged, disrupted or destroyed by a climate hazard.
7. **Providing benefits beyond resilience:** Design features that enable the sanitation technology to provide other benefits to people or to other systems that aid in broader community or system resilience.

The listed design features are options for improving the resilience of a sanitation technology. However, the implementing each feature comes with costs and potentially trade-offs where resilience is reduced in other ways; Annex 2 lists examples of these. Hence, **sanitation technologies are not expected to include every design feature**. Integrating too many features can make a sanitation technology expensive and impractical.

The icons next to each design feature indicate which HETs are most relevant to the feature. For example, the 'raising' design feature can help with resilience against floods and high sea levels, but it is generally not helpful for droughts or severe wind.

Assessing the sanitation technology's design features and identifying design improvements

For each design feature, the team should consider whether the feature is reflected in the sanitation technology design in any way that supports resilience, and select Yes or No in the '**Design feature integrated?**' column. Refer to Annex 2 for more details on each feature.

If the team selects Yes, they should then describe the design feature and how it helps accommodate climate hazards in the '**Description of design feature in sanitation technology**' column.

If the team select No, they should consider if the absence or weakness of this design feature could compromise the sanitation technology's resilience in the '**Climate related risks**' column. They should also consider ideas for incorporating the design feature in the sanitation technology in the '**Potential improvements**' column. However, these columns are optional do not need to be filled out for every design feature. Some design features may be impractical to implement and do not require consideration. Focus on design features that feel the most useful.

Even if the team selects Yes to indicate a design feature is already incorporated, they may choose to still identify risks and improvements if they think of any.

It is helpful to refer back to the Hazards tab for a reminder of the ways that hazards affect the sanitation technology and how physical design reduces impacts (or might fail to). An example of a filled-out row is provided at the bottom of the tab for reference.

* Note that these design features only pertain to climate resilience. All sanitation technologies should also be designed to make sanitation available, physically accessible, safe, affordable and acceptable to users in line with the Humans Rights to Water and Sanitation framework. This includes ensuring that toilets meet the needs of women and are accessible to people with disabilities.

Overall resilience

The team gives the sanitation technology an overall resilience score against each HET based on their judgements stemming from the previous steps.

ClimateFIRST provides an overview of the percentage of hazards that were given low, moderate or high impact ratings inputted during Step 3. ClimateFIRST also auto-calculates an overall impact rating based on these percentages.

The assessment should then:

1. Give an overall low, medium or high '**Resilience rating**' of the sanitation technology to each of the relevant HETs (Low Resilience = Likely to fail or have extended outage; Medium resilience = reduced sanitation technology performance or temporary outage; High resilience = continues to function). These responses should be informed by the activities completed in Steps 3 and 4 and the auto-calculated impact rating.

   As an extreme example, if all hazards from Step 4 had a high impact on the sanitation technology, it is expected that the overall resilience would be low.

2. In the '**Justification**' column, briefly justify why the low, moderate or high rating was given.

5 Overall resilience self-assessment

Step 5: Consider the overall resilience of your technology to each hazardous event and trend.

Instructions - for each hazardous event or trend:
1) Look at the overall impact rating that is auto-calculated based on the proportion of low, moderate, and high impact ratings you provided in step 3.
2) Give an overall resilience rating. You may refer back to step 3 and filter the hazards by the 'Hazardous events and trends' (HET) to remind yourself of the likely impacts.
3) Provide a brief justification for your rating.

	Hazards Impact					
	Low Impact	Moderate Impact	High Impact	Overall	Resilience rating	Justification
Flood	0%	0%	0%	Low Impact		
Changing Precipitation Patterns	0%	0%	0%	Low Impact		
High Sea Level	0%	0%	0%	Low Impact		
Fire Weather	0%	0%	0%	Low Impact		
Severe Wind	0%	0%	0%	Low Impact		
Droughts	0%	0%	0%	Low Impact		
Changing Air Temperature	0%	0%	0%	Low Impact		
Extreme Heat	0%	0%	0%	Low Impact		

Summary Reports

ClimateFIRST summarises the content documented by the assessment team across four tabs:

- **Overall:** A summary of the auto-calculated impact rating, the resilience rating, and the justification for the resilience rating for each relevant HET.
- **Impacts:** A list of the hazards that the assessment team rated as having 'moderate' or 'high impact' on the sanitation technology and the justification for the rating.
- **Strengths:** A list of the resilience design features that the assessment team indicated were integrated into the sanitation technology and a description of the feature.
- **Improvements:** A list of improvements that the assessment team suggested could be done to incorporate resilience design features, and corresponding climate related risks they could reduce.

