



Latrine Design for Challenging Environments

Final Report

29 December 2012



HCD iLab
Human Centered Design
Innovation Lab



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Background

Special thanks to:

This design project was funded by the **Bill and Melinda Gates Foundation**, the **Stone Family Foundation**, and with technical support from the **Water and Sanitation Program of the World Bank (WSP)** as part of the Sanitation Marketing Scale-Up (SMSU) Project implemented by iDE Cambodia.

The design team was supported by an Advisory Group that consisted of members from **Ministry of Rural Development (MRD)**, **WaterSHED Cambodia**, **Engineers Without Borders**, and **Live & Learn Cambodia**.

Project background

The Need: Easy Latrine was designed in 2009 as the first packaged latrine product in Cambodia. It helped to ignite the sanitation market, as it is affordable for the rural poor and is produced and sold by businesses within an optimized supply chain.

However, the Easy Latrine isn't suited for Cambodia's more *challenging environments* that experience seasonal flooding or have high levels of ground water.

Opportunity: In order to make affordable latrines accessible for users, our next step is to design sanitation solutions for challenging environments that affect large portions of Cambodia's population.

Goals

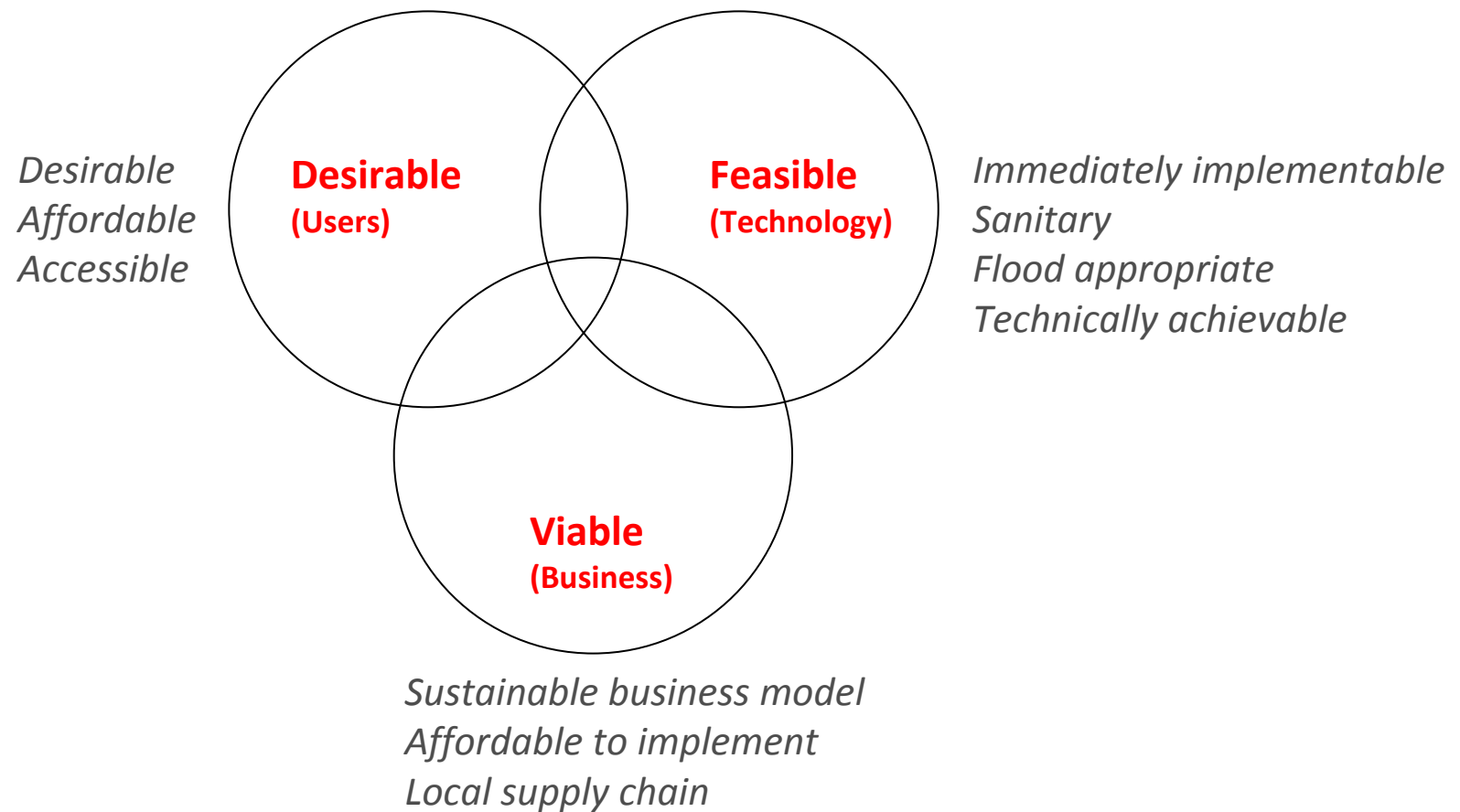
Project goals

Design a latrine solution for challenging environments that is:

- Desirable
- Accessible
- Affordable
- Sustainable
- Immediately implementable
- Market based, using local supply chains and materials

Project goal

Develop sanitation solutions for challenging environments, that are accessible, affordable, and desirable for the target population, given the local context and supply chain.



The Design Process

Methodology: Human Centered Design (HCD)

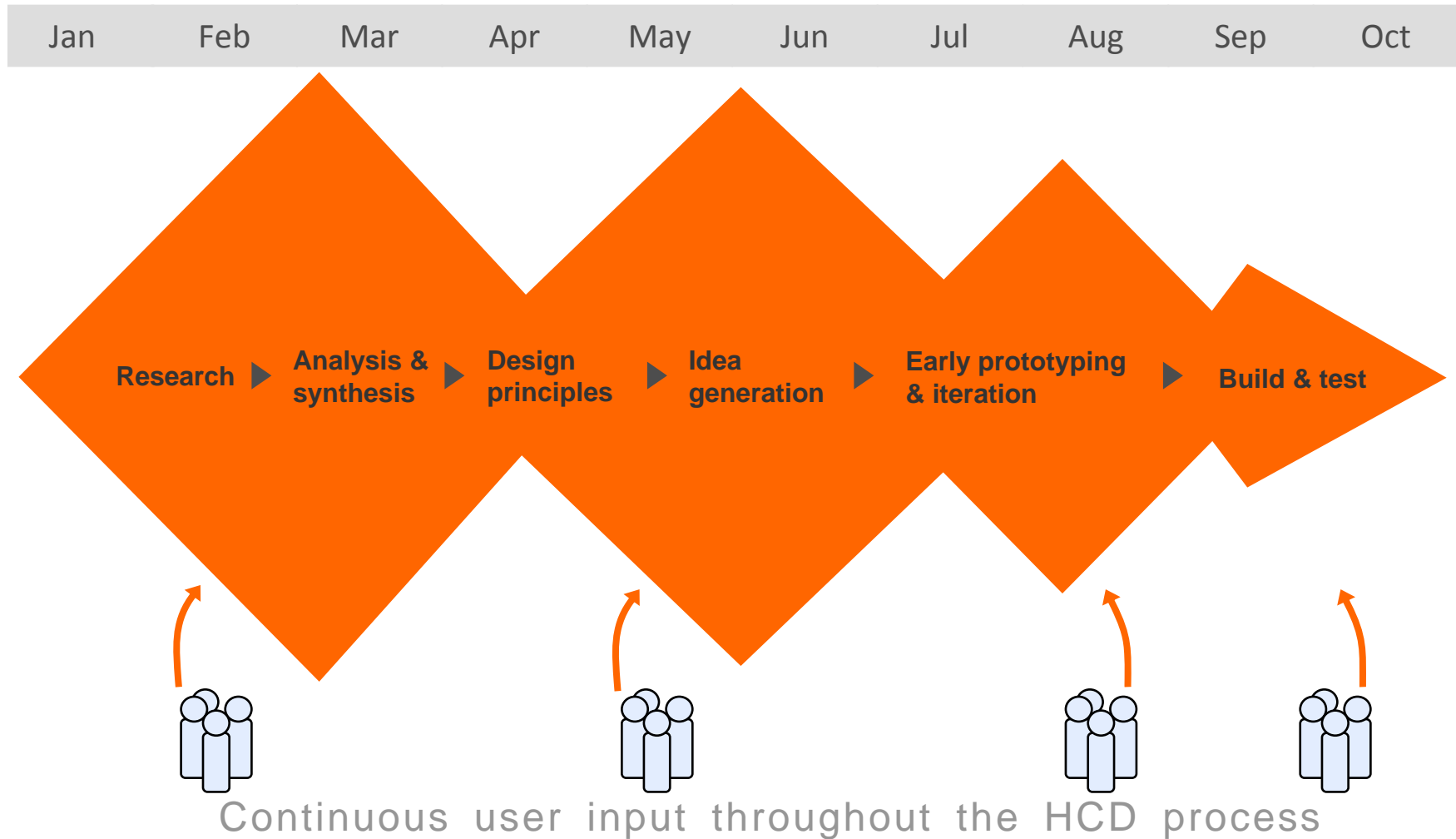
Human Centered Design is a leading innovation methodology used to design breakthrough solutions to real, human problems. HCD focuses on identifying and addressing the needs, wants, and limitations of human users throughout the entire design process.

Resulting solutions are holistic, encompassing not only the product/service design, but also the design of the user experience at every touch-point, including before purchase consideration, during purchase, during usage, and after usage. HCD recognizes the equal importance of addressing the needs of end-users, as well as the individual needs of all actors and influencers within the supply chain.

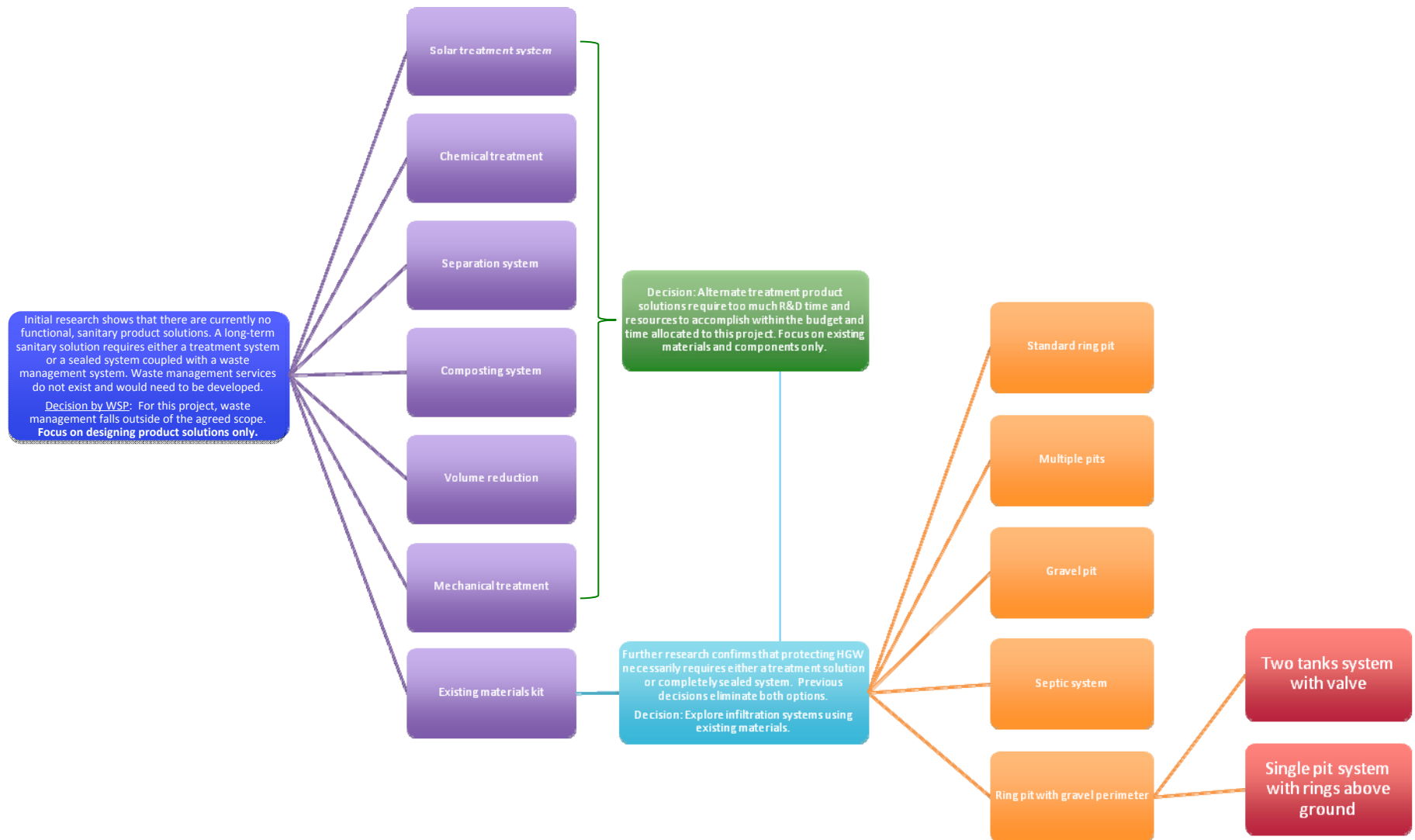
HCD has been used for decades by the world's most innovative companies (including Apple, Unilever, Nokia, Coca-cola) in order to develop markets for new products, services, and technologies. Leading social enterprises such as iDE, d.light, and VisionSpring have successfully used HCD in recent years to design business models that serve the world's poor.

Human Centered Design (HCD) Process

A multi-stage process, where we expand (explore/generate) and narrow (select/evaluate) several times along the project.

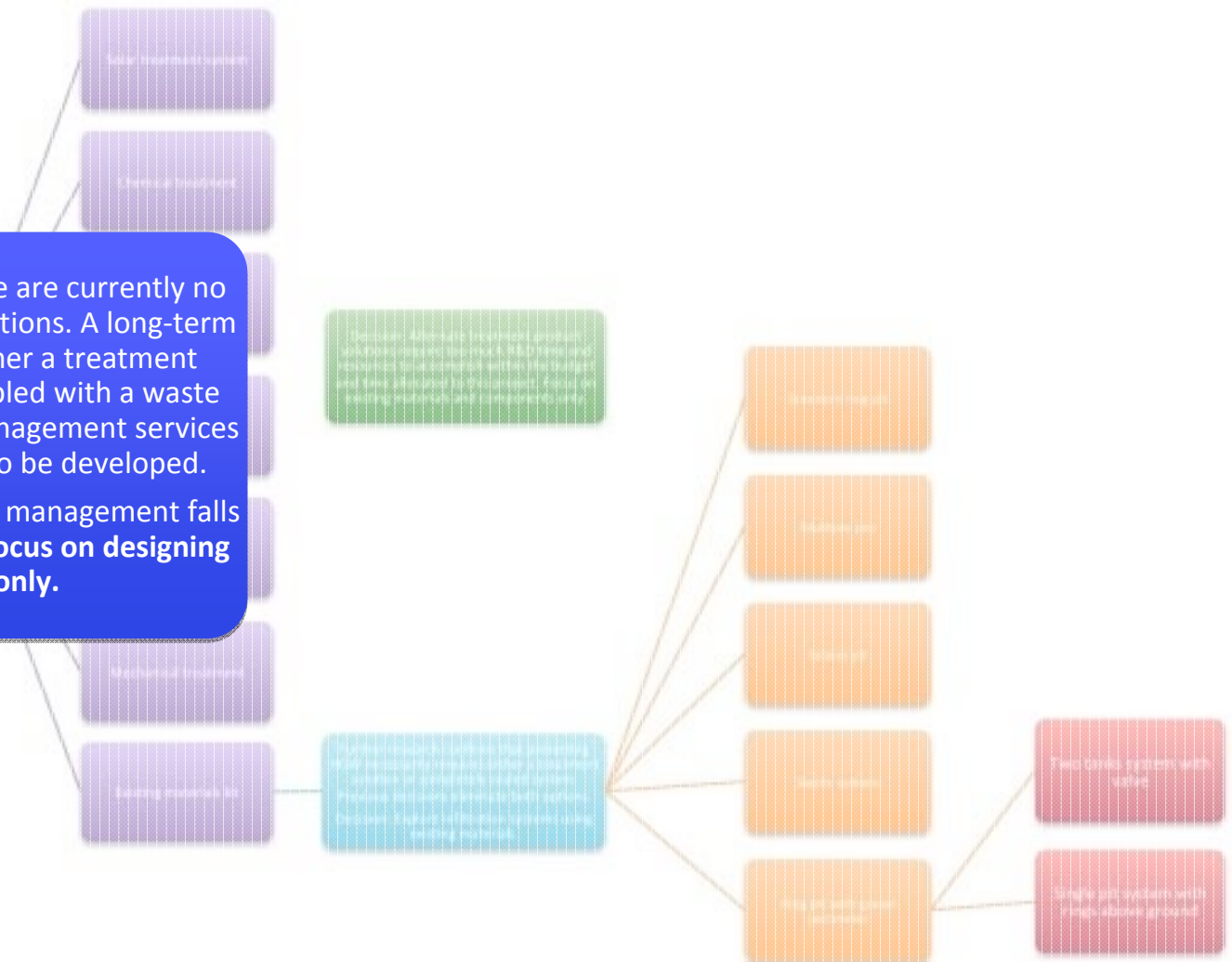


Product design: Stages and key decision points

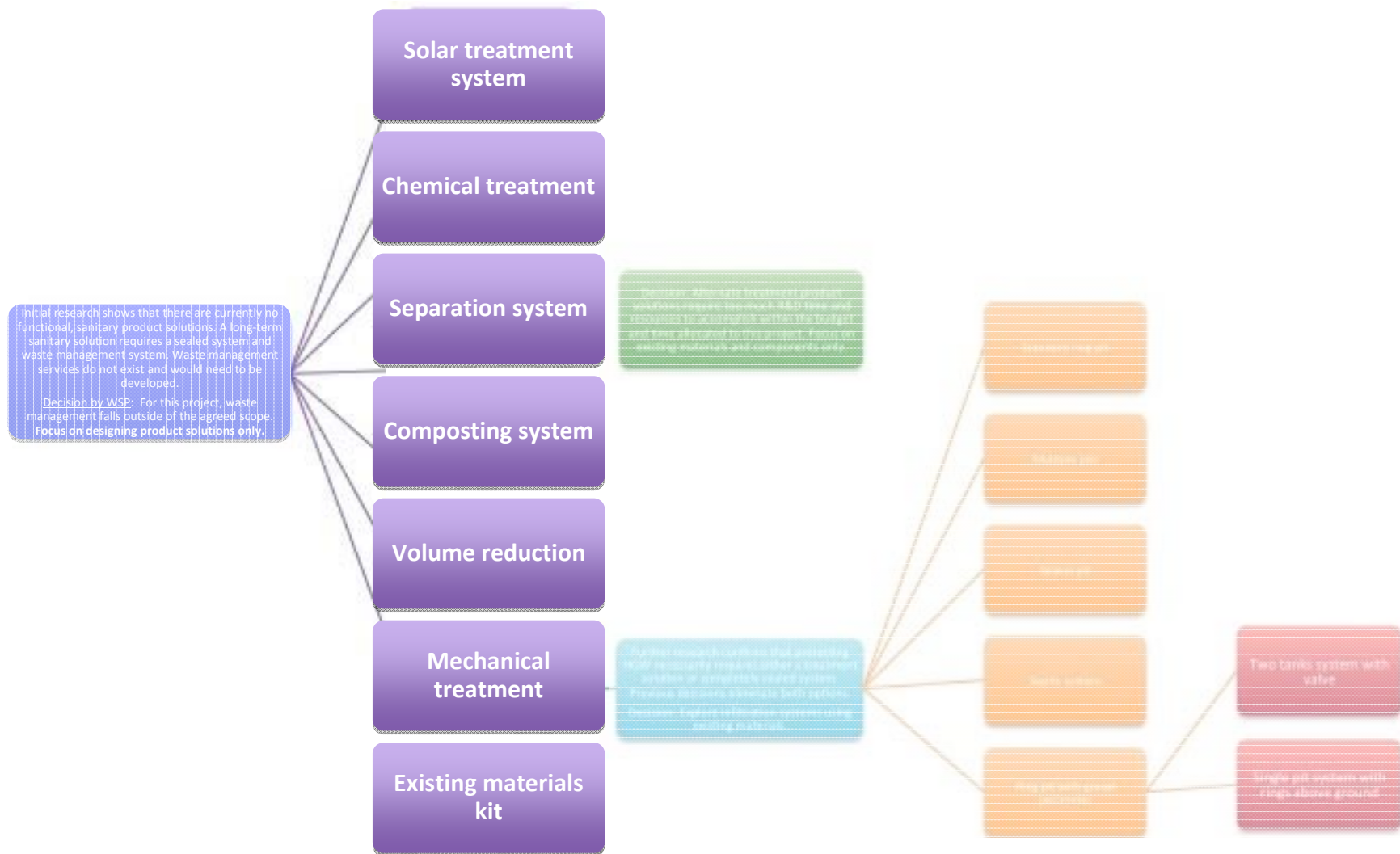


Decision #1: Focus on designing product solutions (vs. waste services).

Decision: For this project, waste management falls outside of the agreed scope. **Focus on designing product solutions only.**

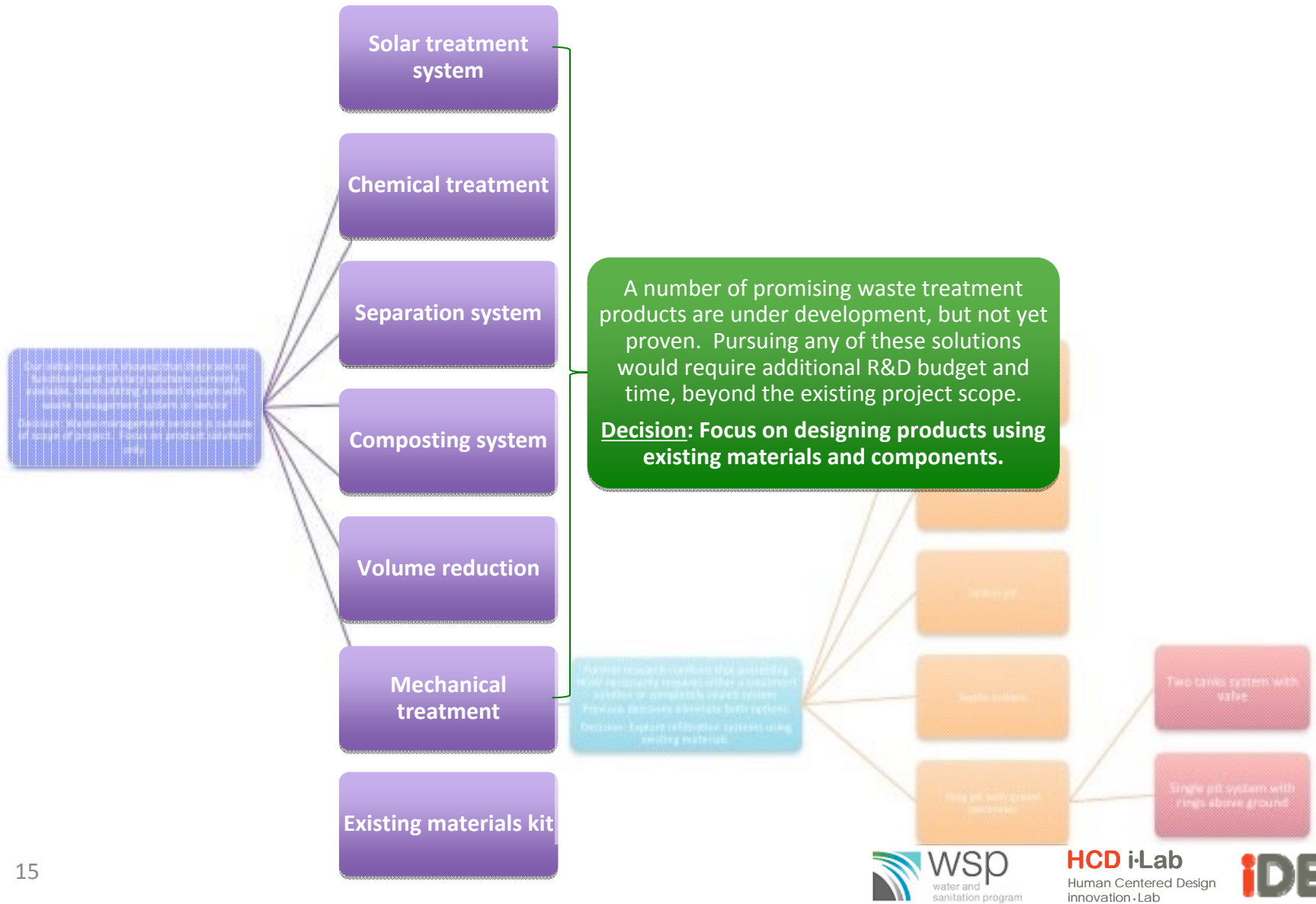


There are a number of promising product concepts currently under development in the international sanitation community.



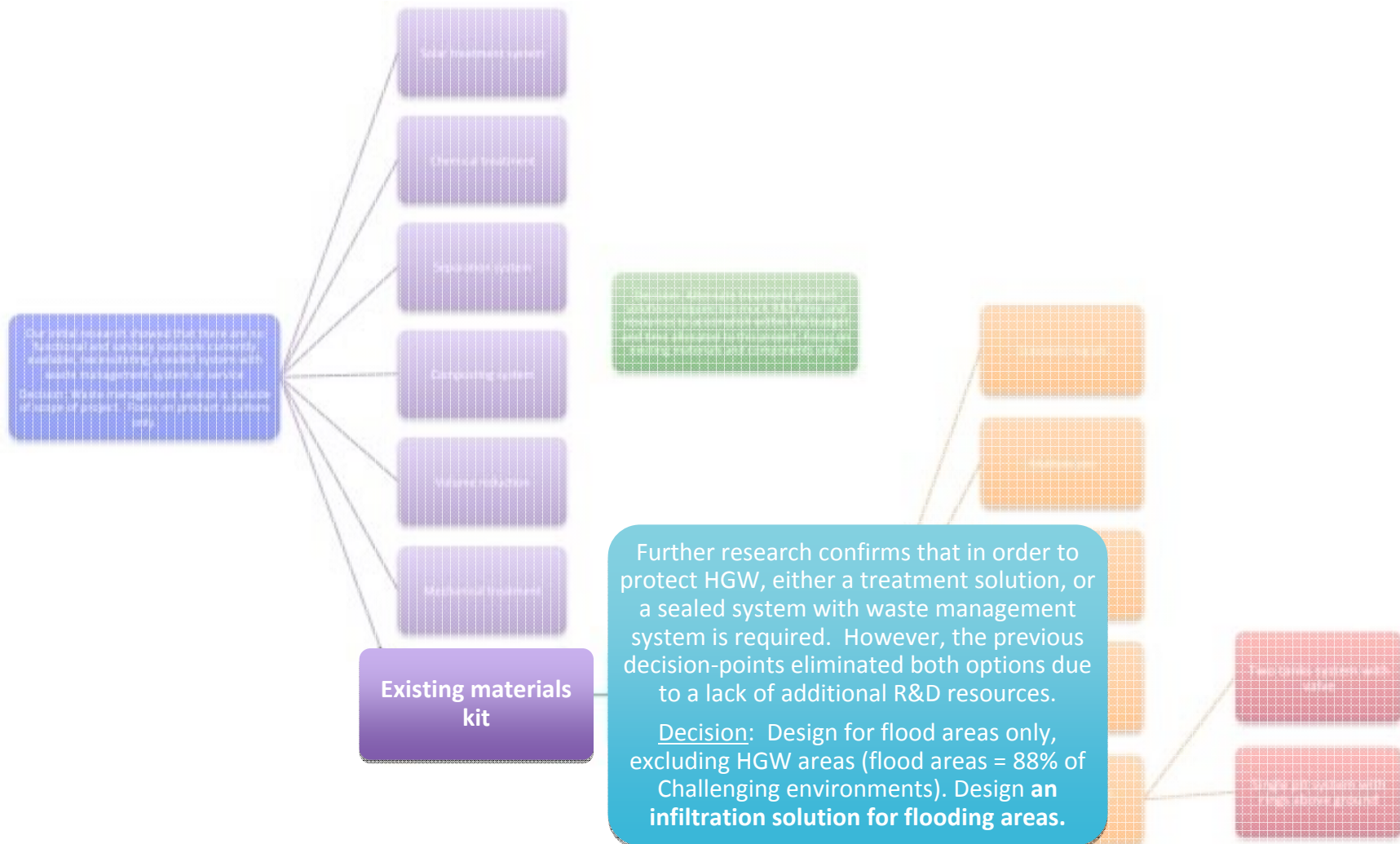
However, designing waste treatment products requires additional R&D.

Decision #2: Design using existing supply-chain materials.

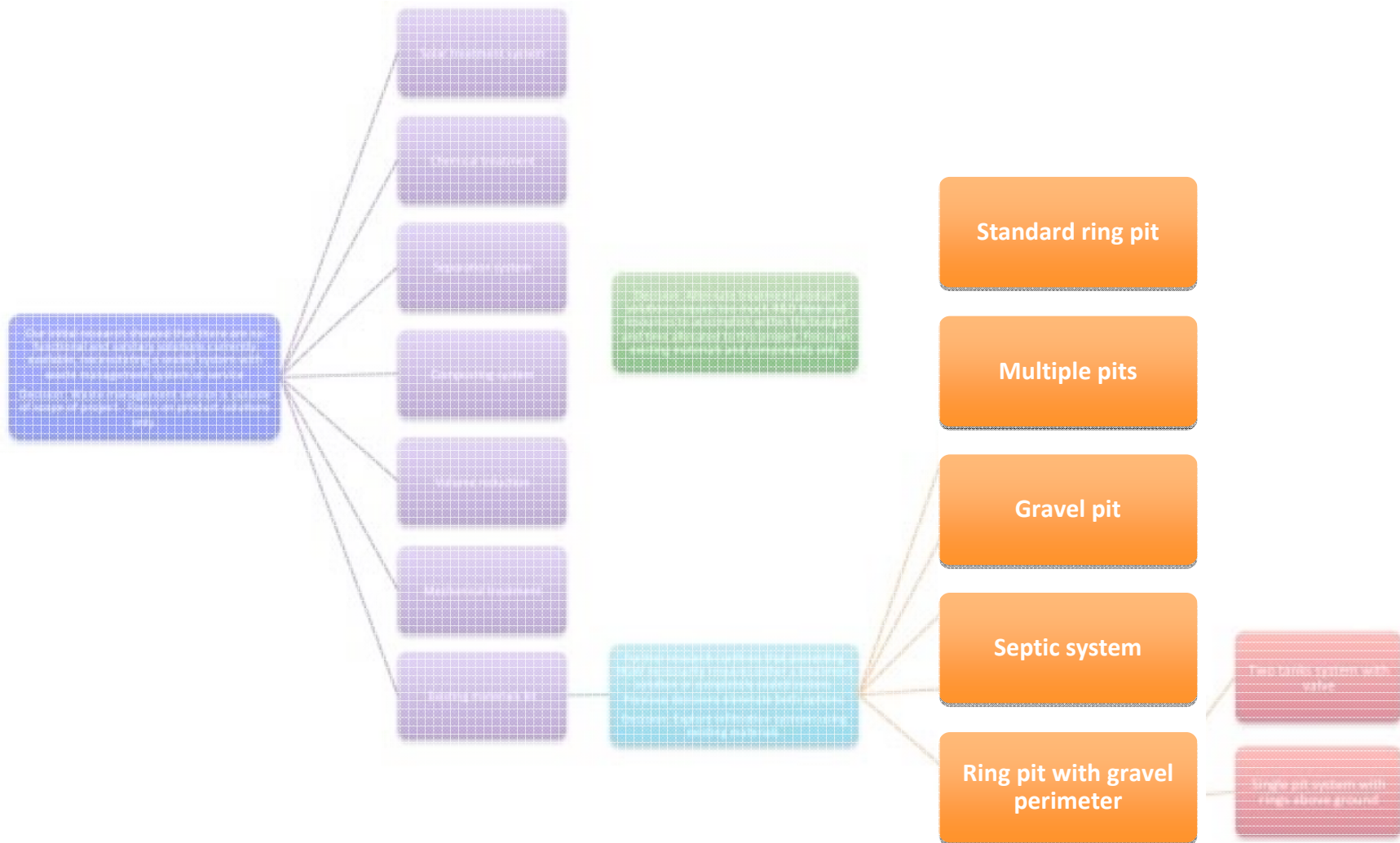


Designing with existing supply-chain materials and actors makes an affordable, marketable, sanitary HGW solution impossible.

