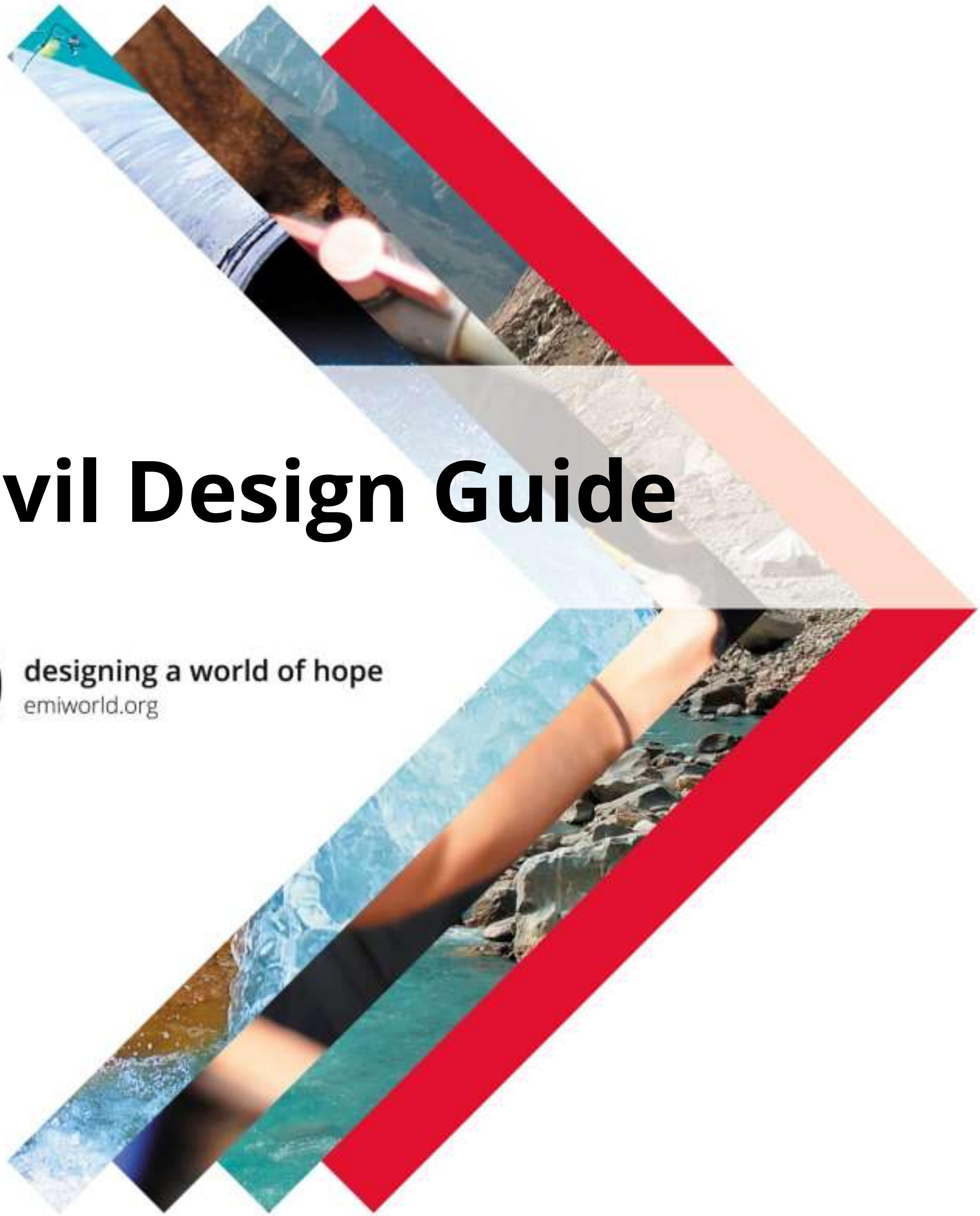
Civil Design Guide



designing a world of hope
emiworld.org

Introduction

EMI DESIGN PHILOSOPHY

Vision
People restored by God and the world restored through design.

Mission
To develop people, design structures, and construct facilities which serve communities and the Church.

Core Values
EMI revolves around the person of Jesus and serves the global Church to glorify God through:

> ***Design:*** *EMI works within the local context to design and construct culturally-appropriate facilities that are sustainable, affordable, and transformational.*
>
> ***Discipleship:*** *EMI develops people spiritually and professionally through intentional discipleship and mentoring.*
>
> ***Diversity:*** *EMI builds the Church by connecting people of diverse backgrounds, abilities and ethnicities to demonstrate our love for God, our love for the nations and the unity we share in Christ.*

DESIGN GUIDE FEATURES

The purpose of this design guide is to support the vision, mission, and core values of EMI in civil engineering design. The standards and procedures contained in this guide combine experience of EMI staff and volunteers as well as many other external resources. Since each project, client, and context is unique, this guide does not propose one-size-fits-all solutions. Instead, it provides consistent methods for common EMI designs and it equips civil engineers with a resource for evaluating alternative and appropriate designs where applicable.

This design guide contains hyperlinks and references to provide access to supporting material. The user must ensure to have the entire and latest **EMI Civil Design Manual** folder, which includes the *EMI Civil Design Guide* (this document) and all supporting files, to include the following subfolders:

- ***Design Tools*** provide templates that aid in collecting information on the site and processing data in Microsoft Excel. There are three subfolders:

   - ***Checklists*** to aid in Client Needs Assessments, Preliminary Research Guide and Site Evaluations.
   - ***Global Templates*** provide EMI standard design templates for EMI projects. These templates should be used for the project for standard calculations.
   - ***Testing Field Packets*** are printable guides that aid in Soil Testing, Solid Waste, and Water Quality Testing and provide templates for collecting data.
- ***References*** provide external resources and supporting documentation for the topics discussed in the design guide.
- ***Region Specific Guidelines*** provide information about the civil engineering practices for available countries or regions.
- ***Training Videos*** provide videos for accessing the design guide file structure and how to use templates.

DISCLAIMER

It is expected that the reader possesses the proper education/training to apply this information properly; this Guide is NOT as substitute for professional expertise.

EMI works in many countries with no established design standards or code enforcement. Therefore, this document complies with internationally accepted standards whenever possible. The office specific detailed descriptions may include specific design standards for the country where the office is located. For specific projects, any governing standards and codes applicable to the site location take priority. Design shall follow the latest edition of the local standards regardless of any specifications explicitly or implicitly set forth in this document.

DETERMINING SCOPE OF WORK

As part of project planning, EMI staff will determine the scope of work for each approved project. The project leader will coordinate with the design professionals to determine the necessary design work required to support the overall project objectives and develop an appropriate work scope with the designer(s) for the project. ***Civil Design Deliverables by Project Stage and Type of Site*** outlines the typical deliverables/analysis that are required for specific projects based on the level of design (conceptual vs. detailed) and type of site (undeveloped or "greenfield" vs. modification to existing buildings). Experienced volunteers can use the design guide to understand the level of detail expected for EMI project since it is different from industry experience. While young professionals can learn how to design in an EMI context.

EDITION

This document is a living document and is intended to capture best practices for preliminary design and provide a guide to up-to-date design information needed to complete EMI projects properly. To continually improve the contents of this document, please provide your project leader with feedback on any errors you find, suggested improvements we could make, or your opinion on ways we could do things better. We are particularly interested in adapting this manual to different cultural contexts in which EMI operates.

Table 0- 1 Edition History

Edition	Date	Editors	List of Updates / Comments
Global Civil Design Guide Version 1.0	May 2021	Jason Chandler, PE; Natalie Thompson, EIT	
Global Civil Design Guide Version 2.0	August 2022	Jason Chandler, PE; BJ Elkins, EIT; David Hong	• Bug fixes • New sections: A2.1.1 (ET Estimation), A7 (Region Specific Guidelines) • New Subfolder: Region Specific Guidelines

CONTRIBUTORS

Many EMI staff and volunteers with expertise in Civil Engineering have contributed to this Design Guide. Most of the sections were started from EMI's Uganda office and edited to apply to a global context. A list of contributors can be found in ***Table 0- 3 List of Contributors*** serves as a list of expertise to contact if there are additional questions.

FEEDBACK

This is a living document and a review committee will be reviewing the Civil Design Guide and its' file structure on an annual basis. General feedback regarding the guide and platform can be recorded on the ***User Feedback Form for Civil Design Guide***. Any comments and suggestions can be made on the ***Suggestion Form for Civil Design Guide***. Any urgent error that needs to be addressed before the annual review can be sent to ***Civil@emiworld.org***.

Table 0- 2 Civil Design Deliverables by Project Stage and Type of Site

Deliverable	Section	Greenfield		Existing Site		Notes
		Conceptual	Detailed	Conceptual	Detailed	
Client Needs Assessment	***1.3***	✓	✓	✓	✓	***Client Needs Assessment- Civil, Existing*** ***Client Needs Assessment- Civil Greenfield***
Initial Site Evaluation	***1.4***	✓	✓	✓	✓	***Site Evaluation- Civil, Existing*** ***Site Evaluation- Civil, Greenfield***
Water Demand Estimate	***2.1***	✓	✓	✓	✓	***EMI Water and Wastewater Design Template--Daily Water Demand Tab***
Water Testing Results	***2.5***	✓	✓	✓	✓	***EMI Water Quality Testing Field Packet*** ***EMI Water Quality Testing Results Template***
Water System Assessment	***2.8***			✓	✓	Summarize in report
Existing/Demolition Water Distribution Plan	***2.8***			✓	✓	Template DWG (varies by office)
Proposed Water Distribution Plan	***2.8***	✓	✓	✓	✓	Template DWG (varies by office)
Water System Details	***2.8***		✓		✓	Standard and site-specific detail DWG (varies by office)
Soil Classification and Analysis	***3.1***	✓	✓	✓	✓	***EMI Soil Testing Field Packet*** ***EMI Water and Wastewater Design Template--Percolation Tests and Soil Classification Tabs***

Deliverable	**Section**	**Greenfield**		**Existing Site**		**Notes**
		Conceptual	**Detailed**	**Conceptual**	**Detailed**	
Wastewater Quantity Calculation	***4.1***	✓	✓	✓	✓	***EMI Water and Wastewater Design Template--Wastewater Quantity Tab***
Wastewater System Assessment	***4.1***			✓	✓	Summarize in report
Proposed Wastewater Plan	***4.2***	✓	✓	✓	✓	Template DWG (varies by office)
Wastewater System Details	***4.2***		✓		✓	Standard and site-specific detail DWG (varies by office)
Rainfall Calculations	***2.3***	✓	✓	✓	✓	***EMI IDF Analysis Template*** ***EMI Stormwater Runoff Template***
Existing/Demolition Site Drainage Plan	***5.3***			✓	✓	Template DWG (varies by office)
Proposed Site Drainage Plan	***5.1***	✓	✓	✓	✓	Template DWG (varies by office)
Site Drainage Details	***5.1***		✓		✓	Standard and site-specific detail DWG (varies by office)
Roadway Details	***5.2***		✓		✓	Standard and site-specific detail DWG (varies by office)
Retaining Wall Details	***5.3***		✓		✓	Standard and site-specific detail DWG (varies by office)
Solid Waste Disposal Details	***6.1***		✓		✓	***EMI Solid Waste Field Packet***

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Global Guide

1 Preparation and Site Evaluation

1.1 PRELIMINARY RESEARCH

Prior to conducting a site visit, the team must conduct research and prepare to maximize the limited time available on-site. This includes research through online resources and satellite maps as well as questionnaires that the client can complete. This data provides a starting point that is confirmed through in-person interviews, on-site evaluation, and coordination with the rest of the design team. The following design tools are available and for customization as necessary for the specific project.

Preliminary Research Guide- Civil provides research guidance for the designer(s) prior to the site visit and will be archived as background information for the project.

Client Needs Assessment- Civil, Existing provides preliminary questions that the client can answer for the specific project and location where existing facilities are present. This is to be customized for the project and sent to the client via the project leader.

Client Needs Assessment- Civil, Greenfield provides preliminary questions that the client can answer for the specific project and location where the site is vacant. This is to be customized for the project and sent to the client via the project leader.

1.2 SITE EVALUATION EQUIPMENT

In addition to any general packing recommendations for a project trip or site visit, some civil engineering specific tools and equipment may be necessary for the site evaluation depending on the scope of the project. As part of the site visit preparation, the team must make plans for getting any necessary equipment to the site. This could include equipment for water testing, soil testing, and/or surveying. Consult with the project leader on the availability of specific equipment from the EMI office. Refer to ***EMI Water Quality Testing Field Packet***, and ***EMI Soil Testing Field Packet*** which include packing lists for the specific needs of surveying, water quality testing, and soil testing respectfully. These documents can be modified to meet your project or office needs.

1.3 CLIENT MEETINGS

The initial meeting with the client will mostly focus on the clients' vision for development. Depending on the scope of the project, this may not get into details of civil engineering right away. However, this is a chance for the civil engineer to begin verifying the preliminary research and client needs assessment checklists. After the initial meeting, the civil engineer can schedule to meet with the client to review (or complete) the client needs assessment.

If the site has existing facilities, include someone familiar with daily operations and a tour of the existing facilities as part of this meeting. The EMI team may need to refrain from pointing out issues to the maintenance personnel if it is unsolicited. This may cause embarrassment and damage the relationship. Document any current issues and challenges as well as any needs perceived by the client, and/or plans for proposed development. Ask open-ended questions that do not lead the client to specific responses.

1.4 SITE EVALUATION

The goal of the site evaluation is to gather all data necessary to complete the design without requiring multiple visits. Due to time limitations, correct prioritization is essential such as stakeholder meetings, sanitary surveys, maintenance tours, and data collection. In addition to assessments that take place on the project site, visits may also be necessary to neighboring sites, contractors, suppliers, and/or government offices to acquire necessary information. Such visits will be coordinated through the client and the project leader. The following design tools are available to assist with the site evaluation and are customizable for the specific project:

Site Evaluation- Civil, Existing provides guiding questions and typical evaluations for a site with existing facilities.

Site Evaluation- Civil, Greenfield provides guiding questions and typical evaluations for a vacant site.

1.5 SITE SURVEY

A topographical survey may be required for proper design of the civil features. In some cases, a client may provide a survey before the project trip. It is important to review the survey before the trip to get an idea of the land and any problem areas to look into once on site. If a survey is not conducted and an EMI survey team is going during or prior to the trip, ensure that information is collected around the site and specific to water and wastewater lines. If there are bodies of water near the site, then surveying may be required off the property line for stormwater modeling.

2 Water

2.1 WATER DEMAND ESTIMATE

Estimating water demand is a critical design step for most EMI projects. The water demand estimate is the foundation for evaluating design components such as water source selection, distribution, storage, and treatment, as well as wastewater conveyance and disposal. There are several methods for estimating water demand, but since many people can work on an EMI project at different times, it is paramount that a typical method be followed and assumptions documented clearly, so that others can follow the work that was done. Be sure to look into the detailed descriptions for local regulations and applications.

2.1.1 DESIGN STAGE

Frequency of Use: All EMI projects involving water and wastewater designs will include a water demand estimate.

Conceptual Design: Perform an initial estimate of the Average Daily Demand (ADDs) and Maximum Daily Demands (MDDs) for the project. Depending on the project, the future estimates may be by phase, or may be for the full buildout of the facility.

Detailed Design: Review and refine the initial demand estimates along with the detailed design scope and any applicable masterplan changes to inform required site infrastructure and building plumbing design. Estimate the peak-hour demand to use in sizing distribution pipes.

2.1.2 DESIGN CRITERIA

An accurate estimate of water use will take into account many factors, such as:

- Actual usage from existing buildings on site by observing the tank volume over time or installed water meters;
- Observations of typical water use within the specific local context;
- Determination of all water uses particular to a site and client application;
- Forecast of population and user type;
- Seasonal fluctuations in water use; and
- Guideline estimation criteria for different types of users and facilities that may be country or region specific.

Water use in the developing world will typically be less than water use in many parts of the developed world, primarily due to limited availability. Increased water availability will typically increase water demand. For example, typical domestic water use for drinking, bathing, cooking, etc. in the developing world can range from 10 liters per capita per day (lpcd) where water is carried long distances to the users, up to 150 lpcd where water is piped to a home or building. In some cases, domestic demands can be higher, particularly in more affluent urban areas or where a high concentration of foreigners are present, and this is to be factored into the water use estimate. Other water uses for various institutions, irrigation, animals, etc. must also be considered for the specific context of the project.

The average day demand (ADD) represents the average water usage on a typical day. This can be calculated by observing typical usage on site or by using the tables in Appendix ***A2.1*****.** The maximum daily demand (MDD) is the highest expected use on any single day. This can be estimated by using a peaking factor or by determining special events that would exceed the ADD.

The following resources and tools are to be used in developing the water demand estimate:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water demand estimate.
- Appendix ***A2.1*** ***Water Demand Estimate*** provides guideline tables for various water uses in different parts of the world.
- References and additional resources can be found in ***R2.1*** ***Water Demand Estimate***.
- The ***EMI Water and Wastewater Design Template*** is to be used as a starting point for the estimate.

2.1.3 DESIGN PROCEDURE

Step 1: Review the information in Client Needs Assessment and Site Evaluation.

Step 2: Determine project lifecycle and phasing.

Step 3: Identify all existing and proposed water using facilities in the ***EMI Water and Wastewater Design Template*****.**

Step 4: Identify all the user types and total number of users for each facility at final buildout.

Step 5: Estimate and input the water use for each user performing each activity at each facility, in lpcd. Use ***A2.1*** ***Water Demand Estimate***, office specific detailed descriptions, Client Needs Assessment, Initial Site Evaluation, and other observations from client meetings to inform these estimates. Include notes in the spreadsheet to document assumptions.

Step 6: Verify calculations of ADD and MDD for each user type and facility type.

Step 7: Record water demand estimate in the appendix of the Project Report. Appendix tables are included in the water demand template for this purpose.

2.2 WATER SUPPLY SOURCE SELECTION

Selecting reliable water supply sources is an important part of providing for on-site water demands. Consider all possible water sources regardless of initial opinions regarding feasibility for development and use. Consider local regulations, including water rights, in the evaluation.

2.2.1 DESIGN STAGE

Frequency of Use: All EMI projects involving water and wastewater designs will evaluate water supply sources.

Conceptual Design: Perform an initial evaluation of available water supply sources for the project using the design criteria and based on water demand (Section ***2.1***). There could be multiple sources utilized depending on water demand, types of use, and availability.

Detailed Design: Collect more information regarding the selected source(s); verify capacity, quality and reliability of the source. Detailed design will also include appropriate water catchment structures, water storage facilities, and water conveyance/distribution systems for each source.

2.2.2 DESIGN CRITERIA

Potential water sources are listed below in order of desirability, based on expected water quality and ability to protect sources from contamination. The desirability/suitability of water sources will be site specific.

1. Municipal water supply (piped water supply)—not available in all situations but if the source is reliable and affordable than could be considered.
2. Drilled wells, existing or new future wells—recommendations for a well location can be made but a professional driller will be required to determine optimum location and cost.
3. Shallow/dug wells—EMI would like make a recommendation of the location and make recommendations to the maintenance team of how deep to dig the well.
4. Springs—naturally clean water that should be contained to prevent contamination from exposure to the environment.
5. Surface water—a stream or lake that could be used but would likely need treatment because of exposure to the environment.
6. Rainwater harvesting—collected from the rooftops, would require further treatment and analysis of rainwater data, see Section ***2.3*** ***Rainwater Harvesting*** for more information.

7. Greywater reuse—water that has not been in contact with human waste that can be treated for reuses, see Section ***2.4*** ***Greywater Separation and Reuse*** for more information.

The table below shows the suitability of a water source for the intended water use.

Table 2.2-1 Water Source Suitability

Water use	Water source					
	Surface Water (Untreated)	Surface Water (treated)	Groundwater (springs, wells)	Rainwater (without first flush diversion)	Rainwater (after first flush)	Greywater
Drinking	X	A	A^2	X	A^4	X
Cooking	X	A	A^2	X	A^4	X
Bathing	A^1	U	A	A^3	A	X
Irrigation (Agriculture)	A	U	A	A	A	A
Toilet flushing	A	U	A	A	A	A
Note: A = Appropriate, U = Unnecessarily expensive, X = Inappropriate						

Source: Mihelcic, James R., et al., 2009

Notes:

[1] Untreated surface water may not be suitable for bathing if it has schistosomiasis (worms that can infect humans through water contact). This is common in Africa and also found in some areas of the Middle East, Asia and the Caribbean.

[2] Untreated groundwater may not be suitable for drinking or cooking (especially water from springs if not properly developed and protected). Groundwater needs to be tested because it can be contaminated in some cases.

[3] Rainwater without first flush diversion can be too dirty for bathing and may need some minimal treatment.

[4] Rainwater, even after first flush, may not be suitable for drinking or cooking depending on where and how it is collected. For example, roof rainwater can carry dissolved bird waste products and chemicals or particles from the roofing material. Ideally, rainwater should be disinfected prior to drinking and cooking use.