These summary outputs may be used as an easy reference to the assessment about what conclusions were reached and improvements that could be made to future designs of the sanitation technology.

Photo: All Seasons Upgrade. Credit: Kim Heng Lay, iDE

Annex 1: List of HETs and associated hazards

	Hazardous events and trends (HET)							
	Floods Fluvial flooding (overflowing of a river or other water body) and pluvial flooding (precipitation intensity exceeds drainage capacity)	**Changing precipitation patterns** Increased variability in seasonal precipitation patterns and inter-annual precipitation	**High sea level** Permanent inundation from sea level rise or temporary seawater intrusion/coastal flooding due to sea level rise, storm surge, high tide or wave setup	**Fire weather** Weather conditions (temperature, soil moisture, humidity, and wind) that trigger and sustain fires	**Severe wind** High wind velocity due to thunderstorms, wind gusts, tornadoes, or cyclones	**Drought** Episodic combination of low rainfall and runoff deficit, and evaporation that leads to dry soil (i.e. hydrological drought)	**Changing air temperature** Increased variability in diurnal and seasonal air temperature	**Extreme heat** Episodic high surface air temperature events that are potentially exacerbated by humidity
Hazards	Landslides Erosion Force of flood waters Increased inflow velocity Increased inflow volume Increased levels of receiving waterways Rise in groundwater level and/or groundwater saturation Water ingress/inundation Changes in pathogen concentration in inflow Disrupted access to sanitation technology for O&M Disrupted access to sanitation technology for major repairs Disrupted electricity inputs to sanitation technology Disrupted faecal sludge emptying services Disrupted water inputs to sanitation technology	Expansion/ contraction of soils Rise in groundwater level and/or groundwater saturation Variable inflow velocity Variable inflow volume	Corrosion Erosion Expansion/contraction of soils Force of flood waters Increased inflow velocity Increased inflow volume Rise in groundwater level and/or groundwater saturation Water ingress/inundation Biological organisms exposed to saltwater Disrupted access to sanitation technology for O&M Disrupted access to sanitation technology for major repairs Disrupted electricity inputs to sanitation technology Disrupted faecal sludge emptying services Disrupted water inputs to sanitation technology	Exposure to flames Temperature driven expansion/ contraction of materials Disrupted access to sanitation technology for O&M Disrupted access to sanitation technology for major repairs Disrupted electricity inputs to sanitation technology Disrupted faecal sludge emptying services Disrupted water inputs to sanitation technology	Uprooting by fallen trees Wind force on sanitation structures Wind-blown debris Disrupted access to sanitation technology for O&M Disrupted access to sanitation technology for major repairs Disrupted electricity inputs to sanitation technology Disrupted faecal sludge emptying services Disrupted water inputs to sanitation technology	Corrosion Expansion/ contraction of soils Reduced inflow velocity Reduced inflow volume Changes in pathogen concentration in inflow Reduced dilution capacity of receiving waters Disrupted water inputs to sanitation technology	Expansion/ contraction of soils Temperature driven expansion/ contraction of materials Extreme heat Variation in inflow or storage temperature	Temperature driven expansion/ contraction of materials Extreme heat Variation in inflow or storage temperature Disrupted electricity inputs to sanitation technology