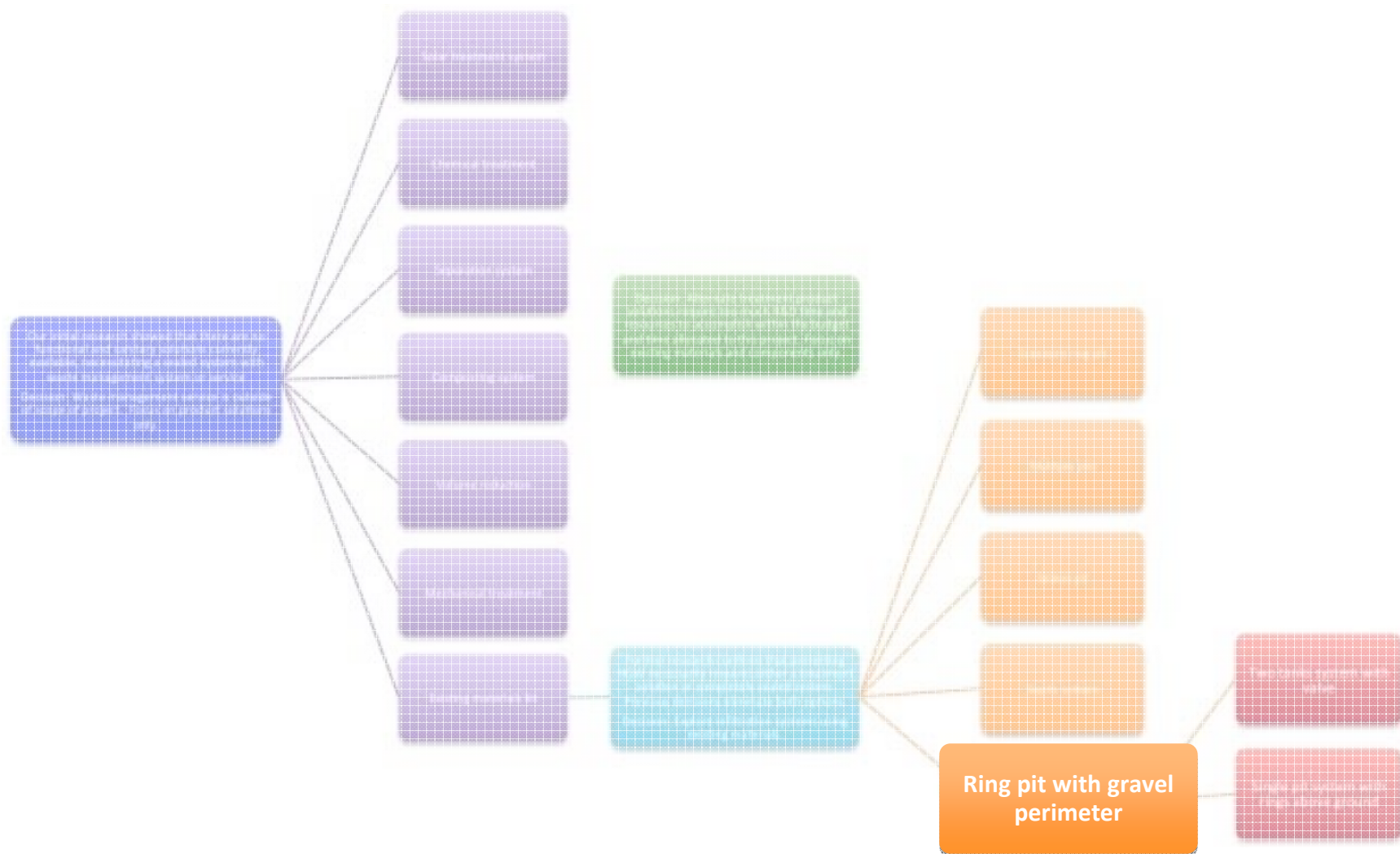
Decision #3: Focus on designing infiltration systems for flood areas.



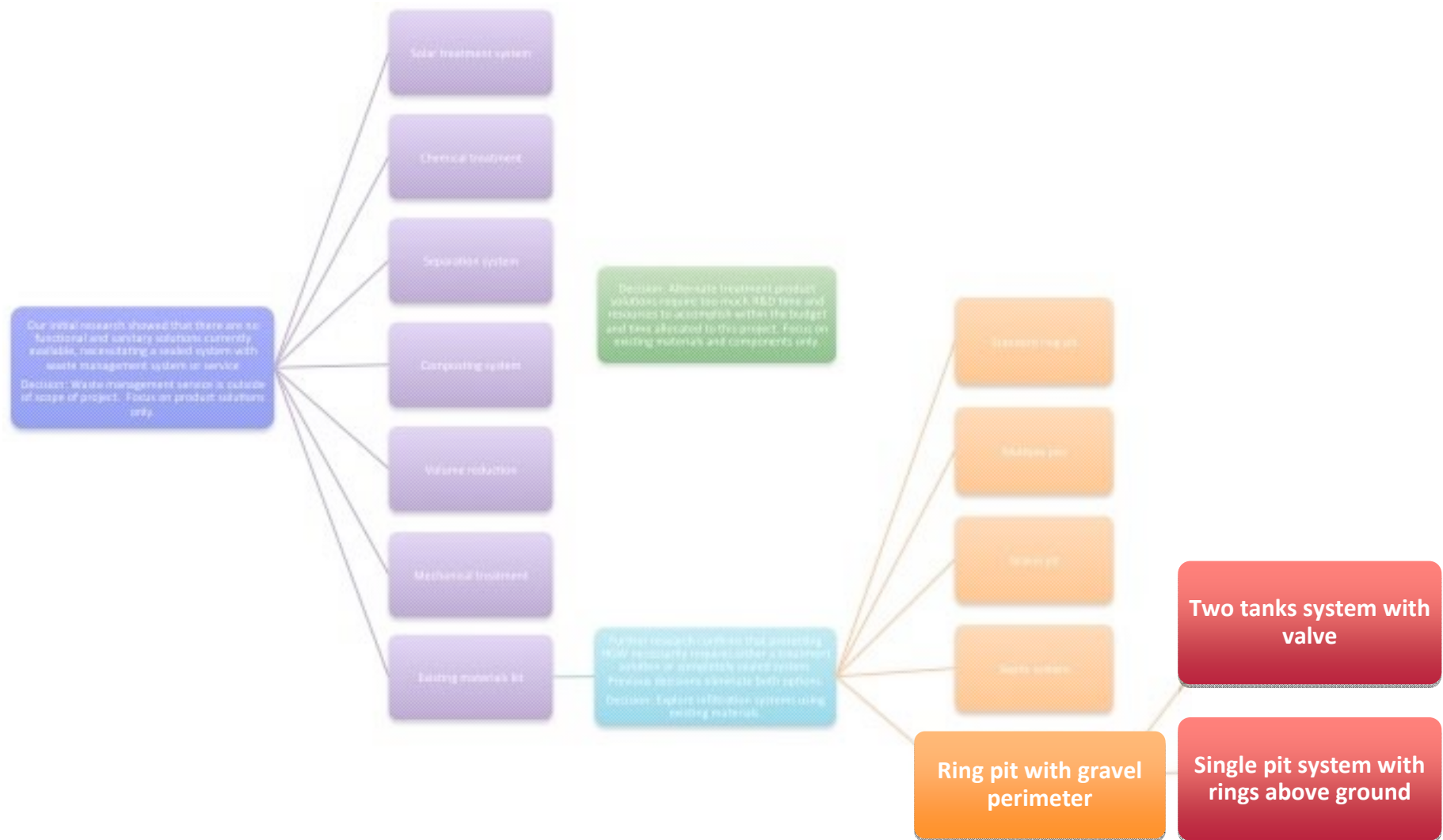
We explored a number of infiltration system options.



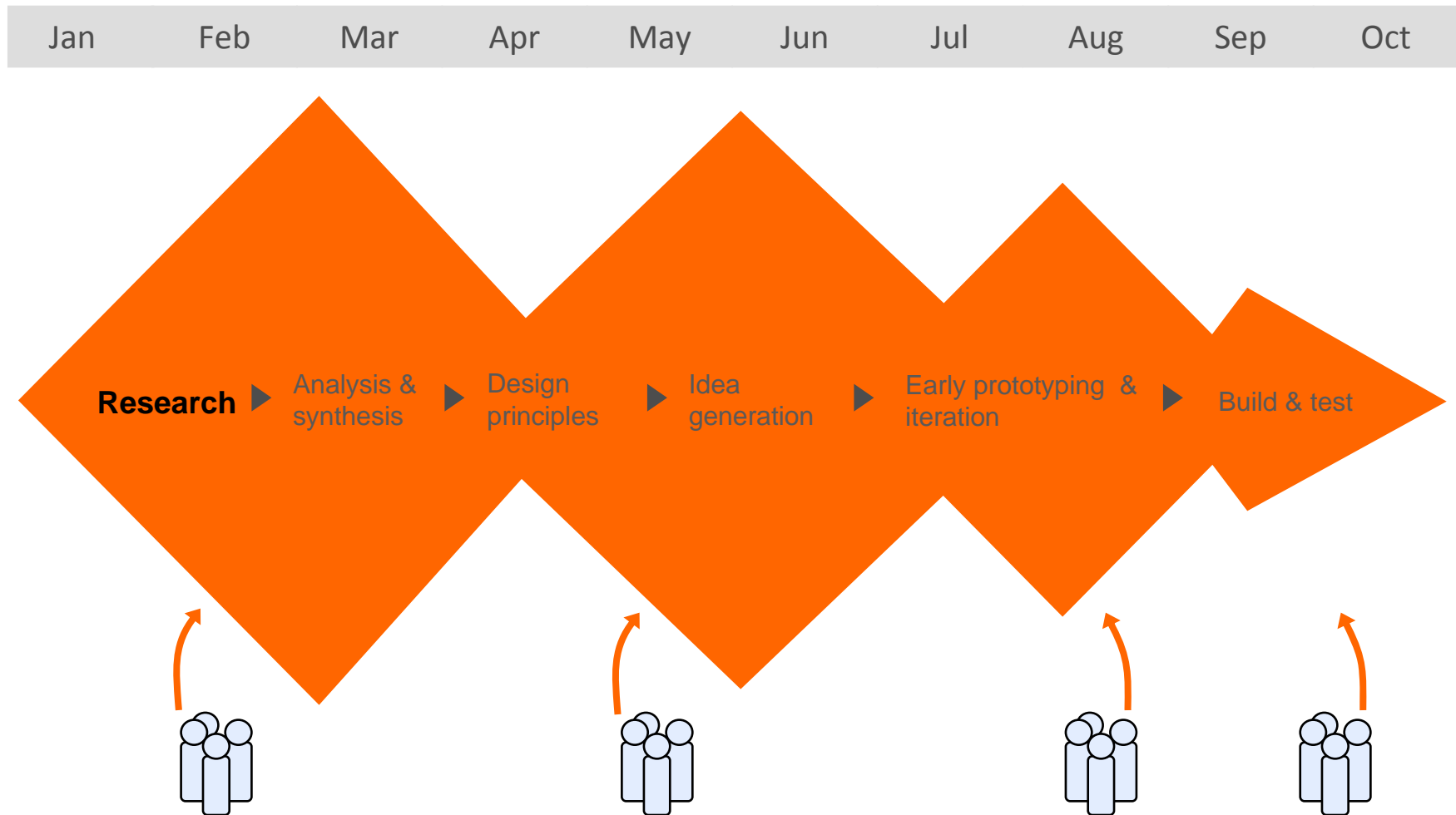
Decision #4: Based on feasibility and viability criteria, design a product solution using a ring pit with gravel perimeter.



Final prototype designs: 2 options for varying flood levels



HCD Process: Design research



HCD Research

Understanding the users and local context.

Uncovering human insights that are barriers to, and catalysts for adoption.

HCD research objectives:

Households:

- Explore cultural nuances of challenging environment contexts.
- Understand how people use latrines in these contexts.
- Identify motivations and barriers of households for buying and installing a latrine.

Supply Chain:

- Identify formal and informal actors within the supply chain.
- Understand supply chain actors' relationships and dynamics.
- Understand business/actors' needs and their impact on the end user.

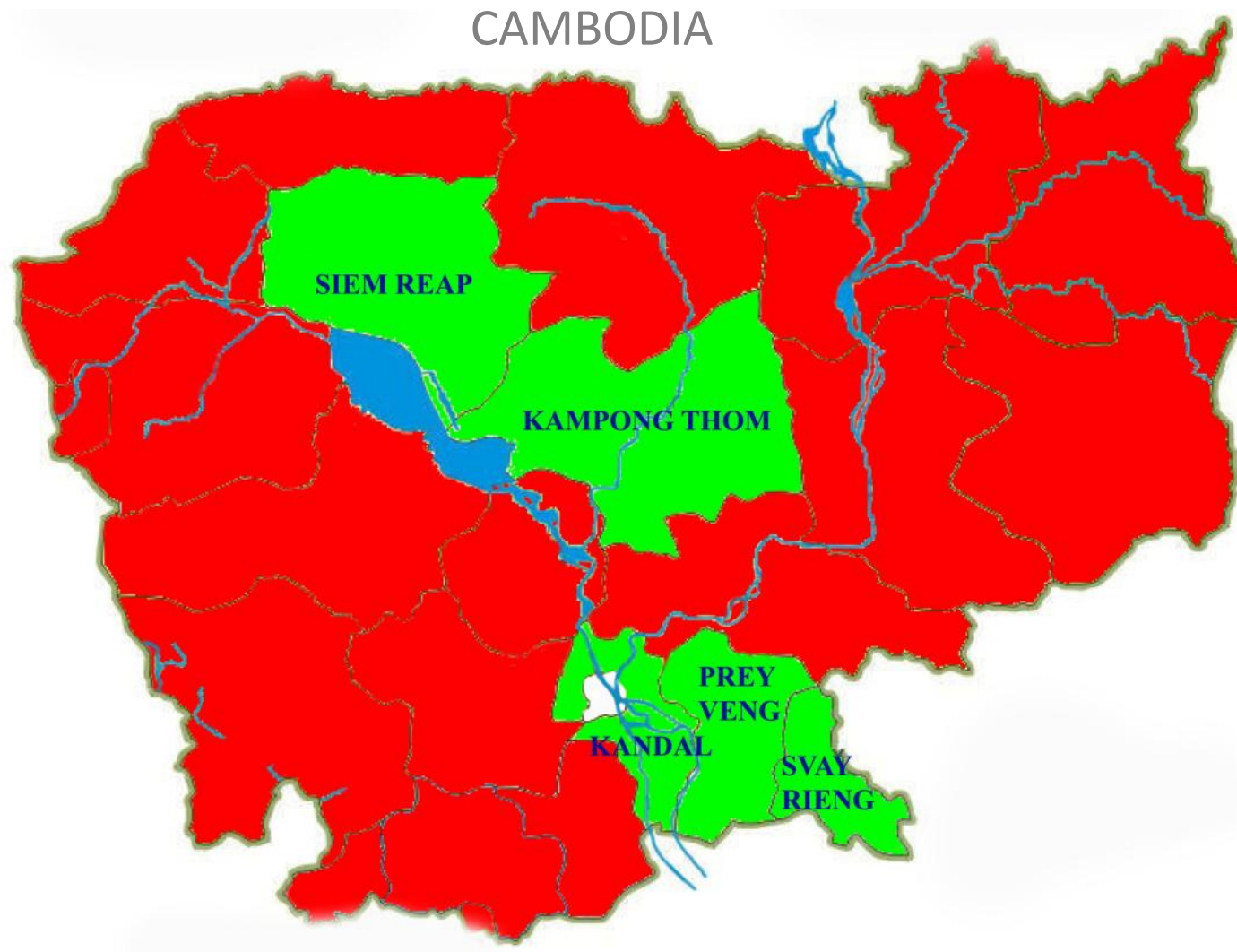
Who did we meet with?

Total of 109 interviews across 50 villages in 5 provinces

- 41 households
- 28 materials suppliers and producers
- 15 village chiefs
- 14 retailers
- 11 masons

Study Provinces:

The five study provinces are highlighted in green.





Retailers



Ring Producers



Masons



Gravel Producers



Supply Chain Actors

Brick Producers



Sand Producers



Transport Agents



Cement Supplier



Mold Producer



Flooded households



Flooded yards



Households

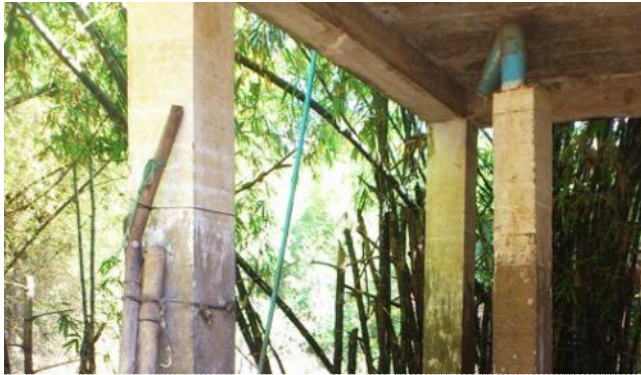


Flooded fields/paths



High Ground Water (HGW)





Latrines on stilts



Ground elevated latrines



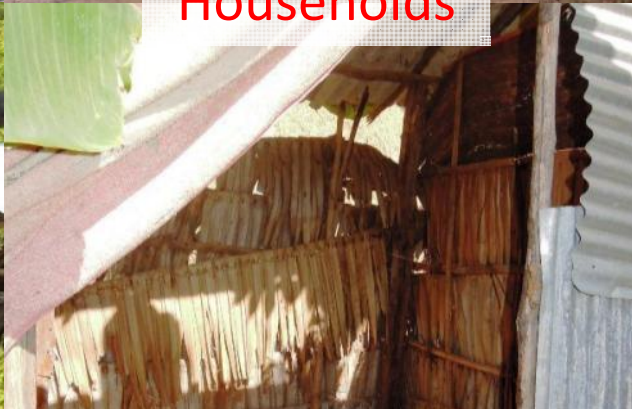
Tank elevated latrines



Households



Ground level latrines



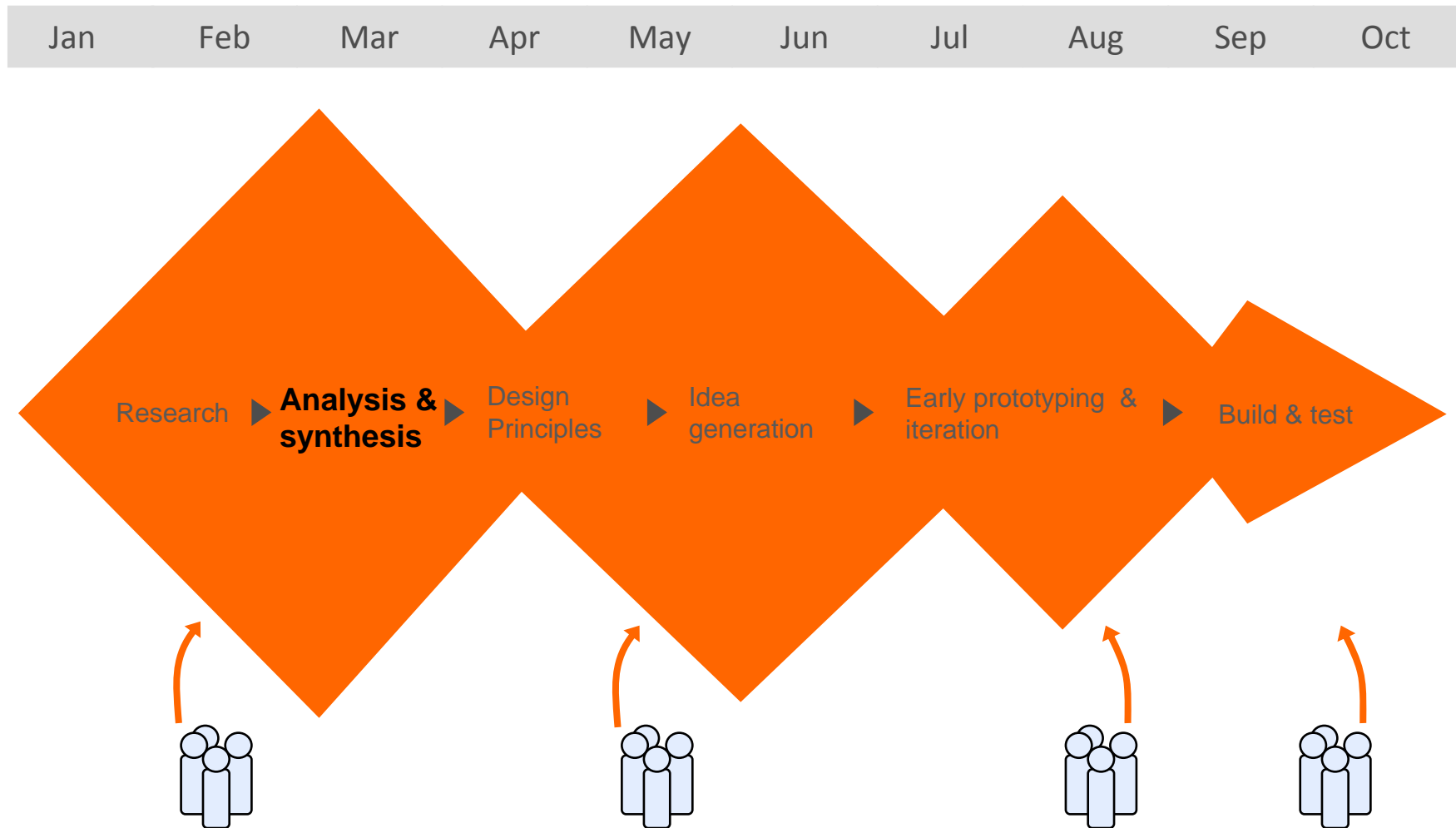
Dry pits



Unsanitary "latrines"



HCD Process: Analysis & synthesis



Analysis & Synthesis

Making sense of the field research.

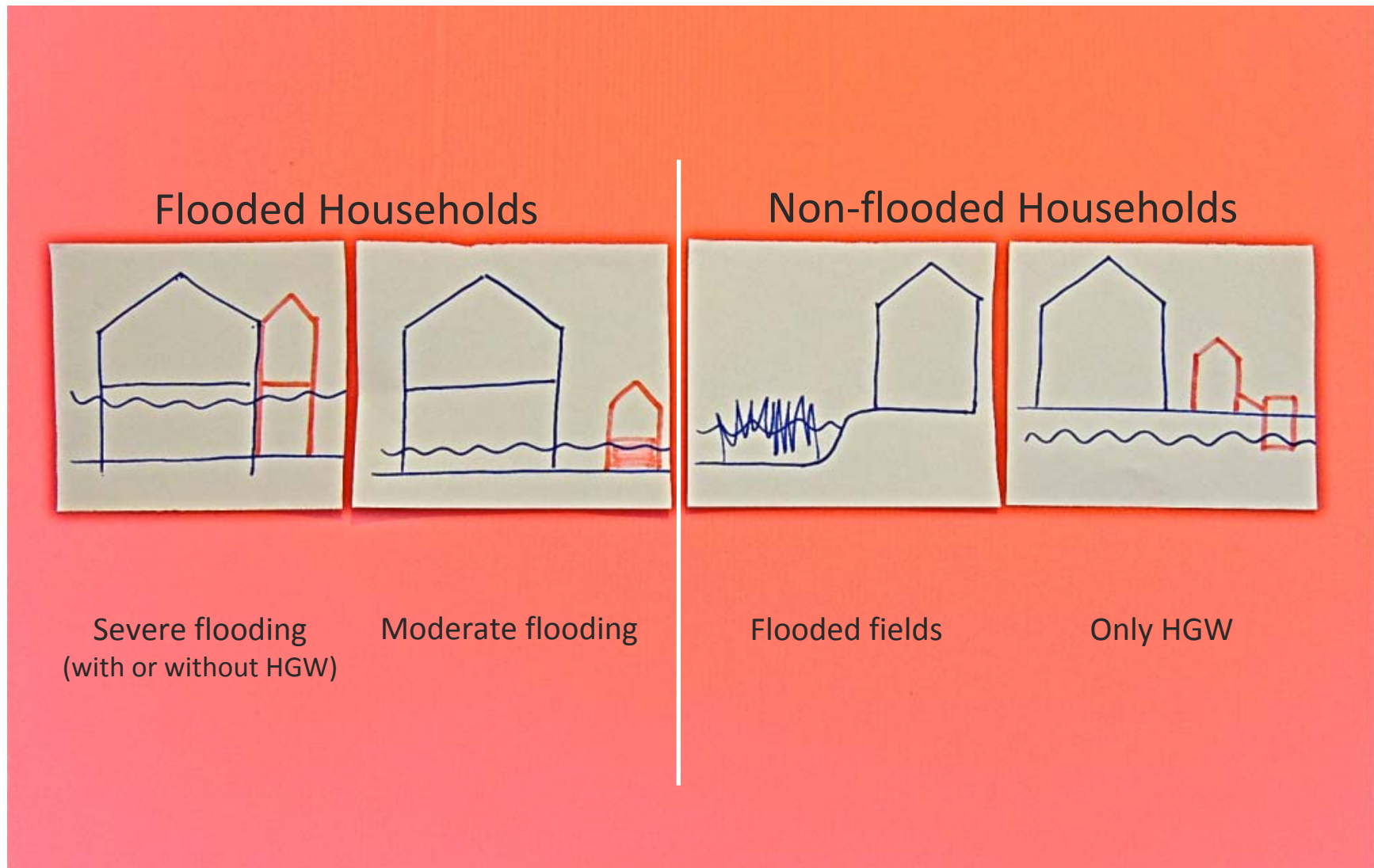
Extracting themes and patterns into key user findings.

Key User Insights

Key User Insights

What are the environmental contexts?

What are the environmental contexts?



Key User Insights

Household behaviours and attitudes

Villages in challenging environments are isolated.



Villages are not always easy to reach, even during dry season. Road conditions are poor due to flood damage and so residents tend not to travel far. This results in less external influence; what neighbours do becomes the main influence on decisions. Each village is a 'cocoon', with its own way of doing things.



Households do not perceive health risks of water contamination to be significant. Drinking water is the only concern.

There is little change in behaviour among households that have been informed of the health risks of building latrines close to pump wells, of defecating into flood water, and of improperly emptying latrines. People are cautious of their drinking water and boil it before drinking. Yet little thought is given to contaminated water used for cooking, washing vegetables, cleaning, bathing, and swimming/playing.

People trust neighbours and family for information.



Neighbours and family are the most trusted source of new information. These information sources influence purchase decisions and actions of a family, from farming techniques to house construction. Households look to neighbours for latrine designs and ask that the mason follow existing designs.

Purchase motivators include status, visibility, pride, and gaining face.



Households prioritize purchasing items that allow them to 'show off' and gain face in their community such as motorbikes, sound systems, and wardrobes.

Purchase priorities



"I bought the wardrobe because everyone has one in the village"

"Latrines are not popular enough"



"My husband bought the speakers. Everyone comes to our house to celebrate end of harvest, and we use them for parties"

"...we just bought a \$1,250 motorbike for my son. He needs to be seen in the village with the bike,"

← **Keeping up with the neighbors** **Showing off** →

Key User Insights

Latrine usage



Defecation habits change with the seasons.

Due to flooding, many latrines are rendered useless during the rainy season. During this time, villagers revert back to open defecating, either finding higher ground on which to go, or defecating directly into the water that surrounds them.



Open defecation is not shameful.

In dry areas (no seasonal flooding), not owning a latrine causes people to lose face, motivating purchase. However, in Challenging Environment areas, open defecation is accepted and does not elicit a strong negative reaction from the community.

A photograph of a man standing in front of a building with multiple doors and ventilation grilles. The man is seen from the back, wearing a light-colored shirt. The building has several dark wooden doors and large, rectangular ventilation grilles on the wall above them. The scene is outdoors, and the lighting suggests it might be late afternoon or early morning.

Local schools, pagodas, markets, and health centers are a common reference for first latrine use.

Unless a relative has a latrine, most households have little exposure to them. Most first-time latrine use happens at schools, pagodas, markets, and health centres.

“Do you want to see a good latrine? Go to the pagoda.”

“We bought the latrine because my children use it at school and they insisted.”

People want to minimize the effort needed to defecate.



A major perceived advantage of having a latrine is that it reduces the effort needed to defecate. During dry season, people no longer have to walk long distances to 'find a place to go'. Latrines make defecating at night easier and safer. Elderly household members are a major driver for latrine purchase. On the other hand, in high flood areas it is easy to defecate directly from the house into surrounding water, so there is little incentive to use a latrine.



Bad smell is a driver for action.

If the latrine smells, either due to poor maintenance or flooding, it is often abandoned. The smell of dry pits is a motivator to upgrade to an offset pour-flush toilet. In some areas, ponds are used to defecate. They contain fish that eat feces, so there is little to no smell. In such cases there is low motivation to own a latrine.

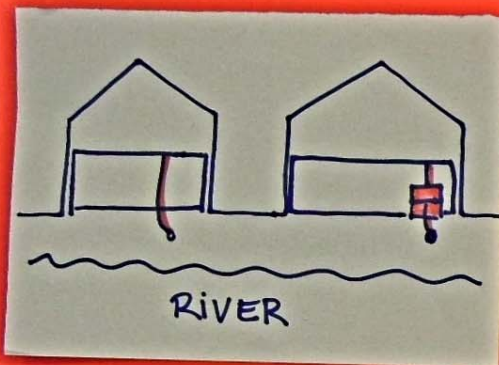
“A pond is better than open defecating because it doesn’t smell,”

Key User Insights

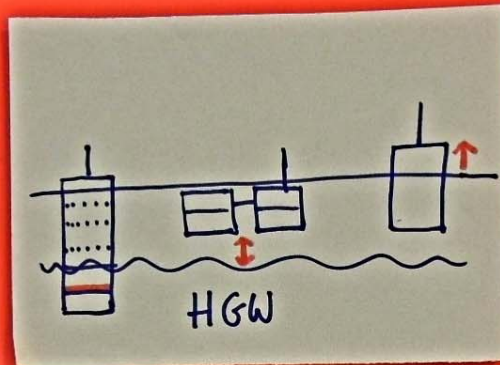
Latrine construction

What are the different underground constructions, and why?

Physical conditions determine design

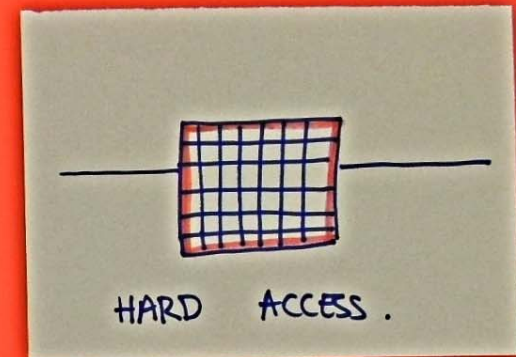


- Pipe discharges directly into river



- Joints between bottom 2 rings sealed together
- 2 pits to avoid HGW
- Rings elevated above ground to avoid HGW

Accessibility determines design



- Tanks made of brick due to difficulty transporting rings



Land and money constraints are a barrier to latrine construction in flood areas.

In areas with under 1.5m floods, households may elevate the ground prior to construction by building a mound of soil above anticipated flood levels. The soil is usually dug by machine or hand, which can be costly. This requires the household to own land or to have access to soil.

In severe flood areas, concrete pillars may be used, adding material and labor cost.

Key User Insights

Pit emptying and waste management



Little to no thought is given to pit emptying.

Because most latrines are relatively new, little thought is given to emptying. Many households believe that they will never need to empty. In some areas where the soil is looser, emptying may not be needed for many years.

In cases where there is some awareness, households who can afford it will build larger pits, or a 2-pit system as a way to delay the eventual need to empty.



In areas with heavy flooding, households open their pits to empty.

As flood waters rise, households open the pits or unplug an opening in the pipe. This allows continued usage of latrines during the floods as the waste flows from the pits into the surrounding flood water. If the pits are kept closed, they would fill (saturated soil does not allow waste to seep out) and render the latrine useless.

Services for pit emptying are not readily available.



Pit emptying is a job that requires specific skills (e.g. proper protection, avoiding smell while emptying). Though some services exist such as manual labour to empty or pump machines for hire, these are uncommon and can be costly. Information from NGOs on emptying is limited.

Key User Insights

Supply chain and masons

Some areas are not accessible by road.



During wet season, trucks are unable to reach some challenging environments areas due to high water levels and flood damaged roads. In these cases, materials are transported by moto or by boat.


A man with dark hair, wearing a white button-down shirt, is shown from the chest up. He is looking slightly to his left and appears to be speaking. His hands are clasped in front of him. The background consists of lush green trees and foliage, suggesting an outdoor setting. A semi-transparent text box is overlaid on the top part of the image.

Mason availability varies from village to village.

The number of masons in each village varies, with some villages having none. The villages with many masons are usually ones with major construction projects underway (schools, pagodas, etc). Most villages have one or two masons who service multiple villages in the area.



Most masons do not have formal training.



Most masons learn skills informally, on the job. Starting as unskilled labourers, masons learn from co-workers and the chief mason. Few masons have received formal NGO training on proper latrine construction. In some cases, a design is recreated after visual observation, with guesses to fill in the details.

A man with dark hair, wearing a white t-shirt, is seated outdoors. He is looking down and writing on a piece of paper with a blue pen. The background shows a dirt area, some greenery, and a building with a tiled roof. The text "Masons dictate purchase lists." is overlaid in red at the top left.

Masons dictate purchase lists.

Masons give detailed lists of construction materials to client households, as households do not know what to buy. The list includes details such as sand grain size and color, gravel size, and cement brand. Households follow the list when going to the market to purchase materials. In some ways, this makes the mason the customer of the retail shops. Households simply select the retailer and pay.

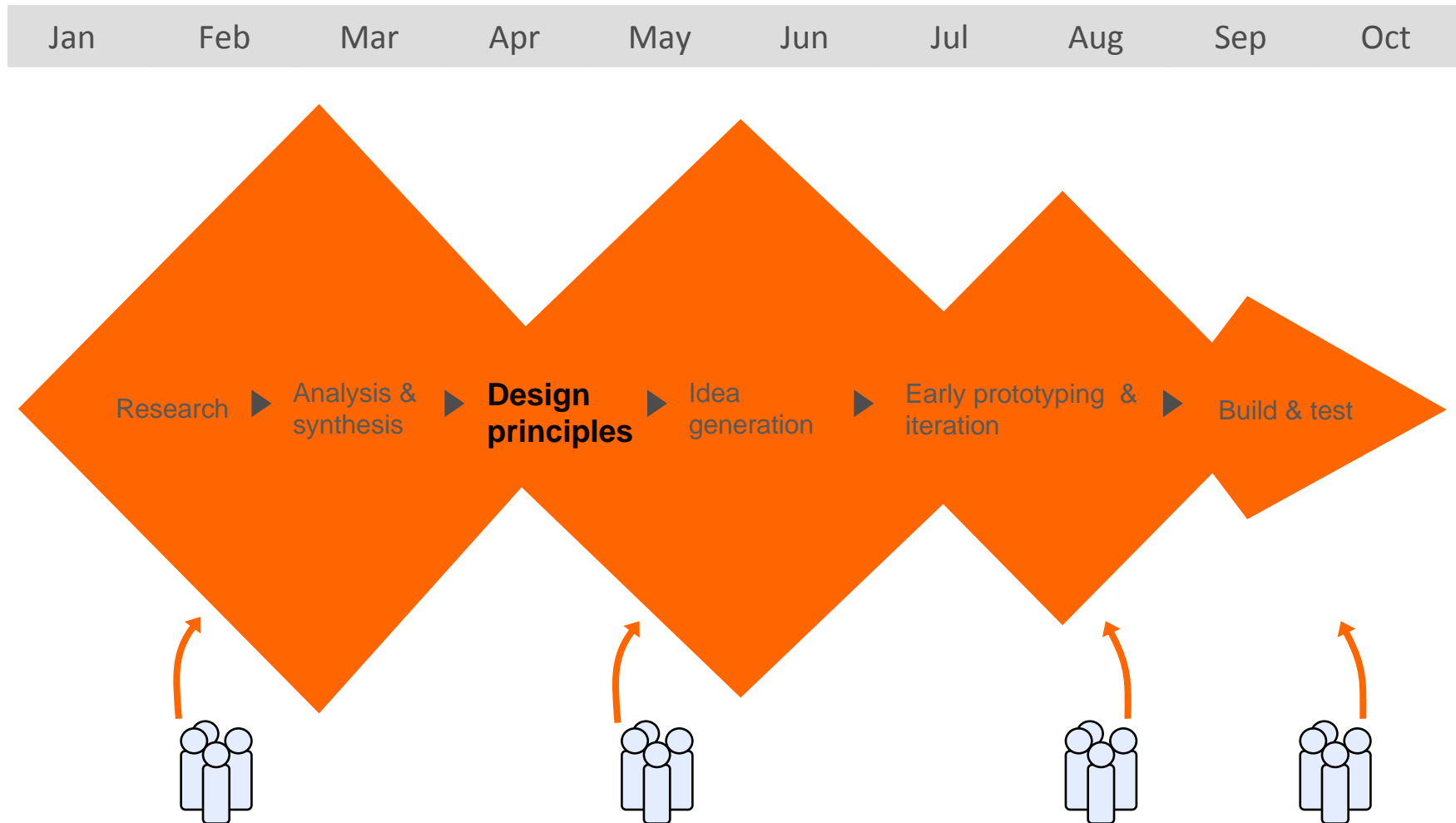


Masons' recommendations are not always followed.