Simple water source data gathering can be performed to measure the following characteristics:

- Flow rate: using a bucket and watch
- Quality: looking at a sample in a glass jar for how clear the water is and if it has any smell
- Reliability: asking local maintenance staff/local residents

The criteria listed below should be considered when comparing water sources:

1. **Quantity**: The minimum quantity of water available at the source should be sufficient to meet present and future demand, including seasonal variation in water demand and supply capacity.
2. **Quality**: The source of water should meet the applicable quality standards for the intended use. If not, determine level of treatment needed treat the source to water quality standard up to the intended use (See Section ***2.5*** ***Water Quality Testing*** for further information on water quality testing.)

3. **Cost**: The capital as well as the operation and maintenance costs of the source should be acceptable to the ministry. And if needed complete a cost benefit analysis to compare viable options, see the ***EMI General Treatment Matrix Template*** for guidance.
4. **Technology**: Verify that the ministry has the appropriate technology (equipment, power, treatment chemicals, etc.) and expertise to operate and maintain the water source and associated water treatment and transmission facilities. Compare the relative demands for operation and maintenance of each viable source.
5. **Protection**: The water source must be protected from present and future pollution and contamination. Determine the vulnerability of each viable source to future changes including groundwater depletion, weather pattern changes (longer dry season, heavier storms), future development in the watershed for the source, etc. Include a setback distance of 30 meters and uphill from septic tanks, soak pits, property lines, livestock and animals and the water source, see ***Table 4.3-6 Setback Distance Between Septic Tanks and Nearby Features*** and ***Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features*** for more information.

Table 2.2-2 Setback Distances for Well Protection

Subsurface Sewage Treatment System (SSTS) Component	Well	
	(m)	(ft.)
Buried sewer pipe	15	50
Cesspool	45	150
Greywater dispersal area	30	100
Holding tank	15	50
Leaching/seepage pit, dry well	30	100
Privy	30	100
Seepage land application site	30	100
Septic tank	15	50
Subsurface dispersal field	30	100
Subsurface dispersal field serving a facility with infectious or pathological wastes	90	300
Watertight sand filter, peat filter, constructed wetland	15	50
Disposal area for water treatment backwash	30	100
Source: Minnesota Protection Control Agency, 2010, pg. 2		

6. **Proximity:** Consider the proximity of the water source to the facility location including distance and elevation. Land ownership, water rights, regulatory requirements, and other water source demands need to be considered.

7. **Reliability:** The water source needs to be reliable for the water demand that is required and sustainable long term. Any equipment and infrastructure required needs to be considered including pumping and availability of electricity.

The following resources and tools are to be used in selecting the water source:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water supply source selection process.
- References and additional resources can be found in ***R2.2*** ***Water Supply Source Selection***.
- The ***EMI General Treatment Matrix Template*** can be used to determine a cost benefit analysis if treatment is required for the water source.

2.2.3 DESIGN PROCEDURE

Step 1: Complete and review Section ***2.1*** ***Water Demand Estimate***.

Step 2: Identify all potential water supply sources at, or near, the project site. Consider all of the sources listed under ***2.2.2*** Design Criteria. Eliminate any that are not present or practical to use at the site.

Step 3: Collect sufficient information about each of the viable water sources at the project site, including the likely minimum capacity (including seasonal variations) of the system, the expected quality of the water, reliability, and the capital and operating cost of each viable source.

Step 4: Ask the ministry, or local well drillers, if there are any well drilling reports available for wells drilled at or near the site. Review the report, and any anecdotal information about the performance of nearby wells, to estimate the potential depth to groundwater, well yield, and water quality for any possible new proposed wells.

Step 5: Determine the suitability of each source for the intended use of the water. Consult ***Table 2.2-1 Water Source Suitability***.

Step 6: Compare each viable source with the other options based on the criteria listed under Design Criteria.

Step 7: For wells, surface waters and springs, examine the required minimum setback distances to ensure the water source (and if applicable, a replacement source) can be located on the project site in accordance with these recommended setback distances see ***Table 4.3-6 Setback Distance Between Septic Tanks and Nearby Features*** and ***Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features*****.**

Step 8: Consider the five criteria and appropriate setback distances, select at least one primary water source and one secondary water source. Multiple source may be specified for different water uses (e.g. rainwater harvesting for cleaning, and a well for drinking). Document the selection process.

Step 9: If an existing well will be used as a source, review the well testing report to ensure the sustainable yield of the well is great enough to supply the maximum water demand with the well pump running less than 12 hours per day (see Section ***2.9 Pump Selection***). The well should recover to its original water depth in less than 12 hours after the pump stops. If the existing well does not have sufficient capacity, propose either a deeper, larger well or a second well. If no well report is available, contact a well driller to perform a pump test on the existing well to determine its capacity.

Step 10: Complete the preliminary design of the selected water source(s), transmission and storage facilities, and overall water distribution system for the site master plan. If new well(s) are proposed, suggest to the ministry partner that the well should be drilled as soon as possible to ensure there is adequate water available and to determine the exact position of the well(s).

2.3 RAINWATER HARVESTING

Note that using rainwater or greywater for drinking water would require additional treatment beyond this section, described in Section ***2.6 Water Treatment***. Rainwater is rarely used for drinking due to the cost and complexity of treating it to a high enough quality to allow for human consumption depending on the local requirements and practices.

2.3.1 DESIGN STAGE

Frequency of Use: Rainwater is not often used to supplement other water supplies, but can be considered where potable water is very difficult or expensive to obtain. However, small, simple rainwater capture systems are commonly used for small amounts of water used for cleaning or irrigation. Rainwater is can be used for potable water but requires extensive treatment and disinfection before they can be made suitable for human consumption.

Conceptual Design: Determine if rainwater capture is needed to meet the water demand of the facility. If so, provide design recommendations for collection, treatment, piping and storage for the system. Before recommending water treatment, ensure the client has the resources and personnel needed to properly monitor and operate the treatment system.

Detailed Design: Refine the calculations for storage and provide a detailed piping design, storage tank(s) and support designs as needed. Design any treatment system recommended.

2.3.2 DESIGN CRITERIA

Determine the desired amount of rainwater storage. Stored rainwater provides water for use during dry periods. The amount of water to be stored can vary from a small amount to supplement other sources, or it can be designed to provide water throughout the year. To provide a year-round source of non-potable water, there must be enough storage to meet the demand during the longest anticipated dry period. The storage volume will depend on the demand for rainwater and the frequency and duration of dry periods in the region. Review historic precipitation records to determine the required storage time, then estimate the storage volume by multiplying by the daily rainwater usage.

Using the ***EMI IDF Analysis Template***, estimate the average storm intensity and duration. This information allows you to calculate the normal rainfall amounts during wet periods. The volume of rainwater available for capture can be calculated by multiplying the normal rainfall amounts by the roof area being used to capture the water, and subtracting the first flush water diverted during each storm even. Ensure there is sufficient roof area to generate the required water retention volume (daily storage volume available equals the net water captured per day minus rainwater used each day) during rainy periods of the year. Situate one or more rainwater storage tanks near the buildings where rainwater is being captured.

In many cases, rainwater is seen as only a supplement to other sources and the roof area for capture is arbitrarily chosen. This roof area multiplied by the rainfall intensity and duration then determines the storage tank volume, assuming the tank will be sized to handle a certain number of large rain events.

Depending on the usage of the rainwater, this section will explain the primary treatment required which can be used for non-potable uses. If rainwater is intended for drinking use, then the treatment provided is preliminary and Section ***2.6 Water Treatment*** would be required.

Rainwater draining off of a roof or other hard surfaces often contains large amounts of contaminants during the first few minutes of flow. This "first flush" rainwater will contain dust, leaves, bird droppings, and other material. Most systems have a mechanism to collect this first flush water and dispose of it after the storm is over. The first flush volume should be 0.2 l per m^2 of capture area. The first flush volume is typically diverted into a tee that directs the water to a storage device, (tank or large diameter pipe). Once the storage device is full, water is directed to the rainwater storage tank for use. The retained first flush is then disposed of onto the ground by manually opening a drain valve or by using a small drain hole drilled in the bottom of the tank or pipe.

Considerations:

- Rainwater from a roof should be estimated and the first collection of rainwater should be purged due to the solids collected. See Figure 1 for an example of a First Flush Tee Device. Note that rainwater collection requires a solids trap for debris such as leaves, dirt, bird waste, or anything else that is on the roof from which the water is being collected, see Section ***2.4 Greywater Separation and Reuse***. The first flush bypass will remove some of this material but the solids trap will remove any that remain.

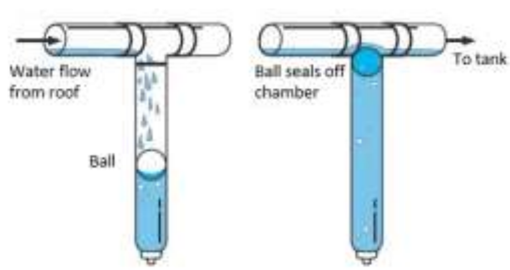


Figure 2.3-1 First Flush Tee Device

- Rainwater collection systems require gutters, first flush diversion devices, screens, and piping from the roofs to the storage tanks. If underground piping is used, a sand trap can be installed prior to the holding tank.
- In some cases, the water can be used for higher quality uses after treatment, disinfection, and distribution. In those cases, the water is filtered and disinfection occurs, usually by chlorine addition, in addition to treated water storage and distribution. Following the secondary treatment, the rainwater could be stored with additional source water.
- See a proposed treatment system in Figure 2. Be aware that this kind of treatment system requires well trained operators, consumable chemicals and supplies, reliable electricity, and proper operation and monitoring to ensure the water is safe for human consumption. Many organizations in developing countries cannot provide

these resources and thus **treating rainwater to drinking water quality is usually not appropriate.**

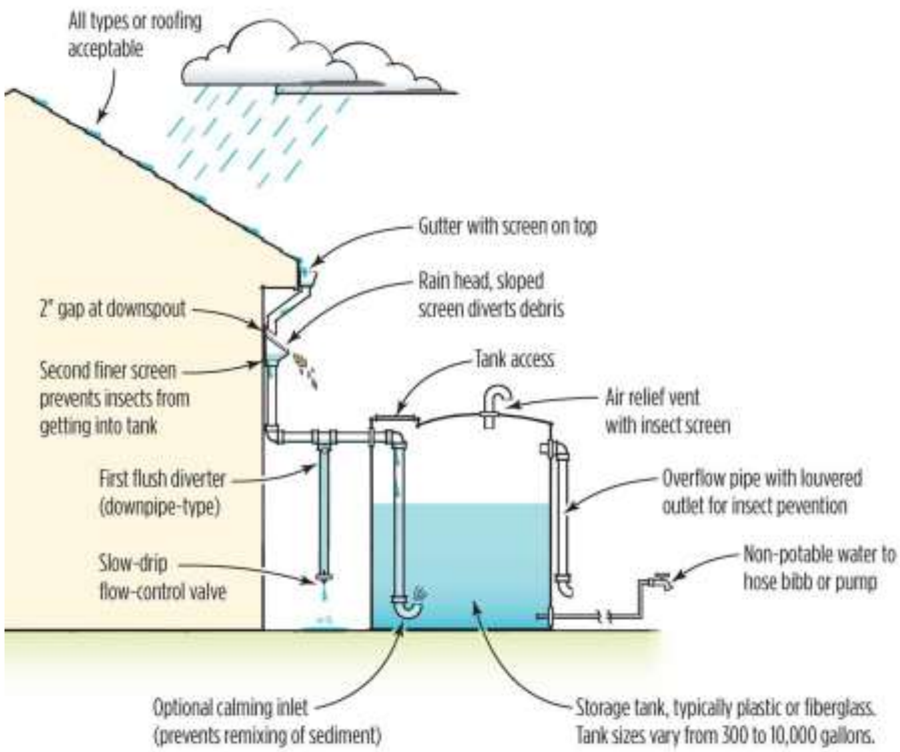


Figure 2.3-2 Example Rainwater Catchment System

Source: https://www.watercache.com/rainwater/residential

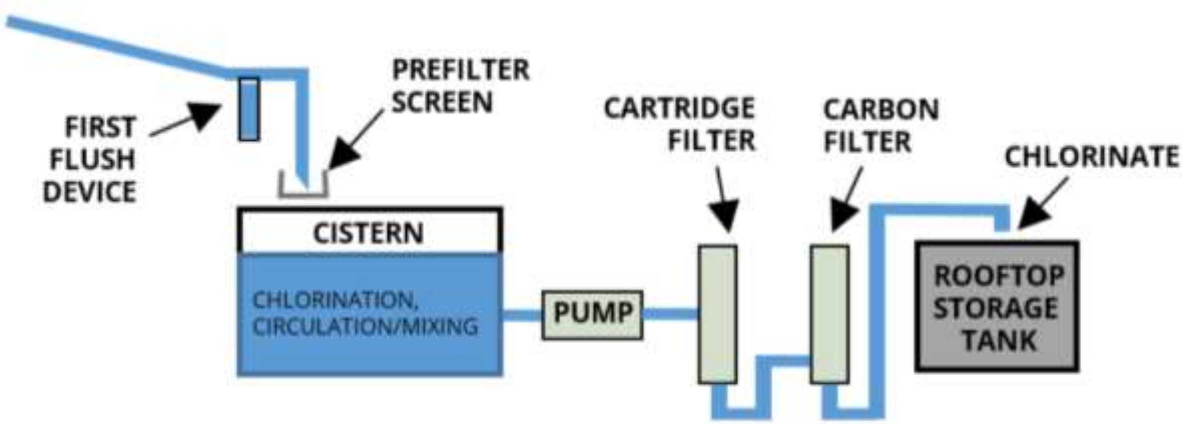


Figure 2.3-3 Example Rainwater Treatment Process

The following resources and tools are to be used in developing the water demand estimate:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can guide the conversation of using rainwater harvesting.
- References and additional resources can be found in ***R2.3*** ***Rainwater Harvesting***.

- The ***EMI IDF Analysis Template*** can be used to determine the rainfall data for the region.
- The ***EMI Rainwater Harvesting Template*** can be used to calculate the roof area and storage requirements for rainwater harvesting.
- More treatment options, visit the ***Akvopedia Water Portal and select Rainwater Harvesting.***

2.3.3 DESIGN PROCEDURE

Step 1: Calculate the rainwater runoff area needed based on the required storage volume and the ***EMI IDF Analysis Template***, and then determine the required roof area using the ***EMI Rainwater Harvesting Template***.

Step 2: Design a first-flush device and solids trap for the system. Ensure the water volume captured by the system is adjusted for the amount of water wasted by the first flush diverter like the one shown in ***Figure 2.3-1***.

Step 3: Design a storage tank system to hold the anticipated volume. Based on water quality testing (Section ***2.6 Water Treatment***) when treatment is needed, determine level of treatment based on the intended use—non-potable or drinking water. Identify technically suitable treatment alternatives. During detailed design, select the proposed treatment system to achieve these water quality criteria.

Step 4: Design the piping, tanks and supports for rainwater collection, treatment and distribution. Ensure there are no cross-connections between potable and non-potable water systems.

Step 5: Develop design report including figures/drawings, construction/installation instructions, O&M requirements, and cost estimate as needed.

2.4 GREYWATER SEPARATION AND REUSE

Greywater refers to wastewater from laundry tubs, showers, hand basins and baths. It excludes wastewater from a kitchen, toilet, urinal or bidet. Greywater is not directly contaminated by fecal material or other sources of human pathogens. Because the water does not come into contact with human waste, it is as low strength wastewater with much lower concentrations of BOD, nutrients and pathogens compared to sewage from toilet wastewater (blackwater). Greywater, if it is segregated from blackwater, can either be disposed of by soil absorption systems or reused for a non-potable use on site. In this section, greywater separation will be discussed.

2.4.1 DESIGN STAGE

Frequency of Use: Greywater is not often used to supplement other water supplies, but can be considered where potable water is very difficult or expensive to obtain and if supplemental water is required for site gardens. Separate collection and disposal of greywater is fairly common where this approach can reduce the cost of septic tanks enough to justify the additional complexity of the sewer system.

Conceptual Design: Determine if greywater is needed to meet the water demand of the facility. If so, provide design recommendations for collection, treatment, piping, storage for the system, distribution to irrigation for gardens and outlet designs such as free-flow to mulch, concealed flow within rocks or subsurface infiltration gallery. Before recommending water treatment, ensure the client has the resources and personnel needed to properly monitor and operate the treatment system. For greywater disposal only, design the necessary sewer piping and related features.

Detailed Design: Refine the calculations for storage and provide a detailed piping design. Design any treatment system recommended.

2.4.2 DESIGN CRITERIA

In an effort to reduce the demand on the potable water supply, or in an area with an unreliable water source, greywater reuse may be considered. Reuse of greywater can be recommended, but to be accepted by the end user, there must be considerations beyond engineering judgement. Clients must be aware of the operational requirements to use either system successfully. Treated greywater can be used for various non-potable uses like surface cleaning (floors, sidewalks, walls), vehicle cleaning, laundry, animal care, irrigation, toilet flushing (manual pour flush or cistern flush if suitable infrastructure exists to pipe pressurized greywater to toilets). It is not recommended that greywater be reused for drinking water.

In many cases, greywater is not needed to supplement the potable water supply so it can be disposed of along with black water from toilets and kitchens. Since greywater usually does not contain large amounts of solids or organic material, it can be discharged to the on-site wastewater disposal system without pretreatment in septic tanks. This requires designing separate sewers to collect the greywater and direct it to the absorption system's distribution box, bypassing the septic tank. A sand trap is usually included to remove heavy particles like sand and soil to prevent premature plugging of the absorption system.

Risks of using greywater

- Human health – Large numbers of disease causing organisms can be present in greywater. These organisms may include bacteria, viruses and protozoa among others. Transmission of these organisms can be through ingestion of greywater, aerosols from spray irrigation and contact with contaminated items.
- Environment – Long-term application of greywater containing contaminants can affect sensitive plants and soils. These contaminants may include fats, oils, food scraps, nutrients, salts like sodium and phosphorus, detergents, cleaning products, sunscreens and personal care products.

Before recommending the greywater reuse, the potential appropriate uses of the water should be estimated to ensure there is adequate need for this kind of water. The degree of motivation the ministry partner has to manage and maintain the system should also be assessed since it will require additional commitment to keep the system operational. The benefits as well as potential risks and cost of greywater reuse should be discussed with the client during the master planning effort to determine if this would be a desirable option to pursue further.

Piping and Storage

- Greywater will often contain a sufficient amount of organic matter to cause the water to turn septic rapidly, resulting in odors and unusable water. The system should be sized such that stored water will remain in the tank less than 24 hours to avoid this problem. If the water is not all used by the end of the day, the tank should be emptied. Because of this organic matter, sludge and biofilm can build up in the bottom of the storage tanks, and pipes and pumps can plug quickly, causing operational problems. The cost and complexity of a greywater storage and distribution system should be carefully considered before making such a recommendation.
- For the case of a small facility, a bucket can be placed below an open sink drain and manually transported to the point of use, or a short length of drain pipe can convey the wastewater directly to the point of use (garden plot).
- A dedicated piped system can be used for larger volumes of greywater especially in public places like schools, restaurants and hostels among others. The piped system limits contact between the user and the greywater hence ideal for the protection of health.
- If a client chooses to reuse greywater, a dual-plumbing system would be required that separates the greywater from blackwater. Greywater collection systems should be designed the same way as blackwater collection systems and distribution systems, including long-sweep elbows, cleanout tees and access risers, to prevent plugging and

allow periodic cleaning. Flow-splitter piping, fittings and controls should be designed as required to provide the required greywater flow distribution to irrigated areas. If greywater reuse for toilet flushing is required, tanks and pumping systems should be designed as necessary. However, since greywater contains fewer solids compared to blackwater, sewer diameter can be smaller. The pipes should be a 2% minimum slope because even a small amount of sediment in greywater can cause problems, unless sedimentation is provided for any wastewater discharge.

Treatment

Greywater can be treated to remove substances that may be harmful to plants, human health, or the environment, or may clog the greywater reuse system. It can also help reduce odors and biofilm buildup in storage tanks and piping systems for greywater distribution. Several treatment options and applications are shown in ***Table 2.4-3 Suitable Greywater Reuse Application According To Treatment*** additional treatment techniques are included in the Appendix ***A2.4 Greywater Separation And Reuse***.

Table 2.4-3 Suitable Greywater Reuse Application According To Treatment

TREAMENT	GREYWATER REUSE APPLICATION
Coarsely filtered untreated greywater (excluding kitchen greywater)-greywater diversion device	Sub-soil irrigation Sub-surface irrigation
Treated and disinfected greywater (to a standard of 20mg/l BOD5, 30mg/l SS and 30cfu thermotolerant coliforms/100ml)-greywater treatment system	Sub-soil irrigation Sub-surface irrigation Surface irrigation
Treated and disinfected greywater (to a standard of 20mg/l BOD5, 30mg/l SS and 10cfu thermotolerant coliforms/100ml)-greywater treatment system	Sub-soil irrigation Sub-surface irrigation Surface irrigation Toilet flushing Laundry use

Source: New South Wales, 2000

Solids Trap—Required for Soil Absorption and First Step in Reuse

Greywater requires additional treatment compared to the sources in Section ***2.2 Water Supply Source Selection*** and separate storage from the other sources and treated water. The first level of treatment is a solids trap, shown in ***Figure 2.4-1 Typical Solids Trap***. Greywater may contain soil, sand, or other solids that need to be separated.