Annex 2: Resilience design features

Avoiding exposure to hazards

Features that reduce the likelihood that critical components of the sanitation technology become directly exposed to a climate hazard.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Raising: Raising the technology or critical components so they are less likely to come into contact with floodwater, groundwater, or rising sea levels (Azevedo de Almeida & Mostafavi, 2016; Fewster, 2012; GWP & UNICEF, 2017; Kirchhoff & Watson, 2019; Sherpa et al., 2014; Uddin et al., 2013; USAID, 2015a; World Bank, 2020).	Pit latrine where the superstructure is raised on higher foundation or stilts to avoid floods (Islamic Development Bank, 2021). Septic tank built above ground to avoid rising groundwater tables (USAID, 2015a). Raising of drain/leach field for septic tanks to move above saturated groundwater (Cooper et al., 2016; World Bank, 2020). Floating sanitation technologies that rise as floodwater or groundwater rises. Sensitive equipment (e.g. electrical components such as motors, switchgears, motor control centres, cathodic protection systems, and exhaust fans. chemicals) are raised to avoid flood waters (USAID, 2017; World Bank, 2020).	Raising can increase exposure to wind pressure. Raising can make toilet interfaces difficult for people with physical limitations to access.	Raising may have higher upfront costs. Floating technologies may require specialist expertise to install correctly and require capacity to maintain.
Burying: Installing the technology or its components underground so that they are less likely to come into contact with wind pressure, fire, or force of flooding (Schweikert & Deinert, 2021).	Installing containment, treatment and disposal technologies underground (Howard et al., 2010; Luh et al., 2017; Sherpa et al., 2014; USAID, 2017).	Burying can increase exposure to flooding and rising groundwater. Increased ground movement from extended and increased periods of dry or wet and cold or hot cycles can impact buried infrastructure. Burying can introduce corrosion risk and make failure diagnosis more difficult.	

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Portability: The ability of the technology to be easily moved to a new location to avoid exposure to a hazard (UNEP, 2021).	Container-based sanitation units or other forms of portable toilets that can be easily transported if needed to avoid flooding or forecasted hazards (GIZ, 2021).	Moving sanitation facilities may be a lower priority for communities and government in the face of an impending disaster. Resources are needed to move technology, there are also time cost to move equipment.	Institutional capacity may be required to coordinate the movement of technologies.
No/low inputs: Technologies that require little or no inputs (e.g. electricity, water, human operators) to operate, thus reducing the need for inputs that could be exposed to hazards.	Sanitation technologies that continue to operate without skilled staff during or following a climate emergency. Sanitation technologies that reuse greywater (Swanson et al., 2021; GIZ, 2021; Islamic Development Bank, 2021; Schoen, et al., 2015; USAID, 2015a, 2017). Low flush toilets and modified sewerage (including 'condominial' and small bore sewerage) that operate with less water than conventional sewer (GIZ, 2021; GWP & UNICEF, 2017; Howard et al., 2010; Islamic Development Bank, 2021; Luh et al., 2017; USAID, 2015a). Nature-based treatment technologies that continue to operate without external inputs or controls, such as constructed wetlands (Abtahi et al., 2021). Gravity-based treatment that moves waste through the system via gravity instead of pumping or other conveyance that requires energy inputs. Dry toilets, such as composting toilets and urine-diverting dry toilets, that require no electricity or water inputs, and hence can continue to function during water scarcity or power failures (Charles et al., 2010; Swanson et al., 2021; GIZ, 2021; GWP & UNICEF, 2017; Howard et al., 2010; Luh et al., 2017; Mills et al., 2020; Schoen, Hawkins, et al., 2015; Sherpa et al., 2014) (Charles et al., 2010; Swanson et al., 2021; GIZ, 2021; Howard & Bartram, 2010; Luh et al., 2017; Mills et al., 2020; Schoen, Hawkins, et al., 2015; Sherpa et al., 2014).	Low maintenance systems are treated as 'no-maintenance.	Dry toilets may face resistance from users who prefer flush toilets and hence require socialisation. Some examples require additional space or are more limited by site suitability.

Withstanding exposure to hazards

Features that enable the sanitation technology to resist a climate hazard. The sanitation technology continues to function "as normal" (i.e. no changes in hardware or operations) even when exposed to climate hazards