Though households look to masons to design and build a latrine, the household decides the final design. To reduce costs, households will change the design, even if it means installing an unsanitary latrine. As long as the function of the latrine is not compromised (waste is not seen/smelled), hygiene is not a priority.

“They wanted me to build a drain pipe directly from the pan to the river behind the house even though I wanted to build a tank. I do what the client asks.”

HCD Process: Design principles

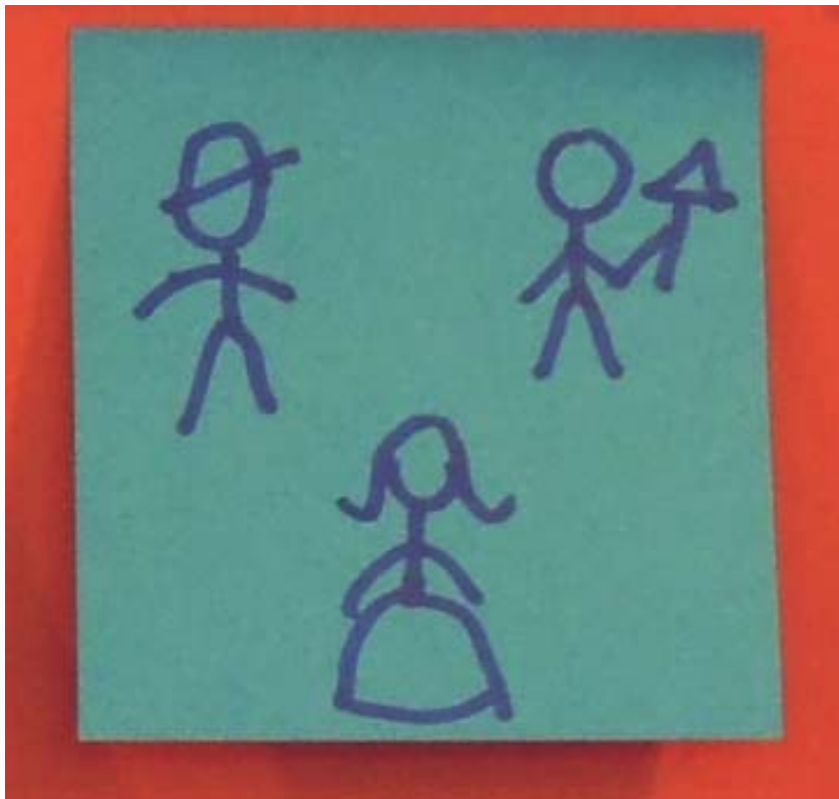


Design Principles

Transforming key findings into a set of core design guidelines.

Design Principles are the foundation on which ideas are generated, and the solutions built.

Leverage local influencers.



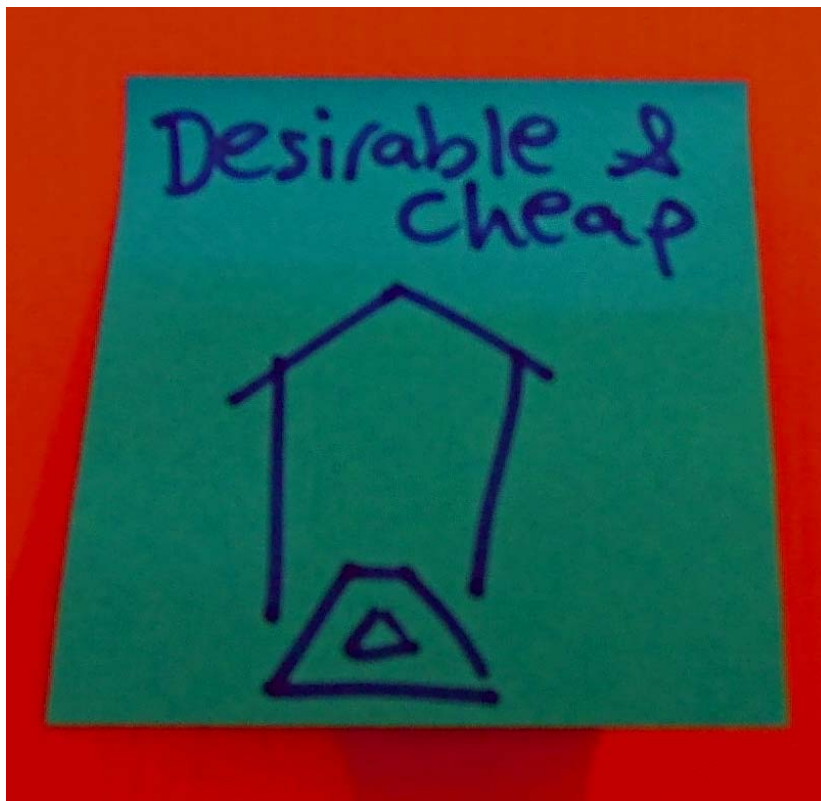
People who have been exposed to latrines typically experience them for the first time at schools, pagodas, local health centres, and markets. These sources, as well as trusted family and neighbours, have a strong influence on the decision to buy a latrine and the type of latrine built. However, there is still little exposure to latrines among the target population.

Increase hygiene awareness.



Out of convenience, villagers routinely contaminate local water sources with waste. Yet the immediate, personal health hazard of their unhygienic behaviors are not actually known or understood. This prevents more hygienic practices and products from being desired or adopted.

Be affordable but stay aspirational.



Product options must be affordable but must also meet users' tastes and desires. The product offering must be aspirational and aesthetically pleasing to trigger purchase and satisfy consumer desires.

Design for affordability needs to be balanced against product desirability.

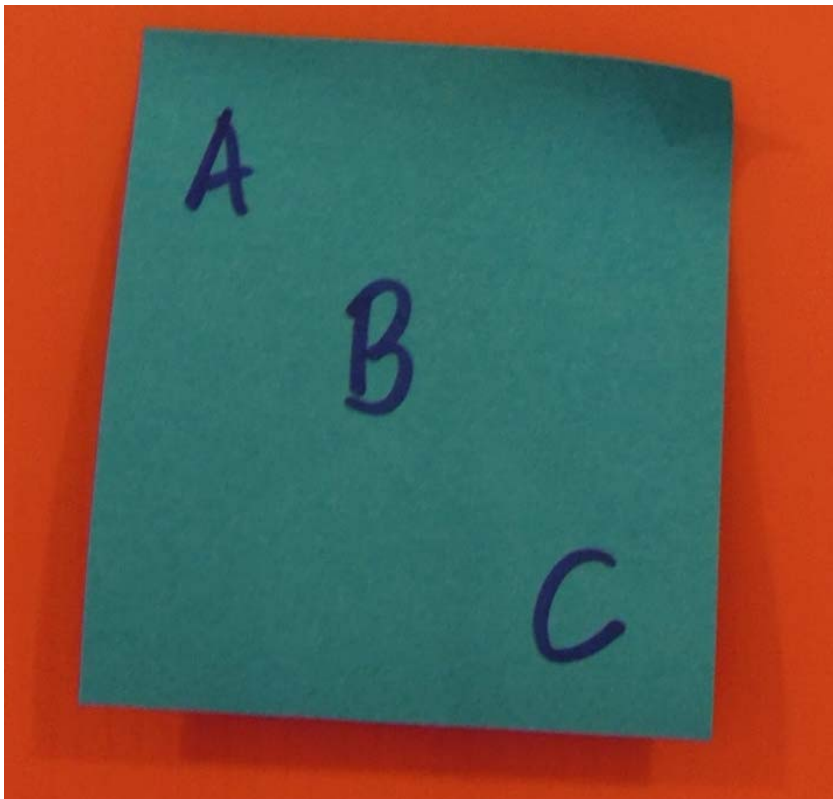
Create flexible credit options.



These are key characteristics that end-users prioritize in considering credit options:

- Small amounts
- Low or no collateral
- Individual instead of group credit
- Accessible quickly

Design for varying mason skill levels.



There is a wide range of skill levels and latrine knowledge among masons. Among households with latrines, many of the latrines were the first one that the mason had ever built. The final product design must take into account the fact that there are still few masons with latrine experience.

Design with masons' needs in mind.



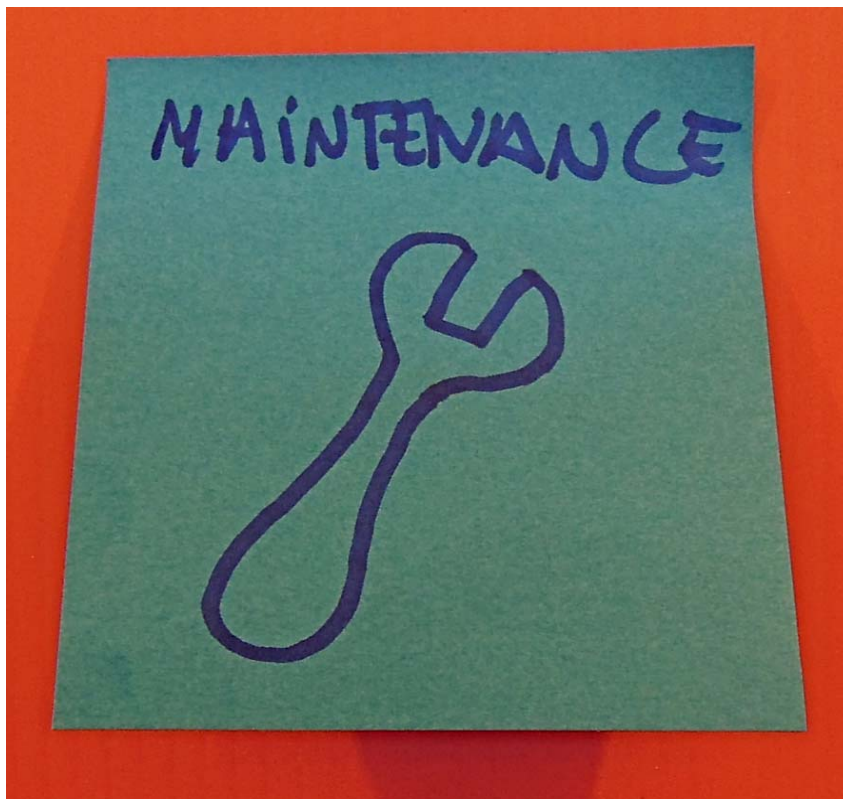
Masons are usually the first point of contact between households and the supply chain. They make design decisions and recommendations, tell customers what materials to buy, and where to buy them. The few designs that exist do not take into consideration the needs of the masons, which is critical for market execution and adoption.

Enhance masons' knowledge on clients' needs.



Masons have to construct for varying flood types as well as varying high ground water levels, depending on the location of the latrine. However, masons are not always knowledgeable about how to address each household's specific needs.

Design for ease of use and maintenance.



A major driver for latrine purchase is to reduce the difficulty associated with open defecation (finding a private location, walking long distances to go, safety, etc). A new product offering must be easy to use while also requiring minimal effort to maintain over time.

Design for easy transportation.

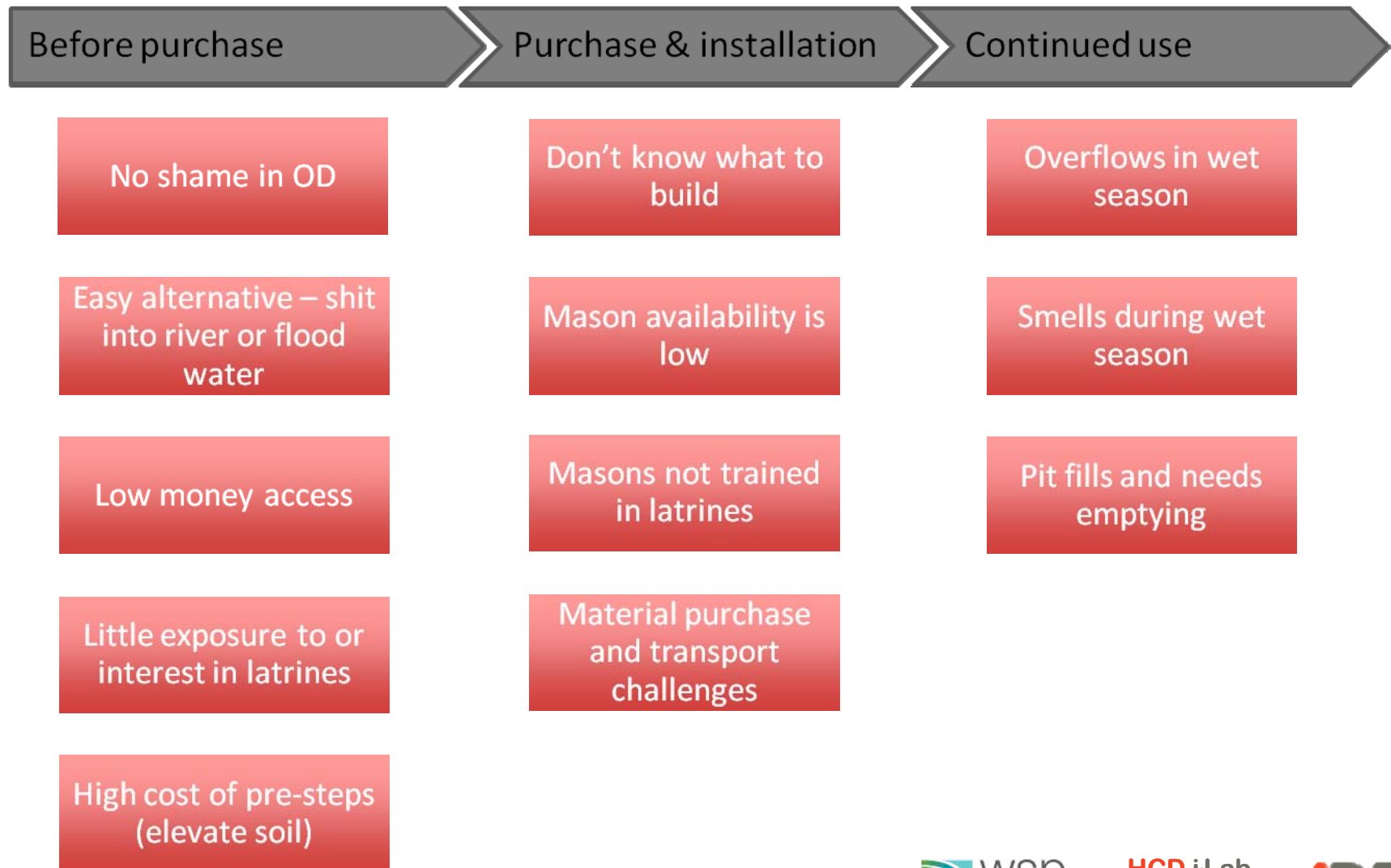


Given the inconsistent and often difficult access to challenging environments areas, designs should consider size, weight, and packing for the most efficient transport of one or many latrines, and minimize breakage.

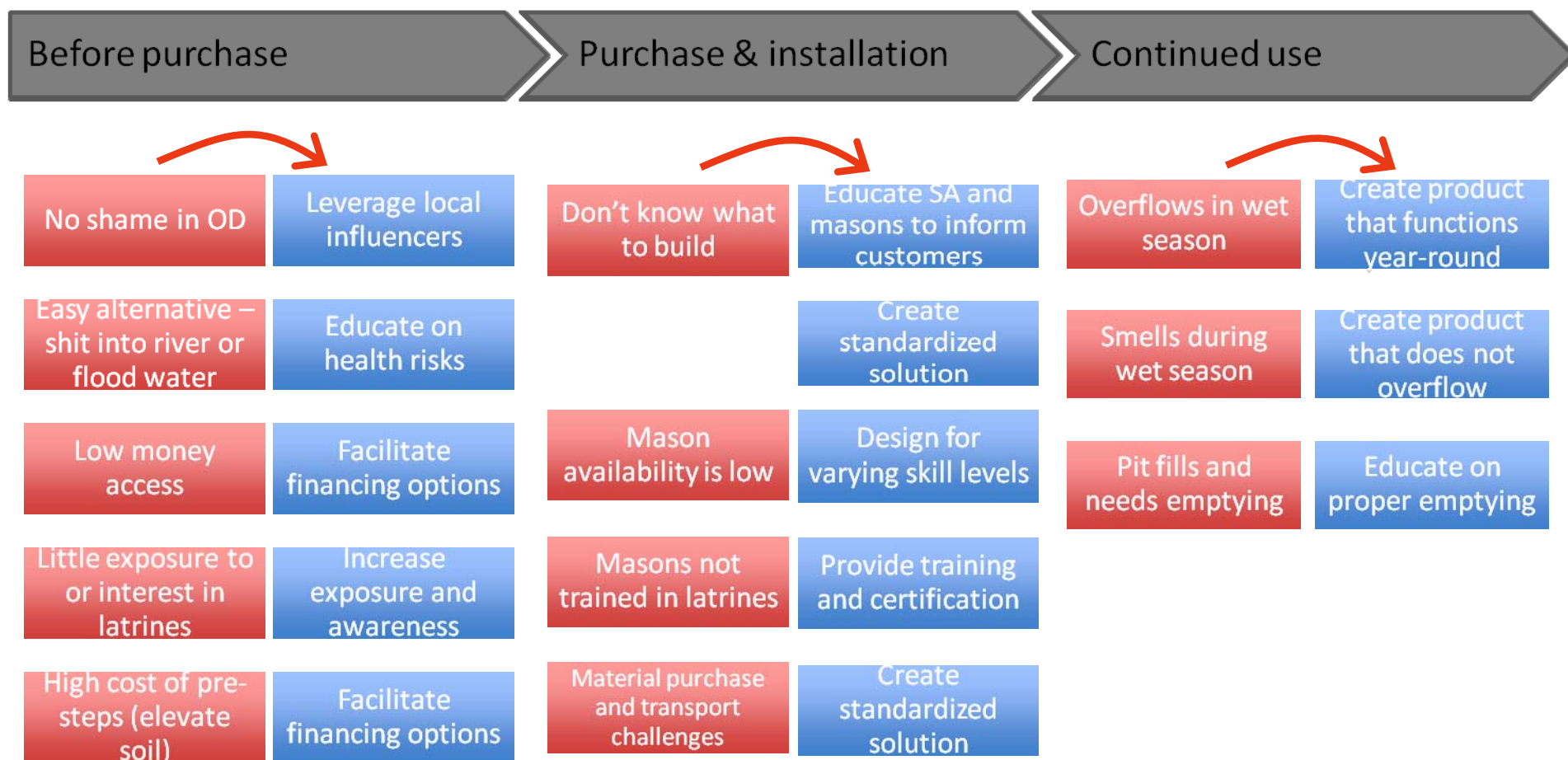
User Journey

Identifying and mapping key barriers and catalysts at each step on the path towards adoption.

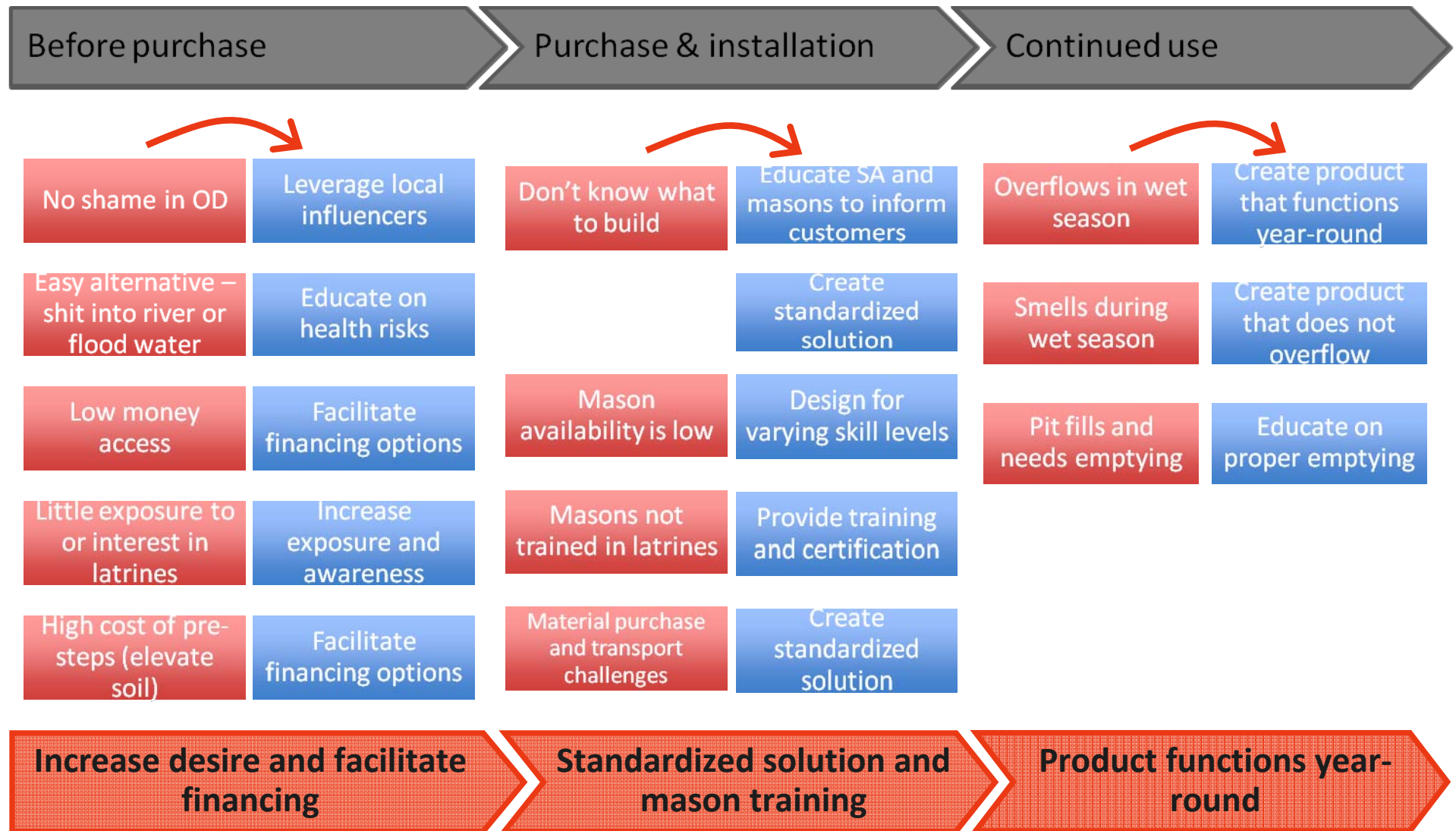
User Journey: Major barriers to consideration and adoption



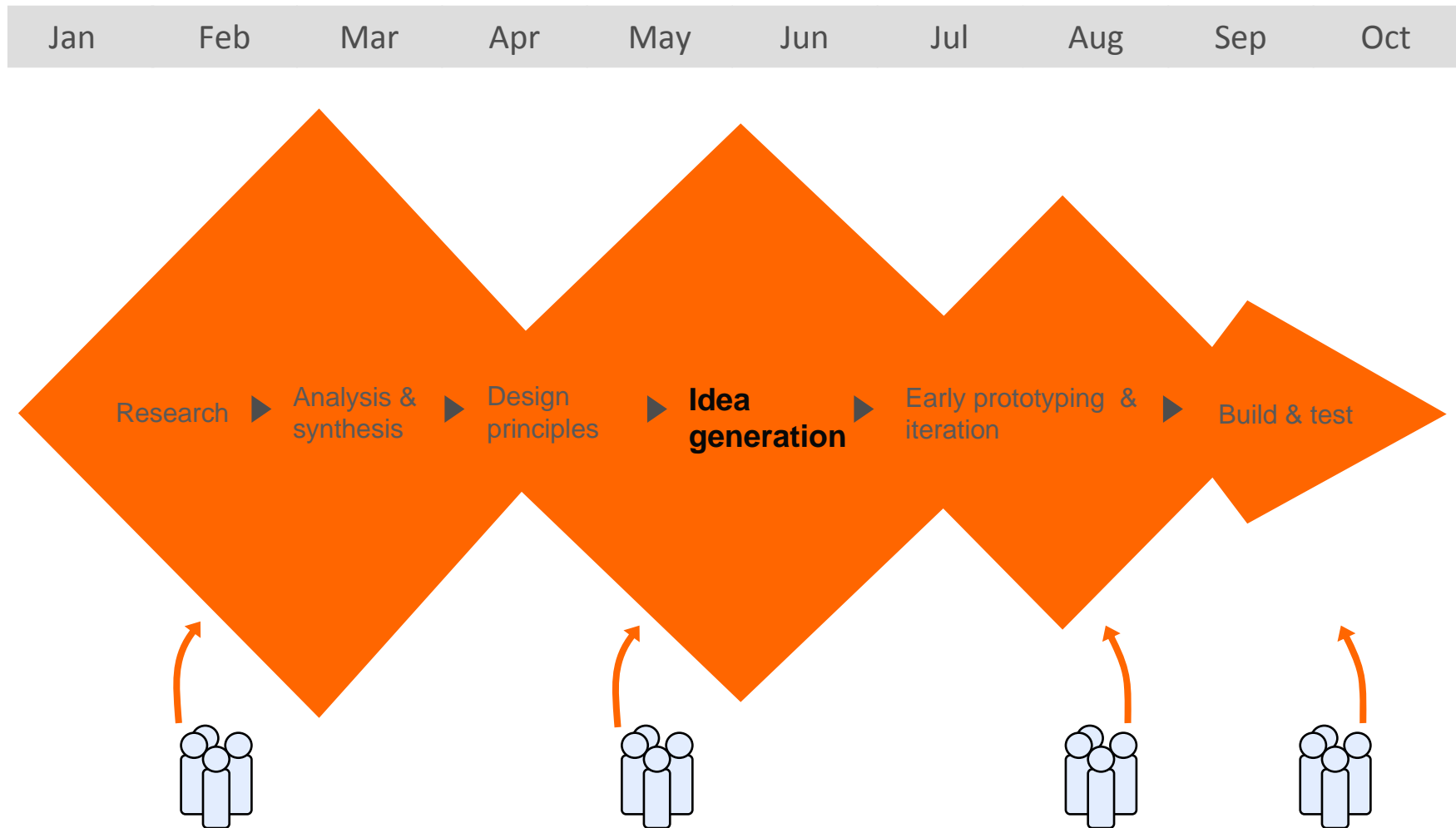
User Journey: How to overcome barriers to consideration and adoption



User Journey: Guidelines for designing a holistic user experience



HCD Process: Idea generation

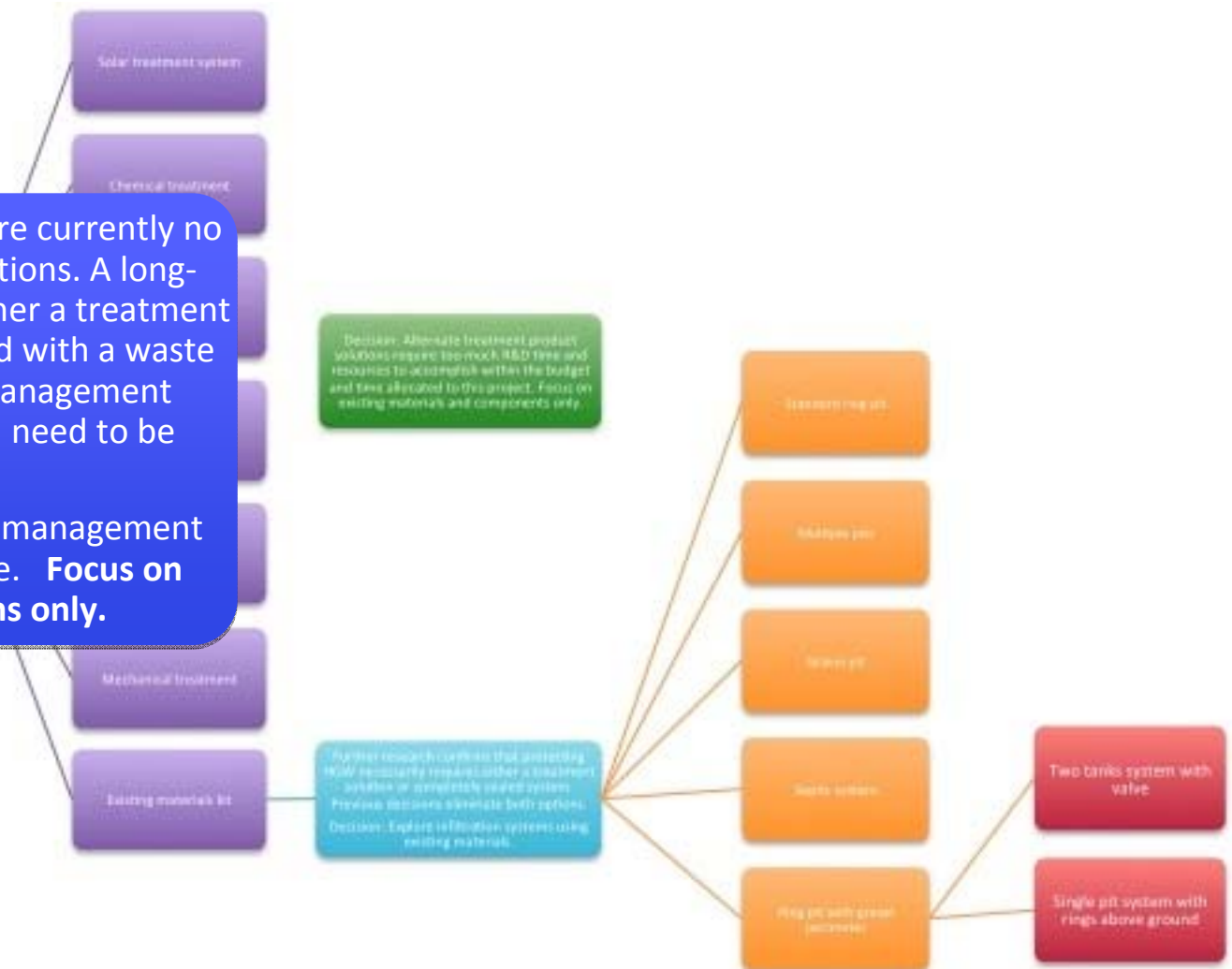


A significant challenge:

It was decided that waste management services would not be explored within the project's scope.

Initial research shows that there are currently no functional, sanitary product solutions. A long-term sanitary solution requires either a treatment system or a sealed system coupled with a waste management system. Waste management services do not exist and would need to be developed.

Decision: For this project, waste management falls outside of the agreed scope. **Focus on designing product solutions only.**



Idea generation

Brainstorming ideas with the guidance of the project brief, key findings, and design principles.

Without a waste management system, designing a low-cost, sanitary product solution is difficult

If we were to adapt the common ring-pit latrines that exist in the market, the pits would need to be sealed to prevent flood/ground water contamination.

However, the common single pit, 3-ring storage system would fill up in less than 3 months if it is sealed. *For a family of four, it would fill in 75 days...*

Without waste management systems, existing latrine pit options will not be feasible.

Calculations:

Pit Volume: 1.2m^3 (1m diameter, 0.5m height, 3 rings)

Avg urine + shit volume per person per day: 2L

Avg volume water used for cleaning per person per day: 2L

Pit Volume/Waste Volume = 300 days...for 1 person → 75 days for 4 people

Initial categories of ideas to address the brief, design principles, and user findings:



Initial product solution ideas:

How might we delay the need to empty?

Ideas for Separation:

User separation (2 separate holes), automatic separation (strainer type), mechanical (mechanical compression), membrane filtration, settling, valve to separate urine and feces, centrifugation

Ideas for Volume reduction:

Encourage floating gardens fed with poo, removable sponge, chemical dehydration, heating, evaporating the urine, self-heating plastic bags

Ideas to Minimize water requirement:

Use ash instead, collect rainwater directly into the water basin to flush the toilet, minimize the pan hole size

Initial product solution ideas:

How might we facilitate the emptying process?

Ideas for Easy to transport:

Tank with wheels, ready to be lifted, partially sealed for emptying, modular tank to facilitate transport, include ash while transfer to eliminate smell, solidify/gel liquid waste, biodegradable, “cleanwaste.com”, all in one store-transport-install

Ideas for Easy to empty:

Plastic bag inside rings, integrated siphon pump, integrated hose to empty

Get to know when it's full:

Transparent line at top of rings, color change when full, tank that stretches and shows when full

Ideas to Facilitate access:

Cola can, strew cap, valve that sucks the contents, simple lid, valve to puncture it, break the cover to open, peeling the container to access contents

Ideas for Shared service:

Community cleaning & maintenance service provider

Initial product solution ideas:

How might we treat waste to eliminate the need to empty?

Animal treatment:

Effective microorganisms, worm composting, anaerobic digestion for electricity, briquettes for cooking, algae-based treatment systems, fish ponds

Chemical treatment:

Raise PH to kill pathogens, raise PH to make NH₃, chemical dealer business, external tank and staff to add chemicals, rice husks, powder to be integrated or distributed

Mechanical treatment:

Vacuum system, underground filtering pit to allow water out but not in, sand filter, bicycle operated vacuum pressurized system, sealed surface flow treatment for HGW, steam sterilization, large “Life Straw” to transform pit into well

Heating:

Indicator thermometer, passive solar treatment, treatment bag with temporal gauge, heating donut pit, above ground solar treatment, electric heated prong in pit

Others:

Large PooPee bags (biodegradable treatment bag)

Initial product solution ideas:

How might we keep products cost down?