The EMI standard detail is a 500mm sump, shown in ***Figure 2.4-2 Standard Solids Trap Detail (For Greywater)***. Using a detention period of 45 seconds, the solids trap is adequate for a flow of 4 l/sec. However, when designing for a larger population with many showers and the greywater is expected to contain a large amount of soil, then the sump would need to be bigger. Zurn Plumbing Products Group recommends recommend a 50 mm diameter inlet pipe and 38 mm diameter outlet pipe. Screens can also be included at the outlet end of the sump to prevent solids from escaping through the outlet pipe into the absorption system.

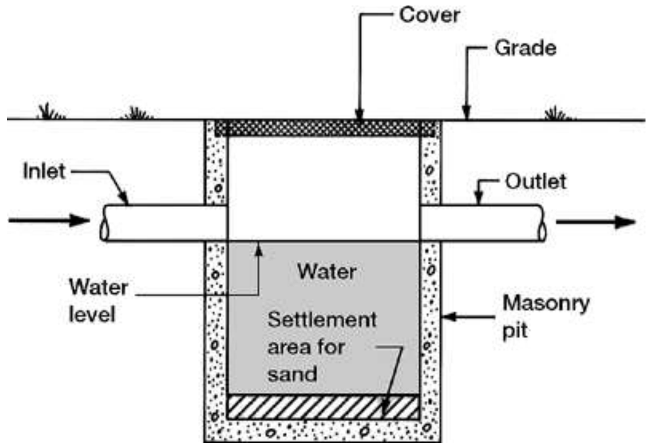


Figure 2.4-1 Typical Solids Trap

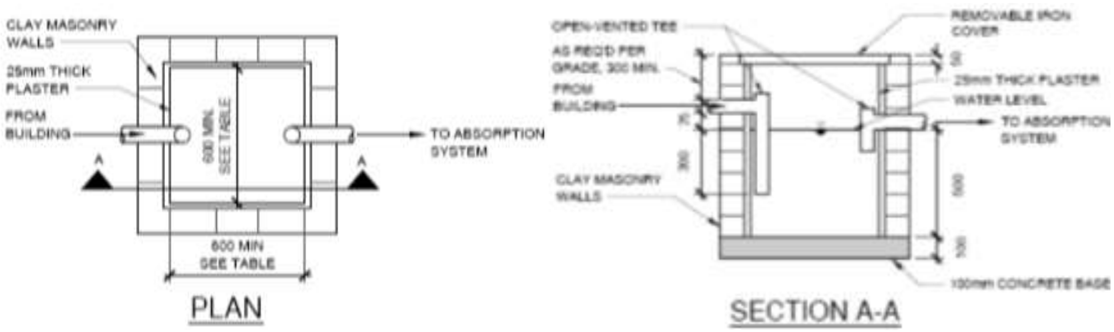


Figure 2.4-2 Standard Solids Trap Detail (For Greywater)

The following resources and tools are to be used in developing the water demand estimate:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water demand estimate.
- Appendix ***A2.4.1 Greywater Treatment Options*** for additional greywater treatment options:
  - Filtration
  - Sedimentation
  - Reed bed filtration
  - Sand filtration
  - An open earthen lagoon
  - Disinfection
  - Solar Distillation Unit

- References and additional resources can be found in ***R2.4*** ***Greywater Separation And Reuse***.
- The ***EMI Water and Wastewater Design Template*** can be used to separate the wastewater streams.

2.4.3 DESIGN PROCEDURE

Greywater Disposal to Absorption Field

Step 1: Identify the greywater streams. These may include wastewater from washing machines, laundry tubs, showers, hand basins and baths.

Step 2: Calculate the greywater volume using the ***EMI Water and Wastewater Design Template***. In the template, columns can be added to quantify greywater and black water (wastewater from kitchen, toilet, and urinal) separately.

Step 3: Design a sewer to collect the greywater and direct it to either a dedicated absorption system or to the system used for disposal of septic tank effluent. Use the volume to design the disposal system. The required setback distances should be incorporated during the process of siting locations for these systems. Refer to Section ***4.3 Septic Tanks*.**

Step 4: Design a solids trap for the system as shown in ***Figure 2.4-1 Typical Solids Trap*** and ***Figure 2.4-2 Standard Solids Trap Detail (For Greywater)***.

Step 5: Design the separate sewer system for greywater. Sewers should be designed with the proper slopes to ensure that the greywater is safely delivered to the absorption system. Refer to the Section ***4.2 Wastewater Conveyance***.

Step 6: Develop design report with drawings, cost estimates and general O&M procedures

Greywater Reuse

Step 1: Identify the greywater streams. These may include wastewater from washing machines, laundry tubs, showers, hand basins and baths.

Step 2: Design a solids trap, or other pre-treatment system as required, for each segment of the collection system as shown in ***Figure 2.4-1 Typical Solids Trap*** and ***Figure 2.4-2 Standard Solids Trap Detail (For Greywater)***.

Step 3: Calculate the greywater volume using the ***EMI Water and Wastewater Design Template***. In the template columns can be added to quantify greywater and black water (wastewater from kitchen, toilet, and urinal) separately.

Step 4: Use the volume to design the treatment and storage system, if one is needed to prepare the water for use, determine level of treatment based on the intended use—sub-surface irrigation, surface irrigation, laundry, toilets, or washing buildings. If greywater is to be used for irrigation, the layout and design of the crops or landscaping should be based on the projected volume of greywater available.

Step 5: Design the separate sewer system to collect greywater for storage and treatment as necessary.

Step 6: Design a treated water distribution system from the treatment system to the point of use. Ensure there is no potential for no cross contamination with the potable water system.

Step 7: Develop design report with drawings, cost estimates and general O&M procedures.

2.5 WATER QUALITY TESTING

Water quality testing may be important to determine if any contaminants are present in the source water or if natural materials are present in high enough concentrations to cause problems with the use of the water. Determining the water quality will inform appropriate water treatment. Note that the EMI Water Quality Test Kits (***Table A 2.5-15 EMI Water Testing Kits Contents***) are limited and the accuracy and precision of these tests is often low and care is needed when assessing the results of the testing. If available, sending water samples to a local laboratory that has an ISO certification would be beneficial.

2.5.1 DESIGN STAGE

Frequency of Use: Most projects with an on-site water supply.

Conceptual Design: Perform testing of all potential and existing water sources to determine the need for water treatment.

Detailed Design: Repeat testing or submit samples for more complete or authoritative analysis to a certified laboratory if a question remains.

2.5.2 DESIGN CRITERIA

Water Sources:

Groundwater

Arsenic and fluoride occur naturally in some groundwater aquifers. Both present a health concern if levels are elevated. Elevated levels of nitrate/nitrite are typically caused by poor quality subsurface sewage disposal practices. They may also result from infiltration of agricultural fertilizers, although this is less common in developing countries where fertilizer use is less common.

Iron and manganese also occur naturally. They are often found together. They do not present a health concern but elevated levels of iron and manganese can make the water unacceptable aesthetically, to the extent that people will not wish to use the source.

Unfortunately, treatment options for arsenic, fluoride, nitrate/nitrite, iron, and manganese can be complicated and expensive. In some cases, a different source of water may need to be used. Refer to section ***2.6 Water Treatment***.

The microbiological quality is a concern for any water, whether groundwater or surface water. Generally speaking, if a groundwater well is drilled to below a confining layer and is properly constructed with a sanitary seal, it should preclude microbiological contamination.

Depending on the well construction, including the well screen, and the aquifer matrix, a well may produce sand, total dissolved solids (TDS), and/or turbidity. These could contribute to making a water undesirable aesthetically, and could also interfere with disinfection, if disinfection was needed.

It is also possible that a groundwater source would have unacceptably high levels of alkalinity and hardness. These are also aesthetic properties.

Surface Waters

The microbiological quality is always a concern for a surface water source, whether a river or lake. This may also be the case for springs. See the specific discussion on springs that follows. A surface source is always vulnerable to microbiological contamination, with levels varying depending on storm events and upstream activities of humans and animals.

The turbidity level of surface waters is a concern. It is not a direct health concern, but has treatment implications. Turbidity will need to be reduced to make a water aesthetically acceptable and to allow disinfection to be more effective. A challenge with measuring turbidity in a surface source is that it may vary significantly seasonally or even daily because of storm events. Measurements of turbidity during a site visit will provide at best a limited understanding of the range and average levels.

Naturally occurring color in a surface water is also a factor to consider. Color may result from organic or inorganic sources. Elevated levels of color may render a water source unacceptable from an aesthetic perspective. Elevated levels of color may also interfere with disinfection if ultraviolet (UV) light is used or may indicate a high chlorine demand. Color could also result from industrial discharges into the water body, which may indicate other contaminants are present as well.

If the location has seasonal variations in climate, it is helpful to know the range of water temperatures. These may impact treatment decisions.

Generally, elevated levels of iron and manganese are not a concern in surface waters, but this is not always true. There may be iron and manganese that accumulate in the streambed, and they may periodically be released into the water column when there are reducing conditions.

Springs

Ideally, a spring is a groundwater source, where the aquifer intersects the ground surface. In this case, it may provide microbiologically safe water. The discussion about groundwater quality would apply. A spring may be influenced by surface water runoff and if so, will not reliably provide microbiologically safe water. The absence of turbidity spikes during storm events can be an indication that the spring is a groundwater source. Another method of determination is temperature—a spring will tend to have a constant temperature throughout the year, such as water from a well will, if it is mostly or solely groundwater.

Parameters:

An explanation of relevant parameters is listed below. First priority should be to research the local water quality standard, as a minimum WHO standards, shown in ***Table A 2.5-14 Global Water Quality*** Standards of Appendix ***A2.5*** ***Water Quality Testing*** should be followed. The USEPA and other national standards in this appendix may not be directly applicable in most cases but might be useful for comparison.

pH

While there is no health-based guideline, pH is important for all water sources because it reflects the acidity of the water, which can cause scaling or corrosion in the distribution system. Additionally, chlorine disinfection of water becomes less effective at higher pH. In general, the pH should be below 8.0 for effective chlorination. The WHO recommends a pH between 6.5—8.5 but an exact pH should be determined based on the composition of the water and construction materials used in the water distribution system (WHO Guidelines 2017, pg. 227).

Microbiological

Microbial quality presents the greatest health risks for consumers of all potential contaminants in drinking water. Microbiological contaminates can cause various health issues, such as gastrointestinal illnesses, if consumed. Infants, elderly, and immunocompromised individuals are at even higher risk for developing serious health concerns from contaminated drinking water consumption. Typically, as water seeps into the ground, microbiological contaminants are filtered and removed by microorganisms in the soil as water returns to underground aquifers. However, ground water can still contain microbiological contaminants even at significant depth. Leaks in well piping or improper disposal of wastewater can also introduce microbiological contaminants into ground water source. Groundwater can also be contaminated once removed from the ground by improperly built storage tanks or cross contamination. Therefore, it is essential that ground water be tested for microbiological contaminants at the time of drilling, tested on a regular basis as the water is being used, and treated as necessary to sanitize the water.

Total coliform, are used to indicate the presence of bacteria in a water sample and the general cleanliness of the water. Some coliforms have a fecal origin but other coliforms can originate from the environment. As a result, the presence of total coliform does not necessarily indicate the presence of fecal contamination or microbiological pathogens. Therefore, the count of total coliforms in a sample of water from a tap is used to determine if bacteria may be entering or growing in the system.

Colitag, and other similar presence/absence microbiological provide information only about the presence of bacteria, not the count of bacteria present. Other microbiological tests, including Easy Gel, Pertifilm and AquaGenx methods, can be used to obtain a total coliform colony count. The presence/absence test can also be used to determine if fecal coliforms, specifically the indicator organism *Escherichia coli (E. coli)*, are present. *E. coli* is a type of fecal coliform found in human and animal feces. Some strains of E. coli cause diarrhea. An illustration of the relationship between these different measurement parameters is shown in ***Figure 2.5-1 Microbiological Contaminants Relationship Flow Chart***. The presence of *E. coli* in a water sample is the best evidence of fecal contamination in the water system and suggests the water must be treated appropriately possible microbiological pathogens (WHO Guidelines 2017, pg. 57).

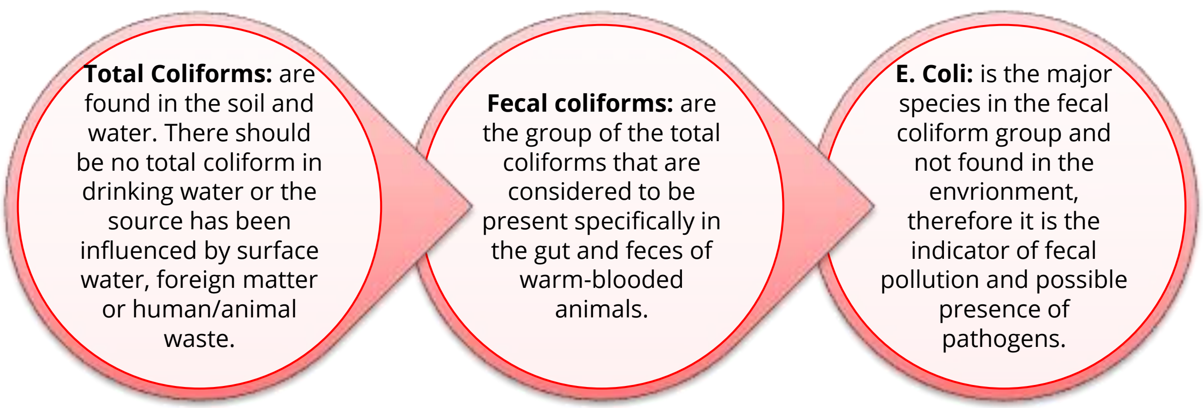


Figure 2.5-1 Microbiological Contaminants Relationship Flow Chart

Source: WHO Guidelines 2017, pg. 295 & New York State Department of Health, 2004.

Types of Microbiological Contaminants

Bacteria: Single-celled organisms lacking well-defined nuclear membranes and other specialized functional cell parts which reproduce by cell division or spores. Bacteria may be free-living organisms or parasites. Bacteria (along with fungi) are decomposers that break down the wastes and bodies of dead organisms, making their components available for reuse. Bacterial cells range from about 1 to 10 microns in length and from 0.2 to 1 micron in width. They exist almost everywhere on earth. Some bacteria are helpful to humans, while others are harmful. Bacteria are easily treated by filtration or disinfection.

Viruses: Parasitic infectious microbes, composed almost entirely of protein and nucleic acids, which can cause disease(s) in humans. Viruses can reproduce only within living cells. They are 0.004 to 0.1 microns in size, which is about 100 times smaller than bacteria. Most viruses can be treated by disinfection. Most water filters do not remove viruses but some special types of filters are designed to remove viruses as well as bacteria.

Protozoa: Capsules or protective sacs are produced by many protozoans (as well as some bacteria and algae) as preparation for entering a resting or a specialized reproductive stage. Similar to spores, cysts tend to be more resistant to destruction by disinfection. Fortunately, protozoan cysts are typically 2 to 50 microns in diameter and can be removed from water by fine filtration. The most common types of protozoa in drinking water are giardia and cryptosporidium. Protozoa are infectious at small numbers and resistant to chlorine, but easily removed by filtration methods with a pore size small enough to eliminate them (Water Quality Association).

Turbidity

Turbidity, or cloudiness, of water is an important physical parameter to maintain in a potable water system. Turbidity accounts for the suspended solids such as clay, silt, and other organic matter in a water source. Turbidity can be tested by shining a light through a water sample and measuring how much light is scattered by the suspended particles. The more light that is scattered, the higher the turbidity of the water. The standard for turbidity is 4 Nephelometric Turbidity Unit (NTU) while disinfection requires at least 0.5 NTU, but averaging 0.2 NTU or less to be disinfect successfully (WHO Guidelines 2017, pg. 285). While turbidity is not necessarily a health concern itself, particles in the water can shield pathogens from chlorine and prevent them from being inactivated. This increases chlorine demand, the total amount of chlorine needed to maintain the target residual, and can also cause sedimentation in the tanks and pipes. Highly turbid water entering small filter membranes, such as reverse osmosis (RO) units, can overwhelm and damage the fragile internal membranes resulting in more operation and maintenance costs. For these reasons, it is most often necessary to reduce the turbidity in water before it begins other treatment or enters into a distribution system. The most common method of turbidity treatment found locally is sand filters or sedimentation basins.

Turbidity can be measured in the field using an electronic turbidimeter. Other methods, such as a secchi disk, use a visual method estimate turbidity

Total Dissolved Solids (TDS)

TDS is another physical parameter of water that refers to the dissolved salts, ions and other molecules dissolved in water. Testing for TDS provides information only on the amount of dissolved solids in the water, and not the type of them. While there is no health-based guideline for TDS, the palatability of water less than 600 mg/L is considered good while above 1,000 mg/L becomes increasingly unpalatable (WHO Guidelines 2017, pg. 285). Elevated TDS levels can cause the water to be more corrosive and damage water piping or contain a “brackish taste.” The U.S. Geological Survey states that most of the dissolve solids include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica which can form salt compounds in the water (USGS, 2020). The dissolved ions that result in a high TDS value can include ions such as nitrates, lead, and copper, which present their own health risks (Oram, 2020). TDS is measured in the field using electronic meters that use the conductivity of the water as a surrogate for the amount of dissolved material.

Chlorine Residual

Microbiological contaminants can be treated in a water system using chlorine. The chlorine dose must be calculated to treat all microorganisms and maintain an adequate chlorine residual in the system to ensure the distribution system piping remains clean. Additionally, chlorine requires a calculated contact time related to the volume and flow to treat all water. Since chlorine will be “used up” to treat contaminants in the water, one can determine if sufficient chlorine is being added to the water by testing for residual free chlorine. If adequate free chlorine residual is present, it can be concluded that all the microbiological pathogens in the sample have been eliminated since chlorine remains in excess. A free chlorine residual of 0.2-0.5 mg/L upon receipt by the consumer should be maintained to ensure no microbiological contamination in the distribution system (WHO Guidelines 2017, pg. 141). If water is clear (less than 10 NTU) then the chlorine dose should be 2 mg/L and if the water is turbid (above 10 NTU) then the dose should be approximately 4 mg/L (WHO Guidelines 2017, pg. 141).

Equation 2.5-1 Residual Chlorine Calculation

$$Chlorine\ Dose - Chlorine\ Demand = Residual\ Chlorine$$

Chlorine residual can be tested for using test strips, manual color wheels or digital colorimeters. For test strips the strips are placed in the sample of water and then removed. The color which appears on the strip after a certain time has passed is then compared to the chart on the side of the test stripe bottle, the hue is associated with a chlorine residual. A more accurate testing method is a manual color wheel. For the color wheel test a sample is collected in a test tube and a powdered reagent is added. The chlorine in the sample water reacts with the reagent and changes color, the color of the water is compared to a color wheel using a holder/viewing device, the matching color on the wheel is the chlorine value. A digital color meter works the same way as the color wheel except the color value is read optically by the meter instead of manually by eye.

Nitrate/Nitrite

Nitrate (NO_3) concentration is a physical property of water. High nitrate concentrations are common in ground water sources, especially in rural areas. Consumption of nitrates can pose serious health risks for infants by causing methemoglobinemia, also known as “blue-baby” syndrome. Due to its impacts on infant health, the standard maximum permissible limit for nitrates in drinking water is 50 mg/L as NO_3 (WHO Guidelines 2017, pg. 183,196). Note to convert from units of nitrogen (NO3-N) to nitrate (NO3), multiple the value by 4.427. A typical cause of high nitrate concentration in ground water is from fertilizer and wastewater. The presence of nitrates in water can also be indicative of other contaminants including microbiological contaminants and pesticides in the water.

Nitrite (NO_2) can be chemically reduced from nitrate and nitrite can be chemically oxidized to form nitrate depending on the nitrifying bacteria found in the soil. Nitrite can cause additional health implications for adults if consumed. However, if nitrate levels are maintained to be below the standard of 3 mg/L as NO_2, the health risks of nitrite are mitigated (WHO Guidelines 2017, pg. 183).

Nitrate testing in the field can be done using test strips, color wheels, or electronic colorimeters.

Total Hardness

Hardness is the amount of calcium and magnesium or other dissolved minerals in the water. Especially with groundwater there can be high hardness. The USGS guidelines for classification of waters are: 0 to 60 mg/L (milligrams per liter) as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard (USGS, 2021). Depending on the hardness of water, corrosion can be determined. The Langelier Saturation Index (LSI) can be used to determine the solution's ability to dissolve or deposit calcium carbonate based on pH, temperature, calcium hardness, total alkalinity, and total dissolved solids. See ***Equation A2.5-2 Langelier Saturation Index*** for the calculation information.

Office Test Kits

Each office may have different test kits, however the US office has a relationship with Hach Company in Colorado that manufactures and distributes most of the products in the EMI Test Kits, contents are shown in ***Table A 2.5-15 EMI Water Testing Kits Contents***.

If an office requires any tests, contact the WASH coordinator, Jason Chandler.

Many of the tests are very low tech, especially the test strips, and are a good indicator if there is a serious concern. More precise measurements should be taken if there is a parameter of concern. Due to the complexity of water quality standards, and EMI's limited analytical tests, which only give a rough indictor of water safety, EMI is not capable of determining if a given water system is safe to drink. EMI personnel should refrain from stating that a water supply is safe based on the field tests performed. Even if the tests performed did not identify a problem, the water could become contaminated during storage or use, or parameters that were not tested could make the water unfit for human consumption (a common example of this is fluoride, which is difficult to analyze in the field but is a common contaminant of groundwater in Africa).