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Armouring and strengthening: Hardening or stiffening the technology or its components against a hazard (Karamouz et al., 2019; Park et al., 2013).	Concrete rings to reinforce pits in pit latrines, and sealing of joints, to resist pit collapse and water ingress into pits respectively (GIZ, 2021). Anchoring of sewer lines or tanks to the ground (Fewster, 2012; Howard & Bartram, 2010; World Bank, 2020). Use of phase-change materials to reduce number of freeze–thaw cycles in cold environments (Swanson et al., 2021). Submersible pumps that retain functioning when inundated (Baca et al., 2021; World Bank, 2020). Protective structures around critical components to reduce possibility of damage by wind-borne projectiles (World Bank, 2020).	Stronger materials may be more difficult to adapt or modify later.	Strength is related to the quality of installation; skilled builders and quality assurance may be required during construction. Stronger materials may have higher upfront costs and may require maintenance/service/repair.
Oversizing: Increasing the tolerance or capacity of the technology or its component so that it can accommodate extreme conditions, projected changes in conditions, or changes in the number of users (Park et al., 2013).	Buffer containment or buffer treatment units that can hold peak flows temporarily when large inflows occur (Olyaei et al., 2018). Large pipes that can carry higher volumes of wastewater if inflow increases during the wet season or if numbers of users increase (USAID, 2015a). Temporary storage of sewage input or overflow for later treatment during times of flood, for example, via constructed wetlands (Karamouz et al., 2019). Extra storage to accommodate extra users in times of climate related migration or changes in usage patterns.	Oversizing may take up more space. Oversizing may affect the performance of system components (e.g. sedimentation in sewers during low-flow or solidification of solids on bottom of tanks).	Oversized infrastructure will have higher upfront costs

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Shapes that distribute pressure: The shape of the technology creates more uniform distribution of stress over its cross-section, thus reducing the risk of failure at weaker points (UNEP, 2021).	Construction of superstructures in geodesic shapes, instead of cubic shapes, that better distribute pressure from wind and force of flooding. Cylindrical pits and tanks that distribute external water pressure from rising water levels. Sloped soil/drains at the foundation of the superstructure to divert runoff away from structure and prevent water from pooling, and reduce erosion risk.	Diverting surface runoff away from the sanitation technology can create risks elsewhere (e.g. pooling of surface runoff near homes).	Geodesic and cylindrical shapes may be more difficult to manufacture or build properly. When runoff is diverted, the runoff area should be properly designed and maintained to manage runoff.
Circumvention: Technology materials or designs that allow wind or water to pass through so that the stress on the technology or component is reduced (UNEP 2021).	Waste water treatment plant with high flow bypasses to avoid damage (Batson et al., 2019; Hughes et al., 2021; Karamouz et al., 2019; Olyaei et al., 2018). Treatment facilities with porous or vegetated surfaces around the facility to absorb surface runoff, and reduce waterlogging and erosion (Azevedo de Almeida & Mostafavi, 2016; Swanson et al., 2021; GIZ, 2021; USAID, 2015a). Pit latrine superstructure with gaps or holes in that allow wind or water to pass through.	Bypassing treatment will likely release untreated faecal waste to the environment. Compliance with local regulations regarding overflows may be required.	Porous or vegetated surfaces may require institutional capacity for maintenance.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Sealing and barriers: Integrating seals, barriers or other forms of protection into the technology to protect critical components or processes from being disrupted by a hazard (Curt and Tacnet, 2018).	Water treatment plant with gates or barriers that prevent flood inundation or storm surge (Baca et al., 2021; Howard et al., 2010; Kirchhoff & Watson, 2019, 2019; USAID, 2015a; World Bank, 2020). Sewer systems with shut-off valves to avoid sewer backflow during sea level rise/storm surge (Fewster, 2012; Howard et al., 2010; World Bank, 2020). Water tight joints between the toilet slab and tank rights in UDDTs to resist floods (Sherpa et al., 2014; Uddin et al., 2013). Septic tank, or decentralised water treatment systems, with non-return valves to reduce sewage backup into homes (GWP & UNICEF, 2017; Howard et al., 2010; Islamic Development Bank, 2021; Schoen et al., 2015; Sherpa et al., 2014; USAID, 2015a). Sealing/waterproofing electrical equipment and pumps (Baca et al., 2021; Schoen et al., 2015; USAID, 2017). Container-based sanitation that minimises exposure to floods through enclosed faeces storage (GIZ, 2021; Mills et al., 2020) Insulation or shading structure to prevent excessive heat impacting treatment system or superstructure. Flame retardant insulation for critical sanitation infrastructure (Schoen et al., 2015). Sealed covers for septic tank lids (Howard & Bartram, 2010; Sherpa et al., 2014).	Septic tanks may float when sealed due to pressure differential. Sealing and covers can make access to components cumbersome, leading to operators or users circumventing the protection (e.g. removing covers). Sealed manhole lids may cause other parts of the structure to 'pop' (i.e. lift up) when exposed to excessive pressure.	