Materials:

Tanks made of silicone, motorbike wheels, tree trunks, concrete water jars, tetra-paks

Elevated structures:

Hanging from stilted house, adjustable height, integrated stilts in shelter, hanging shelter from tall structure, triangular structure

Other structural elements:

Folded shelter, tube toilet, toilet without one wall (house acts as wall), thinner walls

Floating pits:

Toilet on boat, tires to float, hot air balloon toilet, inflated toilet

Molds:

Standardized molds

Shared (structural design):

Extended family toilets (modular to increase storage), shared village underground pipe/tank, public toilet for pregnant women, shared tank among 3 households, community shit garden, community biodigester

Initial ideas:

How might we design the marketing?

Service:

Pay per use, toilet credit (like cell phone), toilet subscription – family packages, hourly schedule mobile toilet, zip latrines with credit, 2 stage process – village storage

Stakeholders' involvement:

Sales/promotion by monks, village toilet at school, community toilets at pagoda to improve lives, toilet use 'credit' includes cleaning tax, complementary sales via cell credit, “get sick if your neighbours don't have one”

Masons' offer:

2 different products for masons: DIY vs. Ready-to-install, maps of drinking water sources for masons to install correctly

Tiles and basin:

Giant tiles for immediate installation

Initial ideas:

How might we design the marketing (continued)?

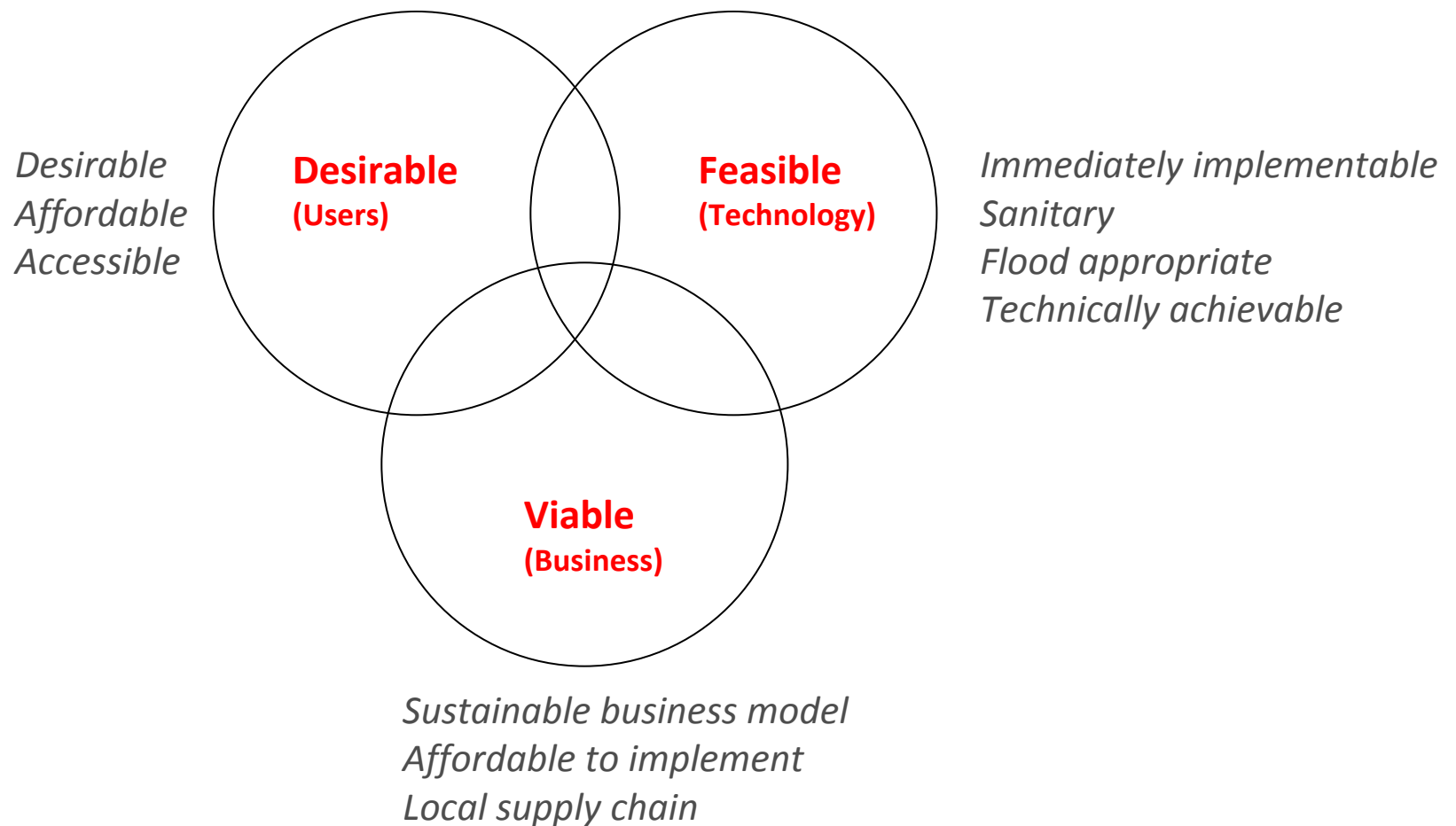
Immediate:

Toilet in a box, install toilet “use now, add pit later”, instant toilet truck delivery and installation, instant toilets at weddings, instant toilets in health centres, toilet as gift

Cross-selling:

Build toilet and house at same time

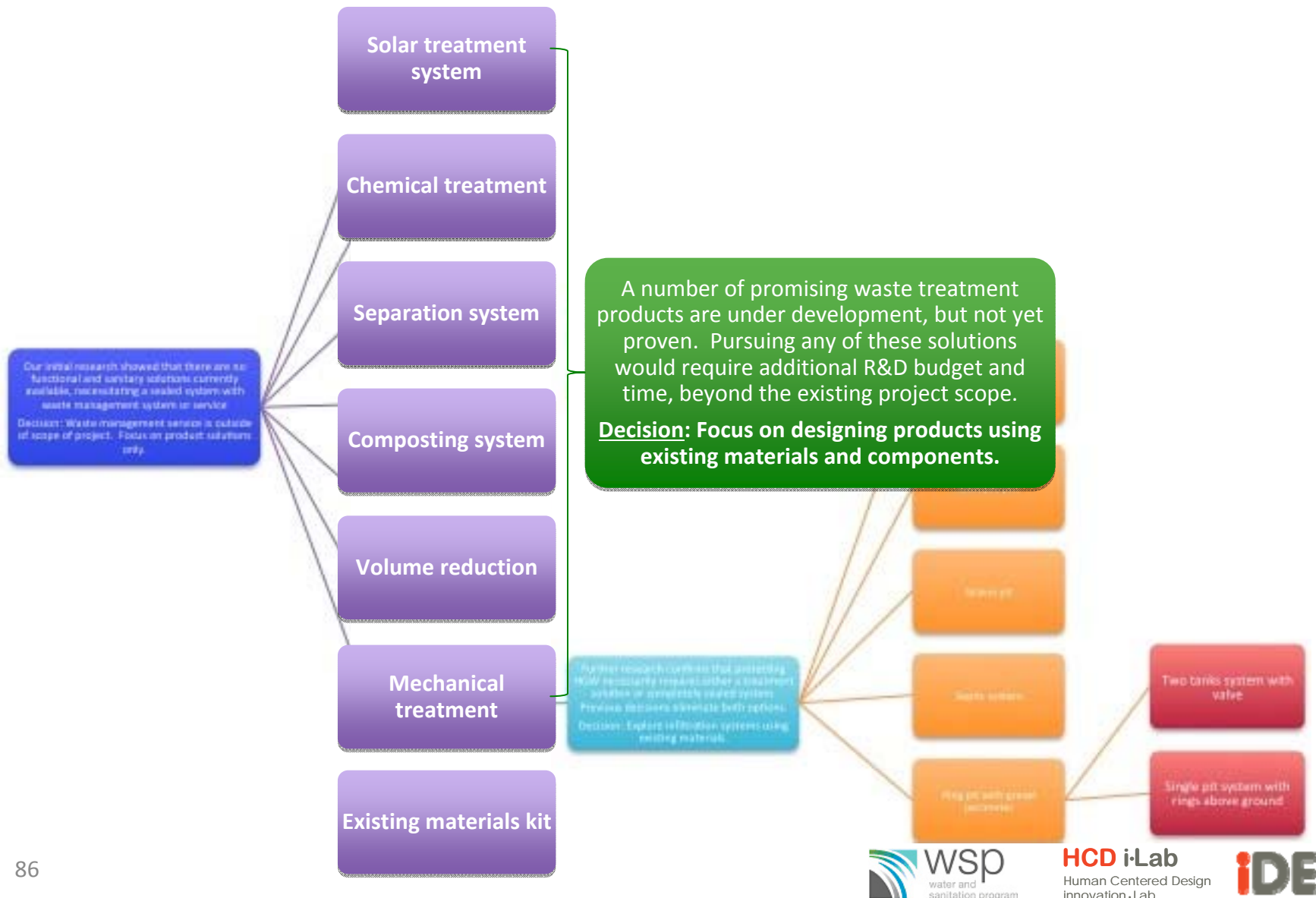
Evaluating the Ideas: Promising concepts are identified using HCD criteria of Desirability, Feasibility, Viability.



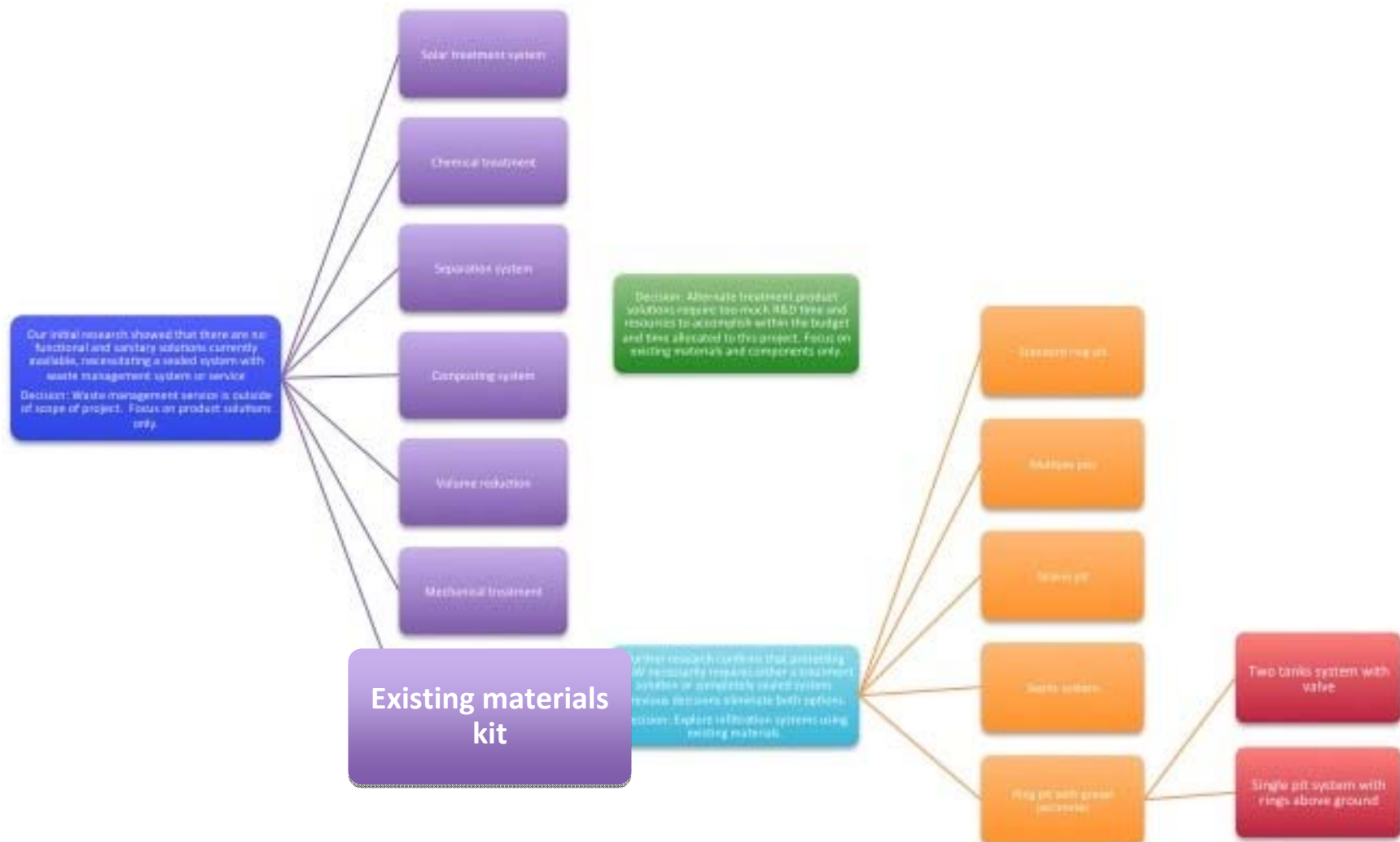
There are a number of promising product concepts currently under development in the international sanitation community.



However, designing waste treatment products requires additional R&D.
Decision #2: Design using existing supply-chain materials.



Design direction: Use existing materials and processes to develop a suitable latrine product.



Develop a “Latrine Kit” that uses existing supply chain actors and materials.

A Latrine Kit solution addresses some **key user insights** and research findings, and is the most **immediately implementable** solution given the resource realities (time/budget available). The Latrine Kit will leverage and build on **existing materials, actors, and dynamics** within local supply chains.

For the longer-term (though outside the scope of this project), we should keep in mind that there are a number of promising technologies and product concepts at different stages of research and development; but they have yet to be proven. Almost all of these alternative concepts will require significant additional R&D resources to implement successfully.

What's the user insight behind the Latrine Kit?

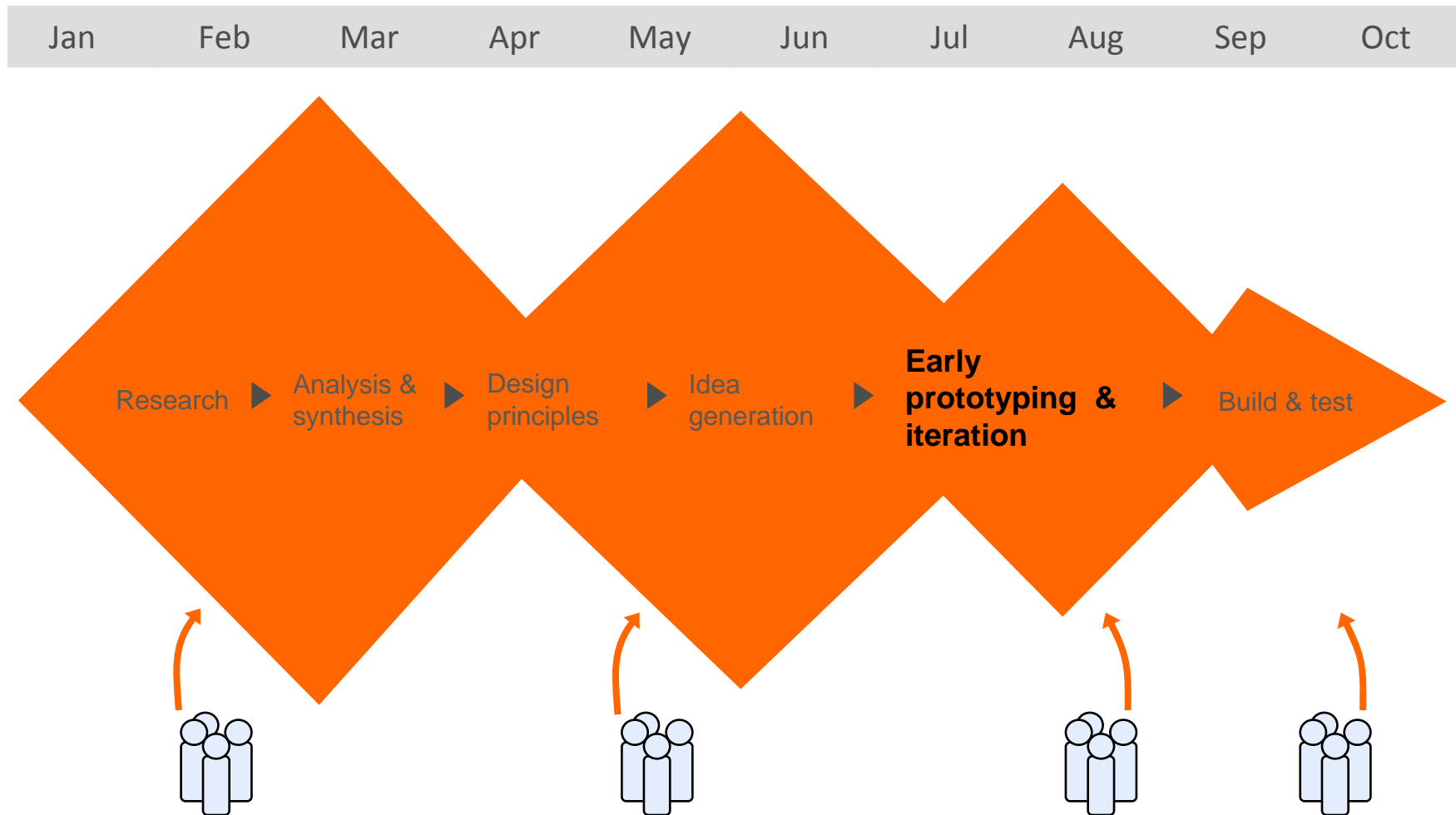
The latrine kit **eliminates key purchase-barriers** identified in the purchase-to-installation process. Ease of purchase, ease of installation, and confidence in getting 'the best price' are critical user needs for toilet adoption. Purchase barriers include:

- Materials difficult to transport due to poor roads and distance from villages to markets. Some villages are inaccessible by truck.
- Lack of available masons.
- Of the available masons, few have latrine construction experience.
- Anxiety in purchasing the right amount of materials – users often under/overshoot their purchase quantities.
- A need to visit multiple retailers, often in several markets, to purchase all needed materials.

...However, our next challenge:

*A **technical solution** that functions properly and is sanitary in challenging environment areas still **needs to be developed**.*

HCD Process: Early prototyping & iteration

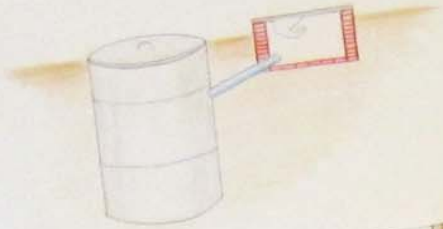


Early prototyping and iteration

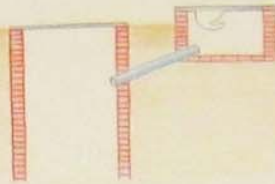
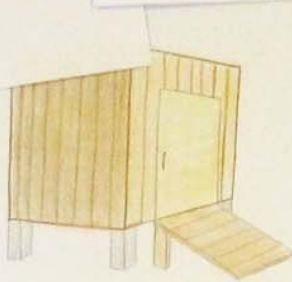
Gathering user feedback on concepts early and often, prior to final-build and testing.

Maximize user input and critical refinements to the design, while minimizing investment in costly prototypes.

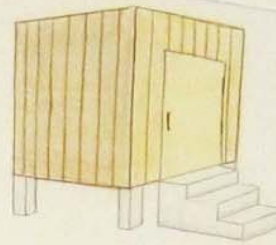
Low resolution prototyping



សិទ្ធិបណ្តាញ
បង្កើន ឥរិយាបថ
Sanitary toilets

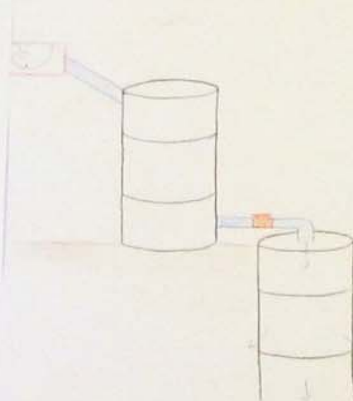


សិទ្ធិបណ្តាញ
បង្កើន ឥរិយាបថ
special version for flooded areas

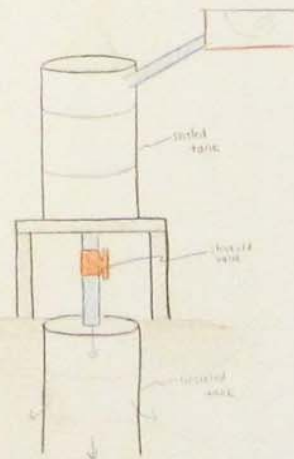
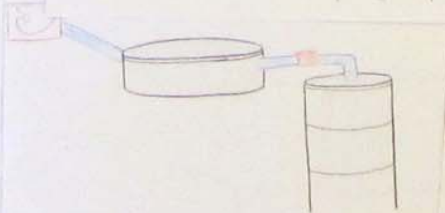


សិទ្ធិបណ្តាញ
បង្កើន ឥរិយាបថ
specialized version for special
toilets

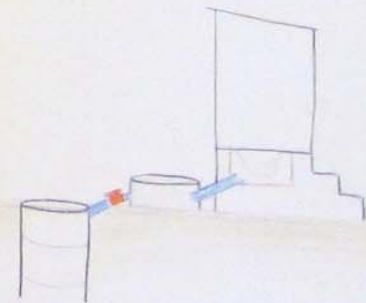
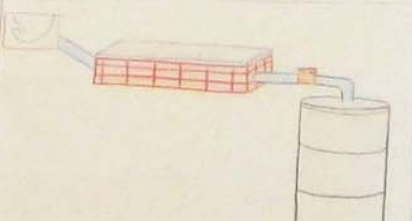
សិទ្ធិបណ្តាញ ការ
សាងសង់
សេ ឥរិយាបថ
Special advice



សិទ្ធិបណ្តាញ = ឥរិយាបថ
បង្កើន ឥរិយាបថ
Technical construction



សិទ្ធិបណ្តាញ
បង្កើន ឥរិយាបថ
certified expert version

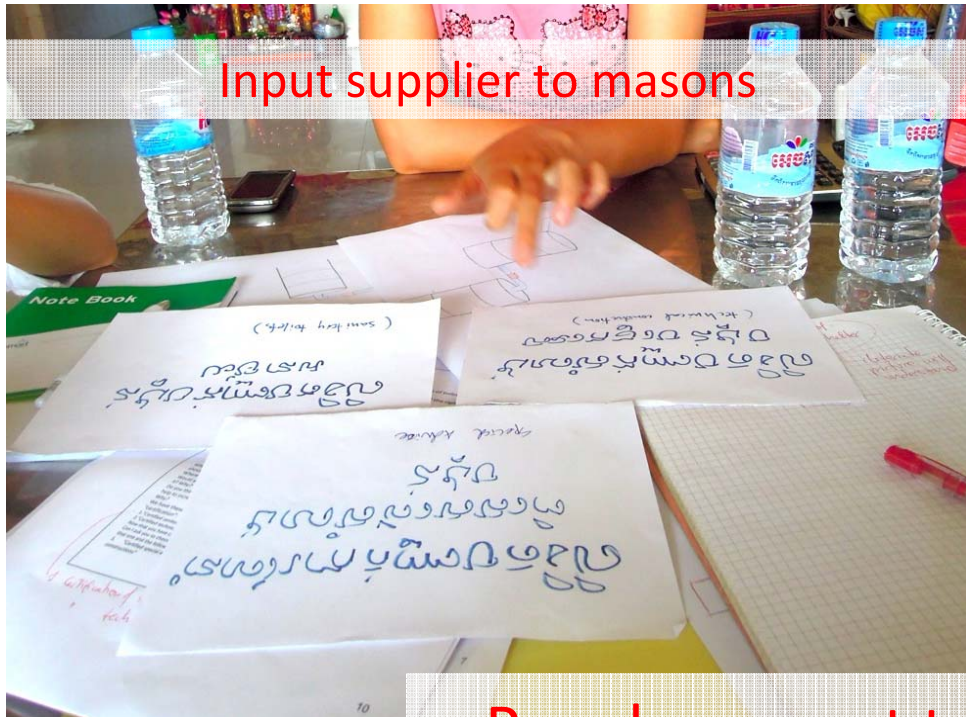


Low resolution prototyping

The goal is to **understand user perspectives and interest** in possible toilet constructions and marketing strategies. We used drawings and slogans to discuss concepts with masons, households and input suppliers.

We investigated:

- Brick tank vs. ring pit
- Ring sizes and geometries
- Stairs vs. ramp for elevated designs
- Various messages to be used in sales/marketing
- Local knowledge about HGW
- Mason and retailer certifications



Input supplier to masons



Households



People we met to gather feedback



Masons

Prototyping challenges with HGW areas:

1. Inability to identify HGW areas:

Through prototyping user research, we learned that households do not know if they have HGW. No accurate data exists to identify ground-water levels or its seasonal changes (HGW can be seasonal).

2. Technology constraints of HGW Design:

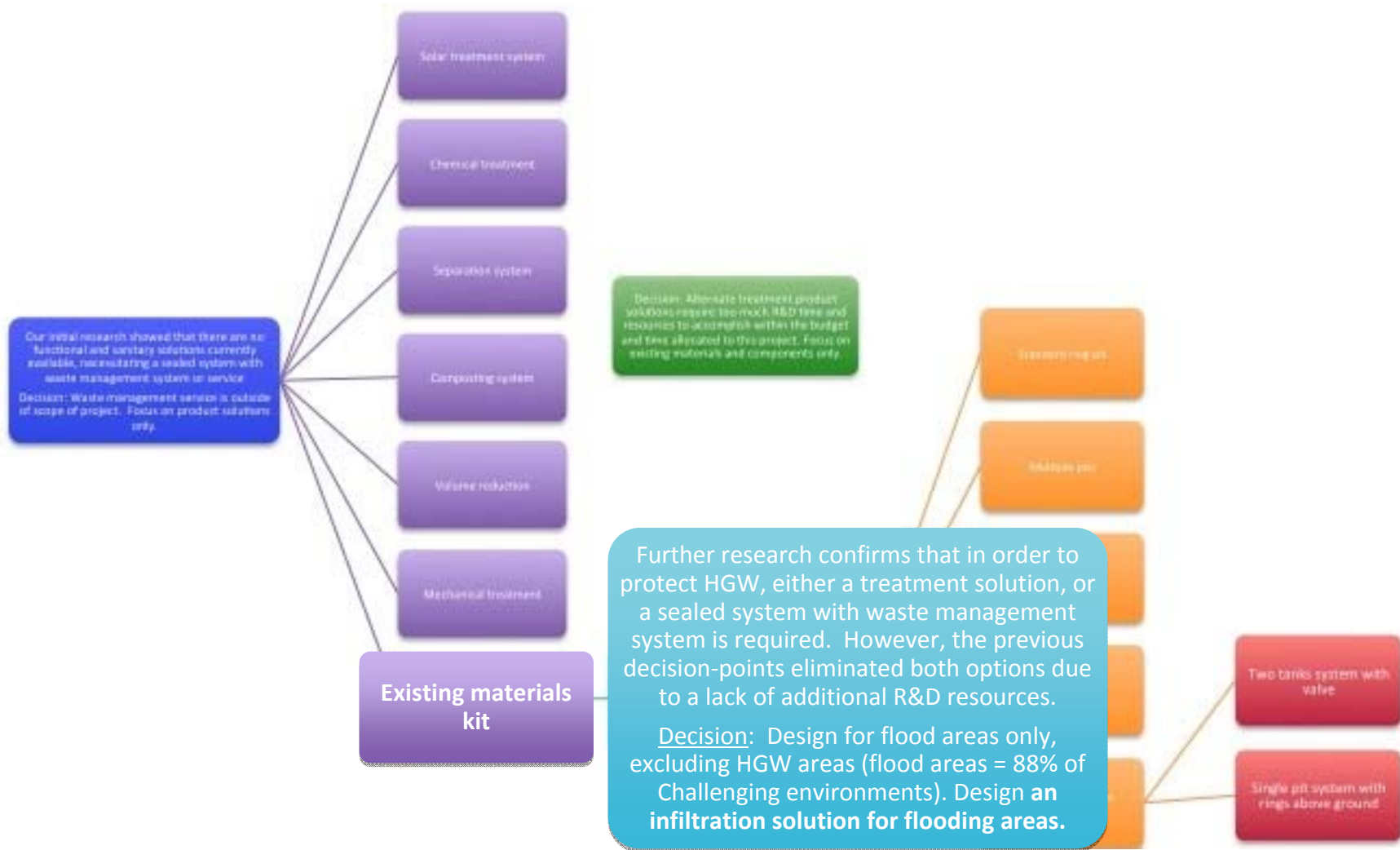
A product that protects HGW must be either:

- A sealed system to isolate waste, with waste management system to regularly empty, or,
- A product that treats the waste to avoid emptying

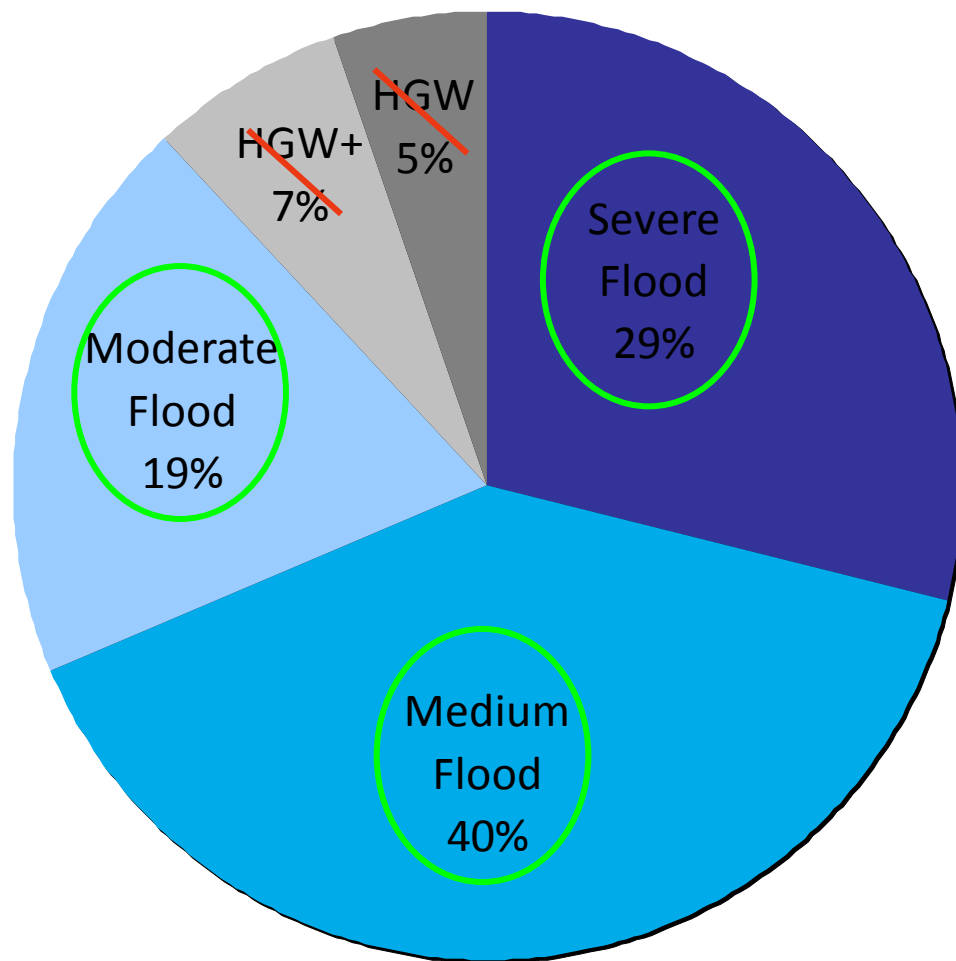
...but both solutions require significant additional R&D resources.

Designing with existing supply-chain materials and actors makes a sanitary HGW solution impossible.

Decision #3: Focus on designing infiltration systems for flood areas.



Designing for flood areas will address 88% of Challenging Environments users. HGW represents only 12% of CE areas.