The following resources and tools are to be used for water quality testing:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the strategy for water quality testing on site.
- ***Table A 2.5-14 Global Water Quality*** Standards shown in Appendix ***A2.5 Water Quality Testing*** provides a list of water quality parameter guidelines from WHO and USPEA in addition to a brief explanation the health concerns.

- ***Equation A2.5-2 Langelier Saturation Index*** shown in Appendix ***A2.5*** ***Water Quality Testing*** provides details on how to calculate corrosivity in water.
- ***Table A 2.5-15 EMI Water Testing Kits Contents*** shown in Appendix ***A2.5*** ***Water Quality Testing*** provides a list of the testing supplies EMI typically uses.
- References and additional resources can be found in ***R2.5*** ***Water Quality Testing***.
- The ***EMI Water Quality Testing Field Packet*** provides information that is relevant for field work and can be easily printed. The following is provided:
  - Water Quality Testing Packet List that can be modified to meet project needs.
  - Water Quality Testing form that can be modified and printed to document water quality testing results in the field. These forms should be scanned upon returning from the project trip as a way to log the water quality testing done in the field.
  - Water Quality Testing Procedures that include instructions and pictures for the EMI test kits.
- The ***EMI Water Quality Testing Results Template*** provides a template to log field results from the project trip and compare to WHO or national water quality standards.

2.5.3 DESIGN PROCEDURE

Step 1: Review the client questionnaire to determine if any water quality testing has been done previously and if there are any parameters of concern and how many testing sites are present.

Step 2: Use the packing checklist to prepare for your project trip and print enough water sampling forms.

Step 3: During project trip collect water samples, conduct the appropriate water quality tests, and record results in the water sampling form. If there is a parameter with results high enough to be of concern, look into a local ISO certified lab to do further testing.

Step 4: Compile results in the ***EMI Water Quality Testing Results Template***.

2.6 WATER TREATMENT

The need for water treatment will depend on the quality and consistency of the water supply as well as the quality of the design, operation, and maintenance of the distribution system. Due to the unreliability of field bacterial testing results, and the fact that EMI is not involved with ongoing testing, maintenance or and monitoring programs for client ministries after the design or construction is complete, EMI typically suggests that drinking water should be treated even if the original source testing results (if such testing was done during the design phase) indicated no contamination was present. Such treatment can involve centralized treatment of the source or point-of-use treatment of only the water used for drinking or cooking. If initial testing indicates the source is known to be contaminated, of likely to become contaminated in the future, a water treatment system should be included in the project design.

When designing a water system, consult local sources to determine if there are any regional regulations in effect that govern design, installation, and testing of water supply, treatment or distribution systems.

2.6.1 DESIGN STAGE

Frequency of Use: Most projects with an on-site water supply.

Conceptual Design: Determine the need for treatment of water at the source. If source treatment is needed, research locally available water treatment options and make recommendations. This may involve visits to nearby facilities and discussions with local vendors. If only point-of-use treatment is being suggest, provide several locally-available options that the client can implement. Consider local acceptability of water treatment options before making recommendations. For example, some cultures will not drink water with the taste of chlorine or water that has been boiled. If centralized treatment is recommended, prepare a preliminary selection and sizing of the recommended system.

Detailed Design: Conduct further water testing and analyses. For complex treatment schemes, a pilot test of the treatment process may be needed. Reassess the preliminary selection of the treatment approach and verify the sizing of facilities, identification and recommendation of specific equipment, complete the hydraulic design, and possibly prepare detailed construction drawings.

Ensure the client has the financial and personnel resources to operate and maintain such a water treatment system. If there are doubts the client can properly operate and maintain the facility, consider looking for an alternate water source that does not require treatment.

If only point of use treatment is being recommended, no detailed design is required.

2.6.2 DESIGN CRITERIA

The type of source water described in Section ***2.2 Water Supply Source Selection*** and based on the water quality testing results as described in Section ***2.5 Water Quality Testing*** will impact the water treatment design. When the source is a properly constructed deep well, that is regularly tested to show it is free of bacterial commination at the source, and the produced water is regularly tested at several points of use, it may be possible for the client to provide water without treatment. An ongoing testing program is needed to verify the source remains clean and the water throughout the distribution system is clean to ensure the water is safe to drink without treatment. When the quality of the source is poor or unreliable, or the storage or distribution systems are subject to contamination, low pressure, leakage, cross contamination, or poor maintenance, treatment of the water is recommended. Such conditions are very common in developed countries, and thus water supplied by such systems should usually be considered potentially contaminated.

- **Piped municipal source:** Water provided by a government agency may be improperly treated, treatment may be incomplete (inadequate chlorine to keep it clean in the pipeline), or it can be contaminated by dirty water entering the pipe during periods of low water pressure. The primary concern is microbiological contamination. The safest approach it is to provide point-of-entry disinfection or point-of-use disinfection for only the drinking water.
- **Well:** Water from drilled wells may be safe and may not need to be treated if the well was installed properly and the sanitary seal remains in good condition. Ideally, well water should be periodically tested by a qualified laboratory to ensure it remains safe. However, if the quality and integrity of the well is uncertain, or if the well has not been tested to confirm the water is clean, the water should be disinfected before consumption. As noted in Section ***2.5 Water Quality Testing***, water produced from a well may require treatment for other parameters, including arsenic, fluoride, iron, manganese, or nitrates.
- **Surface water (streams, lakes, shallow wells, unknown sources):** Water collected from untreated, natural sources, including surface water and shallow, hand-dug wells, will require treatment for microbiological contaminants and particulate removal. For disinfection to be effective, the sediment and suspended material needs to be removed. Both centralized and household treatment systems can be considered.

Determining Water Treatment System

There are two general categories for water treatment: centralized and point-of-use (POU). Centralized systems may consist of treatment of a water source developed for a facility (e.g., iron and manganese removal treatment for a new well) or may consist of point-of-entry (POE) treatment which is a subset of centralized treatment, for a city supply to a facility. POU treatment may consist of treatment installed for a single faucet or group of faucets (e.g., a kitchen area), or it may consist of installation of household-scale treatment for residences in a facility.

Point of Use Treatment Systems

A POU treatment system should be suggested based on the water quality and needs of the campus. Selecting a system that is locally available and easily trainable is also essential. See Appendix ***A2.6.1*** ***Point of Use Treatment for Low Turbidity Waters*** and Appendix ***A2.6.2*** ***Point***

of Use Treatment for Surface Water for a list of EMI's recommended POU systems. The choice of a POU system is usually up to the client once construction is complete. However, EMI can provide suggested alternatives based on an assessment of locally available systems.

Centralized Treatment Systems

Centralized treatment plants may not be desirable because of the complexity of operation, availability of replacement parts and consumable chemicals, and high potential for contamination if not properly operated or maintained. Some larger clients such as hospitals or universities may utilize a centralized treatment plant since they would have the resources to operate them properly. In order to consider designing centralized treatment for a ministry, the minimum requirements would be a robust a maintenance program with personnel that have the required technical knowledge, a treatment system design that includes components and consumables that can be sourced locally in the event of repairs or replacements, the clients ability to properly maintain and operate the system, and a commitment to ensuring regular and routine testing to ensure treated water is meeting target standards. A matrix of various treatment systems available is a good resource to create if considering a centralized system. If a centralized system is considered, local suppliers should be contacted and supplied with the relevant site-specific water quality information to provide options of treatment equipment available locally. Developing a water treatment matrix can be helpful to see the benefits of each type of system, the ***EMI General Treatment Matrix Template*** is a good start. It might be wise to consult local water engineers or NGOs that provide water treatment systems to get advice on suitable water treatment options, if such exist in the project area.

The following resources and tools are to be used in developing the water storage design:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water treatment design process.
- Appendix ***A2.6.1*** ***Point of Use Treatment for Low Turbidity Waters*** and Appendix ***A2.6.2*** ***Point of Use Treatment for Surface Water*** are helpful researched lists of water treatment.
- References and additional resources can be found in ***R2.6*** ***Water Treatment***.
- An example matrix to compare treatment technologies can be created using the ***EMI General Treatment Matrix Template***. The following information should be researched for each treatment:
    - Methodology
    - Product Examples
    - Advantages and Disadvantages
    - Operational Requirements
    - Capital Cost

- Life Cycle Cost

2.6.3 DESIGN PROCEDURES

Step 1: Review source water Section ***2.2 Water Supply Source Selection*** and the water quality testing results as described in Section ***2.5 Water Quality Testing*.**

Step 2: Determine the campus needs—either POU or centralized.

Step 3: Research locally available technologies and maintenance capabilities of the ministry team.

Step 4: Complete a water treatment using the ***EMI General Treatment Matrix Template*** to determine the best options for satisfying centralized, POU or centralized treatment needs that are sustainable in the local context.

2.7 WATER STORAGE

Water storage design aims to accomplish several goals, including balancing diurnal swing of water demand, providing pressure to a water distribution system, and providing uninterrupted water supply during temporary water source failures. Water storage can also be a factor in the water treatment design process, such as allowing sufficient chlorination contact time, or to allow a water treatment facility to operate at a constant rate, as opposed to matching the fluctuating demand (diurnal swing).

2.7.1 DESIGN STAGE

Frequency of Use: Most EMI projects involving water demand will provide a recommendation for water storage.

Conceptual Design: Determine desired number of days and volume of water storage, size water storage tanks/facilities, and identify water storage locations and elevations within the project area. Determine if facility will be served by a single pressure zone (with multiple reservoirs, if provided, set at the same maximum water level) or if multiple zones will be used. If multiple pressure zones, consider if storage will be provided in each or how storage provided in an upper zone will also serve a lower zone.

Detailed Design: Provide detail drawings on non-standard water storage facilities (vaults, concrete tanks, reservoirs etc.).

2.7.2 DESIGN CRITERIA

An accurate water storage design takes many factors into account. Below are several important considerations in the water storage design process.

Diurnal Swing of Water Demand

Although the water demand is usually calculated in terms of Average Daily Demand, water demand fluctuates throughout the day. It is important to ensure that the water storage provided will act as a sufficient buffer to withstand the increased demand during the peak periods.

The peak flow factor can vary widely depending on the type of facility and the size of the population it is serving. A larger population will typically result in a smaller peak factor, and a smaller population will typically result in a larger peak factor.

The pattern of water demand can also vary depending on the type of facility. For instance, in largely commercial water networks, demand tends to peak in the middle of the day, whereas in general population networks, demand peaks in the morning and evening.

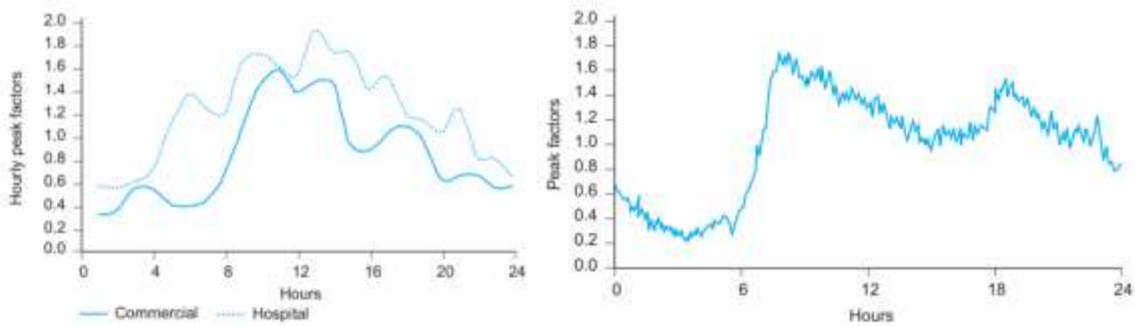


Figure 2.7-1 Example Water Demand Patterns
Left: Commercial/Hospital. Right: City of Amsterdam

Source: Trifunovic, 2006

This is especially considered when a low-volume water source is used to re-supply the on-site water system. It is possible that water pumping or retrieval may be required at night to meet the higher demands of the daytime. In these cases, it is important to supply enough storage to meet these daytime demands.

Irrigation can also create a large peak in water demand. The timing of irrigation will also be an important consideration on the demand from the system. Timing the irrigation to avoid peak demand periods may be crucial in maintaining adequate pressure and supply.

Pressure of Water System

In many EMI designs, elevated water storage provides pressure to a distribution pipe network with little or no need for booster pumps. While not the only factor in determining pressure, the elevation of water storage tanks will play a large role.

For this reason, central water storage facilities are often located at the high end of the site to facilitate pressure by gravity. However, proximity to the water source is also something that should be considered in locating water storage facilities to reduce the length of required piping.

Note that operating pressures will be lower in most developing world settings than in Western countries. An operating pressure at most fixtures of 1-2 bar (approx. 14 to 28 psi) is generally acceptable, and a pressure of 4-5 bar (approx. 56 to 70 psi) is the maximum. It will also be important to think about any water facilities that may need higher water pressure than typical fixtures.

In most designs it is generally preferred to have a single pressure zone. This reduces system complexity and need for additional equipment. However, there may be some cases that multiple pressure zones may be necessary, such as sites with large elevation differences. In these cases, be sure to specify how these pressure changes will occur. While pressure-reducing valves (PRVs) can enable a higher pressure zone to supply a lower zone, they are mechanical devices requiring frequent maintenance to ensure reliable operation. If specifying multiple pressure zones, stress the importance of keeping the pressure zones separate.

Volume of Water Storage Provided

There are many factors that will play into ascribing the actual volume of the water storage provided.

Types of Water Storage to consider

- Operational Storage (volume needed to meet daily demands of site)
- Equalizing Storage (related to the diurnal swing mentioned previously)
- Emergency Storage (need for reserve water in case of failure, discussed more below)
- Fire Suppression Storage (usually not required, check with local requirements)

<u>Consequences of temporary failure in water source</u>

In the event of a failure in the water system, there are several factors to think about when determining the amount of storage-days provided for the site:

- Importance of maintaining uninterrupted supply of water to users (e.g. it is usually more important to maintain supply in a hospital than in a school).
- Reliability of water source(s)
- Number and variety of water sources (design redundancy)
- Availability of qualified technicians for repair

<u>Tank Design</u>

- Unusable storage in water tanks (outlet pipes are usually installed several inches from the bottom of the tank). Typically, this is a 2-5% adjustment, but engineering judgement should be used.
- Pumps that feed water storage tanks often operate on a float switch that will turn on the pump when the water reaches a certain level, meaning that the water storage tanks will often not be full.

Further tank design considerations are discussed below.

Water Storage Tank Design and Appurtenances

When considering materials for the water storage tanks, manufactured plastic water storage tanks are typically recommended on EMI projects. These tanks are usually readily available in most countries, making the replacement and repair of the water storage system much simpler (in most cases).

When considering the quantity of tanks to hold the required volume, a battery of tanks is usually recommended over a single large tank. A battery of tanks allows maintenance or replacement of one of the tanks to occur without disrupting the water supply to the site.

If providing detail drawings, storage tanks should always include:

- Screened vents (with a downturned elbow being ideal)
- Valve drain
- Overflow with a screened outlet or flap valve
- Access hatch.
- Options to consider:
    - If hatch should include a hasp and lock
    - Water level gauge
    - Method of interconnecting tanks to allow for removing one for service/maintenance and to accomplish the desired flow pattern, whether in series or parallel.

Other Considerations

- Existing water storage facilities should be examined for reusability and need for maintenance or improvements.
- Local and regional water storage regulations, practices, and available products should be considered and carefully adhered to where appropriate and safe. In rare cases, local practice (or even code requirements) will require water storage provisions for fire suppression. In this case, consult the local code and engineers for these design provisions.
- Cost implications, both initial and recurring should be considered when proposing solutions. Seek for ways to reduce cost to the client if possible and safe.
- As previously mentioned, water storage can also factor into water quality designs, like allowing sufficient chlorine contact time or allowing a water treatment facility to operate at a constant rate, despite fluctuating demand.
- In some water systems, it may be desirable to only treat water for certain uses. For instance, if a project includes irrigation for crops it may not be necessary (and perhaps less economic) to treat such water. In these cases, it could be advantageous to specify both untreated and treated water storage.
- Provide sample taps upstream and downstream of storage tanks to facilitate water quality measurements.

The following resources and tools are to be used in developing the water storage design:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water storage design.
- References and additional resources can be found in ***R2.7*** ***Water Storage***.

- The ***EMI Water and Wastewater Design Template*** includes a tab for water storage that will link to the water demand for the site. This template allows for the possibility of a single and/or multiple storage locations.

2.7.3 DESIGN PROCEDURE

Step 1: Complete and review information in Client Needs Assessment and Site Evaluation.

Step 2: Determine desired water storage (in days of storage and volume). Include any adjustment factors, such as unusable water volume in tanks, design redundancy, etc. Traditionally EMI has recommended at least two days of reserve water storage as a starting point but may vary based on factors listed in Section ***2.7.2***. Volume required is typically calculated by using the Average Day Demand (ADD) determined in Section ***2.1.Water Demand Estimate***

Step 3: Determine whether water storage will be in a single, centralized location, in several locations, or a combination of both. Determine location(s) of water storage facilities. Evaluate the pressure head that will be provided to determine the desired elevation for storage. Based on this evaluation, determine if a tank stand will be needed and what its base height should be.

Step 4: Determine the quantity and size of tanks, to provide the required storage volume. Coordinate location(s) and space required with architects. Provide detailed design drawings if necessary.

Step 5: Write all assumptions, summarize design, and record results in report. Keep longer calculations and large tables in the Appendices.

2.8 WATER DISTRIBUTION

Water distribution is the system that transports water from the source, through any water storage and treatment facilities, and to all of the various water users at the site. Such systems are designed to provide water at a sufficient pressure to prevent contamination even at the highest expected flow rate. Different methods of calculating peak flows and different assumption about timing of water usage onsite can produce dramatically differing results and engineering judgment is always needed in the design of water distribution systems. The designer must have a very thorough understanding of the fixtures and usage patterns on the site as well as a strong understanding of the benefits and downfalls of the various methods for calculating peak flow.

Other types of water distribution systems may be required depending on the project. These include gravity water pipelines from springs, water for agricultural purposes, or fire-fighting water systems. This section does not cover these types of systems.

2.8.1 DESIGN STAGE

Frequency of Use: Projects that include any water distribution at concept or detailed level of design.

Conceptual Design: Determine the preliminary layout for the main water distribution system. Identify approximate pipe sizes for main pipe loops based on calculated peak flows in the system. Determine the volume, location and height of required tanks and if the water distribution system is gravity flow, or if pumped systems or segments are required.

Detailed Design: Refine the piping system design as the site layout matures. Determine final pipe placement, pipe sizing and type, as well as appurtenances needed, trenching and supports for above grade pipe sections (including elevated pipe stands/towers as applicable). And storage tank height, type and size, see Section ***2.7 Water Storage***. If pumped systems are required, the location, flow rate and pressure, and types of pumps required need to be designed, see Section ***2.9 Pump Selection***. If very high pressures are encountered from collection of spring water high on a mountainside, for example, pressure regulation might be required to reduce the water pressures to safe values—final design should include this as necessary. Prepare construction drawings for installation. For irrigation pipe design, pipe turnouts, gate structures, drop structures, culvert structures and sometimes energy dissipation structures need to be designed.

2.8.2 DESIGN CRITERIA

A looped piping system should be used where feasible, but a branched system may be necessary when the building is confined in an urban setting. Looped systems provide the following advantages over dead-end pipe runs:

- More evenly distributes pressure and flow throughout the system
- Provides redundancy and flexibility, allowing portions of the system to be shut off for maintenance
- Eliminates long, dead-end runs of pipe where water may sit and become stagnant

Because of variable conditions encountered in hydraulic design, it is impractical to specify definite and detailed rules for designing water distribution systems in all cases. In small, simple installations, it is often possible to size pipes based on rules of thumb derived from experience and convention. In more complicated cases, the pipe sizes and system layout shall be designed in accordance with good engineering practice utilizing the methods discussed below.

The information presented below applies to the design of site water distribution systems. While much of the theory can also be applied to the design of building plumbing systems, interior plumbing is not specifically addressed in this section.

Methods for Determining Flow Rates

One of the most critical components of designing a water distribution system is to determine the design flow rates within the system. The designer must assign a flow rate (in liters per second, lps, or liters per minute, lpm) for each building or other discharge point on the site. The designer must use engineering judgment and the methods discussed below to determine flow rates that provide an accurate, conservative design that meets the needs of the water users. It is usually necessary to consider multiple different flow scenarios and ensure that the distribution system can provide adequate service under various combinations of flows.

Peak Factor Method:

- Peak Flow = Average Daily Demand x Peak Factor
- The designer should use the Average Daily Demand based on the ***EMI Water and Wastewater Design Template*** and Water Usage Rates described in ***A2.1*** ***Water Demand Estimate***. An appropriate peak factor for each individual building should be determined. Typical values range from 1.5 to 2 depending on facility type.
- See more detailed about the Peak Flow method in addition to two detailed methods, Fixture Count and Water Service Fixture Unit, in Appendix ***A2.8.1*** ***Detailed Description Of Methods For Determining Flow Rates.***

Minimum Acceptable Pressure

EMI's current design standard is to ensure that common plumbing fixtures, and all points in the water distribution system, maintain a minimum of 2.0-5.0 meters of hydraulic head (residual pressure, static pressure minus pressure losses) under peak flow conditions. Designing to a minimum residual pressure standard is a simple a way to ensure that under peak flow conditions, the distribution system still has a bit of excess capacity and is not too close to failure. Designing for a minimum residual pressure ensures the water pressure is always positive to prevent infiltration of possibly contaminated water into the distribution system, contaminating the water and piping system. Typically, 3.5 m (5 psi) for sinks, low-pressure showers or toilets in single story faciliities with gravity flow in the developing world. An irrigation sprinkler head typically requires about 30 psi (21 m) of pressure, while irrigation drip systems require pressure between 9 and 21 m (10-30 psi).