Enabling flexibility

Features that enable the sanitation technology to be adapted or reconfigured, or have its operation changed, in order to continue providing services when exposed to climate hazards.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Adaptability: The technology can be adapted or upgraded easily to function better under the changing environmental conditions (e.g. increasingly wet or increasingly dry conditions) (Howard & Bartram, 2010; Mills et al., 2020).	Anaerobic digesters can be insulated to maintain a constant treatment temperature (Schoen et al., 2015). Real time monitoring of treatment inflows and quality to adjust pumps, treatment process or dosing to suit (World Bank, 2020). Adjustable outlet levels to adapt treatment to changing inflows (e.g. maintain adequate water depth in constructed wetlands during dry conditions, or adjust residence time in tanks based on inflow). Pit latrines can be readily modified based on climatic conditions (compared to a more sophisticated system), e.g. raising, or lining pit with concrete rings in instances of increased rainfall (GWP & UNICEF, 2017; Howard et al., 2010, 2016; Mills et al., 2020; Sherpa et al., 2014). Wetland treatment systems that cope with increased effluent concentrations at times of high rainfall, and have improved operations in high temperatures (Abtahi et al., 2021)		
Modular design: Additional modules can be added (plug-in type model) or removed to increase or decrease capacity of the system to accommodate variability in demand and environmental conditions (Neumann et al., 2015; Spiller et al., 2015; World Bank, 2020).	The use of prefabricated filtration modules (e.g. in anaerobic baffled reactors) that can be expanded as the population served by a water treatment plant grows (World Bank, 2020). Including space for additional pumps in the design of an influent pump station's concrete pad (World Bank, 2020). Public toilets that share a treatment system and can have additional toilets added as demand grows. Aeration tanks in a wastewater treatment plant that can operate in parallel during times of high inflow, but still work optimally if some aeration tanks are disconnected during times of low inflow. Use of push-fit joints for sewage pipes rather than bolted, screwed, or glued joints, making modules easy to install (Spiller et al., 2015)		Requires a supply chain that provides ready access to modular parts. May require specialist expertise to swap modular parts in and out.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Platform design: The technology shares components with other similar technologies, making it easier to transition between technologies to suit customer demand or prevailing environmental conditions. (Neumann et al., 2015).	Sanitation technologies that use a standard toilet pan and slab (or other component) that can be transferred over from existing (obsolete or inferior) sanitation technologies. Standard pipe sizes for household wastewater conveyance. sanitation technology uses components (e.g. electrical equipment and pumps) that are standard for the area and follow local conventions.	Platform design approach may limit the range of solutions that can be implemented.	May require institutional capacity for creation and enforcement of building standards.
Redundancy and diversity: The technology has diverse and redundant components that work in parallel or that act as back-ups to each other. In the case of component failure(s), the back-up component enables the technology to continue functioning by performing the same functions in a different way (Brown, 2019).	A sanitation technology that has multiple pits, tanks or treatment components that can function independent of the other pits/tanks/treatment components. Toilets can alternate between being wet or dry depending on water availability. A treatment technology has separate processes for treating waste when inflows are very low in the dry season and very high in the wet season. Backup generators/batteries for treatment facility are available if primary power source fails (Fewster, 2012; Kirchhoff & Watson, 2019; Schoen, Ma, et al., 2015; World Bank, 2018, 2020). Backup pumps to combat inundation from storm surge, rising sea levels, or floods (Swanson et al., 2021; Kirchhoff & Watson, 2019; USAID, 2015a; World Bank, 2020).	Adding redundant components may take up available space.	May require additional supply chains to support diversity of components. Redundant parts may result in additional upfront costs. Requires operator capacity to understand multiple operation methods and when to switch between them.
Signalling: The technology, by the nature of how it functions or by intentional design, has a way of signalling to operators or users when the sanitation technology requires modification to prevent failure or to enhance its performance (Linkov et al., 2013).	A control panel installed at a treatment facility that measures biological oxygen demand, nutrient content, etc (Spiller et al., 2015). Flow meters to signal changes in flow rate that may require changes to operations (GIZ, 2021).		Requires the operator or person observing the signal to have the capacity to respond.