Severe Flood:

Every day or months at a time

Medium Flood:

Weeks at a time every year

Moderate flood:

Week or less annually

HGW+:

Any of the above with HGW

HGW:

HGW only, no flood

Medium-Resolution Prototyping: Technical product design

We learned from and gathered design input from a wide and deep array of topic experts:

Live & Learn | www.livelearn.org

Aruna Technologies | arunatechnology.com

Resource Development International | www.rdic.org

Design Technology Workshop | www.dtw.org

Apsara Authority | autoriteapsara.org

Nature Healing Nature | naturehealingnature.org

Massachusetts Institute of Technology | www.mit.edu

Stanford University | www.stanford.edu

IDEO | www.ideo.com

FBA & Agriculture programs at iDE | www.ide-cambodia.org/fba

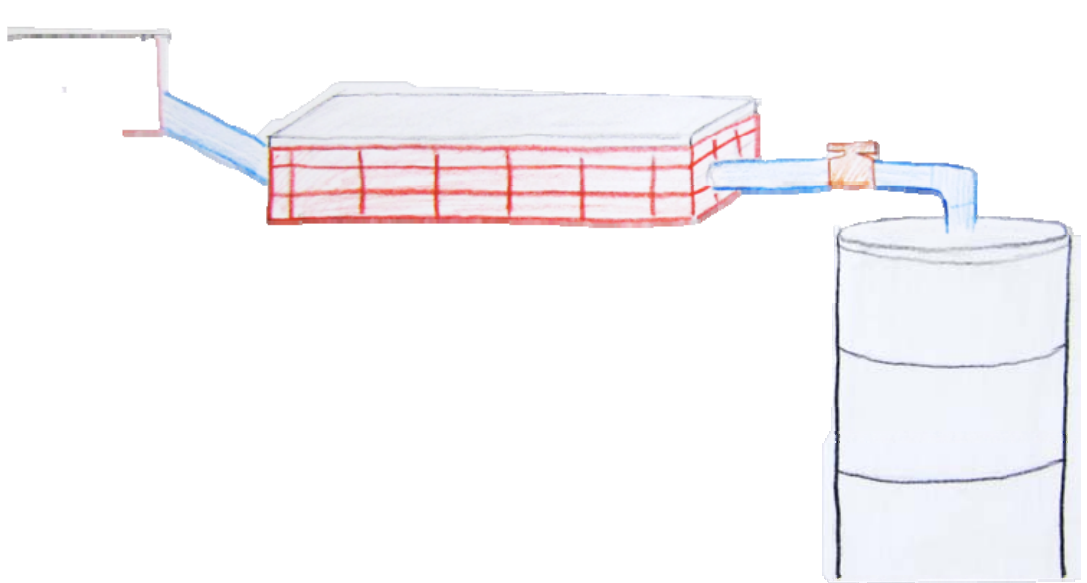
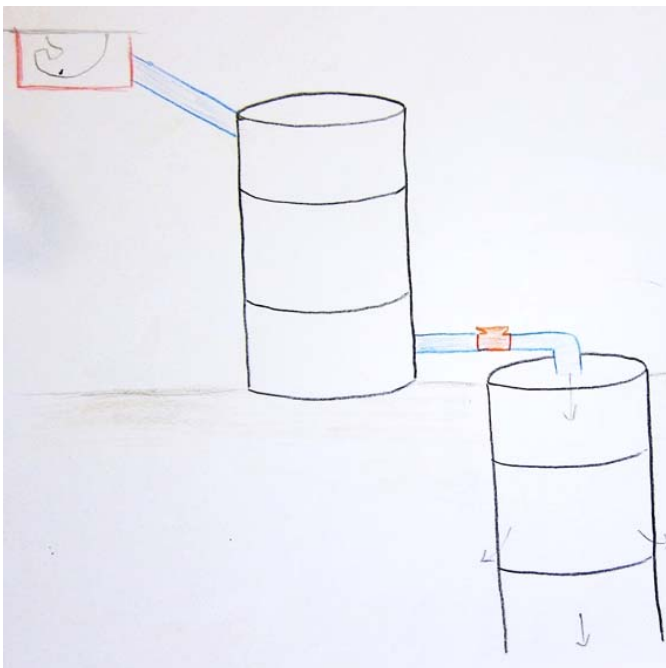
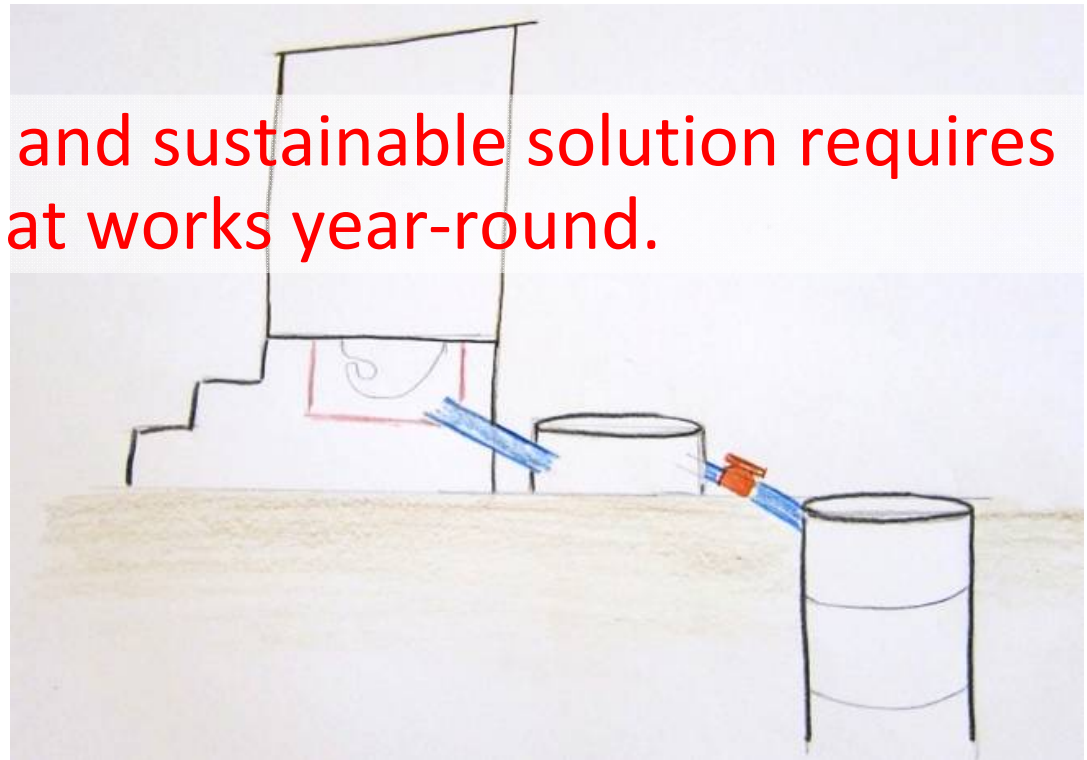
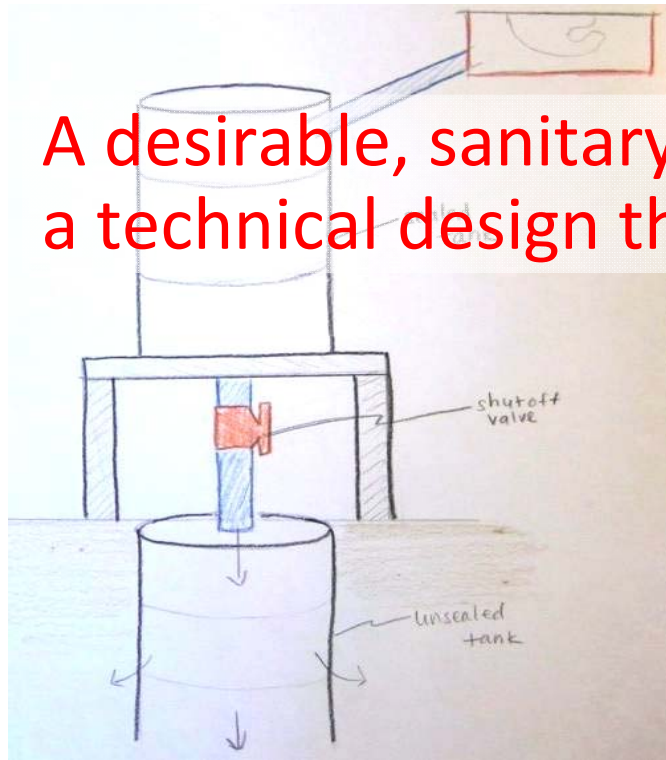
iDE Bangladesh | www.ide-bangladesh.org

We learned from and gathered design input from a wide and deep array of topic experts:

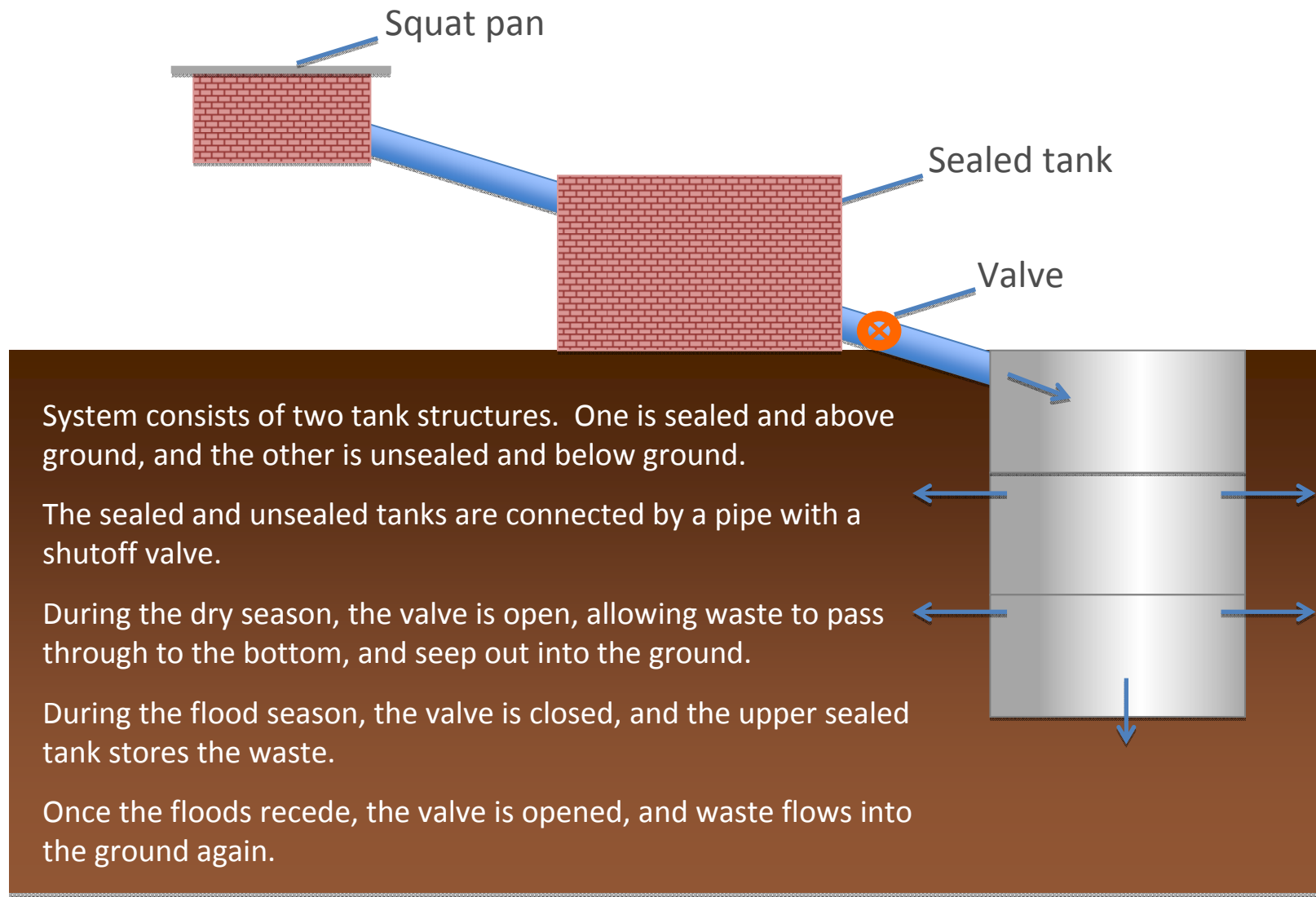
Additional individual topic experts include:

- Internationally based sanitation specialists
- Locally based sanitation specialists
- Internationally based water treatment engineers
- Locally based water treatment engineers
- Internationally based hydro-geologists
- Locally based hydro-geologists

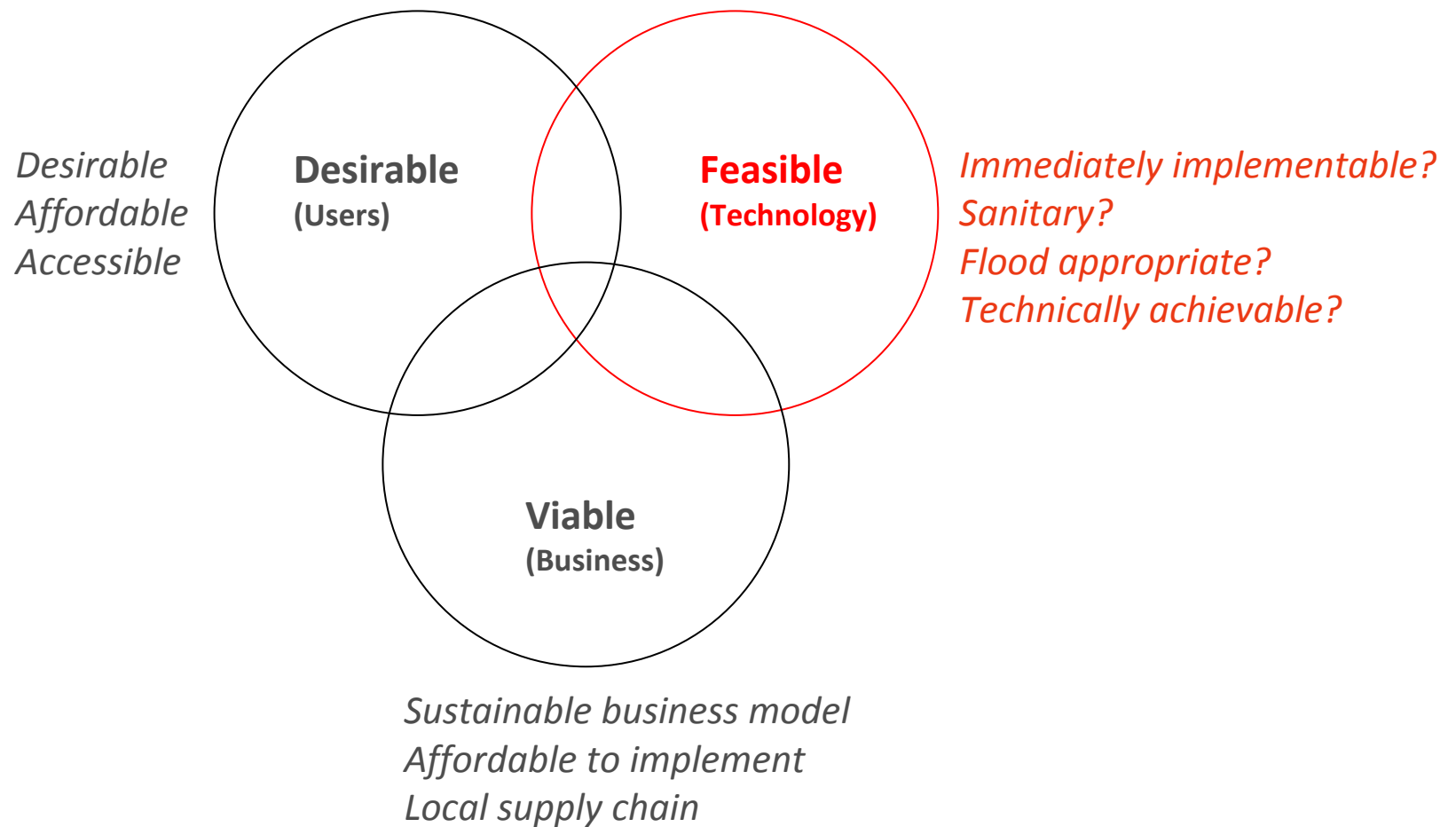
A desirable, sanitary and sustainable solution requires a technical design that works year-round.



Proposed technical design concept: 2 tank system



Evaluating technical **feasibility** through HCD criteria



Key technical considerations for product design

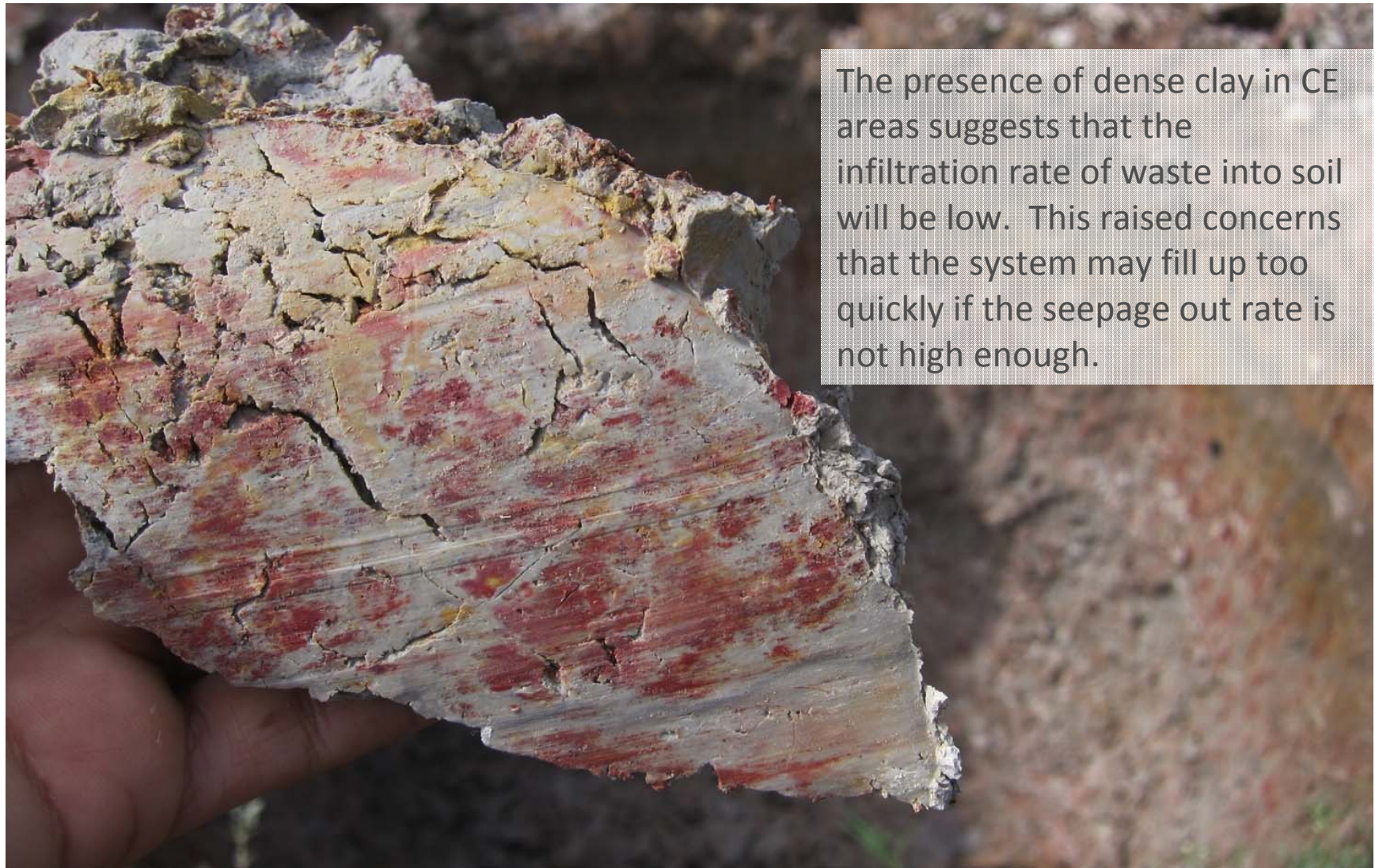
An analysis of the proposed design raised questions around some important technical unknowns:

1. Seepage out rate vs. waste input rate and the below-ground structure
2. Sludge accumulation and the above-ground structure
3. Storage capacity of the above-ground structure

Key technical considerations for product design

1. Seepage out rate vs. waste input rate and the below-ground structure
2. Sludge accumulation and the above-ground structure
3. Storage capacity of the above-ground structure

Dense clay means low soil infiltration.
Pits may fill too quickly.

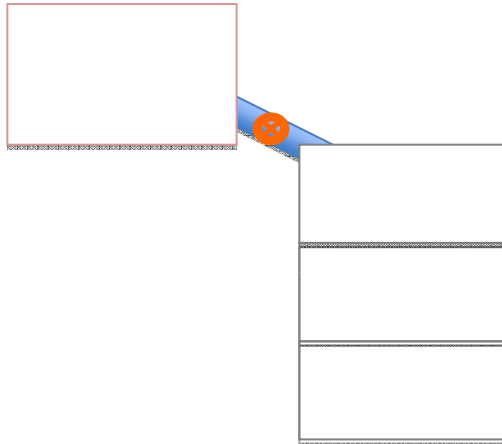


The presence of dense clay in CE areas suggests that the infiltration rate of waste into soil will be low. This raised concerns that the system may fill up too quickly if the seepage out rate is not high enough.

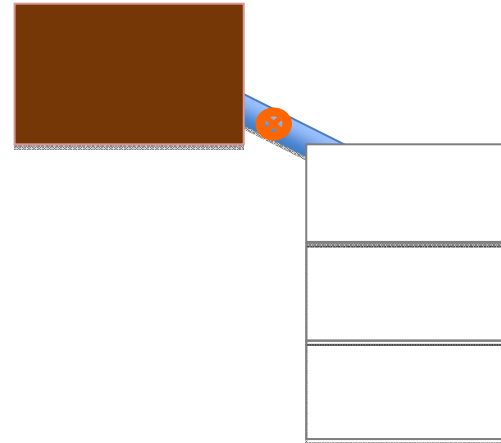
Question: Will waste-input rate be greater than output rate?

Assuming both tanks are of equal volume...

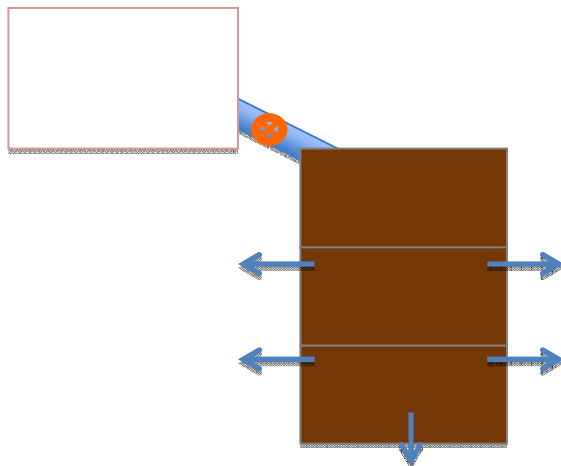
1. Upon installation, both tanks are empty.



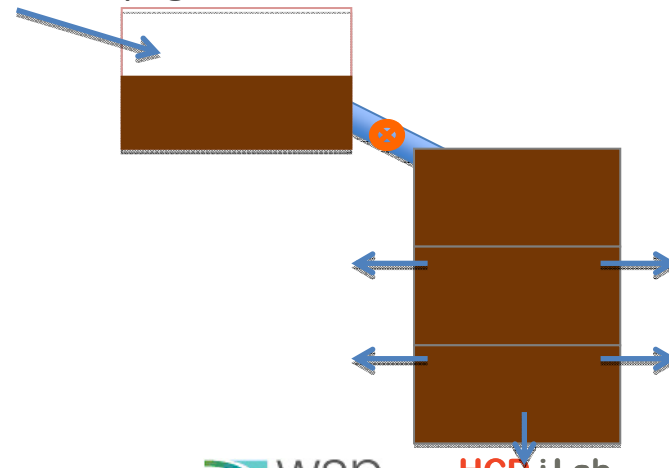
2. Wet season: valve is shut, top tank fills.



3. Dry season: valve open, contents flow down. Bottom tank is now full.



4. Will waste input rate be greater than seepage out?



Question: Will waste-input rate be greater than output rate?

Technical consideration: If the waste-input rate is greater than the output (seepage) rate, the above-ground storage will begin to fill. Once the flood season returns, and the valve is shut, the available waste storage area for the season will be reduced.

Next Step: Can we calculate the seepage-out (infiltration) rate to determine the extent of the potential problem?

Calculating the infiltration (seepage-out) rate:

Darcy's Law: Volume flow rate is a function of permeability, hydraulic gradient, and cross-sectional area.

$$q = v * A$$

$$v = k * i$$

q = volume flow rate

v = flow velocity

A = cross-sectional area

k = coefficient of permeability

i = hydraulic gradient

Unknowns:

- Soil permeability (**k**)
- Hydraulic gradient (**i**)

There is a range of values for **k** based on soil type. However, these potential values range by several orders of magnitude, making any calculations of little use.

There is no data for soil permeability in Cambodia (per topic experts: RDI, Live & Learn, Nature Healing Nature, Aruna). The coefficient of permeability must be determined by onsite testing. The hydraulic must also be measured on site.

Range of values for k (m/s)	
10 ² 10 1 10 ⁻¹	Clean gravels
10 ⁻² 10 ⁻³ 10 ⁻⁴	Clean sands Gravel-sand mixtures
10 ⁻⁵ 10 ⁻⁶	Very fine sands Silt and silty clays
10 ⁻⁷ 10 ⁻⁸ 10 ⁻⁹	Clay silts (>20% clay) unfissured clay

Calculating the infiltration rate:

Darcy's Law: Volume flow rate is a function of permeability, hydraulic gradient, and cross-sectional area.

$$q = A * k * i$$

Calculation assumptions:

A = 0.785m² (concrete ring 1m diameter, assumes seepage out of bottom. However, in reality, once sludge accumulates at the bottom, seepage will only occur at the seams between the stacked rings)

k = ranges from 10⁻⁹ to 10⁻⁵ m/s

i = .01

Seepage out: ranges from 6.8x10⁻⁴ – 6.8 L/day

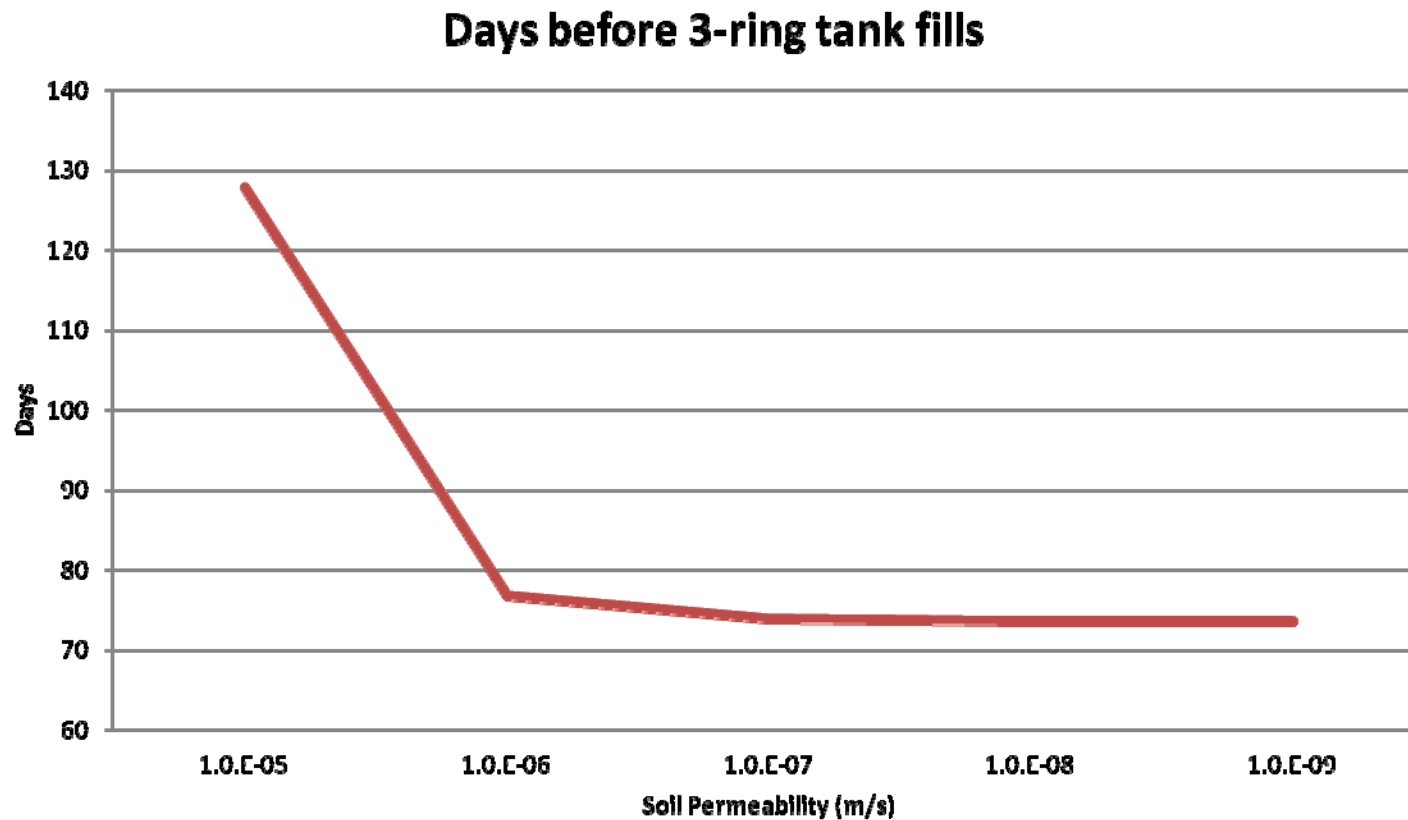
Waste input: 12 L/day...family of 4 producing 2L urine and shit + 1 L cleaning/flushing water per person per day

Range of values for k (m/s)

10 ²	Clean gravels
10	
1	
10 ⁻¹	Clean sands Gravel-sand mixtures
10 ⁻²	
10 ⁻³	
10 ⁻⁴	
10 ⁻⁵	Very fine sands
10 ⁻⁶	Silts and silty clays
10 ⁻⁷	Clay silts (>20% clay) unfissured clay
10 ⁻⁸	
10 ⁻⁹	

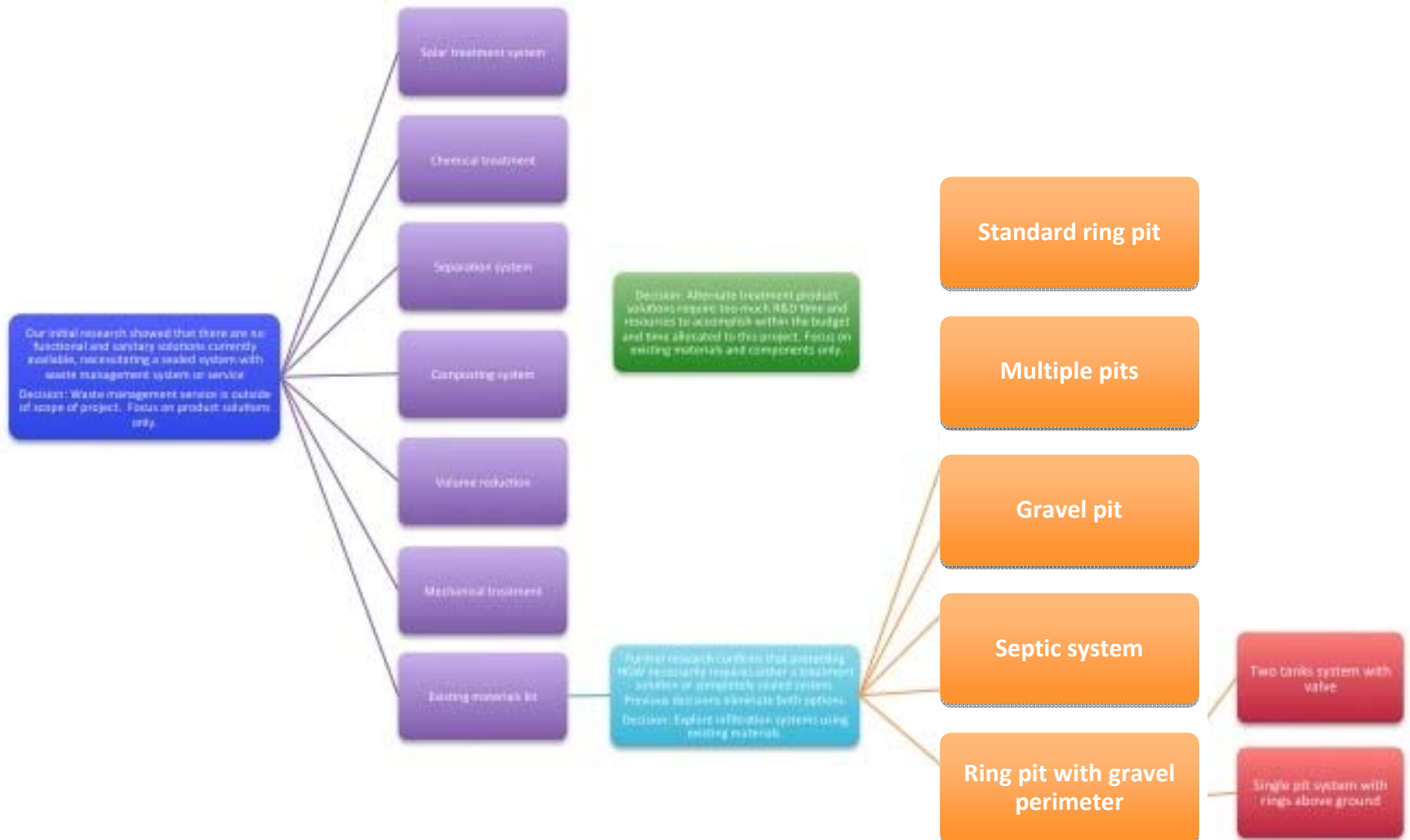
Even in the best case scenario, input rate > output rate...

Infiltration rate is too slow. Even in the best case scenario for soil permeability, the latrine will fill in 128 days.



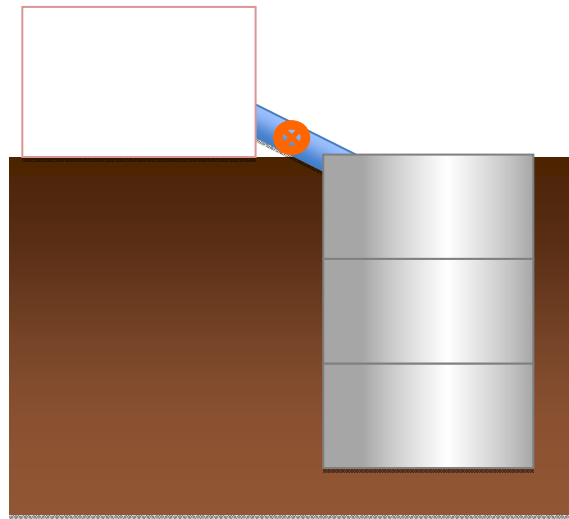
Latrine will fill in 4 months in the best case. With less permeable soil, it will fill in 80 days. With no available waste management system, the product itself must facilitate infiltration and delay the need to empty.

We explored a number of infiltration systems that can increase the infiltration rate.



Exploring underground pit options:

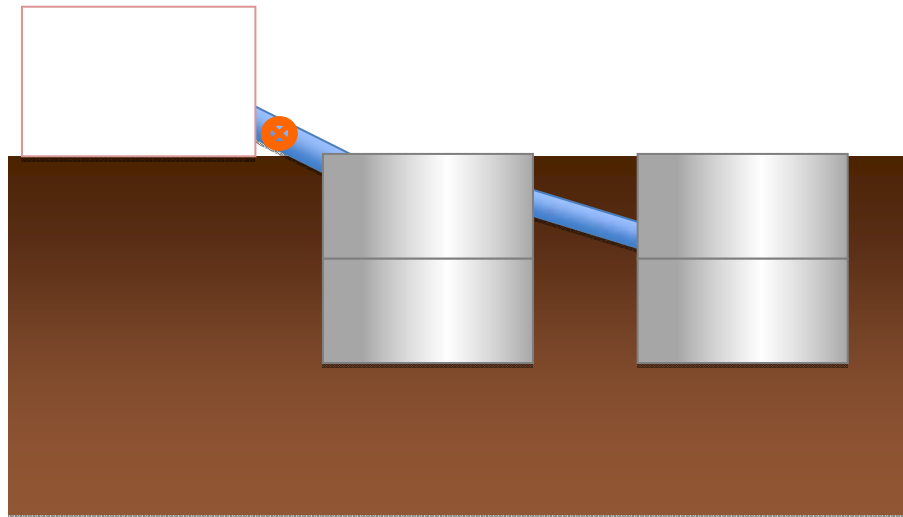
1. Standard ring pit



Although this is the most common underground construction, an alternative that increases the seepage out rate is necessary.