In many developed countries, the requirements for a high residual pressure is based on the need to be able to provide fire-fighting flows when needed. As this criterion is not applied to most EMI projects in the developing world, there is not a need for a high residual pressure as long as the system is effectively supplying the peak flow rates required and maintains at least 2m of head throughout the system under peak flow conditions. For fire-fighting flows, minimum pressures need to be in accordance with local regulations and are usually much higher, typically 30 to 40 m. When designing a system for firefighting purposes, the larger flow rates needed, as well as the higher pressure, must be take into consideration.

Higher service pressure may be needed if the system is used for irrigation or to meet local regulations. Higher pressure may also be needed if the system will use point-of-use treatment, depending on the type of treatment. However, be careful when recommending minimum residual pressures greater than 2-5m. Piping and pipe fittings in developing countries are often of poor quality and installation practices are often poor, leading to major leakage or system failures where pressure is highest. Water consumption will also increase with higher pressure which would increase water demand and require a larger capacity wastewater disposal system.

Building A Distribution System Model

Designing distribution systems, particularly a looped system, is a complex process. EMI typically uses EPANET software to build a model of the site's distribution system. EPANET allows the entire distribution system to be modeled to determine the effects of varying flow rates, elevations of inlet and outlets and pipe size and material. Such a model allows many parameters to be altered to arrive at the desired 2-5m pressure at all points in the system under the most demanding situation. See Appendix ***A2.8.2*** ***EMI EPANet Guidelines*** for more instructions. Other software for modelling water distribution systems is available, but all require similar inputs from the designer.

The sections above discussed methods for determining the peak flow rates to the buildings, or if a building has multiple water inlet points, the peak flow at each inlet. These flow rates now must be built into a model that accurately represents the water usage patterns on the site. If the peak flow to each building is calculated individually and then each of those is built into the model, you will likely be over-estimating the actual usage on the site. It is unlikely that every building on the site will experience peak flow at the same time. For example, at a boarding school, the peak flow in the dorms might be in the evening when students are showering, while the peak flow in the academic buildings will likely occur during the school day – to model both dorms and academic buildings experiencing peak flow at one time is probably overly conservative.

You must run many different scenarios in your water distribution model. Use the calculated peak flows for each building as a guideline and then use engineering judgment to consider different times of day and different types of usage patterns that will occur on the site. The water distribution system should provide adequate pressures under many different usage and flow conditions. You should also consider unusual situations, such as when parts of the system are shut off for maintenance. If designing for firefighting, evaluate the ability of the system to handle fight-fighting flows from several locations in the system. The minimal pressure should be achieved under all reasonable scenarios

Do not think of the water distribution model as a formula with a single correct answer, but as a tool to help you understand the distribution system; it allows you to experiment with different layouts, pipe sizes, and demand patterns. The optimization of the model and the selection of a final distribution system design will be based on your thorough understanding of water usage patterns on the site and on weighing the pros and cons of the many different design parameters that you experiment with using the model.

Pipe Selection

HDPE PN6 pipe (PN number is a common method of stating the pressure range of a pipe. The table below shows the pressure rating of various types of pipe) is usually specified for underground use, and polypropylene random copolymer (PP-R) or chlorinated polyvinyl chloride (CPVC) for above ground use. Available sizes are listed below. When building the water distribution model, make sure to use the inside diameter of the pipe and use the appropriate friction factor for the pipe material.

Table 2.8-4 Maximum Pressure for Different Pipe Classes

Pressure class	PN	Bar	Metres head	MPa	kPa	Psi
A	3	3	30	0.3	300	45
B	6	6	60	0.6	600	90
C	9	9	90	0.9	900	135
D	12	12	120	1.2	1,200	180
E	15	15	150	1.5	1,500	225
F	18	18	180	1.8	1,800	270
No Class defined	10	10	100	1	1,000	150
No Class defined	16	16	160	1.6	1,600	240
No Class defined	20	20	200	2	2,000	300
No Class defined	25	25	250	2.5	2,500	375

Table 2.8-5 Commonly Available Pipe Sizes

PP-R Pipe	Wall Thickness (mm)							
Size OD (mm)	PN10	Inside diameter	PN16	Inside diameter	PN20	Inside diameter	PN25	Inside diameter
20	1.9	16.2	2.8	14.4	3.4	13.2	4.1	11.8
25	2.3	20.4	3.5	18	4.2	16.6	5.1	14.8
32	2.9	26.2	4.4	23.2	5.4	21.2	6.5	19
40	3.7	32.6	5.5	29	6.7	26.6	8.1	23.8
50	4.6	40.8	6.9	36.2	8.3	33.4	10.1	29.8
63	5.8	51.4	8.6	45.8	10.5	42	12.7	37.6
75	6.8	61.4	10.3	54.4	12.5	50	15.1	44.8
90	8.2	73.6	12.3	65.4	15.0	60	18.1	53.8
110	10.0	90	15.1	79.8	18.3	73.4	22.1	65.8

Source: Simba Pipe (Multiple Industries)

HDPE Pipe	Wall Thickness (mm)							
Size OD (mm)	PN6	Inside diameter	PN10	Inside diameter	PN16	Inside diameter	PN20	Inside diameter
20	1.8	16.4	1.9	16.2	1.9	16.2	0	0
25	1.8	21.4	2.3	20.4	2.3	20.4	3	19
32	1.9	28.2	2.7	26.6	2.9	26.2	3.6	24.8
40	2.3	35.4	2.7	34.6	3.7	32.6	4.5	31
50	2.9	44.2	3.3	43.4	4.6	40.8	5.6	38.8
63	3.6	55.8	4.2	54.6	5.8	51.4	7.1	48.8
75	4.3	66.4	4.5	66	6.8	61.4	8.4	58.2
90	5.1	79.8	5.4	79.2	8.2	73.6	10	70
110	6.3	97.4	6.6	96.8	10	90	12.3	85.4

Source: Gentex Enterprises

Common pipe fittings are also shown in Appendix ***A2.8.3 Pictures Of Different Pipe Fittings***.

Appurtenances

Consider whether the piping system requires any of the appurtenances listed below:

- Isolation valves to facilitate maintenance of pipes by isolating one section from the remainder of the network. Isolation valves are particularly valuable in looped networks. Isolation valves, and valve boxes, should be placed in easy-to-find locations out of roadways or walking paths. They should be located at all major pipe network intersections and along long stretches of pipe.
- Tap stands or manholes for air release or sediment cleanout. On a large distribution system with significant high points and low point in the piping system, consider placing a tap stand at these high and low points. Tap stands at high points will allow air to be released from the system while tap stands at low points will allow sediment to be flushed from the system. High points should have adequately sized combination air release valves and low points should have turnouts with valves for blowoff flushing when needed. Some long reaches of pressure pipelines (increasing slope) may require air/vacuum valves, and long nearly horizontal runs may require air release valves.

- Water meters are needed at key locations in the distribution system to track usage of water and to identify potential leakage points. If a pay-for-use system will be put in place, water meters will be needed at each significant user to track consumption.
- Unless special high-pressure pipe and fittings are specified, break-pressure tanks are needed under certain circumstances when the water supply source or storage tanks are located at a much higher elevation (over 100m this will depend upon the type and pressure rating of the pipe and joints, example steel pipe with butt welded joints can often take higher pressures than HDPE or PVC) than the project site. This situation is common in spring capture systems that utilize a gravity flow pipeline to convey the water to the site. For high pressure long delivery pipelines, water hammer (pulsed water pressure added when a downstream valve is closed) also needs to be considered in the design.

The following resources and tools are to be used in developing the water demand estimate:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the water demand estimate.
- Appendix ***A2.8.1*** ***Detailed Description Of Methods For Determining Flow Rates*** provides alternative calculations for flow rates such as:
  - Peak Factor Method
  - Fixture Count Method
  - Water Service Fixture Unit Method
- Appendix ***A2.8.2*** ***EMI EPANet Guidelines*** offers guidance on the use of EPANET. It is public domain software that is free and available on the internet that can aid in complex looped networks.
- Appendix ***A2.8.3*** ***Pictures Of Different Pipe Fittings*** helps designers identify pipe fittings.
- References and additional resources can be found in ***R2.8*** ***Water Distribution***.
- The ***EMI Pipe and Channel Sizing Template*** uses Manning's Equation to calculate pipe and channels sizing. This is a detailed tool and not used in concept level design.

2.8.3 DESIGN PROCEDURE

Different methods of calculating peak flows and different assumptions about timing of water usage onsite can produce dramatically differing results and engineering judgment is always needed in the design of water distribution systems. The designer must have a very thorough understand of the fixtures and usage patterns on the site as well as a strong understanding of the benefits and downfalls of the various methods for calculating peak flow. Document any assumptions used in this design process.

The following process is recommended in designing site distribution systems:

Step 1: Determine the average daily water demand for each building. See Section ***2.1 Water Demand Estimate*** for information on calculating average daily water demand. If a building is large or complex, multiple water supply locations may be needed. In such cases, estimate the demand at each inlet point.

Step 2: Calculate the peak flow to each building using the peak factor method.

Step 3: Calculate the peak flow to each building using the fixture count method, or other suitable method. Document the method used.

Step 4: Compare the two methods and determine which to use for each building. If there are dramatic differences between the results from the two methods, try to understand where the differences come from and then make an engineering judgment call to determine the design flow.

Step 5: Build an EPANET model of the distribution system. See Appendix ***A2.8.2 EMI EPANet Guidelines*** for more information on using EPANet. On most EMI projects, the pressure in the system is provided by the elevation of the storage tank. Model the system under the scenario where the tank is nearly empty. Do this by setting the elevation of the tank 0.50M above the height of the stand. This ensures that you are modelling the limiting scenario; when the tank is full, pressures will be higher.

Step 6: When building the water distribution model, it is usually acceptable to create one node per building and apply the peak flow for the entire building at that single node. Set the elevation of this node at the elevation of the highest fixture in the building.

Step 7: Run the model under several different scenarios, remembering that it is not likely for all the buildings on the site to experience their peak flows at the same time of day.

Step 8: Once you have a "worst case scenario" that you feel is representative for the design of the distribution system, calculate the total flow in the system by summing all of the flows to the buildings.

Step 9: Use the Water Service Fixture Unit method or LPCD method (as described in the 2018 International Plumbing Code) to determine a peak flow for the entire site. This method assigns a certain number of fixture units to each fixture or group of fixtures per the table in Appendix ***A2.8.1 Detailed Description Of Methods For Determining Flow Rates***.

Step 10: If the WSFU method yields a peak flow that is dramatically higher than your model; you may have underestimated some flow rates. If the WSFU method yields a peak flow that is lower than your model; you are likely overestimating the peak flow rates.

Step 11: Adjust peak flow rates as needed based on engineering judgment and a comparison of the three peak flow calculation methods.

Step 12: Run the model under several different scenarios, changing system parameters to as needed to ensure that the minimum acceptable pressures are maintained. The goal is to have a minimum of 2.0 meters of residual head at the critical fixture (highest elevation fixture) within the building and each node within the system. If you have modeled the entire building as a single node, make sure that the node has a minimum residual pressure of 2.3 meters. Experience on past projects leads to the estimate that about 0.30 meters of head will be lost to friction within the interior building piping system.

Step 13: If the model is producing unacceptably low pressures the following are some ways to increase the pressure in the system:

- Increase sizes of critical pipes. In EPAnet you can view the unit head loss in each pipe and quickly see which pipes might be undersized.
- Add extra loops/connecting pipes into the system.
- Branch the system as early as possible. The pipe coming out of the tank will have the highest flow rate and likely high friction losses. Branch the system early to shorten the distance in which the flow for the entire site is contained in a single pipe.
- Increase the height of the tank stand or add pump station(s) into the system.

Step 14: Update CAD drawings to include the proposed piping system on the Civil Site Layout and include CAD standard details for appurtenances where needed.

Step 15: Determine the regionally appropriate pipe material by contacting vendors or researching online or in country.

Step 16: Use the material cost and CAD drawing to determine a cost estimate, if needed.

2.9 PUMP SELECTION

In some cases, water distribution may be possible to be carried out entirely by gravity. However, in many cases pumps are needed to add sufficient pressure to distribute water to treatment facilities, to water storage tanks, or to fixtures within buildings.

In EMI designs, pumps are most commonly applied in water distribution, so this section will be based on water pump design with some additional attention to pump design in wellbore use. In the event of designing a pump for a liquid other than fresh water, it is important to adapt the process and calculations to the circumstances.

In EMI designs, pumps are most commonly used to transport fresh water to storage tanks (as opposed to pressurizing a distribution system) and the section below reflects this design intent. In the event of designing a pump to pressurize a distribution system or for a liquid other than fresh water, it is important to adapt the process and calculations to the circumstances.

2.9.1 DESIGN STAGE

Frequency of Use: All EMI projects that will require a pump.

Conceptual Design: Identify where pumps will be needed. Identify location and elevation of water supply and elevated water tanks. Define preliminary system curve and identify design operating point. Identify commonly used pump types, pump manufacturers, and pump suppliers for the project location.

Detailed Design: Finalize system curve. Identify preferred and/or optional pump types for identified applications. Final pump selection should be deferred to local pump manufacturers who will recommend the pump to best fit the system curve and conditions.

2.9.2 DESIGN CRITERIA

Aside from the pump sizing, several factors should be considered in the specification and design of a pump:

- Pump and pipe material(s) locally available. Pipe material will change the friction loss through the pipe.
- Duty cycle and pump cycling (see additional information in design procedure)
- Characteristics of fluids being handled
  - Temperature and resulting viscosity and vapor pressure of water
  - Presence of solids in water (may need to take greater care in ensuring that solids don't settle in pipes)
- Materials of construction (consideration of longevity and corrosion resistance)
- Ministry's knowledge/ability to maintain and repair pumps
- Quality and cost

- For well pumps: diameter of submersible pump, depth of setting, available power, pump to waste feature
- Consideration of dual or possibly more pumps for a booster pump system
    - Added redundancy
    - Varying pumping rates

As mentioned above, this section is primarily used for design of fresh water pumps. While not extensive or complete, below are some things to consider when pumping a liquid other than fresh water:

- Temperature and viscosity of liquid
- Presence of suspended solids (e.g. sewage pumps may require macerating or 'trash' pumps)
- Materials needed for certain applications (e.g. seawater systems require stainless steel or bronze components)

Constant Speed vs. Variable Speed

Constant speed pumps operate at one speed, and one power level usage. Depending on the pressure in the system, the pump will operate at a given flow rate. Variable speed pumps, on the other hand, have the capability to use less electricity and slow the speed of the motor. This allows the pump to have varying flow rates within the same pressure range.

For reasons of simplicity, most EMI designs will incorporate the use of a constant speed pump. Variable speed pumps will be a higher up-front investment, but may reduce power use (and therefore power costs). They can also be more adaptable in systems with changing pressure levels. However, variable speed pumps are also more complex and will require higher expertise in maintenance. Therefore, careful consideration of these factors should be taken into account if specifying a variable speed pump.

Solar Pumps

While not often specified, solar powered pumps may also be worth considering in certain circumstances. Here are some factors to consider when deciding if solar pumps may be suitable:

- Solar pumps have a much higher up-front investment.
- Due to the value of the above-ground equipment, solar systems should be carefully guarded. It may only be suitable within walled compounds or areas that can be easily secured.
- Solar pumps will usually have much lower flow rates than pumps using more traditional power sources (~15-20 L/min or 4-5 gal/min)

The following resources and tools are to be used in developing the pump design:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the pump design.
- References and additional resources can be found in ***R2.9*** ***Pump Selection***.
- The ***EMI Pump Design Template*** can be used to input the variables and will help determine the appropriate pipe size and define the system curve.
- For more information about pumps see: ***https://akvopedia.org/wiki/Powered_pumps***

2.9.3 DESIGN PROCEDURE

For Steps 3 through 6, see the ***EMI Pump Design Template*** for calculations.

Step 1: Complete and review information in Client Needs Assessment and Site Evaluation.

Step 2: Determine flow rate required from pump to meet site demands based on results in Section ***2.1 Water Demand Estimate***. It is important to address the duty cycle of the pump. The frequency of pump starts should be limited to reduce wear on the pump and motor. Additionally, when the pump does start, it should be operated for a minimum length of time to allow for cooling after the higher inrush of power for the motor start. The frequency of pump starts and minimum run time depend on the motor size and pump size. The following values provide reasonable targets for 10 hp and smaller motors:

- Operate the pump for no more than 8 hours total each day
- Pump starts: No more than once every 30 minutes
- Minimum pump operating time: 10 minutes

These values generally can be achieved by selecting the appropriate pump size and by considering the operating band in the receiving reservoir. Operating band refers to the conditions in which the pump will start (low level) and when it will stop (high level). Also important to consider is the presence and volume of storage being provided. Larger storage volumes mean that the pump can operate more consistently and at lower flows since the storage acts as a buffer. A smaller storage volume could mean that the pump flow rate will need to be closer to the peak water demand rate.

In well applications, borehole drilling logs and draw-down/build-up tests may indicate the time needed for a borehole/aquifer to recharge before operating the pump again (e.g. every 2 hours of operation requires 1 hour of recharge). If pumps are needed to run for more than 8 hours each day, confirm with pump manufacturers that the pump can run for the hours needed – this is commonly referred to as the "duty cycle".

Step 3: Determine Net Pressure Suction Head Available ($NPSH_A$)

The $NPSH_A$ is the absolute pressure of the liquid (minus the liquid's vapor pressure) at the intake of the pump and can be expressed in units of pressure (kPa/psi) or head (m/ft.). All manufactured pumps should have a Net Pressure Suction Head Required ($NPSH_R$) which is minimum pressure required at the pump intake.

The $NPSH_A$ must be greater than the $NPSH_R$ to avoid cavitation. To be safe, the $NPSH_A$ should either be 10% higher, or 1.5m (4.8ft) higher than the $NPSH_R$ (whichever is greater)[1]. In water applications, the $NPSH_R$ will be not less than 0 ft. or psi (m or kPa).

Step 4: Determine static head and pressure head.

Static head is the vertical difference between two points in the piped system. The pressure head is the difference in pressure between these same two points.

For simplicity, the static head can be taken as the elevation difference between water surface on the suction side (e.g. dynamic water elevation in wellbore for subsurface designs) and elevation of the discharge pipe (e.g. discharge into storage tank).

The pressure head will be the difference in pressure between these two points. As long as neither the water source nor discharge location are pressurized, the pressure head can be taken as zero, as they are both at atmospheric pressure. If one or the other is operating under pressure, units of pressure must be converted to elevation and added (or subtracted) from the elevation difference to calculate total static head.

Step 6: Determine parameters for dynamic head

Unlike the static head and pressure head, the dynamic head will change based on the velocity of the liquid through the system. This variable head is what creates the system curve. The system curve will relate the flow (Q) to the total dynamic head (TDH) within the system. The TDH is the sum of the static head, pressure head, and the dynamic head.

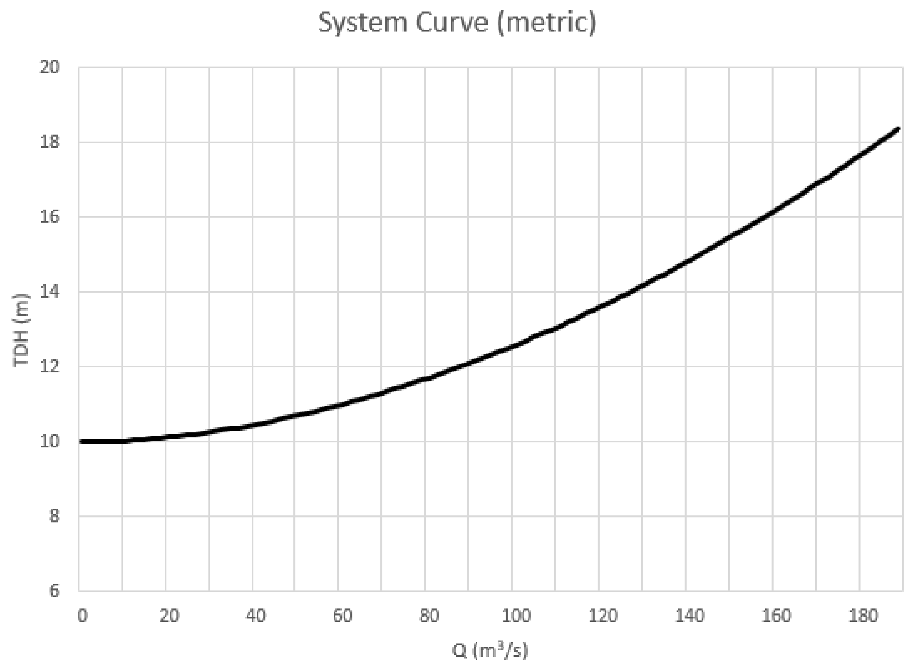


Figure 2.9-1 Example System Curve

The dynamic head will consist of the pipe friction loss, and minor head loss. Aside from the flow rate, the friction loss will be dependent on the pipe diameter, material, and length of piping, as well as characteristics of the fluid being pumped (temperature, viscosity, etc.).