Containing failures

Features that enable the sanitation technology to continue providing basic services and meet user needs despite damage to technology components caused by climate hazards.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Frangibility: Less essential components of the technology are designed to breakaway or fail when exposed to a hazard to protect more essential components of the technology (UNEP, 2021).	Sewer manholes that are designed to burst when pressure from high flows in sewers become too great, thereby protecting the pipes.	Breakage of less essential components still incurs a cost and can pose risks to public and environmental health. Burst manholes may lead to large spills to clean.	
Fail-operational: The technology can still provide its overall function even when components or processes are damaged and undergoing repair (Möller & Hansson, 2008; Schoen, Ma, et al., 2015).	Treatment plant that can still function (at reduced capacity) if one storage pond or the drying beds are temporarily offline. Biological treatment processes continue to treat wastewater, albeit at reduced efficiency, in response to a decrease in air temperature. An automated treatment technology with a chemical feeder that can be operated manually if electricity goes out during power shortages.	Extended periods of time in a 'triage' state may cause the technology to fail completely over time or permanently degrade its performance.	May require increasing monitoring to ensure modifications to treatment do not cause significant health risks.
Decentralisation: Failures in decentralised systems (small-scale individual or clustered systems) are isolated locally rather than centrally (GIZ, 2021; GWP & UNICEF, 2017; Howard et al., 2010; Sun et al., 2020; USAID, 2015a).	Household, on-site sanitation technologies that operate independently of neighbouring household sanitation technologies (Sun et al., 2020). Shorter sewer lines to decentralised treatment creates fewer risks for exposure to possible climate hazards compared to longer sewer lines (GIZ, 2021; Luh et al., 2017; Sherpa et al., 2014). Numerous small scale sludge treatment systems that are located across a city.	Can be complicated to manage because of multiple systems and operators over large areas. Inputs into decentralised systems may be compromised; for example, water, electricity or management expertise that may become unavailable locally at times.	Decentralised sanitation systems usually require decentralised management schemes to operate and maintain the system.

Limiting consequences of complete failure

Features that minimise the negative health and environmental consequences of complete sanitation technology failure due to a climate hazard.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Safe disposal: The materials from the destroyed technology are not toxic to the environment or public health and can be safely disposed (Linkov et al., 2013).	Materials used to build the sanitation technology that can be discarded into a local landfill without posing an additional health risk to the public or the environment.		
Reusable materials: The materials from the destroyed technology can be reused for other purposes (including rebuilding the technology) (UNEP, 2021).	Prefabricated septic tanks (if not damaged) that can be used for other sanitation systems. Use of plastic or ferrous metal pipes that are more suitable for reuse, compared to concrete pipes (Spiller et al., 2015).	Reused material must be cleaned to avoid health risks.	
Fail-silence: If the technology completely fails, it does not pose a health risk to the public or the environment beyond being unable to perform its function (Möller & Hansson, 2008).	The inflow to a treatment technology can be shut off to prevent the technology from overflowing into the open environment if it has been compromised by flooding or another hazard. Pit latrines with shallower pits to reduce the risk of collapse, and limit exposure of faeces to flood waters or rising sea levels (Islamic Development Bank, 2021; Sherpa et al., 2014; USAID, 2015a).	The risk posed by the fail-silence mechanism could be greater than failure itself (e.g. discharge of diverted inflows must be lower than the risk of overflowing the treatment).	May require an operator to activate the fail-silence mechanism.

Facilitating fast recovery

Features that enable the sanitation technology to be quickly rebuilt or restored if they are damaged, disrupted or destroyed by a climate hazard.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Repair speed: The technology and its components, processes, or operations can be quickly replaced, rebuilt or restored if destroyed or disrupted, thereby minimising performance downtime or degradation (Hickford et al., 2018).	Junction boxes that divert the flow of waste so that damaged pipes, pits, etc. can be more quickly repaired. Biological waste treatment processes that can be quickly re-started and brought back to full capacity after being disrupted. Low cost toilets that can be rebuilt quickly in the case of failure (Charles et al., 2010; Howard et al., 2010; Islamic Development Bank, 2021; USAID, 2015a). Pipe fittings that are bolted and can be isolated via shut off valves, can be more easily replaced than a welded/glued pipe without isolation. Filter media in treatment components that can be easily swapped out if it becomes clogged. Water treatment plants where electrical equipment is built to local standards with locally available materials (e.g. wiring and voltages follows local convention). Shallow burial depths for sewers to assist in finding and repairing leaks (Schoen, Ma, et al., 2015).	Technologies that are easy and cheap to rebuild, by their nature, may be more easily damaged/destroyed. People may not be motivated to repeatedly rebuild technologies.	May require institutional capacity to coordinate repair/rebuilding. Requires ongoing financing to fund repairs/rebuilding.
Accessibility for rapid flaw detection and repair: Components or processes of the technology can be easily accessed for examination and repairs (Mottahedi et al., 2021).	Inspection chambers that allow operators or repairers to see inside containments. Manholes/hatches that can be easily opened for inspectors/repairers to conduct examinations or make repairs. Above ground tanks that can be easily repaired in case of leakage (compared to an underground tank). Shallow burial depth of drainage channels or pipes may simplify the finding and repairing of leaks, hence reducing the repair cost and time (Schoen, Ma, et al., 2015).	Easily opened manholes/hatches may pose a risk to public health if people (e.g. children) can access them. Access chambers/channels may pose a risk for water ingress. Shallow burial lines may be compromised by erosion or excavation works.	