Exploring underground pit options:

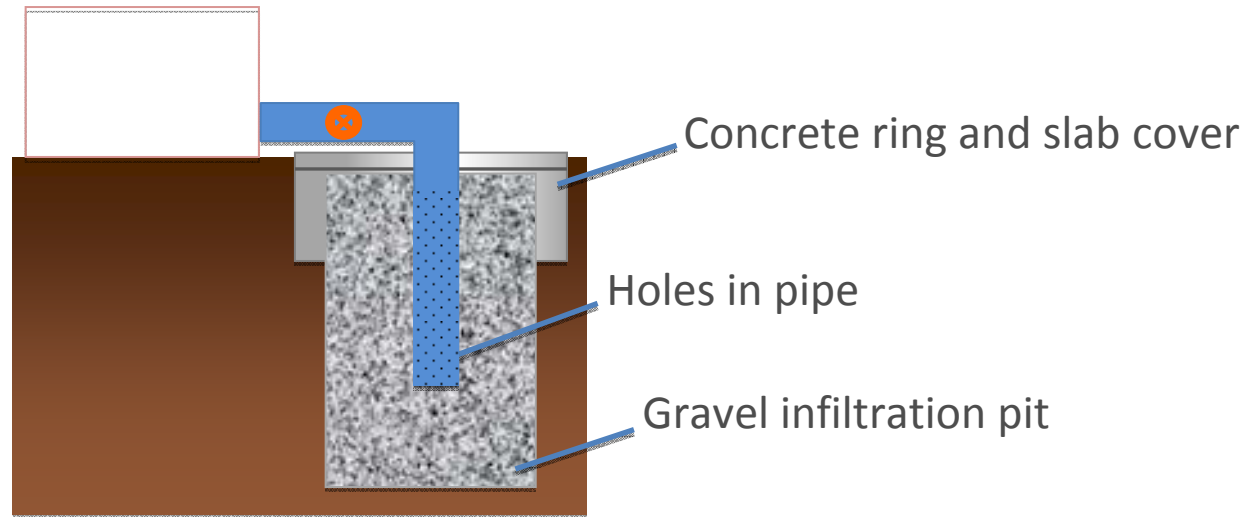
2. *Two Pit System*



This construction would increase the surface area for infiltration, since only one of the pits (the first) will fill with sludge. However, this extra surface area is not enough to offset the input rate.

Exploring underground pit options:

3. *Gravel infiltration pit*



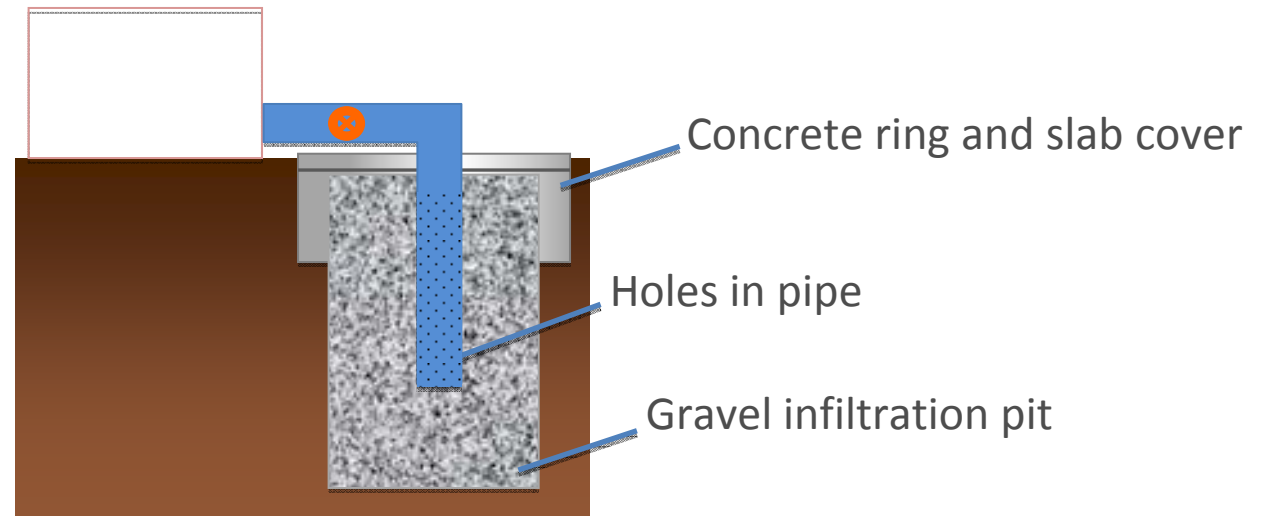
The team of hydrologist and sanitation advisors suggested replacing concrete rings with a gravel infiltration pit to increase infiltration. The cost of a gravel pit is comparable to a concrete ring pit, and is advantageous for transport and installation.

This raised design-related questions:

- *What gravel size?*
- *Are any other linings needed?*
- *Will the pit clog with solids?*
- *How large a pit?* Currently assuming same size as 3-ring pit.

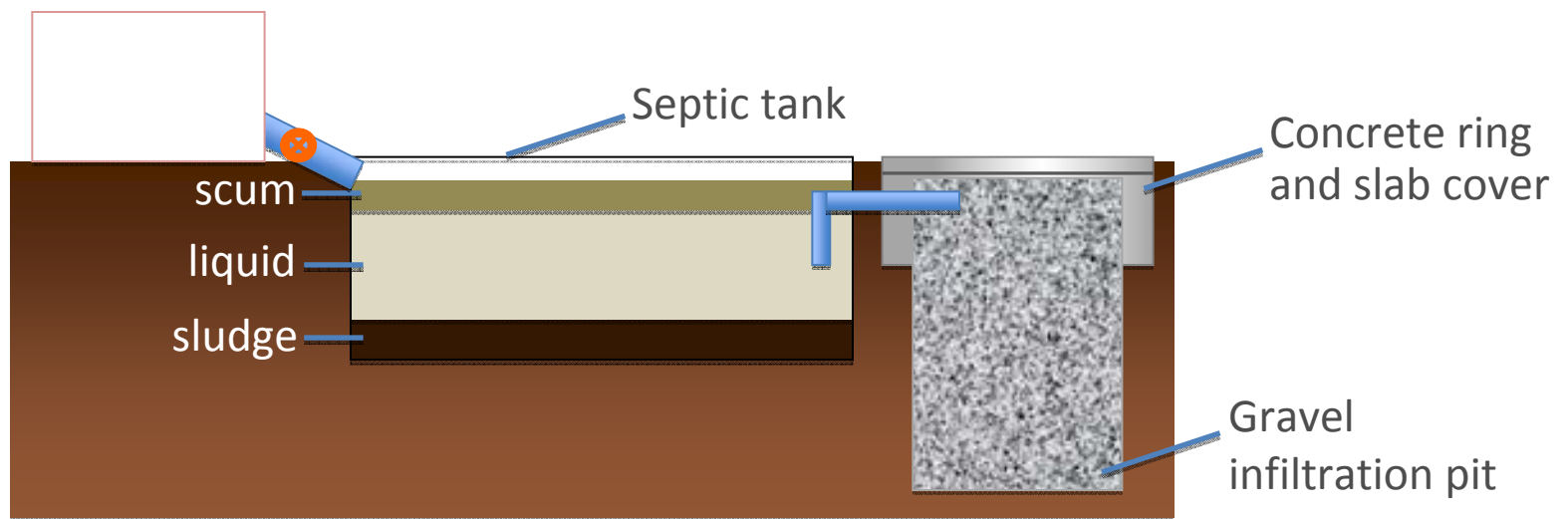
Exploring underground pit options:

4. *Gravel infiltration pit (cont'd)*



Upon further technical investigation, this alternative proves to be unfeasible. A settling stage is necessary to allow solids to settle and break down (i.e. a septic tank) prior to entering a gravel pit. If waste flows directly into the gravel pit, it will quickly become clogged.

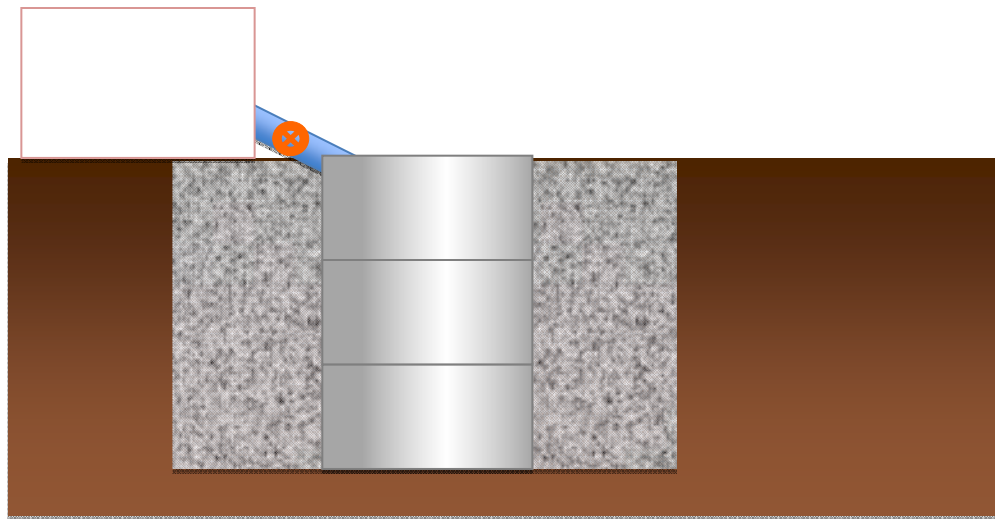
Exploring underground pit options: 5. *Gravel infiltration pit + Septic tank*



Adding a septic tank that outflows into the gravel pit could be a feasible solution. However, there are design challenges associated with a septic tank, including: size, construction, seepage field.

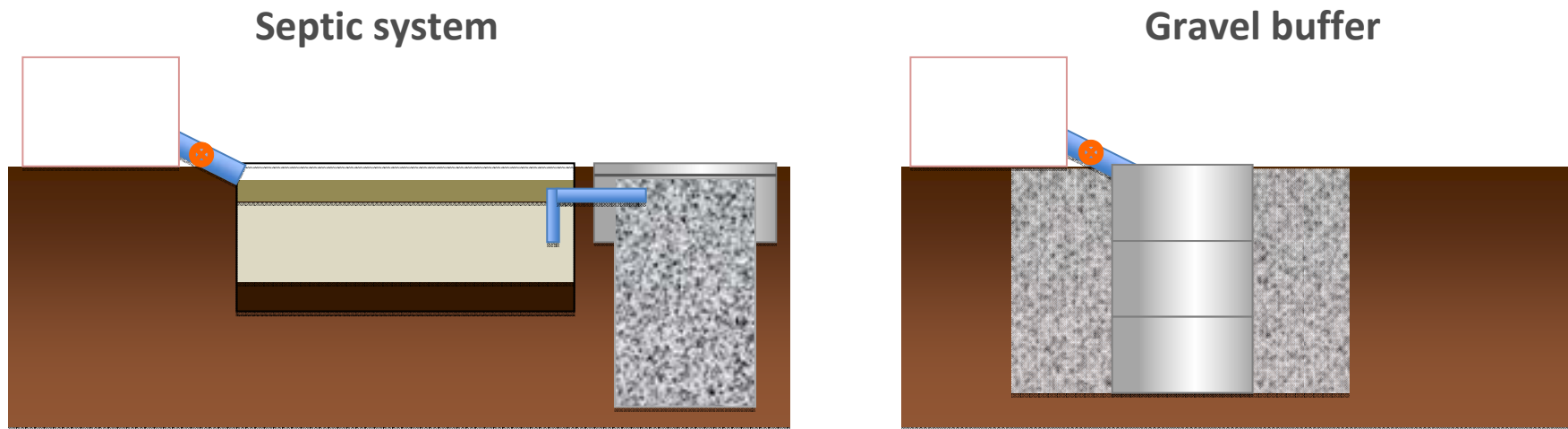
Exploring underground pit options:

6. Standard ring pit surrounded by gravel/sand mixture



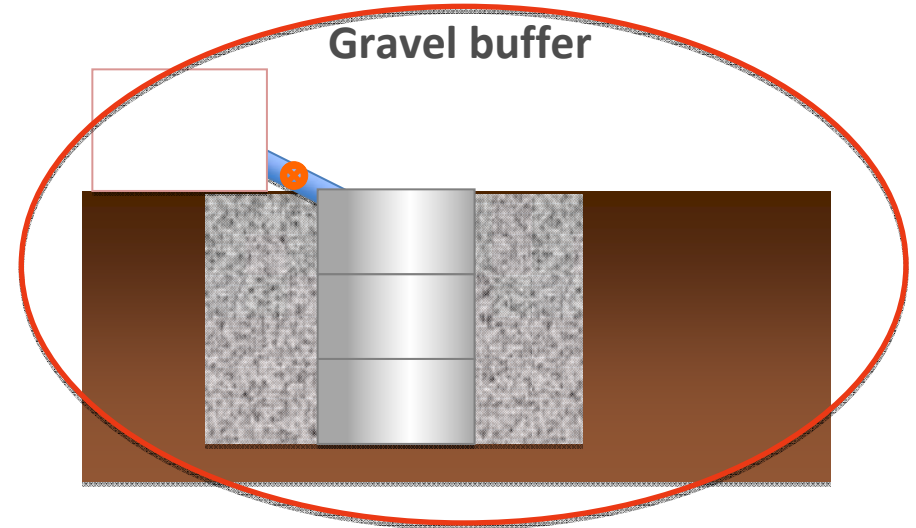
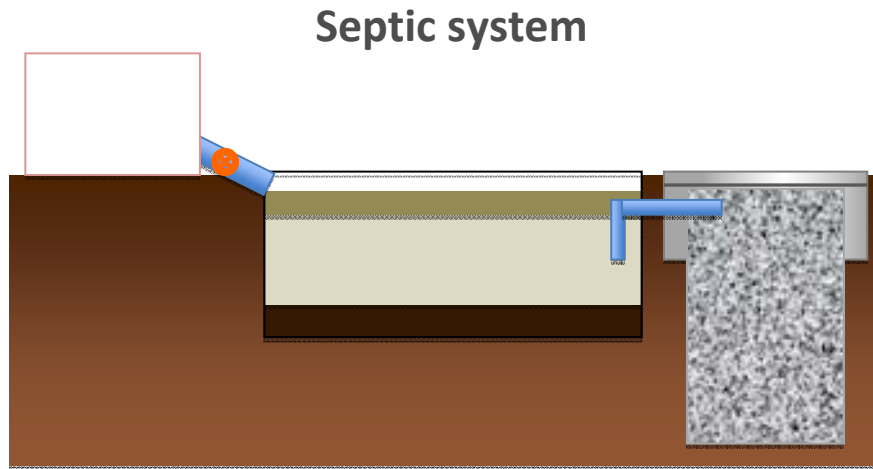
An alternative solution is to surround the concrete ring with gravel. Gravel allows faster infiltration out of the tank (vs. clay) due to higher permeability. Once liquid waste seeps into the gravel, it has a larger surface area (vs. rings alone) through which to seep into the soil.

Evaluating underground pit options: *There are two feasible options.*



Though further testing and optimization would be necessary, we have identified two potentially feasible latrine designs for flooding regions.

Evaluating Underground pit options: *The direction forward*

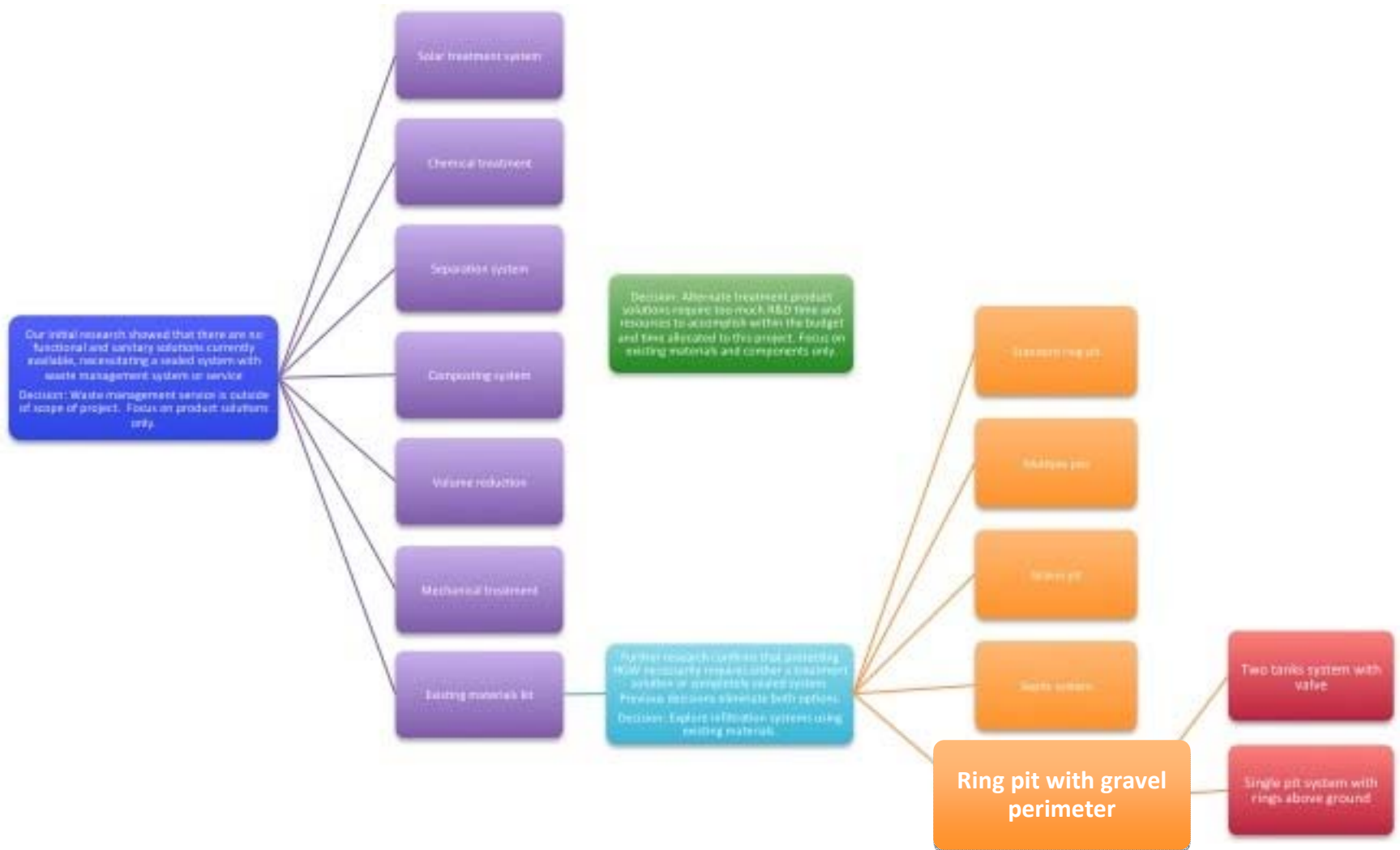


Based on cost research, a septic system design proves to be unviable. The lowest cost (plastic) septic tanks available in the market cost \$180 per piece.*

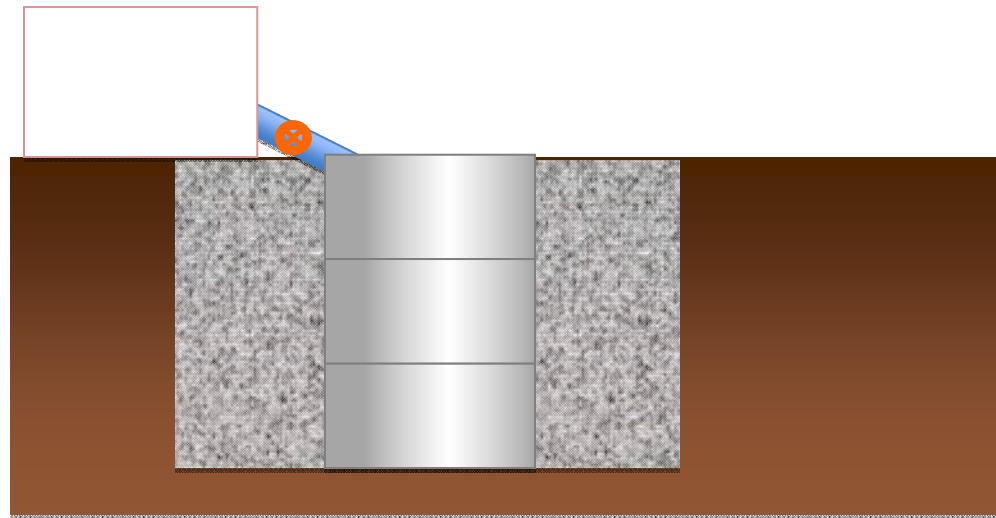
Septic systems are technically more complex to construct (vs. gravel buffer). User insights regarding mason skill-level raises concerns of incorrect installation.

Next Step: Narrow the direction forward to a product design with a gravel buffer surrounding a concrete ring pit. Commence high-resolution prototyping.

Decision #4: Based on feasibility and viability criteria, design a product solution using a ring pit with gravel perimeter.



Technical Design Consideration: *How much gravel is necessary for proper infiltration?*



We know what the volume flow rate (q) should be based on the waste input rate. We can then solve $q = A \cdot k \cdot i$ for A . A is the surface area necessary to achieve the given flow rate. Once we know A , we can know the amount of gravel required to achieve the needed surface area.

How much gravel is necessary for proper infiltration?

Darcy's Law: Volume flow rate is a function of permeability, hydraulic gradient, and cross-sectional area.

$$q = v * A$$

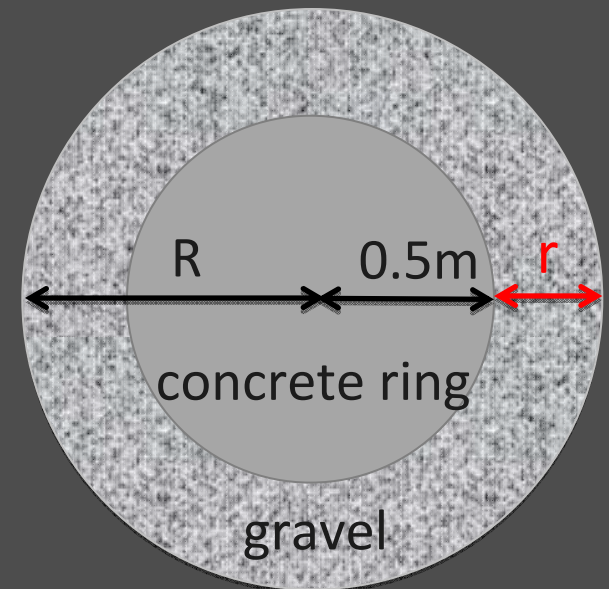
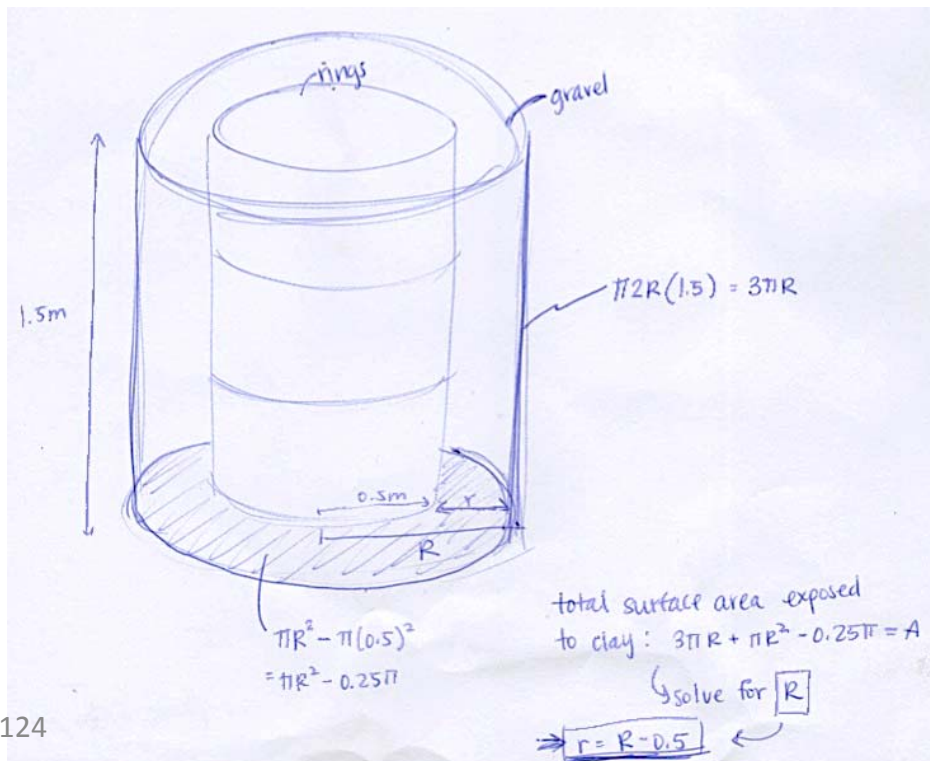
$$v = k * i$$

$$\rightarrow A = q / (k * i)$$

Knowing A, we can solve for r:

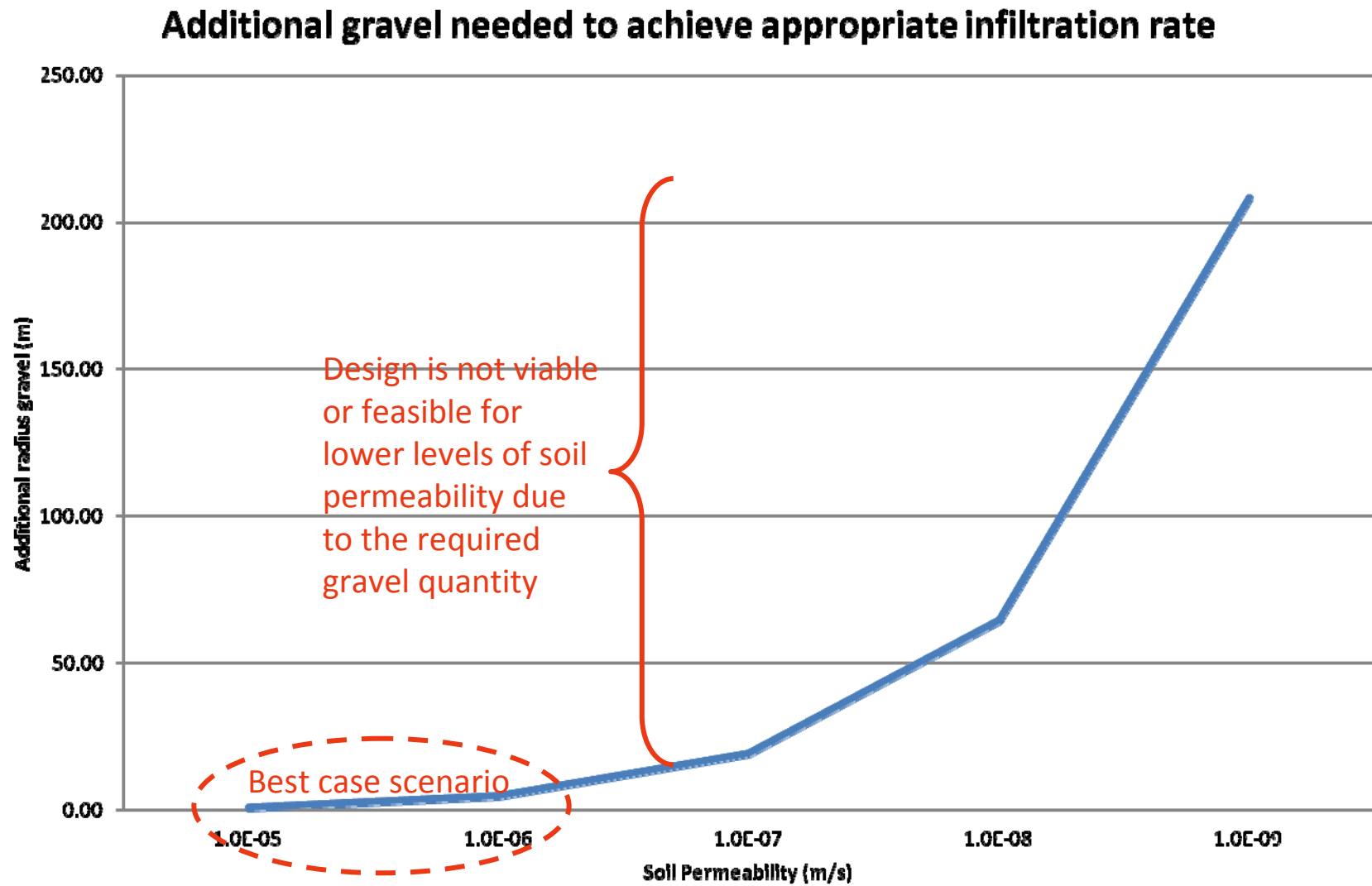
$$A = \pi R^2 + 3 \pi R - 0.25 \pi$$

$$r = R - 0.5$$

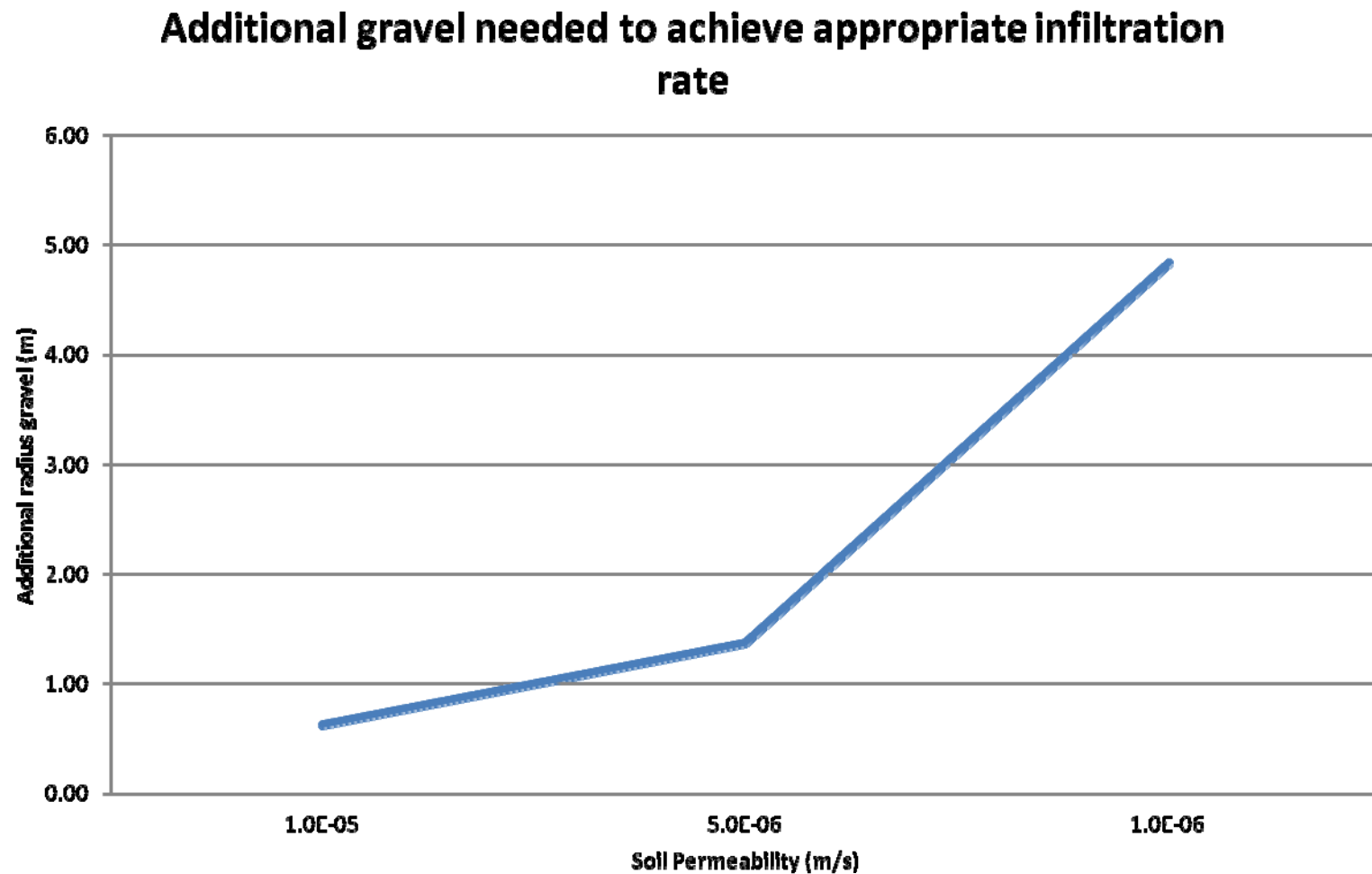


Note: This calculates a best case scenario. It assumes the gravel does not block surface area at the gravel/clay interface (as if the gravel area is empty, and seepage occurs through the entire surface of the cylinder).

How much gravel is necessary for proper infiltration?



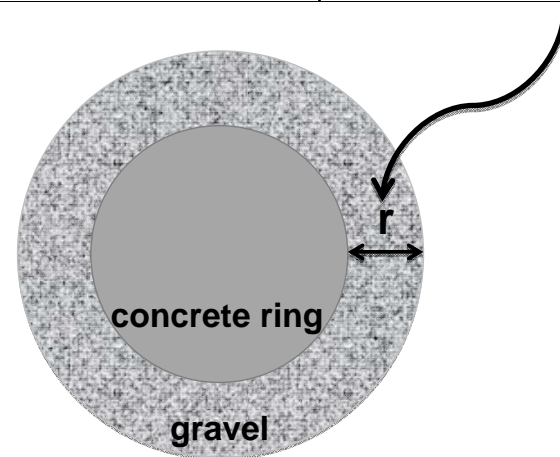
In the best case scenario (higher soil permeability), 1-5 metres of additional gravel radius is needed for proper infiltration.