Pipe material should be based on what is locally available and most likely to be used, and length of piping will be determined by what is needed to transport the water to its destination. The diameter of the pipe can be varied to obtain a desirable velocity based on the design flow rate (too low and solids may settle, too high and the friction head will increase exponentially – square of velocity).

The minor head loss is the head loss in the system due to bends, fittings, valves, etc. Each is treated as a "singularity" and assigned a coefficient (K). The sum of the coefficients produces a head loss proportional to the square of velocity.

Based on Step 1, plot your design flow point on the system curve.

Step 7: Write all assumptions, summarize design, and record results in report. This includes the $NPSH_A$ and the system curve (with preferred design point), which the pump manufacturer/contractor will need to select a suitable pump. Keep longer calculations and tables in the Appendices.

Step 8: If needed, once a pump is selected it should be plotted against the system curve and verify the resulting flowrate will meet the site demands and not exceed any maximum flow rates (e.g. in boreholes).

3 Geotechnical

3.1 SOIL CLASSIFICATION

Soil classification is imperative for estimating the on-site soil properties used to predict soil behavior. Soil properties are used to determine the soil's bearing capacity (see Section ***3.2 Bearing Capacity***) when designing foundations and the absorption rate (see Section ***3.3 Soil Absorption Capacity***) used to design certain wastewater treatment systems.

It is important to know the purpose for which the Soil Classification is to be used: Foundation Design, Drainage and Flood Control, Leach Fields, Agricultural Use.

3.1.1 DESIGN STAGE

Frequency of Use: Soil classification should be performed on every project.

Conceptual Design: Soil properties can be estimated based on accepted correlations.

Detailed Design: A soils report from a local geotechnical engineering firm should be obtained to confirm and/or add additional information about the soils' physical and hydraulic properties. A thorough soils report is especially important when designing a foundation deeper than a shallow footing or slab.

3.1.2 DESIGN CRITERIA

There are many different ways to classify soils and each agency/company typically uses their own standard. In this guide, a mix of USDA and USCS sources are used.

Native soils are comprised of various minerals and form three primary categories: coarse grained material, silt, and clay. Most soils are a combination, but the percentage of each is very important when determining the soils' properties.

- Coarse grained materials include cobbles, gravel, and sand. These are the largest of the three components and can be seen with the naked eye. Sand has a gritty feeling when rubbed between two fingers and will not form into a ball. Gravel behaves very similarly to sand, but is larger, passing through a 75mm (3 in) sieve and being retained on a 2.0 mm (No. 10) sieve.
- Silt has a smooth, floury like texture and is "non-plastic" or very slightly plastic.
- Clay feels sticky when moist and displays putty-like properties within a range of water contents. It is considered plastic.

Individual particles of silt and clay cannot be identified with the naked eye. "Fine-grained" material is made up of more than 50% silt and clay particles ("fines") while a "coarse-grained" material is made up of greater than 50% sand particles (ASTM D 2487).

Fill material is imported and used to artificially change the grade or elevation of a property or fill in depressions. It is important to know if fill material is used and whether it has been compacted well or not. Good fill is typically free from organic matter and biological activity and taken from another area of the site where soil is being removed or transported from another site that is leveling an area for construction. However, most fills will have unnatural materials like trash, metal, or brick and have a mottled color due to its make up as a mixture of different colored soil types.

The following can help in identifying native vs fill soils:

1. Presence of buried organic material (stumps, branches, root mass) below the ground surface.
2. Presence of man-made materials: concrete, slag, garbage, debris, etc.
3. Inconsistent soil structure
4. Inconsistent terrain and landforms
5. Misplaced rounded gravel or angular rock formations

Depending on the availability of public information, background research, or a desk study, should be completed prior to every project**.** Desk studies help to identify geologic hazards and determine the scope of a geotechnical investigation. Lists of available resources are provided in the detailed descriptions for each EMI office.

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform where soil characterization should take place on the site during the project trip.
- Appendix ***A3.1.1*** ***Test Procedures Manual Tests*** provides step-by-step instructions for performing various soil classification tests.
- Appendix ***A3.1.2*** ***Additional Information*** provides flow charts, photos, and additional information for classifying soil correctly.
- Appendix ***A3.1.3*** ***Classification Comparison*** provides correlations between USDA and USCS soil classification.
- Appendix ***A3.1.4*** ***Hand Augering/Boring Location*** provides information regarding hand auger use and boring locations.
- References and additional resources can be found in ***R3.1*** ***Soil Classification***.
- ***EMI Soil Testing Field Packet*** can be printed and taken on the project trip to aid in classifying soil and ensure all pertinent information is recorded.

3.1.3 DESIGN PROCEDURES

The following steps are helpful in classifying the soil type:

Step 1: Identify soil texture by performing a manual test, jar test or sieve analysis as described in Appendix ***A3.1.1 Test Procedures Manual Tests*** and estimate relative proportions of gravel, sand, silt and clay. (e.g. fine-grained or coarse-grained)

Step 2a: If the soil is coarse-grained, estimate the gradation (range of grain sizes) if a sieve is available, moisture content (dry, moist, wet), angularity (angular, sub-angular, sub-rounded, rounded), and color.

Step 2b: If the soil is fine-grained, estimate the moisture content (dry, moist, wet), consistency (very soft, … very stiff), plasticity, and color.

Step 3: Identify whether collapsible, expansive soils, organic soils, or additional hazardous soils are present.

Collapsible soils reduce in volume when wet. They tend to exhibit high strength and stiffness at normal water contents but collapsible when water is added. Difficult to identify by eye.

Expansive soils shrink or expand in volume depending on the water content. Volume change causes great damage to low-rise buildings that do not have sufficient weight to resist the forces due to expansion.

Step 4: Record the soil description including: Group name (group symbol) – color, moisture, description of angularity and gradation (coarse-grained), plasticity (only for fine-grained soils), structure, soil consistency (density or stiffness), and other notable features (cementation).

Note: Besides recording the moisture content of the soil retrieved from the investigation, it would be valuable to note whether the water table is encountered during boring or 24 hours after, and whether the water table is expected to rise or fall seasonally.

Examples:

Sandy CLAY (CL) – light grey, moist, stiff, non-plastic.

Sandy GRAVEL (GW) – brown, dry, sub rounded, dense, well-graded.

3.2 BEARING CAPACITY

Soil bearing capacity is the capacity of soil to carry a distributed load applied by a foundation element. It is the maximum average pressure between the soil and foundation without failing or allowing significant settlement. In many cases, the foundation capacity will be limited by the allowable absolute and relative settlements for that building. While settlement is of particular concern for shallow foundations and non-granular soils, it can also affect buildings with deeper foundations or on loose granular soils.

In most cases, relative settlements are of primary concern. As one part of the building settles relative to another, the building distorts and rotates. This distortion can potentially lead to cracks in building finishes, difficulty with machinery, doors and windows, or can be visually disturbing.

3.2.1 DESIGN STAGE

When buildings will be present on site, the suitability of a soil's bearing capacity should be evaluated to determine appropriate building locations, feasibility of number of stories, and appropriate foundations for structures on the site. For example, if the bearing capacity of the soil at a shallow depth is sufficient for the structure, then a shallow foundation can be used. If the structure has a larger loading pressure, the foundation may need to be at a depth with adequate soil bearing capacity. The estimated settlement should also be analyzed during further study.

Frequency of Use: Bearing capacity should be evaluated on every project involving design of a structure.

Conceptual Design: Bearing capacity can be estimated using safe values depending on the soil type.

Detailed Design: A soils report from a local geotechnical engineering firm, if available, should be obtained to better estimate the soils bearing capacity using ***Equation A3.2-3 Simplified Ultimate Bearing Capacity***. Alternatively, a local geotechnical engineering firm can estimate the bearing capacity following testing.

3.2.2 DESIGN CRITERIA

Bearing capacity should be estimated in locations of future footings at the anticipated subgrade depth because an understanding of a soil's bearing capacity is essential for designing foundations and ensuring overall building stability. An allowable bearing capacity should limit both settlement and shear stress of the soils in the influence zone, either of which can lead to failure. Typically, the design will work to minimize bearing pressure to meet the allowable bearing capacity of the soil; however, in some cases it might be feasible to consider soil reinforcement to increase a soil's bearing capacity.

Bearing capacity depends on:

- Soils shear strength
- Foundations shape, size, depth, and type

- Spacing between foundation
- Erosion and seepage
- Seismic forces
- Frost Action
- Subsurface voids
- Load inclination and slope inclination
- Unit weight
- Groundwater conditions

Types of failure include:

- General Failure: Sudden catastrophic failure with well-defined failure surface (common in dense sand).
- Local Shear Failure: Significant settlement upon loading with the failure surface developing right below the foundation and slowly extending outward with additional loading increments (common in sand or clay with medium compaction).
- Punching Failure: Extensive settlement with a wedge shaped zone of equilibrium beneath the foundation and vertical shear occurring along the edges (common in fairly loose sand or soft clay).

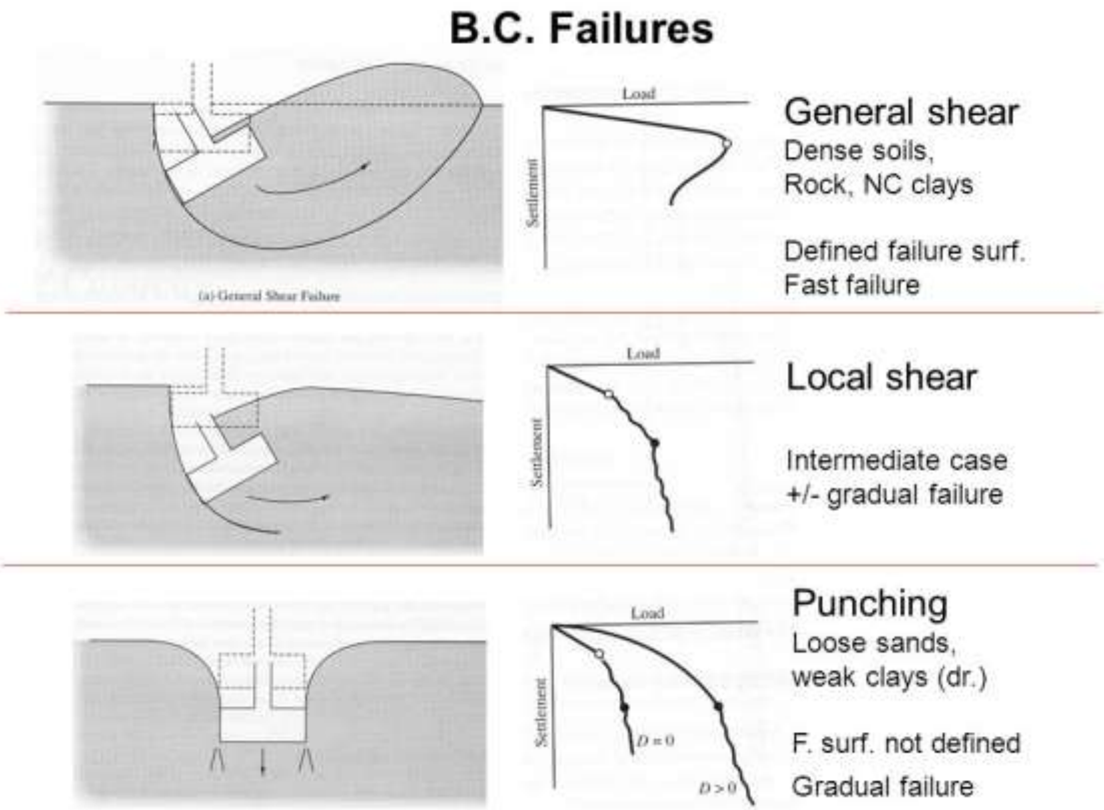


Figure 3.2-1 Types of Bearing Capacity Failures

The following resources and tools can be used in estimating soil bearing capacity:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform if soil bearing capacity should be assessed.

- Appendix ***A3.2.1*** ***Allowable Bearing Capacity Tables*** provide tables with typical bearing capacity values for different soil type and Factor of Safety for different types of structures.
- Appendix ***A3.2.2*** ***In-Situ Soil Strength Test Procedures*** provide guidance in performing in-situ soil strength tests if equipment is available.
- Appendix ***A3.2.3*** ***Ultimate Bearing Capacity*** provides guidance in estimating ultimate bearing capacity if geotechnical data is available and links to additional documentation.
- References and additional resources can be found in ***R3.2*** ***Bearing Capacity***.

3.2.3 DESIGN PROCEDURES

The following steps can be used to estimate bearing capacity:

Step 1: Classify soil following ***3.1 Soil Classification***.

Step 2: Estimate an allowable bearing capacity using values given in Appendix ***A3.2.1 Allowable Bearing Capacity Tables***.

Step 3: Compare estimate with results from an on-site in-situ soil strength test, if available, as described in Appendix ***A3.2.2 In-Situ Soil Strength Test Procedures***.

Step 4: If additional information from a geotechnical report is given, refine bearing capacity estimation using a bearing capacity ***Equation A3.2-3 Simplified Ultimate Bearing Capacity*** to find ultimate bearing capacity, q_u, or use value given by local firm.

Step 5: Using q_u, choose an appropriate Factor of Safety and calculate the allowable bearing capacity, q_a. Common Factors of Safety are given in Appendix ***A3.2.1 Allowable Bearing Capacity Tables***.

Equation 3.2-1 Allowable Bearing Capacity

$$q_a = \frac{q_u}{FS}$$

Step 6: Check that the allowable bearing capacity does not lead to excessive settlement or angular distortion.

Maximum settlement, $S_{T\,(max)}$ (Skempton and McDonald, 1956)

In sand	32 mm
In clay	45 mm

Maximum differential settlement, $\Delta S_{T\,(max)}$ (Skempton and McDonald, 1956)

Isolated foundations in sand	51 mm
Isolated foundations in clay	76 mm
Raft in sand	51-76 mm
Raft in clay	76-127

Maximum angular distortion, β_{max}	1/300

See ***Figure 3.2-2 Angular Distortion***

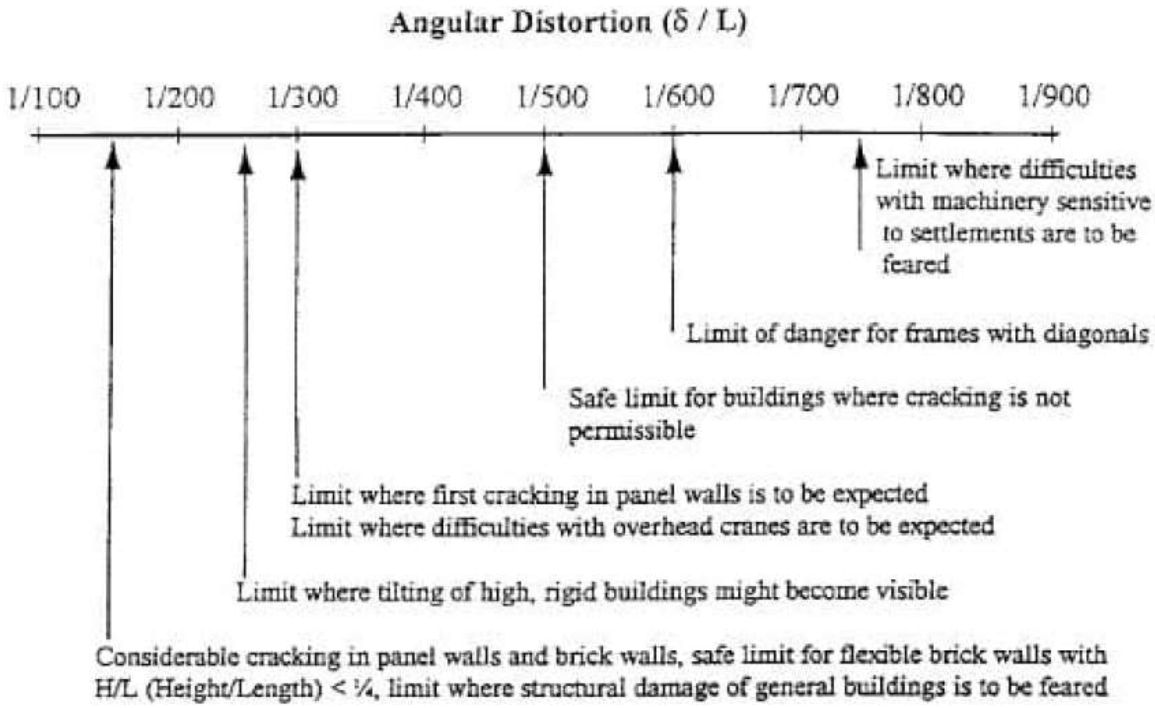


Figure 3.2-2 ***Angular Distortion***

Source: (Skempton and McDonald, 1956)

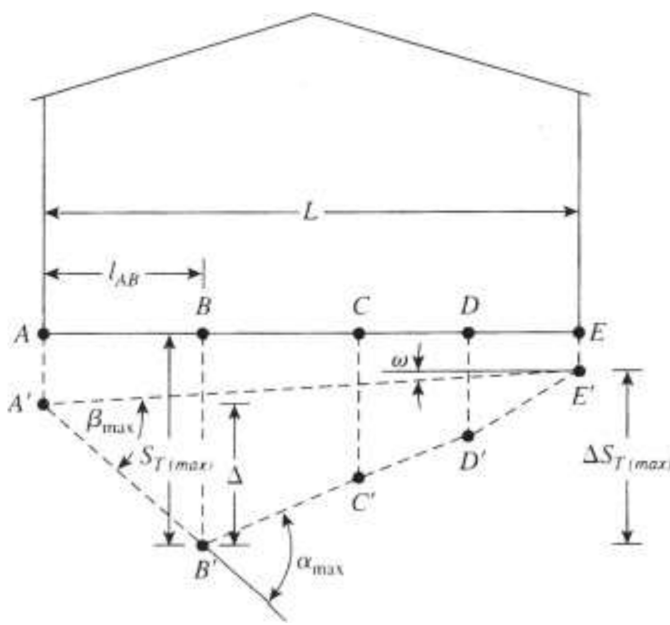


Figure 3.2-2 ***Definition of Parameters for Differential Settlement***

Source: (Das, 2007)

3.3 SOIL ABSORPTION CAPACITY

Soil absorption capacity refers to the ability of the soil pores to absorb water and is typically given as a rate. An understanding of the site specific soil absorption capacity is essential for designing the on-site wastewater disposal systems and can determine whether a site is suitable to develop or not. Such information can also be used when designing a soil absorption system for stormwater management (e.g. infiltration ponds, or rain gardens) or to assess soils in agricultural areas for suitability.

3.3.1 DESIGN STAGE

A soil's absorption capacity should be estimated for every EMI project where on-site wastewater treatment is recommended as the wastewater treatment option.

Frequency of Use: Soil absorption capacity is estimated on most EMI projects.

Conceptual Design: Soil absorption capacity is determined by completing a percolation test and then comparing this result to an absorption rate estimated using typical absorption rates based on the soil's classification.

Detailed Design: Repeat percolation tests and soil classifications performed in the preliminary design and additional tests at the depths and locations of the proposed wastewater treatment options. If possible, a detailed geotechnical investigation should be performed and initial estimates refined using laboratory test results for moisture content, particle size, and hydraulic conductivity.

3.3.2 DESIGN CRITERIA

A soil's absorption capacity will help inform where on-site wastewater treatment should be located on the site. If there is inadequate absorption capacity and no municipal sewage system, an alternative wastewater treatment and disposal system will be necessary.

The absorption capacity depends primarily on the soil texture, determined by the relative percentages of clay, silt, sand and gravel and the macro-structure of the soil (i.e., granular, layered, massive, etc.). Refer to Section ***3.1 Soil Classification*** for more information. Additional factors include the soil's consistency, density, in-situ moisture content, depth to seasonally high ground water table and soil's potential to experience freeze/thaw.

Acceptable wastewater application rates based on the percolation rates and soil type/structure have been determined through empirical testing. These empirical relationships consider the effects of the bacterial biofilm that develops at the soil/wastewater interface and greatly retards the rate of absorption of wastewater. These relationships are displayed in a number of tables, some of which are shown in the Appendix ***A3.3.2 Application Rates***.

Typically, soils primarily comprised of sand and gravel have a higher application rate than silt and clay. Additionally, soils with high organic content will hold more water, and thus have a lower application rate than soil with no organic matter. The soil particle's arrangement in the undisturbed soil column also has a significant effect on the allowable application rate. The tables in Appendix ***A3.3.2 Application Rates*** include many of these factors.

Non-wastewater applications (groundwater recharge, stormwater disposal, agriculture) that depend on knowledge of the absorption potential of soil require additional design resources. The tables provided in the appendix are not applicable. While the direct measurement of infiltration rates as determined by the percolation test may provide some of the information needed for these application, additional information may be necessary.

The following resources and tools are to be used when determining the soil's absorption capacity.