Providing benefits beyond resilience

Features that enable the sanitation technology to provide other benefits to people or to other systems that aid in broader community or system resilience.

Resilient design feature	Examples of applications to sanitation technologies	Examples where resilience may be compromised	Inputs to consider for implementation and O&M
Reciprocity: Through operations, the technology also builds resilience in, or aids, another on-site or off-site system (Brown, 2019).	Treated sludge or wastewater can be used to aid in agricultural production (USAID, 2015b). Biogas from treated waste can be used for electricity production. Treated waste can be made into briquettes for fuel.	Reused sanitation products can cause health risks if not adequately treated or if treatment is compromised due to climate hazards.	May require institutional arrangements, coordination and regulation for managing the transfer of materials.
Hybridising: Unrelated systems or technologies share the same physical space or structure, thus saving space and enhancing opportunities for reciprocity (Brown, 2019).	A biogas system that provides a source of on-site energy.		May require institutional coordination.
Transformative capacity: The technology provides an additional service(s) beyond its usual intent that further aids resilient communities (Brown, 2019).	At sanitation technology that can also accept food or other solid waste (e.g. co-composting).		Requires understanding of how to combine different waste streams and ensure quality and safety of end products.

Annex 2: References

Abtahi, S.M., Aryal, O. and Ismail, N.S., 2021. Emerging investigator series: interacting effects of environmental factors on Daphnia magna removal of Escherichia coli from wastewater. Environmental Science: Water Research & Technology, 7(4), pp.726-738.

Azevedo de Almeida, B. and Mostafavi, A., 2016. Resilience of infrastructure systems to sea-level rise in coastal areas: Impacts, adaptation measures, and implementation challenges. *Sustainability, 8*(11), p.1115.

Baca, M., Schenkman, B. and Hightower, M., 2021. Use of Advanced Microgrids to Support Community Resilience. Natural Hazards Review, 22(4), p.05021012.

Batson, A., Varnon, C. and Nicholas, B., 2018, September. Weathering the Storm: Assessing Flood Mitigation Options versus Acceptable Level of Risk to Build More Resilient Wastewater Utilities. In WEFTEC 2018 (pp. 3372-3383). Water Environment Federation.

Brown, H., 2019. Infrastructural ecology: Embedding resilience in public works. Public Works Management & Policy, 24(1), pp.20-32.

Charles, K., Pond, K., Pedley, S., Hossain, R., and Jacot-Guillarmod, F., 2010. Vision 2030. The resilience of water supply and sanitation in the face of climate change: Technology projection study

Cooper, J.A., Loomis, G.W. and Amador, J.A., 2016. Hell and high water: Diminished septic system performance in coastal regions due to climate change. PloS one, 11(9), p.e0162104.

Curt, C. and Tacnet, J.M., 2018. Resilience of critical infrastructures: Review and analysis of current approaches. Risk analysis, 38(11), pp.2441-2458.

Fewster, E., 2012. Techniques to improve the resilience of community WASH systems in floodprone areas. CARE Nederland.

GIZ, 2021. Climate resilient urban sanitation: Accelerating the convergence of sanitation and climate action.

GWP and UNICEF, 2017. WASH Climate Resilient Development Technical Brief. Linking risk with response: Options for climate resilient WASH.

Howard, G., Charles, K., Pond, K., Brookshaw, A., Hossain, R. and Bartram, J., 2010. Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. Journal of water and climate change, 1(1), pp.2-16.