Shown another way: *How much gravel is necessary for proper infiltration?*

The amount of gravel needed varies with soil permeability.
Lower permeability requires more gravel.

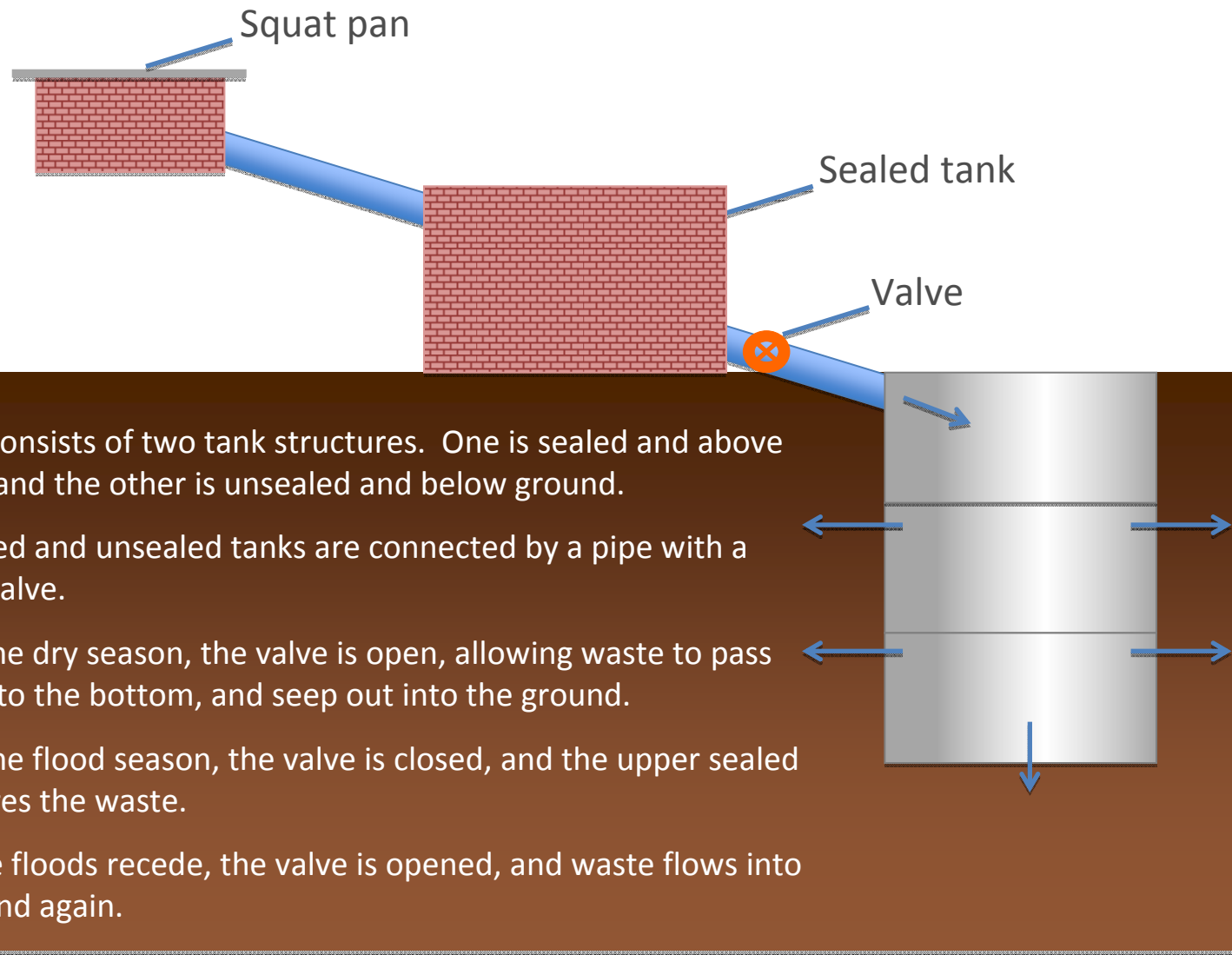
k Value (m/s)	Surface area needed (m ²)	Volume gravel (m ³)	Extra radius (m)
1.0E-05	13.89	3.23	0.63
1.0E-06	138.89	88.61	4.83
1.0E-07	1388.89	1204.30	19.09
1.0E-08	13888.89	13276.19	64.51
1.0E-09	138888.89	136921.31	208.27



Key technical considerations for product design

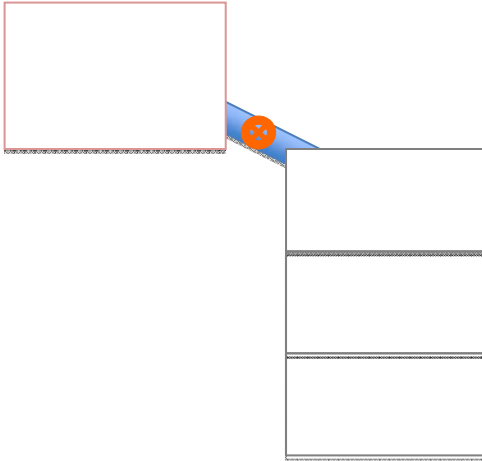
1. Seepage out rate vs. waste input rate and the below-ground structure
2. Sludge accumulation and the above-ground structure
3. Storage capacity of the above-ground structure

Technical design concept: 2 tank system

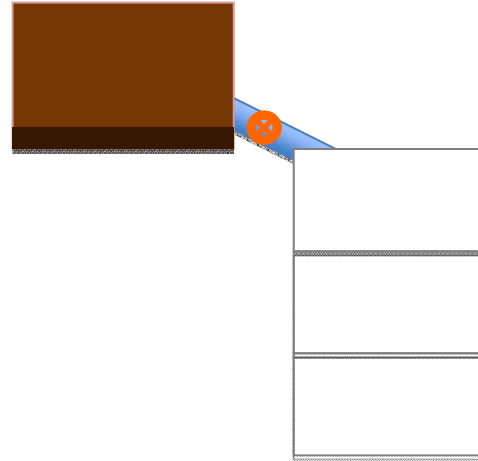


Question: Where and how will sludge accumulate?

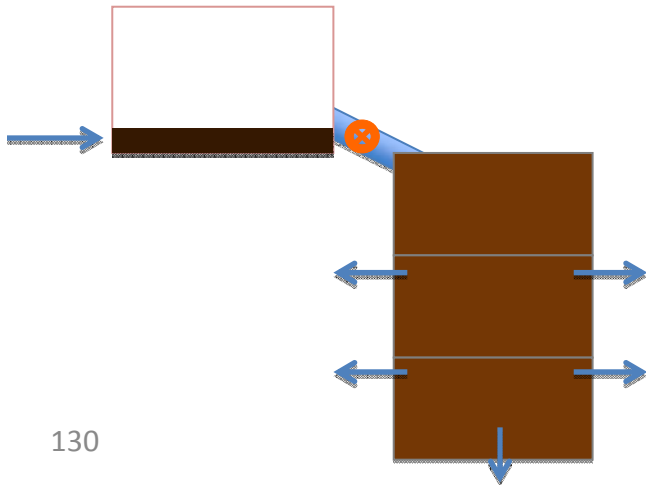
1. Upon installation, both tanks are empty.



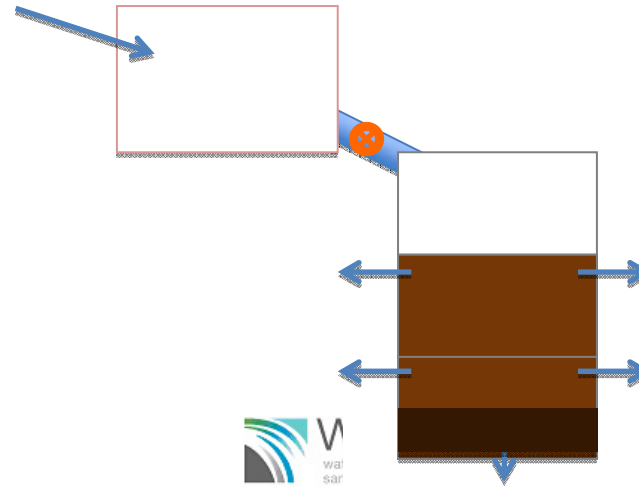
2. Wet season: Valve is shut, top tank fills, and sludge accumulates.



3. Dry season: Valve opens, contents flow down. Does the sludge remain in the top tank?



4. As waste continues to enter the system, will it flush the sludge down with it?



How does sludge accumulation affect the system?

Sludge will accumulate in the sealed above-ground tank when the valve is shut during the flood season. This raises additional technical questions, which must be explored through prototype testing:

- Will the pipe get clogged with sludge?
- Will sludge that accumulates during wet season in the above-ground tank flow down once the valve is opened?
- What effect does sludge and waste have on the valve functionality?

Key technical considerations for product design:

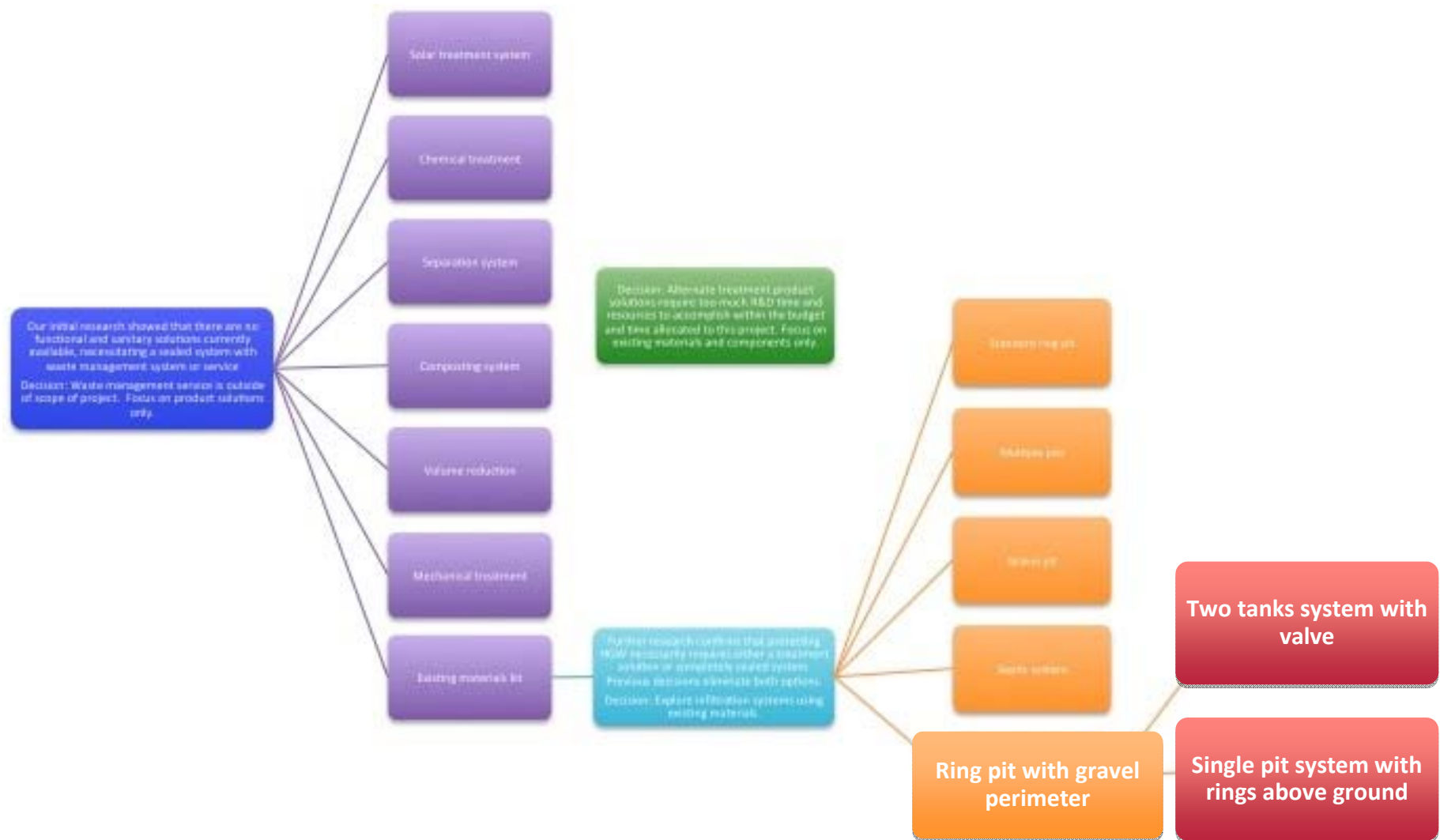
1. Seepage out rate vs. waste input rate and the below-ground structure
2. Sludge accumulation and the above-ground structure
3. Storage capacity of the above-ground structure

Another challenge based on recent findings: *Latrine storage capacity during wet season is limited.*

A brick tank of 1m x 1m x 1.2m, or a 3 ring tank can store waste for a family of 4 for **2-3 months**. In areas where flooding exceeds this time period, the holding tank must be even larger.

Additionally, the previously calculated **input/output rates require the tank to be even larger**, to ensure use over many flood seasons. This will avoid overflowing of the tank after its first season of use. While this is technically feasible, it is **not desirable** from a user perspective, as it would be costly, and would require significant land on which to build.

Final prototype designs: 2 options for varying flood levels



Flooding severity calls for different designs.

Within Challenging Environment (CE) areas, there are varying levels of flood severity:

Moderate flooding areas:

Up to 1 metre of flooding for over 2 weeks at a time.

Severe flooding areas:

Over 1 metre of flooding for over a month at a time.

Flooding severity calls for different designs.

Within CE areas, there are varying levels of flood severity:

Moderate flooding areas:

Up to 1 metre of flooding for over 2 weeks at a time.

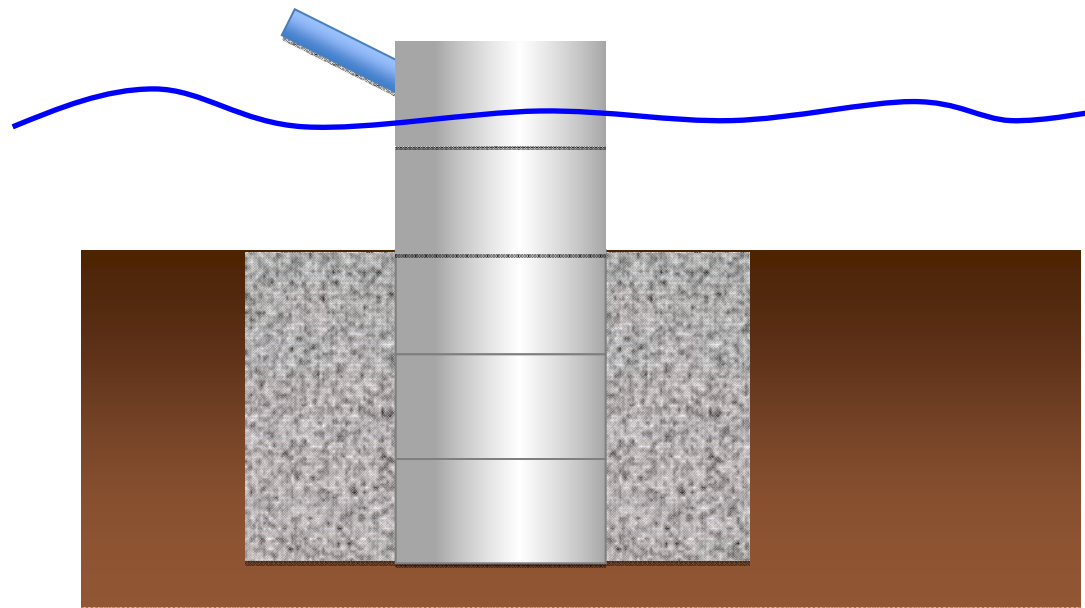
Severe flooding areas:

Over 1 metre of flooding for over a month at a time.

For moderate flood areas, the design can be simplified.

For moderate areas (<1m of flooding), an elevated latrine design* can be installed, adding a gravel perimeter to surround the concrete rings. The gravel area will depend on soil infiltration rates.

Rings are stacked above-ground in addition to underground rings. These must be higher than the maximum flood level.



Flooding severity calls for different designs.

Within CE areas, there are varying levels of flood severity:

Moderate flooding areas:

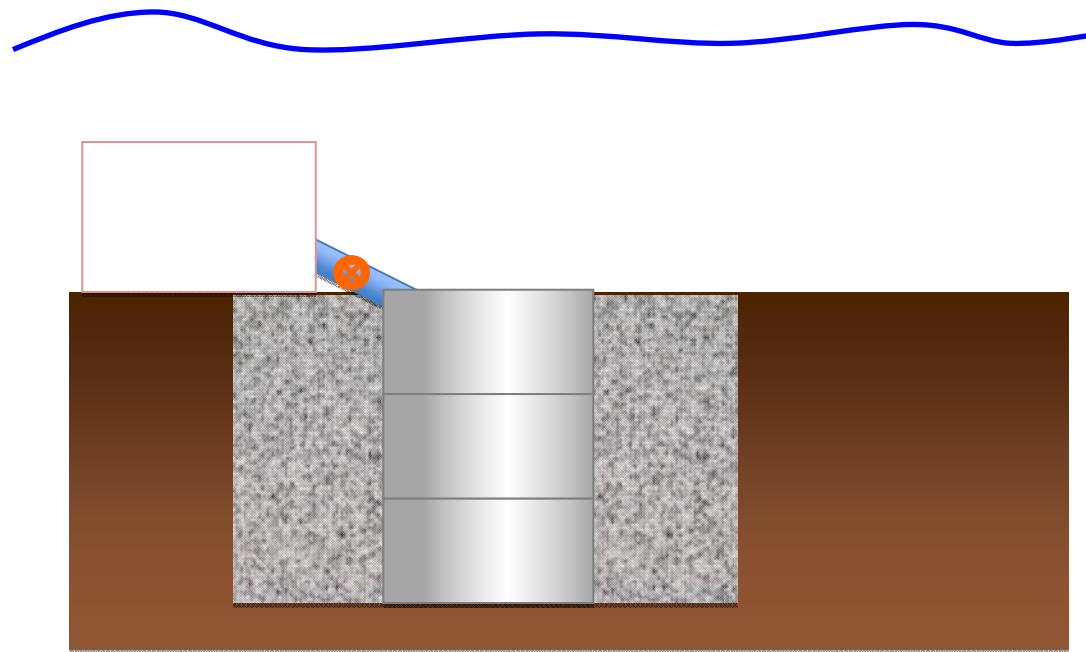
Up to 1 metre of flooding for over 2 weeks at a time.

Severe flooding areas:

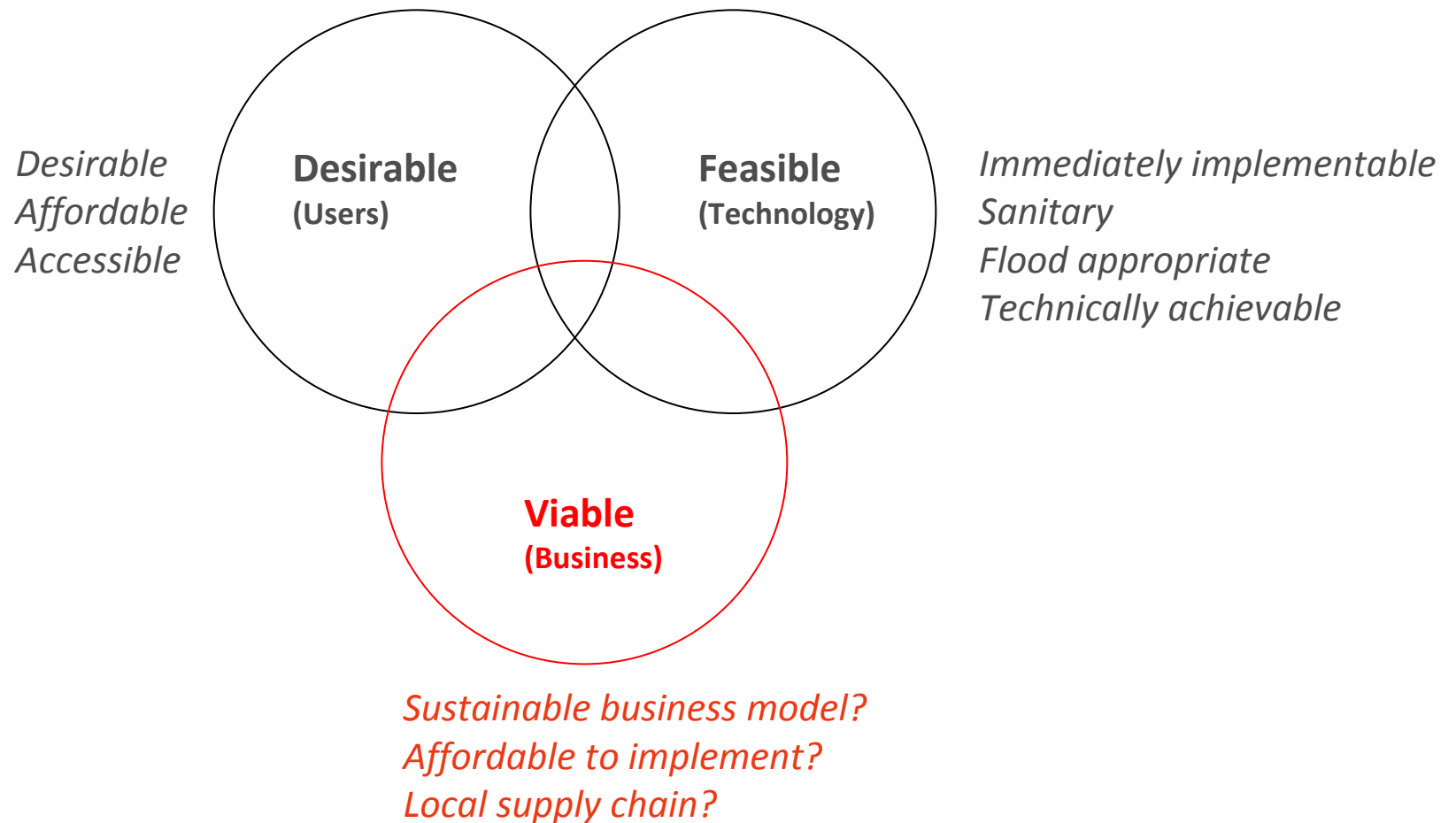
Over 1 metre of flooding for over a month at a time.

For severe flood areas, a 2-tank system is appropriate.

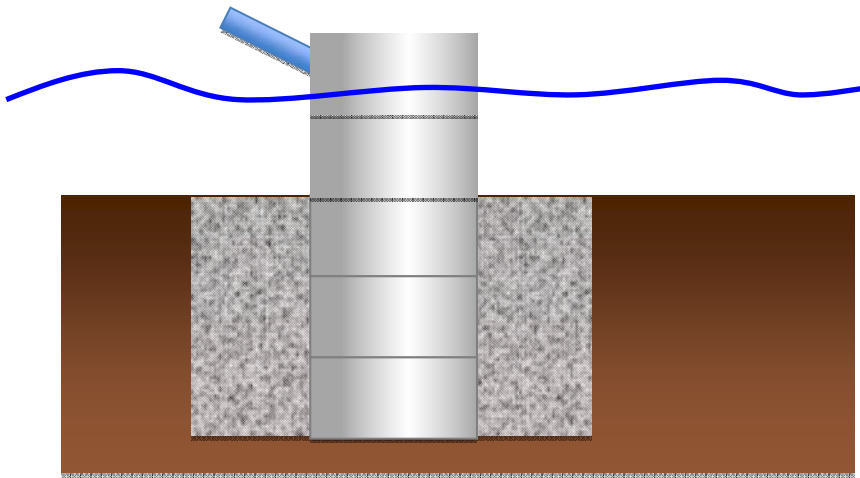
For severe flood areas (>1m of floods), the previously discussed 2-tank system is more appropriate. A closed valve and sealed-off tank allows continued use during flood season, as the latrine will not overflow.



Evaluating business **viability** through HCD criteria:



Cost analysis: Materials costs are high.

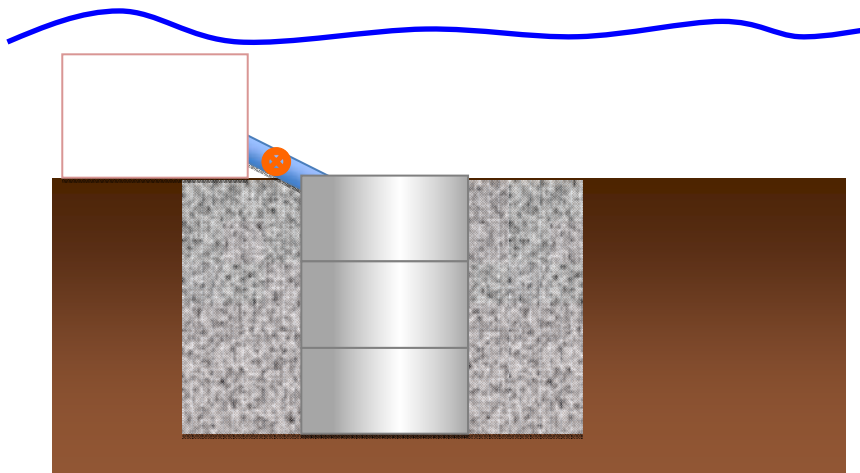


Moderate flooding *Elevated Latrine with Gravel Perimeter:*

\$114 - \$183 for materials
(varies with local gravel prices)

\$100 additional labour cost (approx)

\$50 shelter and installation (approx)



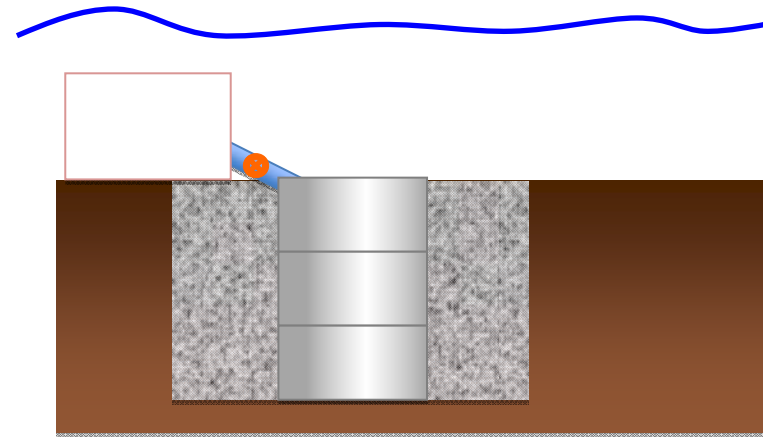
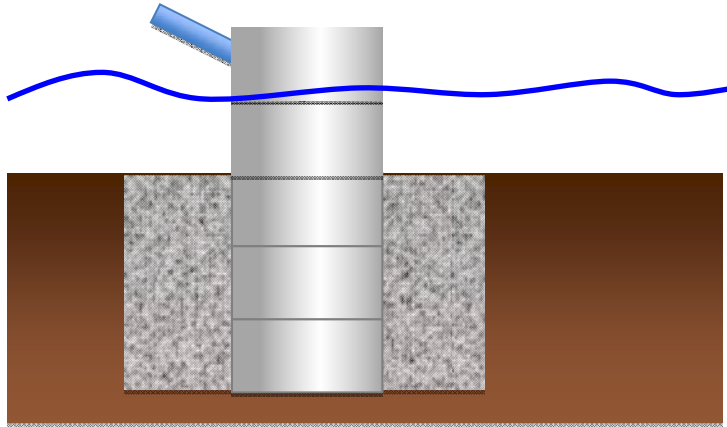
Severe flooding *2-Tank System with Gravel Perimeter:*

\$160 - \$210 for materials
(varies with local gravel prices)

\$100 additional labour cost (approx)

\$50 shelter and installation (approx)

Assessing the viability of both design options:



Due to the variability in soil permeability in CE areas, gravel quantities required for a functional latrine can vary widely. In order to optimize each product for seepage rates specific to a given area, soil assessments are necessary at a local level. Localized assessments require large time and financial resources.

Both designs will require partial subsidy as the cost for materials alone is \$100. The complex nature of the designs and the importance of correct installation require skilled masons. Such labour costs add approximately \$100. A shelter and shelter installation would also add at least \$50.

Both options, while technically feasible, are financially unviable. The need for individual subsidy and required resources for localized soil assessments results in a business model that is **not scale-able or sustainable.**

Assessing the viability of the designs:

Based on the currently available Easy Latrine product, we expect households will pay up to \$35-\$50 USD for a latrine. Research confirms that **users do not see the additional value in owning a latrine that is sanitary**; in their eyes, a ‘functional’ latrine is one that can be used year-round, regardless of whether it is hygienic or not. A latrine that flushes into flood-water offers the same economic value as a hygienic latrine design.

The additional materials required to construct CE-specific latrines provide a sanitary solution, but deliver no additional value to users (vs. an unhygienic latrine). These **additional costs will therefore require subsidy**.

Hypothetically speaking:

How much would it cost to reach 100,000 households?

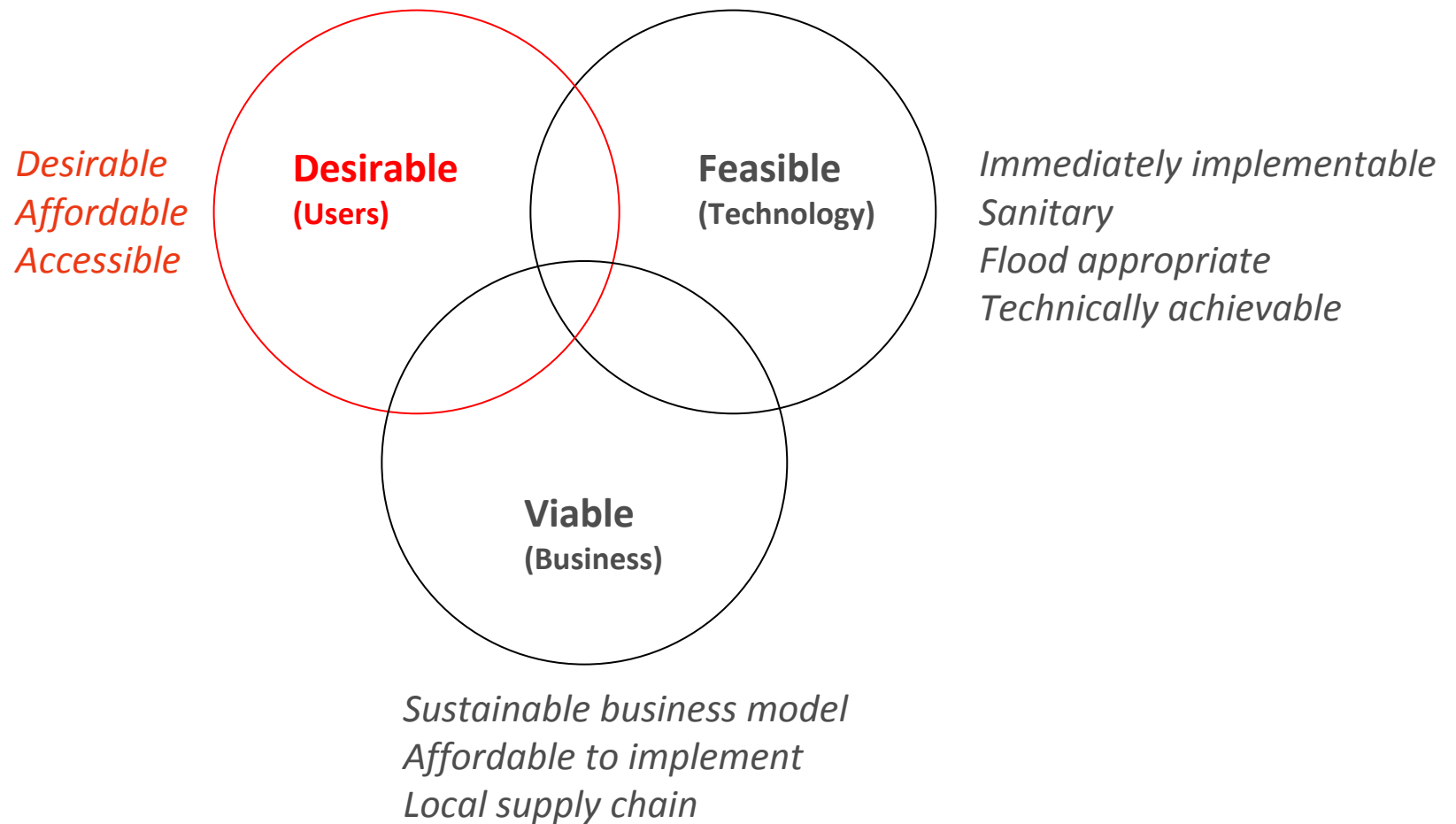
\$7.9 Million - \$17.5 Million of subsidy to purchase materials for 100,000 households. Over 40% of this subsidy is for gravel.