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the soil absorption capacity project needs and where soil testing should occur at the site.
- Appendix ***A3.3.1 Percolation Test Procedure*** provide detailed instructions for performing a percolation test.
- Appendix ***A3.3.2 Application Rates*** provide tables for typical application rates of various soils and the influence of other parameters on application rate.
- References and additional resources can be found in ***R3.3 Soil Absorption***.
- The ***EMI Soil Testing Field Packet*** can be printed and taken on the project trip to aid in classifying soil and ensure all pertinent information is recorded.
- The ***EMI Water and Wastewater Design Template*** has a tab that calculates the Percolation test results and aids in determining the Wastewater Application Rate.

3.3.3 DESIGN PROCEDURE

Step 1: Perform a Site Assessment as described in Section ***1*** paying particular attention to possible locations for on-site wastewater treatment systems.

Step 2: Perform Percolation Tests as described in Appendix ***A3.3.1 Percolation Test Procedure*** in areas where on-site wastewater treatment systems are anticipated.

Step 3: Determine the maximum allowable wastewater application rate based on the Percolation Test results using ***Table A 3.3-28 Recommended Rates of Wastewater Application*** provided in Appendix ***A3.3.2 Application Rates***. This is the first estimate.

Step 4: Classify soil based on soil texture/structure as described in ***3.1 Soil Classification***. The soil profile and macro structure from the surface to below the intended depth of the absorption system should be classified and documented. A test pit, 1-2m deep, that exposes the undisturbed soil column is recommended.

Step 5: Determine the maximum allowable wastewater application rate based on soil texture/structure using the other Tables provided in Appendix ***A3.3.2 Application Rates***. Use the application rate of the least porous soil layer below the bottom of the absorption system, because it will likely control the application rate. This is the second estimate.

It is important to note that additional site characteristics will influence the application rate including soil depth, structure, landscape position, and type of wastewater effluent. Use ***Table A 3.3-31 Influence of Site and Soil Evaluation Factors on Application Rate*** in Appendix ***A3.3.2*** ***Application Rates*** to incorporate these influences to refine the application rate estimation.

Step 6: Compare the maximum allowable wastewater application rates from both estimates to ensure agreement. If rates do not agree, perform the percolation tests and soil classification tests again. If the two figures still do not agree, make a conservative engineering judgement as to which value to use and document the choice.

Underestimation of application rate will cause the size of the treatment and disposal field to be too small thus leading to early failure.

Overestimation of application rate will cause the size of the treatment and disposal field to be too large, wasting space and resources.

4 Wastewater

4.1 WASTEWATER COMPOSITION AND QUANTITY

After estimating water demand, it is important to consider how to treat and safely dispose of wastewater flows. Wastewater composition describes the concentration of dissolved organic material and suspended solids material in the wastewater. Loading is the weight of these wastewater components that must be removed from the wastewater per day. The load is calculated by multiplying the wastewater volume per day by the concentration of the various constituents that must be removed. The wastewater quantity is derived from the average water demand estimate by applying a wastewater generation rate (often 85-90%) to the estimated water demand and adding some amount of flow to account for infiltration and inflow of storm water.

4.1.1 DESIGN STAGE

Frequency of Use: All EMI projects involving wastewater treatment system designs include a wastewater composition and quantity. Projects that utilize only septic systems normally require only the daily wastewater volume to design the system, assuming the wastewater is typical sanitary sewage. Wastewater composition is not normally an issue, unless the wastewater in significantly different from normal sanitary wastewater (large fraction of industrial wastewater).

Conceptual Design: Determine the need for some type of wastewater treatment, beyond septic systems. When necessary, perform an initial estimate of wastewater composition based on information about the processes generating the wastewater or laboratory testing of representative samples of the wastewater. The preliminary estimate of loading can then be calculated based on the Average Daily Water Demand, multiplied by the wastewater generation rate.

Detailed Design: Review and refine the initial wastewater quantity estimate along with the detailed design scope and any applicable masterplan changes to inform required wastewater treatment system design and other site infrastructure.

4.1.2 DESIGN CRITERIA

An accurate estimate of wastewater composition and load primarily considers the amount of waste expected from each water use. The wastewater is usually broken down into the following two categories:

- **Greywater**: wastewater generated from water uses without fecal contamination, generally all uses except for wastewater from toilets. Sources include sinks, showers, baths and laundry facilities. Refer to Section ***2.4 Greywater Separation and Reuse*** on greywater for more information.

- **Blackwater**: wastewater generated from water uses that come into contact with fecal contamination, including the wastewater from toilets, urinals and hand wash sinks near the toilets.

There are two ways to calculate the Wastewater Quantity. The first is to use the average per capita usage rates used in the Daily Water Demand tab of the ***EMI Water and Wastewater Design Template*** this is set up in the template. Look at each of the usage rates and determine the appropriate Wastewater Generation Rate for each Water Usage. The typical range is 85-90%, however, for flushing toilets or drinking water it could be 100%. It is best to use engineering judgment and what would make sense for the site. After the Wastewater Generation Rate is determined, then greywater can be separated out based on the Wastewater Generation Rate from Average Water Usage per Capita. The blackwater quantity is then calculated by the subtraction of greywater from the total wastewater quantity.

The second method for calculating wastewater load is to use the institutional use, such as a hospital bed count or school per pupil count. In this case, the Wastewater Generation Rate would be the 85-90% for the total Average Daily Water Demand for the building type. If desired the greywater can be calculated with a percentage as well, such as 80% of the total wastewater quantity would be greywater and 20% could be blackwater. This modification can be made instead of adding the specific water usage rates that are greywater.

The following resources and tools are to be used in developing the wastewater composition and quantity:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the design.
- References and additional resources can be found in ***R4.1*** ***Wastewater Composition and Quantity***.
- The ***EMI Water and Wastewater Design Template*** is to be used as a starting point for the wastewater estimate. The spreadsheet includes a template for typical site design projects where one or more buildings are expected to be constructed with expected flows of wastewater (greywater and blackwater).

4.1.3 DESIGN PROCEDURE

Not Separating Greywater

Step 1: Review the Average Daily Water Demand in the ***EMI Water and Wastewater Design Template***.

Step 2: Determine the Wastewater Generation Rate (typically between 85-90%) for each building.

Step 3: Record total wastewater flow estimates in an appendix of the Project Report

Separating Greywater

Step 1: Review the Average Daily Water Demand in the ***EMI Water and Wastewater Design Template***.

Step 2: Determine the Greywater and Blackwater Generation Rate (typically between 85-90%) for each building.

Step 3: Record total wastewater flow estimates in an appendix of the Project Report

4.2 WASTEWATER CONVEYANCE

On-site wastewater conveyance systems are used to collect and carry wastewater from the facility where it is generated to a treatment or disposal system. The most common application of wastewater conveyance in EMI projects consists of simple pipe runs that flow by gravity from a building to a nearby septic tank and from the septic tank to an absorption area. Occasionally, EMI projects will use conveyance networks to collect all the wastewater generated on a site and deliver it to a centralized treatment or disposal area.

4.2.1 DESIGN STAGE

Frequency of Use: All EMI projects involving wastewater disposal will include a wastewater conveyance system.

Conceptual Design: Determine a general layout of on-site wastewater conveyance piping and junction boxes as well as preliminary sizing and slope requirements based on known site constraints.

Detailed Design: Verify assumptions of conceptual design. Complete detailed sizing and layout of on-site wastewater conveyance piping. Determine slopes and invert elevations at each junction box and manhole. Coordinate design with other underground utilities and structures.

4.2.2 DESIGN CRITERIA

The following criteria can be used to design wastewater conveyance systems:

- Pipe diameters must be large enough to be no more than half-full at the expected peak flow at full buildout.
- The peak flow can be estimated by multiplying the Average Daily Demand from the Water Demand Estimate by the estimated return percentage (typically 80-90%) as well as a peaking factor for instantaneous flow rate (typically 4-6 for EMI projects). See Appendix for more detailed methods for calculating the Peak Flow for domestic wastewater.
- The slope and size of the pipe must provide a minimum flow velocity of 0.6m/s and a maximum flow velocity of 4.5m/s in order to maintain adequate scour when transporting solids.
- EMI typically uses 110mm diameter pipe at a minimum slope of 2%.
- In some cases, it may be necessary to use 140-160mm diameter pipe at a minimum slope of 1% to meet the capacity and velocity design criteria.
- For greywater conveyance without solids, 75mm diameter pipe may be used.
- EMI typically uses PN6 PVC pipe for wastewater conveyance lines, where available.
- A junction box or manhole is to be placed at intersections, changes of pipe direction, and every 30m of a long run. Clean-outs are needed at all dead-end pipe runs. See Appendix for how to calculate junction box elevations.

Figure 4.2-1 ***Example of a Junction Box Where Pipes Intersect.***

Figure 4.2-2 ***Example of a Cleanout at the End of a Line***

Source: Orange County Sewer Line Clean Out Installation

- When laying out the system, a straight run between junction boxes is preferable to aid in cleaning.
- Separate wastewater lines from water lines by 3m horizontally, and when crossing, wastewater lines are to be a minimum of 450mm below water lines.
- Wastewater lines must not extend under buildings or other permanent structure with the exception of roadways, walkways, and storm drainage features.

The following resources and tools are available for designing wastewater conveyance systems:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the design.

- References and additional resources can be found in ***R4.2*** ***Wastewater Conveyance***.
- The ***EMI Water and Wastewater Design Template*** is used to help determine wastewater system loading.
- The ***EMI Pipe and Channel Sizing Template*** uses Manning's Equation to calculate pipe and channels sizing. This is a detailed tool and not used in concept level design.
- The ***EMI Wastewater Junction Box Design Template*** is an example project that shows how to design junction box elevations. This is a detailed tool and not used in concept level design.
- The steps that can be used to guide the ***EMI Wastewater Junction Box Design Template*** process can be found in ***A4.2.2*** ***Calculating Junction Box Elevations***.

4.2.3 DESIGN PROCEDURE

Step 1: Identify site constraints and wastewater disposal recommendations to determine wastewater conveyance needs. See the Client Needs Assessment and Site Evaluation for more information.

Step 2: Sketch a layout of wastewater conveyance piping from the buildings to the wastewater disposal areas.

Step 3: Use the information in the ***EMI Water and Wastewater Design Template*** to estimate wastewater loading along proposed conveyance lines.

Step 4: For each facility, estimate the time over which wastewater will be generated to calculate the average wastewater flow rate in cubic meters per second (m^3/s).

Step 5: Apply a peaking factor (typically 4-6 for EMI projects). to the average wastewater flow rate for an estimate of the instantaneous flow rate.

Step 6: Determine minimum pipe sizing using the ***EMI Pipe and Channel Sizing Template***.

Step 7: Provide a layout of wastewater conveyance lines on the Proposed Wastewater Site Plan DWG.

Step 8: Continue to detailed descriptions for detailed design and office specific applications.

4.3 SEPTIC TANKS

Septic systems including septic tanks are used for on-site treatment and disposal of wastewater whenever there are no other cost-effective alternatives such as a municipal wastewater treatment system. Septic tanks, which separate solids and oil/grease in wastewater streams, are utilized for primary on-site wastewater treatment. Septic tanks must be accompanied by suitable means of disposal of the treated wastewater, such as an absorption system, further treatment, or transport.

4.3.1 DESIGN STAGE

Frequency of Use: Almost every project.

Conceptual Design: Due to the importance of knowing early in the design process if a site is suitable for on-site disposal, preliminary design tasks are usually similar to final design, except for determining construction details of the septic tanks. The approximate size and layout of all septic system components needed should be determined during preliminary design and the systems shown on the Masterplan. Refer to the design manual section on absorption system design (Section ***4.5 On-Site Wastewater Disposal***) for determining the preliminary size for these elements.

Detailed Design: The sizing calculations for the septic tank should be reviewed and updated as necessary after the architectural program is finalized. septic tank size should be verified and internal details designed. Carefully document the design process.

4.3.2 DESIGN CRITERIA

Not every site can utilize a conventional septic tank and absorption system for on-site disposal of wastewater. Review Other Wastewater Solutions (Section ***4.7 Other Wastewater Treatment***) for other options to consider.

Septic tanks provide the following:

1. Primary sedimentation to remove suspended solids, as well as oil and grease.
2. Digestion through anaerobic decomposition, which can decompose more than 1/3 of the original sludge volume.
3. Storage of solids, and grease and oil accumulating between successive cleanings.

The septic tank design used by EMI consists of two chambers, separated by an intermediate wall. The first chamber removes and stores the bulk of the solids and floating scum. It is sized to provide 2/3 of the total retention time. The second, which has 1/3 of the total volume, provides for additional removal of solids and scum. Baffles are required at the inlet and outlet ends to improve the treatment process.

Since bacteria and viruses remain in sewage effluent from septic tanks, it must be disposed of through subsurface absorption (see Section ***4.5 On-Site Wastewater Disposal***) or through proper treatment and disinfection before being discharged at the surface.

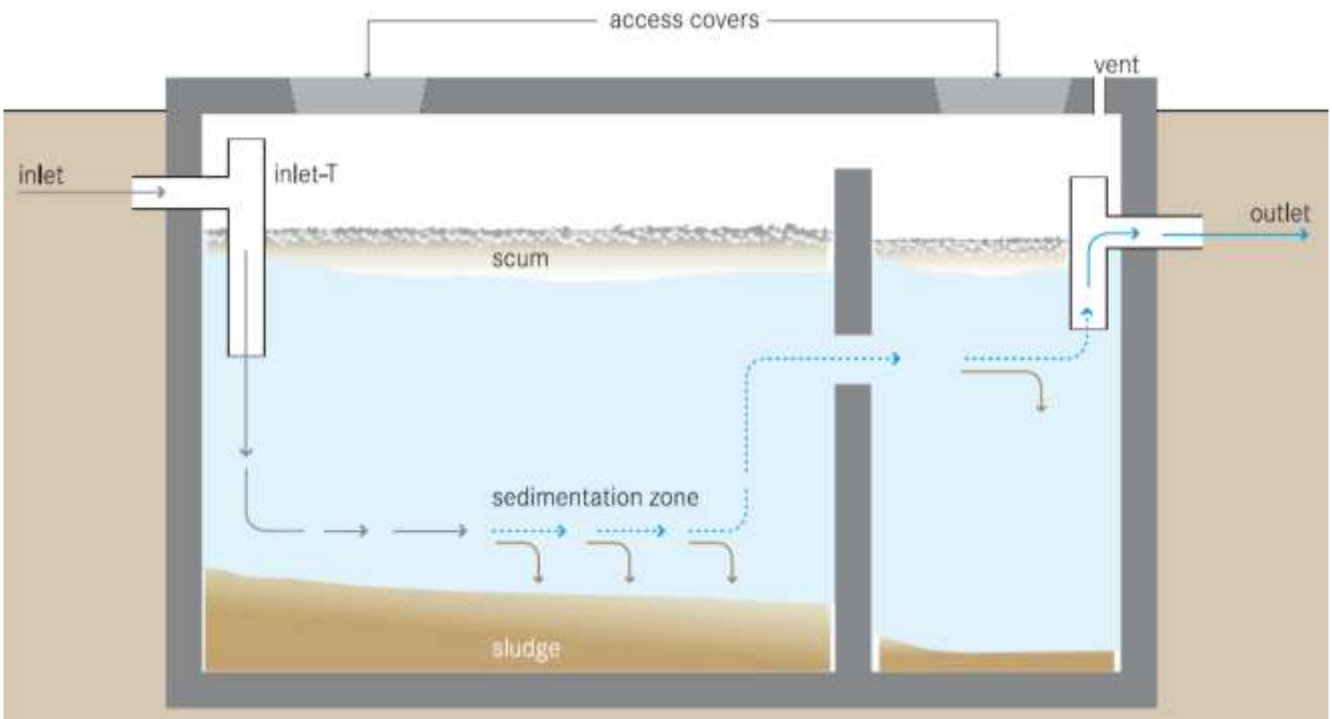


Figure 4.3-1 Septic Tank Design

Source: Tilley et al., 2014

Minimum separation between a septic tanks and other site features

To protect adjacent site structures from contamination, and to protect the septic tanks, a minimum spacing distance must be complied with. is a listing of EMI-recommended setback distances. Local regulations may have a different set of setback distances.

Table 4.3-6 Setback Distance Between Septic Tanks and Nearby Features

Item	Septic Tank	
	(m)	(ft.)
Buildings	1.5	5
Property boundaries	3	10
Shallow Wells, springs, or streams	15	50
Bored Wells	15	50
Streams	15	50
Cuts or Embankments	3	10
Water Pipes (horizontal distance)	3	10
Paths	1.5	5
Large Trees	3	10
Sources: Republic of Kenya, 2008, pg. 86, Code of Colorado Regulations, 2018 pg. 43-45		

Calculating Septic Tank Volume

A septic tank must have sufficient volume to provide a liquid hydraulic retention time (HRT) of at least 24 hours when the tank is at maximum scum and sludge storage capacity (not including stored sludge and scum volume). To ensure adequate volume for sludge and scum storage, the design HRT is usually 48 to 72 hours. The required volume is based on the average daily wastewater flow rate. This method is usually accurate for preliminary design. Size tank for 2 times the daily wastewater flow rate to provide space for sludge and scum.

Equation 4.3-1 Septic Tank Volume

$$V = Q\,x\,2$$

(where Q = design sewage quantity per day in L/day)

The ***EMI Water and Wastewater Design Template*** is used to determine septic tank sizes based on estimated wastewater volume. The spreadsheet includes calculations using this method. See Appendix ***A4.3.1*** ***Alternative Septic Tank Calculations*** for alternative methods to calculate the septic tank volume.

The tank water volume calculated does not include the volume of the intermediate wall, the gas space above the water line, and the water proof cement plaster lining (if used). Septic tank walls should be as leak-proof as possible, and the walls are usually coated with some type of waterproof material, such as cement plaster. Ensure the tank design volume takes these factors into account.

Minimum Septic Tank Size

Regardless of flow, septic tanks should have a minimum internal water volume of between 1,300-3000L, typically 2,000L, to provide adequate space to properly construct the tank and to allow access into the tank to remove accumulated sludge and scum and maintain internal components.

Maximum Septic Tank Size

There is no maximum tank size; however, when the required tank water volume is over 20,000L, the use of multiple tanks in parallel, with flow split equally by a flow splitter box, should be considered. Structural engineers should be consulted for tanks larger than 20,000L.

Material of Construction

Septic tanks can be site-built from reinforced concrete, concrete block, or fired brick. Manufactured tanks may be available, made from plastic, fiberglass or precast concrete. Check local availability of manufactured tanks since the quality of manufactured tanks is usually superior to site-built tanks. Ensure tanks are leak-proof and consider tank buoyancy to prevent the tank from floating during wet periods. (More information can be found in the office-specific details.)

Septic Tank Configuration

- Septic tanks are divided into two chambers separated by an interior wall. The first chamber provides 2/3 of total volume to ensure adequate waste storage capacity.
- The tank length is usually 2-3 times the width to minimize short circuiting.
- Water depth is usually 1.5m but can range from 1.2-2.0m. The maximum depth is three times the width.
- Tank width is at least 600mm for constructability, and can be up to 2.4m wide.
- Inlet and outlet baffles are required and are usually constructed of 4" or 6" PVC plastic tees. Larger tank may require two or more inlet or outlet tees.
- The Inlet tee extends upward to 20% of the water depth above the static water level and downward below the water level to a depth of 20% of the water depth.
- The outlet baffle extends 75mm above the water level and 375mm below the water depth or 35-40% of water depth.
- Provide a minimum 25mm gap between the top of the inlet baffle and underside of tank top for ventilation. Ensure there is a minimum 75mm gap between the top of the outlet baffle and the tank top.
- Baffles extend into the tank interior far enough to provide 50mm space between the outside of the baffle and the unfinished tank wall.
- The interior baffle wall should have multiple round openings or a rectangular slot sized keep the water velocity through opening less than 0.1m/s. Typically two 4" pipe segments, with 90° elbows on the upstream side, are built into the wall. Locate the openings at 300mm apart with the top of the pipes 150mm below the water surface (most guidance says at 35-40% of water depth, and 250mm above maximum sludge depth). Large tanks may require more than two pipes.
- The top of the interior wall should extend at least 75mm above the water surface.
- Set the inlet pipe invert 75mm above outlet pipe invert (static water level).
- Provide access hatches for inspection, desludging and maintenance, above the inlet and outlet baffles. If the second chamber is over 1.5m long, provide a third access hatch above the interior wall.
- Interior surfaces are sealed with a 25mm thick layer of waterproof cement plaster applied in two courses. Round interior corners to make cleaning easier. (This is region specific and could be a different thickness and material.)

The following resources and tools are to be used when designing the On-Site Wastewater Disposal system:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the design.

- Appendix ***A4.3.1*** ***Alternative Septic Tank Calculations*** includes detailed calculations for septic tank volumes. ***Equation A4.3-4 Alternative Septic Tank Calculations*** is not included in the templates.
- Appendix ***A4.3.2*** ***Maintaining Septic Tank and Absorption Field System*** provides guidance for clients to maintain the septic tanks and soak fields.
- References and additional resources can be found in ***R4.3*** ***Septic Tanks***.
- The ***EMI Water and Wastewater Design Template*** is used to determine septic tank sizes based on estimated wastewater volume. The spreadsheet includes calculations references to ***Equation 4.3-1 Septic Tank Volume***. Be sure to check if greywater is being separated and not sent to the septic tank.