Howard, G., and Bartram, J., 2010. Vision 2030. The resilience of water supply and sanitation in the face of climate change. Technical report.

Howard, G., Calow, R., Macdonald, A. and Bartram, J., 2016. Climate change and water and sanitation: likely impacts and emerging trends for action. Annual review of environment and resources, 41, pp.253-276.

Hughes, J., Cowper-Heays, K., Olesson, E., Bell, R. and Stroombergen, A., 2021. Impacts and implications of climate change on wastewater systems: A New Zealand perspective. Climate Risk Management, 31, p.100262.

Islamic Development Bank, 2021. Water sector climate change adaptation: Guidance note.

Karamouz, M., Taheri, M., Khalili, P. and Chen, X., 2019. Building infrastructure resilience in coastal flood risk management. Journal of Water Resources Planning and Management, 145(4), p.04019004.

Kirchhoff, C.J. and Watson, P.L., 2019. Are wastewater systems adapting to climate change?. JAWRA Journal of the American Water Resources Association, 55(4), pp.869-880.

Luh, J., Royster, S., Sebastian, D., Ojomo, E. and Bartram, J., 2017. Expert assessment of the resilience of drinking water and sanitation systems to climate-related hazards. Science of the Total Environment, 592, pp.334-344.

Mills, F., Willetts, J., Evans, B., Carrard, N. and Kohlitz, J., 2020. Costs, climate and contamination: three drivers for citywide sanitation investment decisions. Frontiers in Environmental Science, 8, p.130.

Neumann, M.B., Rieckermann, J., Hug, T. and Gujer, W., 2015. Adaptation in hindsight: Dynamics and drivers shaping urban wastewater systems. Journal of environmental management, 151, pp.404-415.

Olyaei, M.A., Karamouz, M. and Farmani, R., 2018. Framework for assessing flood reliability and resilience of wastewater treatment plants. Journal of Environmental Engineering, 144(9), p.04018081.

Park, J., Seager, T.P., Rao, P.S.C., Convertino, M. and Linkov, I., 2013. Integrating risk and resilience approaches to catastrophe management in engineering systems. Risk analysis, 33(3), pp.356-367.

Schoen, M., Hawkins, T., Xue, X., Ma, C., Garland, J. and Ashbolt, N.J., 2015. Technologic resilience assessment of coastal community water and wastewater service options. Sustainability of Water Quality and Ecology, 6, pp.75-87.

Schweikert, A.E. and Deinert, M.R., 2021. Vulnerability and resilience of power systems infrastructure to natural hazards and climate change. Wiley Interdisciplinary Reviews: Climate Change, 12(5), p.e724.

Sherpa, A.M., Koottatep, T., Zurbrügg, C. and Cissé, G., 2014. Vulnerability and adaptability of sanitation systems to climate change. Journal of water and climate change, 5(4), pp.487-495.

Spiller, M., Vreeburg, J.H., Leusbrock, I. and Zeeman, G., 2015. Flexible design in water and wastewater engineering–definitions, literature and decision guide. Journal of Environmental Management, 149, pp.271-281.

Swanson, D., Murphy, D., Temmer, J. and Scaletta, T., 2021. Advancing the Climate Resilience of Canadian Infrastructure.

Uddin, S.M., Ronteltap, M. and van Lier, J.B., 2013. Assessment of urine diverting dehydrating toilets as a flood-resilient and affordable sanitation technology in the context of Bangladesh. Journal of water, sanitation and hygiene for development, 3(2), pp.87-95.

UNEP, 2021. A Practical Guide to Climate-resilient Buildings & Communities.

USAID, 2015a. A methodology for incorporating climate change adaptation in infrastructure planning and design. Sanitation.

USAID, 2017. Climate-resilient water infrastructure: Guidelines and lessons from the USAid Be Secure project.

World Bank, 2020. Resilient Water Infrastructure Design Brief.

Contact us

Jeremy Kohlitz Jeremy.Kohlitz@uts.edu.au
Juliet Willetts Juliet.Willetts@uts.edu.au

Institute for Sustainable Futures

University of Technology Sydney
PO Box 123 Broadway, NSW, 2007
www.isf.uts.edu.au

UTS Institute for Sustainable Futures

Photo: Sky Latrine. Credit: Tyler Kozole, iDE