In addition:

\$10 Million cost of installation by skilled masons

\$5 Million minimum cost to users for shelter and shelter installation

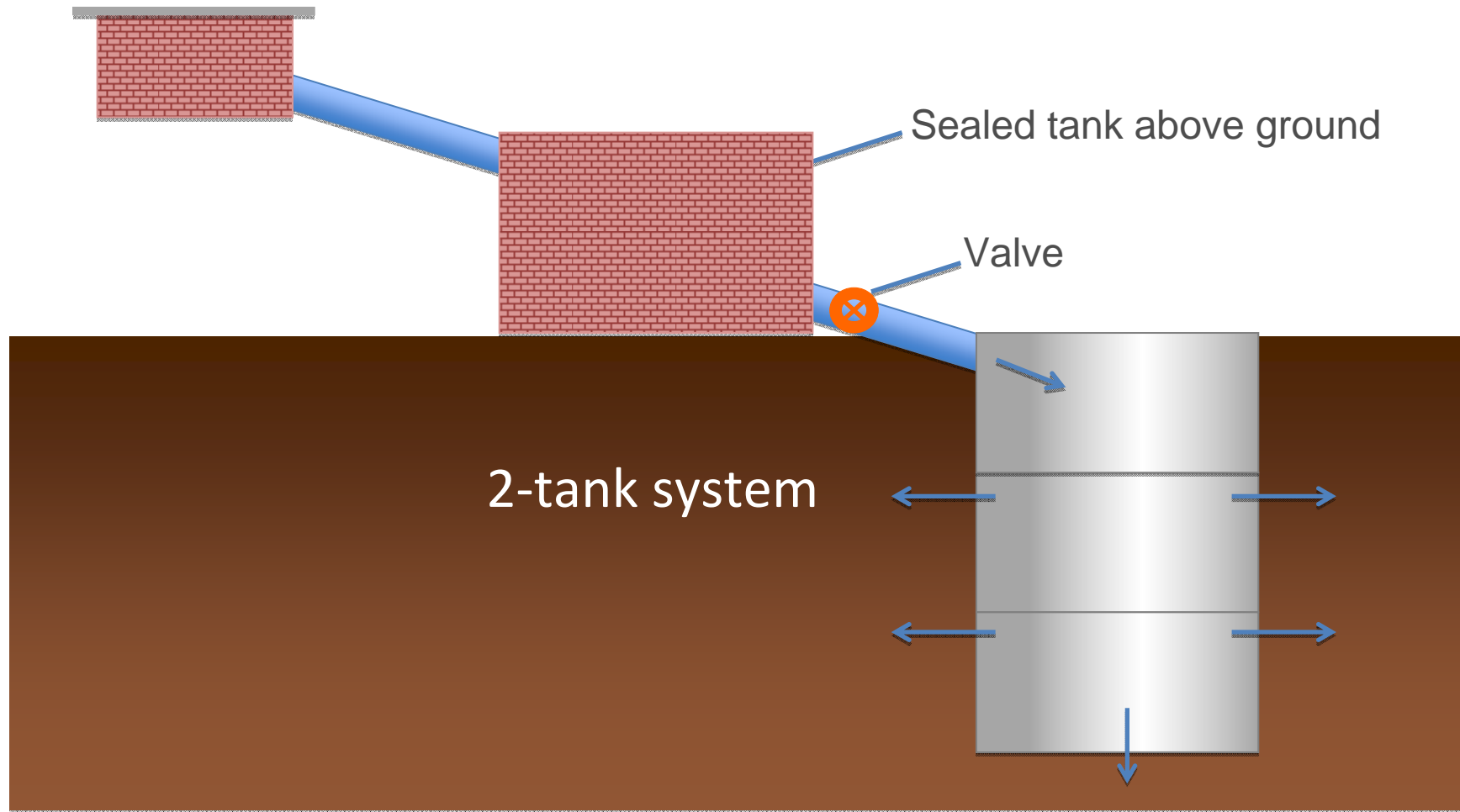
Evaluating user **desirability** through HCD criteria:



User input on Prototyping:

Identifying and adjusting the design Hot Spots

User feedback on Hot Spots: *How do they feel about a 2-tank system?*



2 tanks are needed for a sanitary design that functions year-round, but users don't believe it.



Mason: "It's not true that you need 2 tanks to make a latrine work year-round. As long as you leave the tank open (to flood-water) and elevate the tank above water-level, it won't overflow."

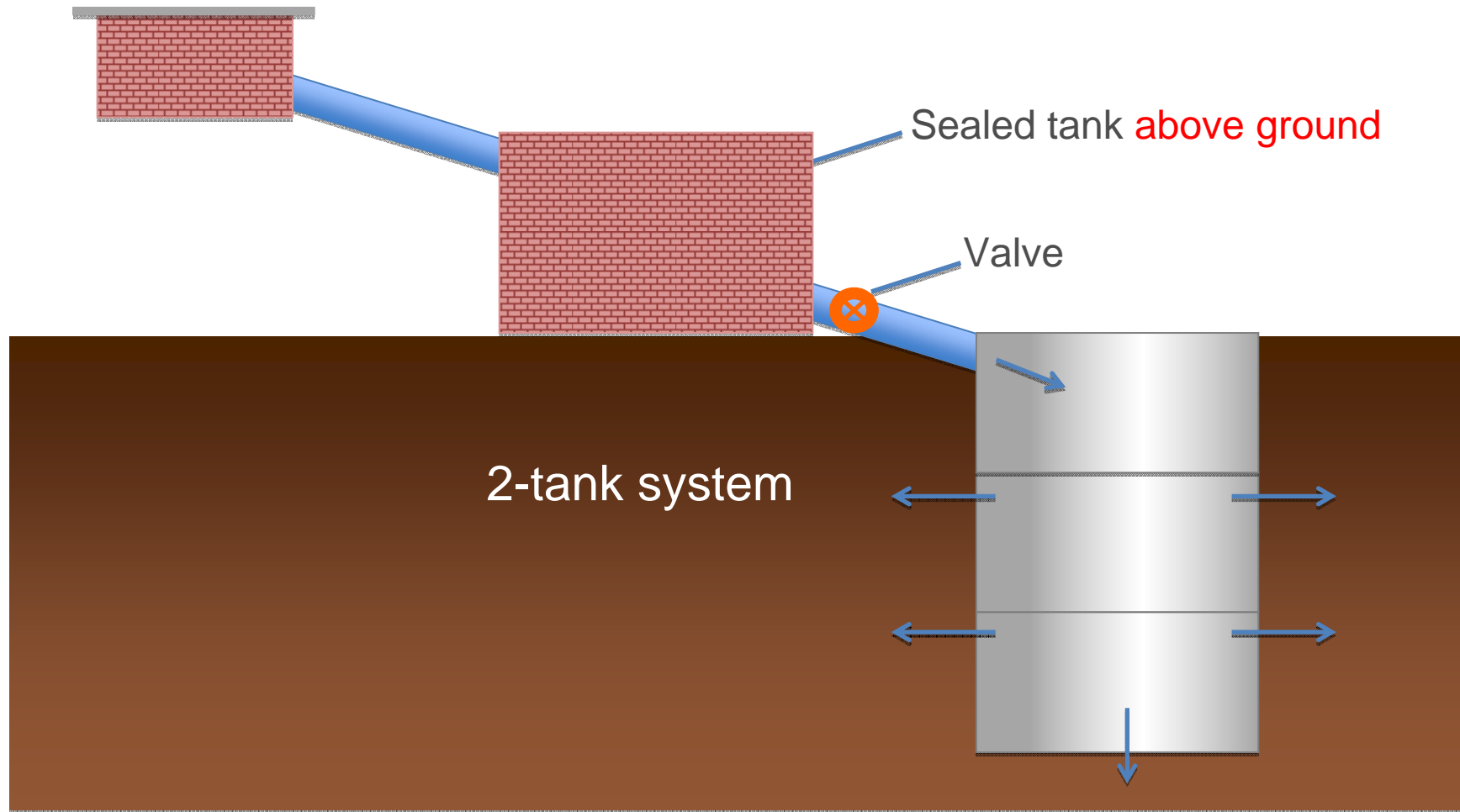


Retailer: "People who can afford 2 tanks will buy 2. People who can afford 1 will buy 1. The difference is the extra storage space 2 tanks provides. It doesn't make a difference in the usability of a toilet."

2 tanks are seen as a “nice to have”.

2 tanks are seen as a “nice to have”, and not as a functional requirement for a latrine. This user feedback confirms our initial insight that **users will eliminate components that add cost if they are perceived as unnecessary.**

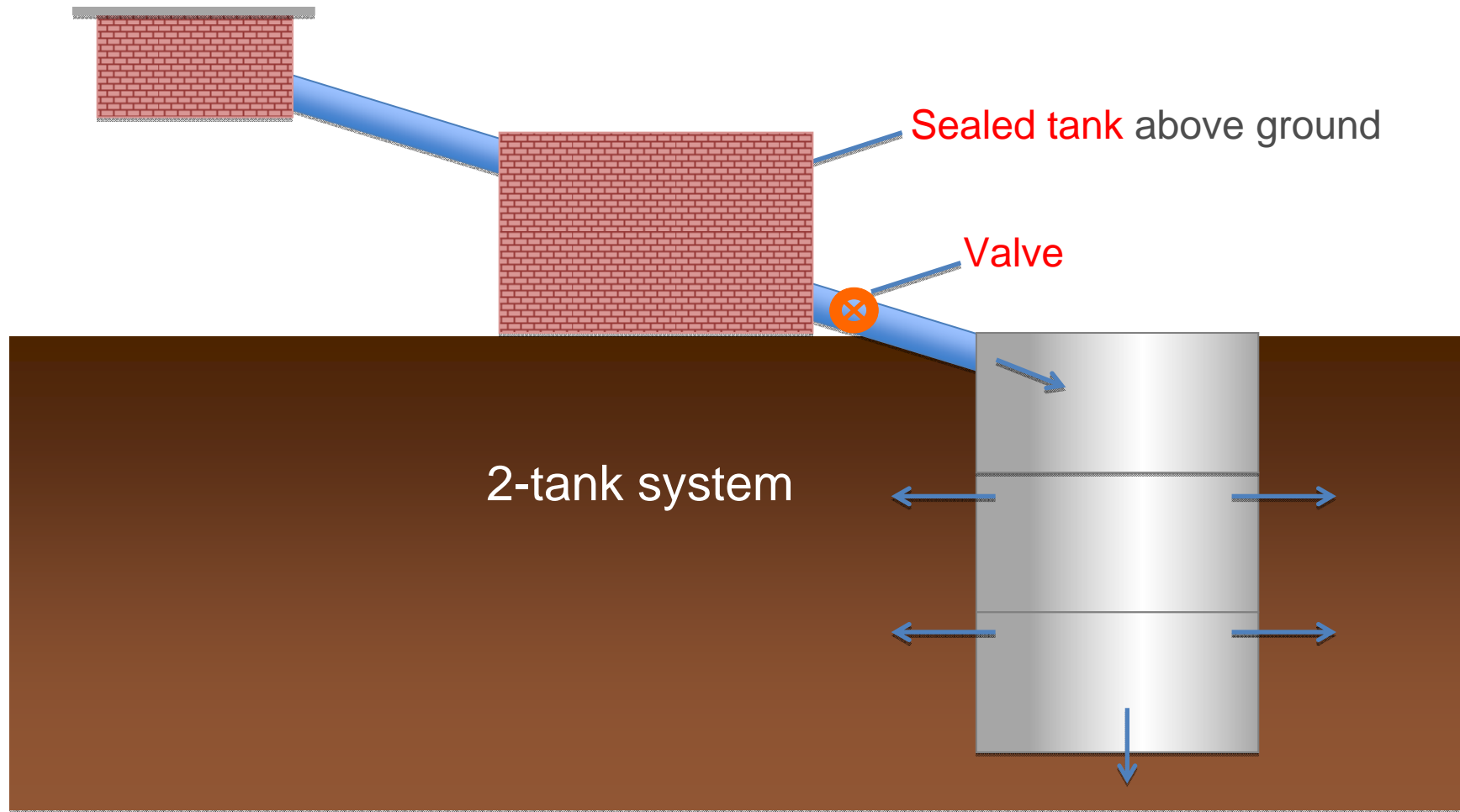
User feedback on Hot Spots: *How do they feel about a tank above the ground?*



A tank or rings above-ground adds no perceived value. It creates a fear of waste leakage and smell.

In flood areas, latrine owners are accustomed to opening the pit lid to release the stored waste into flood waters. This is how they empty the latrine. They **do not see any value in building a second tank** or rings above-ground in order to contain the waste during floods. Furthermore, many users are averse to the idea of stored waste above-ground, due to a fear of waste leakage or smell.

User feedback on Hot Spots: *How do they feel about a sealed tank?*



While a sealed system is necessary for sanitary design, it adds no perceived value to users.

People are accustomed to unsealed tanks, as they are believed to delay the need to empty. Furthermore, alternative solutions exist to address the user need for a latrine that functions year-round. These solutions (e.g. opening the tank to flood water) may not be sanitary, but they provide the full functional benefit sought by users. **Users eliminate cost components that they deem unnecessary. These include a sealed system and an open/close valve.**

Retailer:

"I always recommend to my clients that they leave the bottom (of the tank) open (unsealed)."

Masons:

"The tank needs to be open on the bottom for the waste to seep out. This way it lasts longer".

"Opening or closing [a valve] has nothing to do with the toilet flooding/backing up. If you build it above water-level or you open the tank (to flood waters), you can use it during floods."

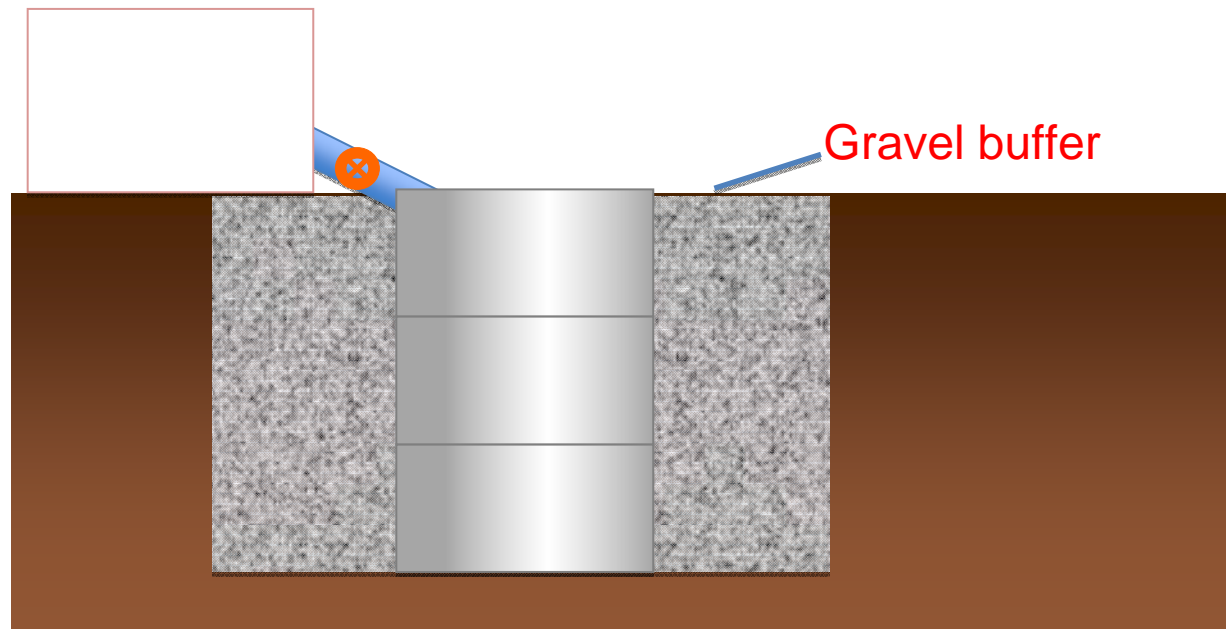
Households:

"I would have to ask the mason. I think you need to leave the tank open to seep out."

"A sealed tank? How long is that going to last? No way!"

"My neighbour uses his latrine during floods and his tank isn't sealed"

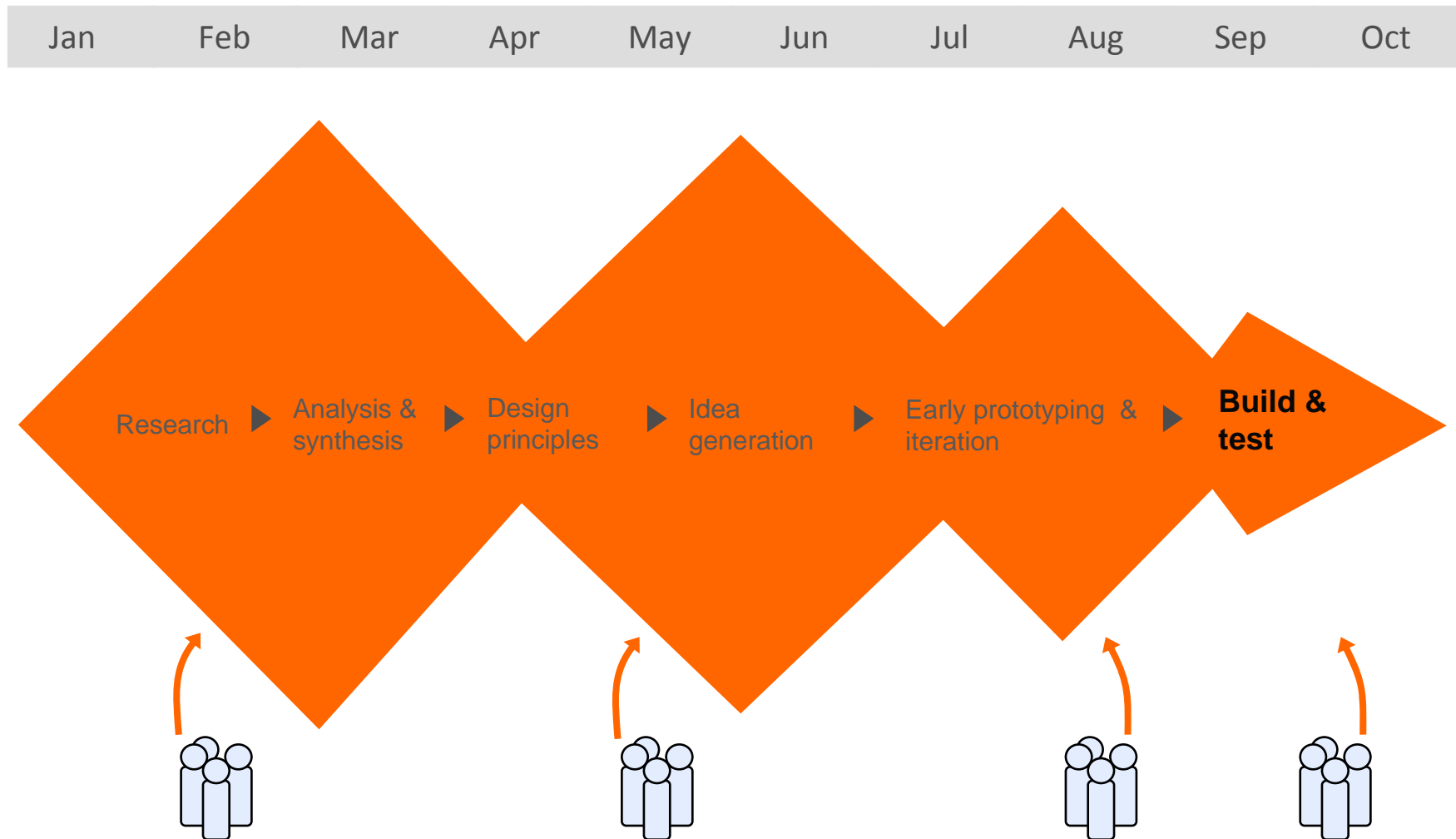
User feedback on Hot Spots: *How do they feel about the gravel buffer?*



A gravel buffer adds significant cost while providing little perceived value to users.

For the same reasons provided with previous hot-spots, users do not see the value in the improved soil infiltration provided by a gravel. The lower cost and ease at which unsanitary solutions (e.g. releasing the waste into flood waters) address user needs makes introducing higher cost sanitary options a challenge. **We can not sell users what they believe they do not need. This includes the gravel buffer.**

HCD Process: Build & test



Build and test

Build final, high-resolution prototypes to test for functionality in the field.

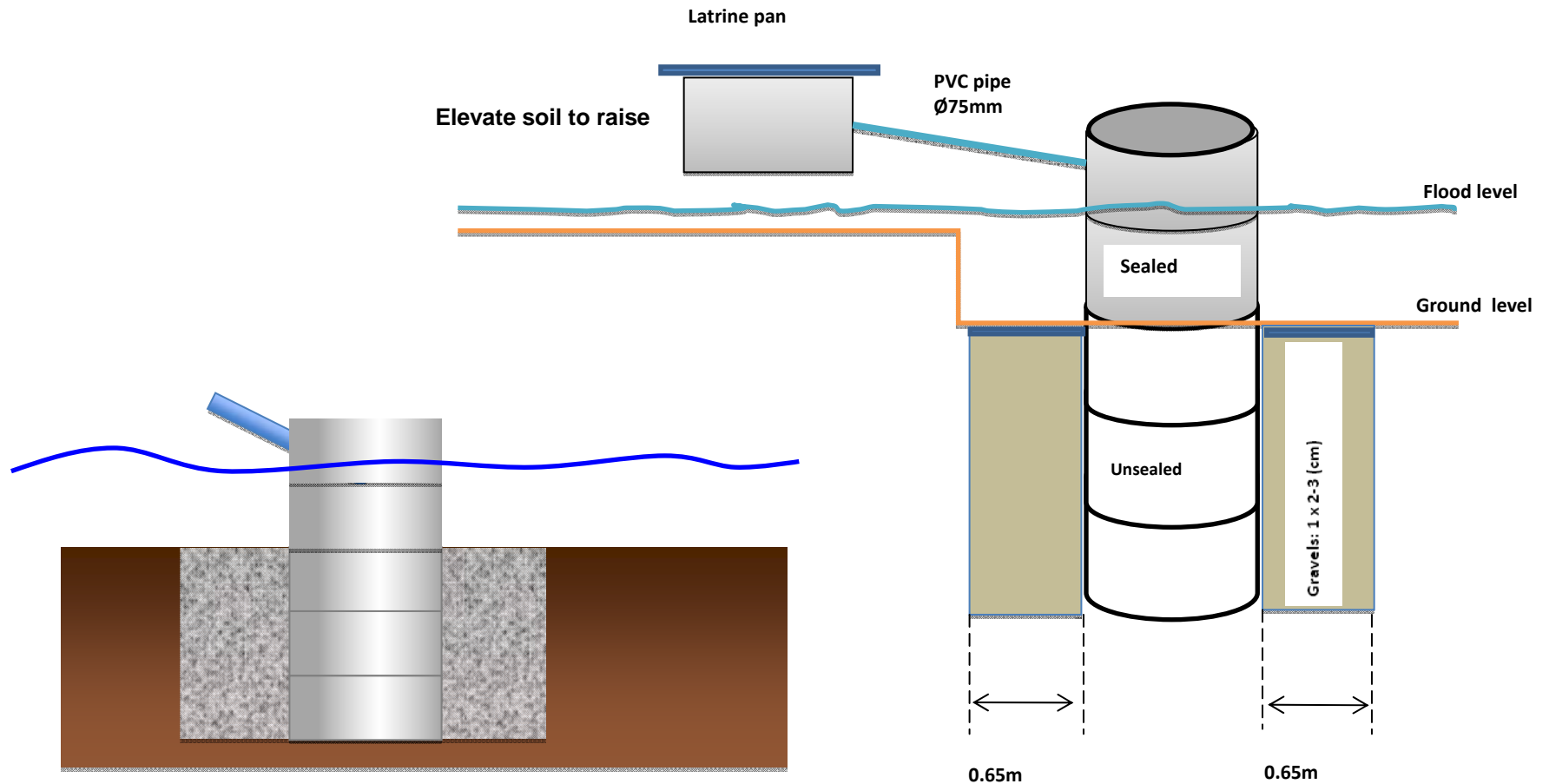
Build and test

4 prototypes built in September 2012

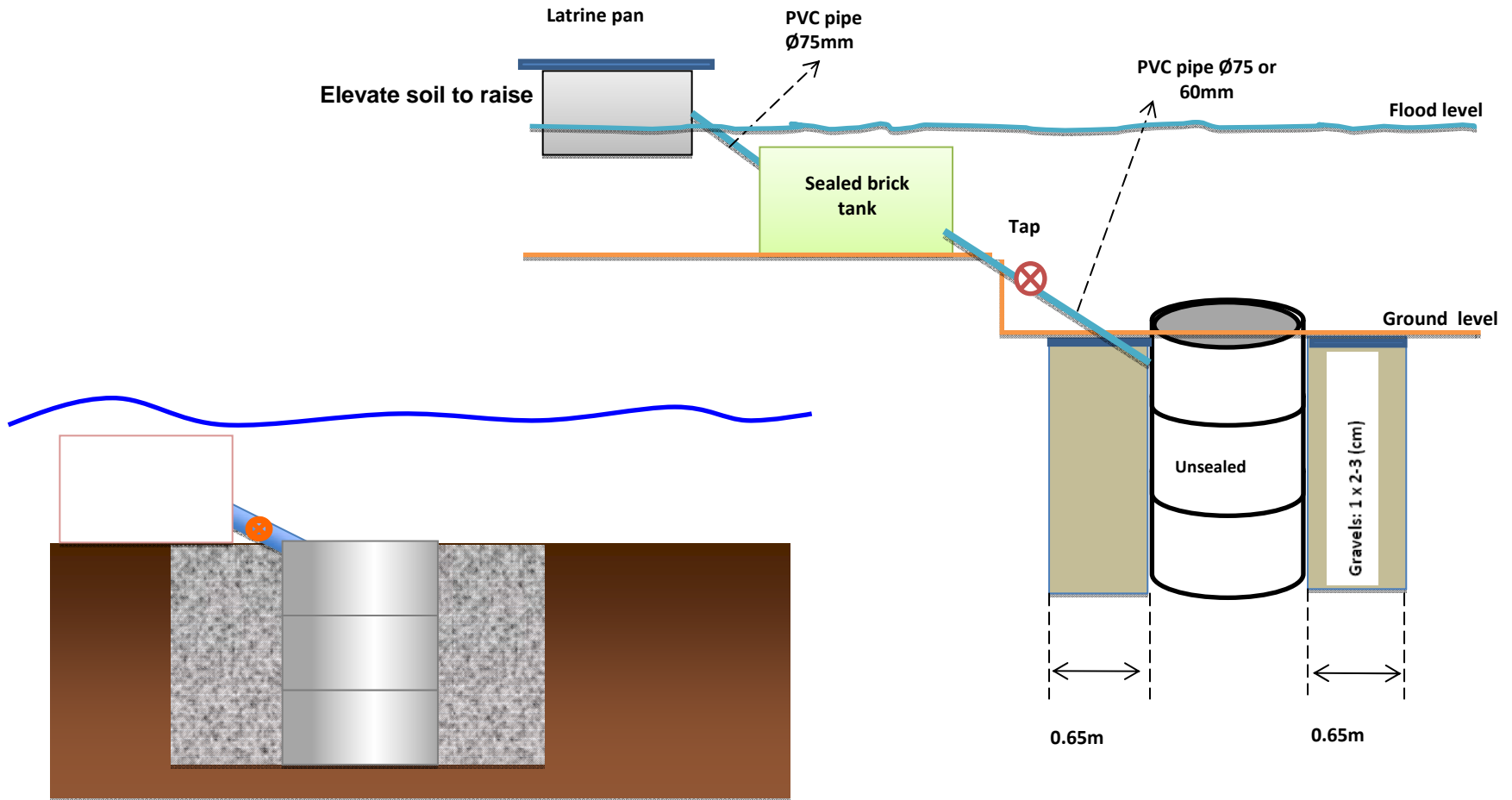
2 for Moderate flood design, 2 for Severe flood design

Svay Rieng province

Field prototype: Moderate flooding design



Field prototype: Severe flooding design



Building prototypes in the field: Moderate flooding design



Building prototypes in the field: Severe flooding design



Field prototypes will be monitored over the next year.

The functional prototypes have been installed and are currently in use by households. They will need to be monitored through a full year in order to observe the technical functionality as well as user behaviours during transition from flood season to dry season.

This year the rainy season was atypical, and households did not experience flooding. The latrines will need to be monitored again through the next rainy season.

In the meantime, the rates at which the tank fills and sludge accumulates can be monitored.

What have learned?
Where do we go from here?

Alternative solutions to infiltrations systems are needed for challenging environment areas in Cambodia.

- Infiltration systems for challenging environments in Cambodia are not feasible, viable, or desirable solutions.
 - Low permeability of soil in Cambodia makes infiltration difficult to implement as a functional solution.
- There is no cost-effective way for households, businesses, or projects to assess soil permeability or presence of HGW.
 - In order to protect HGW, either a fully sealed system with waste management service or a treatment product needs to be developed.

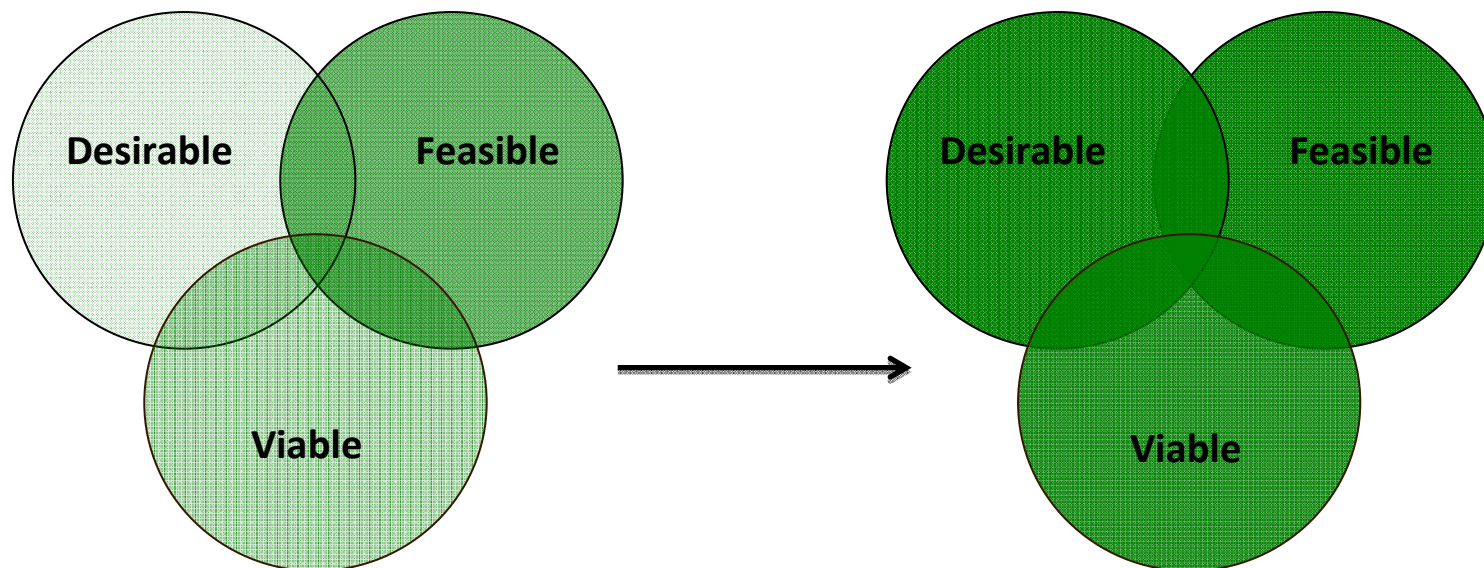
Where do we go from here?

Explore alternative solutions, leveraging our key findings.

Infiltration system:

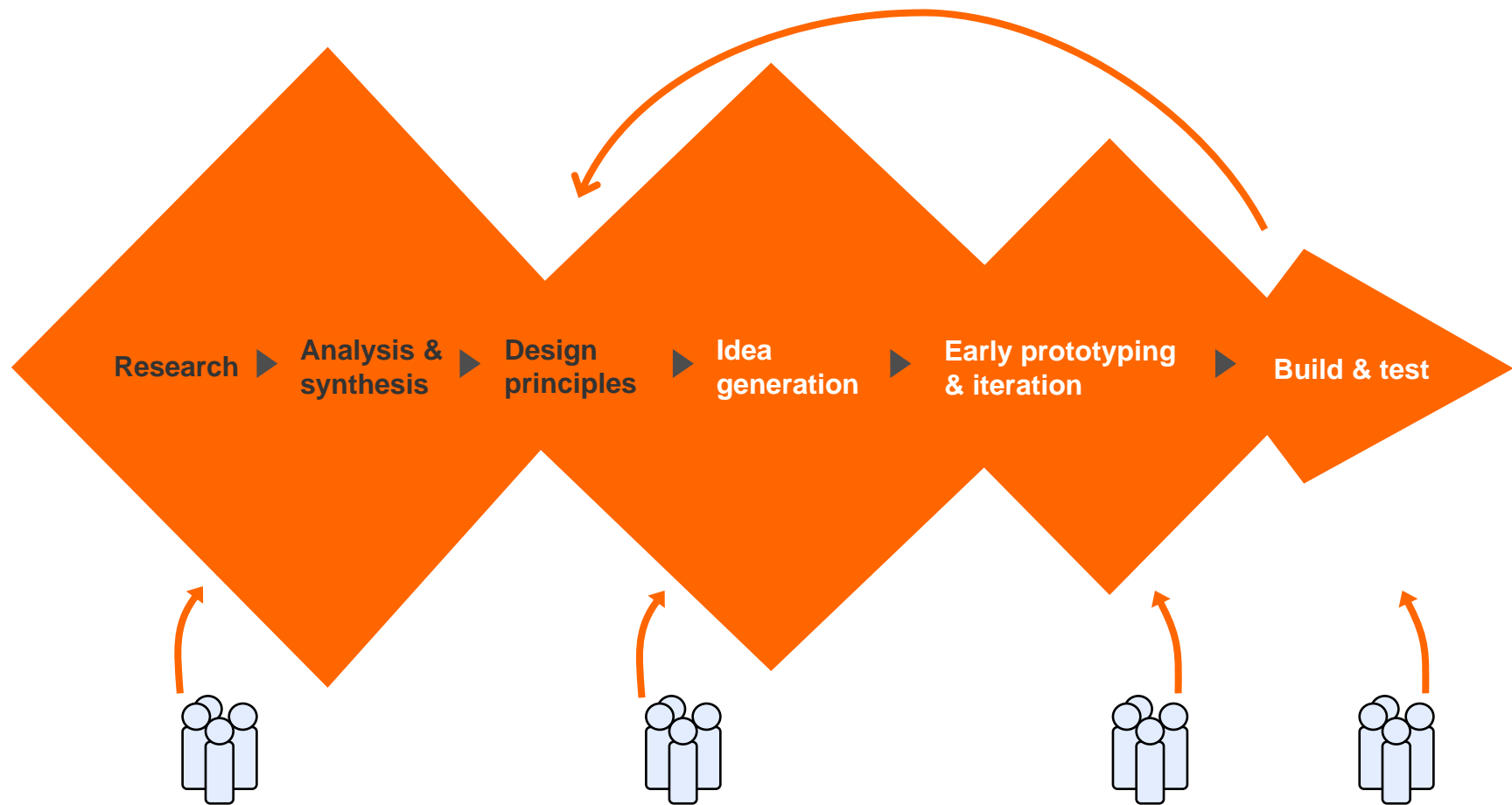
Low feasibility, little desirability, unaffordable for most. Subsidy or finance model is needed.

Shift efforts to R&D of alternative solutions that are feasible, viable, and desirable. Build on key user insights and findings to date.



Human Centered Design is an iterative process.

Use key findings and design principles uncovered during the project as a starting point for future explorations. Future designs will have a significant head-start in the design process.



A head-start in design: Revisit generated ideas



Revisit promising solutions using HCD research findings as a foundation upon which to build.



Thank you!

For further questions, please contact us:

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