4.3.3 DESIGN PROCEDURES

Step 1: Establish a preliminary plan for collecting, treating and disposing of wastewater from the various facilities being designed. The plan will determine how many septic systems are needed and the general location of the systems. Small sites with only a few facilities could be handled with a single septic tank and absorption system, but large complex sites could require many independent systems due to topography and the building layout.

Step 2: Review wastewater composition, loading and volumes (see Section ***4.1 Wastewater Composition and Quantity***).

Step 3: Conduct a site assessment to determine if the ground surface elevations allow for the required minimum 2% slope in the sewer between the source and the septic tank and a 1% slope between the septic tank and the absorption system. (This could change the location of the septic tank.)

Step 4: Based on the site assessment results, and in coordination with the architectural team, produce a preliminary layout of the wastewater treatment system for the site. Septic tanks are usually installed relatively close to the source of wastewater to minimize sewer length and reduce the likelihood of plugging. To prevent damage to the system, and to reduce the likelihood of exposure to the wastewater, the setback distances in ***Table 4.3-6 Setback Distance Between Septic Tanks and Nearby Features*** must be maintained between septic tanks and other structures, including water supplies, structures, stream, lakes and other absorption systems. When selecting the location for septic tanks, ensure there is adequate room for a vehicle to access each septic tank to remove accumulated solids and scum.

Step 5: Calculate the sizes of septic tanks. Use the average daily wastewater flow rates to size the tank. Determine the outside dimension of each septic tank, which must be large enough to hold the required water, sludge and scum volumes as well as the intermediate wall, gas space and inner waterproof lining.

Step 6: Determine the geometry and inner details of the septic tanks during the detailed design phase. Include the detailed drawings and layout in the construction drawings.

4.4 GREASE INTERCEPTOR

Wastewater generated by food preparation contains high levels of organic matter, high temperatures, detergents, and significant amounts of fats, oil, and grease (FOG). If the FOG is discharged to an on-site wastewater septic system, the floating layer of FOG will prematurely fill the portion of the septic tank designed to capture and store floating material, allowing the FOG to pass through to the absorption system. Excessive FOG in the septic tank effluent will plug the absorption system soil surface, resulting in premature failure of the field or leach pit. To ensure the oil and grease does not disrupt the operation of the septic tank and absorption system, FOG must be removed prior to the septic tank by a grease interceptor (GI).

4.4.1 DESIGN STAGE

Frequency of Use: Any project with a kitchen serving more than just a few simple meals will involve grease interceptor design. The clean-up area for dishes may also require a GI, if separate from the kitchen.

Conceptual Design: Identify location of grease interceptor(s) and provide preliminary sizing.

Detailed Design: Determine size and provide detail drawing(s) of grease interceptor(s).

4.4.2 DESIGN CRITERIA

Location: In determining the location of the grease interceptor, there are three primary considerations:

1. The GI should be as far upstream as possible. The shorter the length of pipe between the fixtures and the GI, the lower the chance that grease will cool and solidify within the pipes. This also reduces the length of pipe that would need to be maintained or replaced in the event of grease build-up. On a flat site, a longer pipe means a deeper pipe and GI – increasing the cost of installing and decreasing the ease of maintaining. For a large facility, multiple GIs may be required: one near each kitchen or wash-up area.
2. The GI must be accessible by vehicles for regular cleaning. Ensure road access to the GI.
3. Areas around grease interceptors are often unsightly and can be slippery due to spilled grease. Try to avoid placing the GI near a highly frequented area, especially sitting areas. Although grease interceptors can be vented, some can still produce an unpleasant smell.

Design of a grease interceptor is similar to a septic tank, but has several key differences:

- GI tanks are usually smaller than septic tanks and the size is based on an estimate of the maximum expected flow rate into the tank rather than the average wastewater volume.

- In addition to the inlet and outlet, a grease interceptor will use a pipe tee at the baffle wall instead of an elbow. This allows inspection and cleaning out FOG accumulation within the pipe as needed.
- Instead of extending to the mid-level of the water depth, the pipe tees at the baffle wall and outlet pipe will extend closer to the bottom of the tank to aid in transporting solids and maximize space for FOG accumulation.
- If desired, a grease interceptor can include a small venting pipe routed to the roof a nearby structure to reduce the odor seeping through the manhole and cleanout lids. If a vent pipe is used, the end of the vent pipe should be covered to prevent rainfall from entering and screened to prevent undesired debris and vermin from entering the pipe.

Construction techniques

Refer to region-specific design manuals and details.

The following **resources and tools** are to be used in developing the grease interceptor design:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the grease interceptor design.
- See ***Table A 4.4-34 Grease Interceptor Design Parameters*** in Appendix ***A4.4*** ***Grease Interceptors*** for additional information on design parameters for grease interceptors.
- References and additional resources can be found in ***R4.4*** ***Grease Interceptors***.
- The ***EMI Water and Wastewater Design Template*** includes a tab for sizing grease interceptors.

4.4.3 DESIGN PROCEDURE

Before sizing the grease interceptor, complete and review any information in the Client Needs Assessment and Site Evaluation related to grease interceptors.

Step 1: Calculate maximum instantaneous flow rate (Design Flow Rate) to the grease interceptor. The flow rate to a given GI can be calculated as shown below:

Equation 4.4-1 Grease Interceptor Design Flowrate

$$\textit{Design Flow Rate} = \left(\frac{\textit{Total volume of sinks x } 75\%}{\textit{time to drain sinks}} + (\textit{other expected flows})\right)$$

Time to drain sinks can be taken as 1-2 minutes, depending on the size of sink, size of drainage pipe leaving the sink, and size of the drain within the sink. One-minute drainage time will yield a more conservative answer. Other expected flows may be hand wash sinks or floor drains connected to the grease interceptor and other dishwashing facilities. The flow from these sources will be relatively small. The 75% factor accounts for sinks not being completely full.

For conceptual designs, it is unlikely you will know the size of the sink. In this case you can either find an example kitchen sink in an existing facility or make a conservative estimate.

Step 2: Determine the required GI volume. This can be determined as below

Equation 4.4-2 Grease Interceptor Volume

$$\boldsymbol{GI\ Volume = Design\ flow\ rate\ x\ 125\%\ x\ 30\ min}.$$

The 125% factor will add additional volume for FOG storage**.**

Step 3: Determine interior dimensions of grease interceptor to hold design volume. Make sure to factor in the additional space between the water surface and the top of the grease interceptor (freeboard). The length must also be at least two times the width.

It is possible that the design volume may yield a grease interceptor with dimensions too small to construct with typical build-in-place techniques that rely on brick and plaster. In this case, the minimum size grease interceptor can be specified as 0.5m wide, 1.0m long, and 1.0m deep (interior dimensions). Such a tank would yield a storage volume of approximately 250-400L (depending on desired freeboard), able to handle maximum design flows of 8-13 liters per minute. Be aware that using a larger-than-needed grease interceptor may result in odors due to decomposing food solids that will collect in the bottom of the tank.

Step 4: Determine location of grease interceptor, accounting for the considerations mentioned in the Design Criteria (Section ***4.4.2***). Show on drawings with accurate dimensions according to the sizing in Step 4, taking into account the wall thickness to get the outside dimensions. Ensure the location allows for vehicular access to clean out the tank.

Step 5: Write all assumptions, summarize design, and record results in report. Keep longer calculations and large tables in the Appendices.

4.5 ON-SITE WASTEWATER DISPOSAL

On-site wastewater disposal systems are used on almost every EMI project due to the lack of alternatives such as municipal wastewater treatment systems. Wastewater is typically sent through a septic tank prior to being discharged below ground surface where it is absorbed and treated by the soil and then percolates to the groundwater.

4.5.1 DESIGN STAGE

Frequency of Use: Almost every project.

Conceptual Design: Estimate approximate size and layout of absorption systems using preliminary estimates of wastewater volume and application rate. Identify possible location based on site conditions.

Detailed Design: Verify estimates and supplement with additional site investigations as needed refer to the ***Client Needs Assessment—Civil, Existing*** to assist in a thorough site assessment. Review conceptual drawings and add internal details for the system. Details include wastewater piping design, distribution box design, elevations of all elements of the structure and details of any structures. If possible, reevaluate the seasonal high groundwater table during a period of extended wet weather.

4.5.2 DESIGN CRITERIA

EMI projects typically include an absorption system to provide final treatment of the wastewater to protect the quality of the groundwater. Absorption is a simple, stable, low cost method to dispose of wastewater under proper soil conditions since soil is an excellent treatment medium requiring little wastewater pretreatment. The fields typically consist of an arrangement of trenches containing perforated pipe and porous material covered by a layer of soil. The filtration surface along with piping should be flat and systems typically use gravity distribution. The absorption process is aerobic, so the entire infiltration surface should be used for treatment.

Septic systems involving on-site absorption should only be considered if the site subsurface soil has sufficient porosity to absorb the wastewater load, where the seasonally high groundwater table, bedrock, or any other low-permeability soil layer is at least two meters below the ground surface, and where there is sufficient land available for siting the absorption system (including an area reserved for a replacement absorption system), while complying with the minimum setback requirements, shown in ***Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features***.

Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features

Item	**Absorption system**	
	(m)	**(ft.)**
Buildings	3	10
Property boundaries	3	10
Wells or spring (private or public)	30	100
Streams	15	50
Cuts or Embankments	7.5	25
Water Pipes (horizontal distance)	7.5	25
Paths	1.5	5
Large Trees	3	10
Other absorption systems	3-7.5	10-25
Curtain drains, upslope	3	10
Curtain drains, downslope	7.5	25
Sources: Republic of Kenya, 2008, pg. 86, Code of Colorado Regulations, 2018 pg. 43-45		

Types of absorption systems include:

- **Infiltration trenches** are the most common and effective treatment system, but require a large land area. A single trench can have a maximum length of 50 meters and minimum distance between trenches of 3 trench widths or 1.5 meters. Keep trenches as shallow as possible and alight trenches so they run parallel to the land surface slope. They can be configured in a cascading manner to work well in steeply sloped terrain. A splitter box is needed to distribute the wastewater evenly to trenches at different elevations.
- **Soak beds** require less land area than trenches, but their treatment efficiency is also reduced. Absorption rates are decreased by 25% to 50% when compared to trenches. They are only suitable to flat terrain.
- **Infiltration mounds** are similar to absorption fields, but the surface is located above the natural grade. Porous fill such as sand is imported to create the treatment layer above grade. This is a good option when the seasonally high groundwater table is less than 1 meter deep. However, the cost would be significantly higher due to the need to import suitable fill soil and the sewer system must be designed to discharge to the higher elevation at the top of the mound. A sewage lift station may be required. This option is not in the template.
- **Rectangular or Circular pits** require less land area, but deeper excavations (3-5 meters). They pose a significant risk to groundwater quality and should only be used if groundwater is known to be deep. The seasonally high groundwater table must be at least 1 meter deeper than the bottom of the proposed pit.

The following resources and tools are to be used when designing the On-Site Wastewater Disposal system:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the design.
- References and additional resources can be found in ***R4.5 On-Site Wastewater Disposal***.
- The ***EMI Water and Wastewater Design Template*** is used to determine the area and number of systems required for adequate loading. The spreadsheet includes calculations for infiltration trenches, soak beds, rectangular pits, and circular pits.

4.5.3 DESIGN PROCEDURE

Prior to designing absorption systems, the general configuration of the wastewater collection, treatment, and disposal system must be known. Depending on the complexity of the site, the overall wastewater scheme may require only a single disposal system or multiple systems located through the project site. Each system will need to be designed separately using information specific to each location.

Step 1: Refer to Section ***4.3 Septic Tanks*** to determine primary treatment method and design.

Step 2: Perform a site assessment by referring to Section ***1***. Pay special attention to site topography in order to ensure the required minimum 1% slope between septic tank and absorption system can be achieved. Using the site topographical map, make sure the proposed absorption systems are located in areas that do not flood or retain rainwater after a storm.

Step 3: Perform one or more soil classification tests, shown in Section ***3.1 Soil Classification***, in areas identified previously to verify the feasibility of absorption field locations. Use test results, and identify the soil type and structure, to estimate subsurface soil permeability and groundwater conditions, described in Section ***3.3 Soil Absorption Capacity***. Percolation tests should be performed in test holes that are as deep as the bottom of the proposed system. Follow the test protocol in Appendix ***A3.3.1 Percolation Test Procedure*** as closely as possible since deviations can cause large errors in the allowable application rate. While testing, note soil texture as shown in Appendix ***A3.3.2 Application Rates***, depth to seasonally high water table, depth to bedrock and depth to restrictive layers. Note that suitable soils have a percolation rate between 1 min/25mm to 60 min/25mm.

Step 4: Determine the maximum allowable wastewater application rate based on Section ***3.3 Soil Absorption Capacity***. For pits, average two percolate rates, one measured at ½ the pit depth and the other at the bottom of the pit. If there are more than one valid percolation test results for a single area, average the results. Chose conservative design application rates during preliminary design to avoid major changes during detailed design.

Step 5: Determine the type of wastewater absorption system for each disposal site. Systems must have a minimum of 1 meter of porous unsaturated soil between the bottom of the system and uppermost limiting layer (impermeable soil, rock, or seasonally high groundwater table) and uniform wastewater distribution is required. Additional requirements include no standing water, flooding, vehicular traffic, or permanent construction over the system. Avoid placing absorption systems at the base of slopes to avoid subsurface saturation from groundwater moving down from uphill areas.

Step 6: Determine the size of the absorption system using the ***EMI Water and Wastewater Design Template***.

Step 7: Confirm location of absorption system with architecture team and check that the distances shown in ***Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features*** are met.

4.6 LATRINES

In a developing country context, it is important to understand the culturally preferred sanitation option. Commonly, EMI recommends latrines because they are commonly accepted and preferred in most rural areas. Latrines are a better solution for such areas because flush toilets are not common and often used improperly, become filled with garbage, and are easily broken. Additionally, flush toilets require significantly more water and generate more wastewater than latrines. Several common types of latrines will be discussed in this section. Some latrine design details vary by country. The description in this section are generic but can be adapted to different regional preferences.

4.6.1 DESIGN STAGE

Frequency of Use: Many projects in developing countries will use latrines.

Conceptual Design: Determine the best type of latrine and placement of toilet blocks on a campus in accordance with the architecture team and client's input. Use the ***EMI Latrine Design Template*** to determine the size and number of latrines needed.

Detailed Design: Observe and determine if shallow groundwater levels occur during the rainy season or if unsuitable subsurface soil conditions. If so, modifications to EMI's typical design may be needed.

4.6.2 DESIGN CRITERIA

Latrines are simple sanitation devices also known as pit toilets or outhouses, that consist of a seat or squat pad with a hole where waste is discharged and a pit that collects the waste and urine, and some form of enclosure for privacy. See ***Figure 4.6-1 Sketch of a Typical Latrine***. Simple pit latrines are usually filled in with soil when they are full and a new pit is dug. Where space is limited a dry pit latrine is often used. Such a pit collects the waste and stores it under dry conditions so the waste can decompose to a low-odor earth-like material which can be safely used as a fertilizer. These latrines are emptied about every two years and reused.

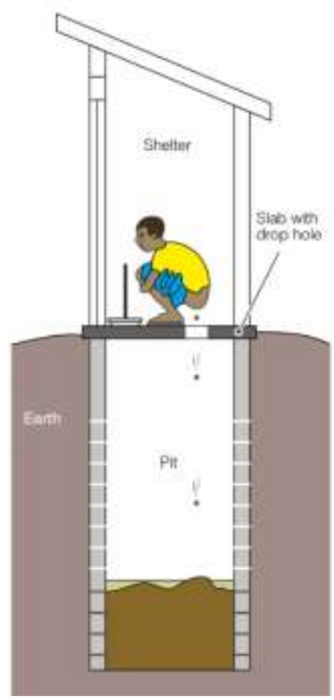


Figure 4.6-1 Sketch of a Typical Latrine

Source: Republic of South Africa, 2002

One important aspect of latrine design is to determine how people in the project area use latrines. Ask the client if the site users prefer squat-type toilets or western pedestal type, and if outdoor facilities are preferred over facilities built into the structure. Observances such as whether it is common to throw trash, water bottles, and other paraphernalia down pit latrines can be helpful in determining what type of latrine design would be an improvement on existing conditions but still functional based on local practices. If throwing trash or water bottles down a latrine is a common practice, methods for dealing with the trash will need to be incorporated into the latrine design. The latrine pits may need to be enlarged to hold this debris as well as the human waste. Don't assume that sanitation habits will change to suite the latrine design.

Another observation would be to note what population is using each toilet facility. It is possible that different user groups have different preferences (e.g., western teachers and staff may have different preferences than students or the local population). Where possible, each group's preference should be met so they can use the facilities intuitively. For consistent group of users, such as staff or students at a school training on how to use an unfamiliar type of toilet may be more effective than for a transient population of users such as patients at a clinic that are constantly changing. Where training is possible, a more advanced type of latrine may be suitable, but the client should agree to this approach.

For example, EMI Uganda has found that the dual vault system they typically specify was not being used properly at several facilities and was causing more maintenance challenges than benefits. In accordance with this, EMI amended the latrine design to include only one vault that would be filled and then cleaned out when full. This reduced construction cost and made the use and maintenance of the facility simpler, though operating cost will be higher.

If recommending a single vault, it is prudent to determine if they have access to a pump truck for more frequent clean-out. If recommending a dual vault system, it is critical that maintenance staff understand and are committed to properly using and maintaining the two-year rotation of vaults. It is recommended to line the vault walls with concrete but not the bottom of the vault floor.

As much information about groundwater conditions during the rainy season should be collected to decide if the latrine pits should be raised higher than the normal depth, French drains added around the pits, or other considerations that high groundwater may have an influence on. Previous EMI clients have experienced vaults that have filled with groundwater, creating odors and interfering with the decomposition of the waste material. Periodically checking for water or saturated conditions in nearby test holes or construction excavations. Looking for soil conditions that indicate saturated soil such as wet, organic soil, or wetland plants may help.

Urine diversion has commonly been implemented into EMI latrine design. Urine diversion can reduce odor and improve the composting of solid waste in the latrine pit. The collected urine can be used as a fertilizer if there is a nearby location to use apply material. It has been found to be more effective for facilities such as dorms where the user population is small and can be trained and monitored to ensure they use it properly, than for latrines that service a larger transient population such as a primary school or clinic. In such cases, normal squat toilet stances, or simple holes in the latrine slab, can be used.

It is recommended to always install urinals in male latrines and it is simple to connect these urinals to a urine diversion system.

Sizing Pit Latrines

The ***EMI Latrine Design Template*** may be used for assistance with sizing pit latrines. It is important to ensure accurate information such as the number of users is known before starting design. Other resources for designing and siting pit latrines can be found in the references ***R4.6***. It suggests a latrine is located 20 m from the nearest well or stream (EMI suggests 50 m when possible), 6 m from the nearest dwelling and 3 m from the nearest property line. WEDC Guides 22 through 30 also provide helpful information on pit latrines. Consult any applicable local regulations on latrine size and location that may differ from these common practices.

Table 4.6-8 Minimum Offset Distance Between Latrine and Nearby Features

Item	Offset	
	(m)	(ft)
Nearest well or stream	20 (50 preferred)	66
Nearest dwelling	6	20
Nearest property line	3	10
Source: Water for the World, 1982, p. 1		

Types of Latrines

See Appendix ***A4.6.1 Description Of Types Of Latrines*** for a detailed description and advantages and disadvantages of each type of latrine. The most common type of latrine used will vary by region. Observe local practices to select the type of latrine people are most familiar with. Some clients may specify other type of latrines, so consult the client before making this choice. One site may use several different types of latrines for different users.

- Ventilated Improved Pit (VIP) Latrine
- Double Vault Latrines
- Dry Vault Latrine with Urine Diversion (Urine-Diverting Dry Toilet, UDDT)
- Compositing Toilets
- Pour-Flush and Aqua Privy

Design of Latrines

Latrine design involves estimating the volume of human waste that will need to be stored, then calculating the pit volume required to hold this volume for the anticipated time interval between cleaning-out the pits. The type of latrine will determine some of the design parameters. Dual vault, VIP, and composting latrines are usually designed to hold the waste generated during a 2-year use period in each vault before they are sealed. For dual pit latrines, only one vault should be used at a time. Once the first pit is full and sealed, the second pit is put into use. After 2 more years, the waste in the first vault will be fully composted and can be emptied and prepared for reuse. Single pit latrines are emptied as soon as they are full, exposing the workers cleaning the pits to greater amounts of viable human pathogens and odors. The anticipated time between cleaning out these pits must be known to properly size them.

Waste generation rates vary by type of latrine, method of anal cleaning, environmental factors and diet of the community using the latrine. ***EMI Latrine Design Template*** will help with pit sizing; however, this step is usually completed during detailed design and exact pit sizes may not be needed for the Masterplan.

Conventional latrines, VIP latrines, or composting latrines do not use water, thus there is no need to estimate wastewater volume or devise a wastewater disposal system. If a pour-flush or water-flush toilet system is proposed, the wastewater generated must be included in the wastewater treatment system design. A soil absorption system may be required for this type of latrine. If urine separation is included in the design, and use of the urine is not anticipated, the urine should be routed to a common sewer or dedicated soak pit (no septic tank is required).

The following resources and tools are to be used in designing latrines for a site:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the latrine design.
- Appendix ***A4.6.1 Description Of Types Of Latrines*** provides a description of the types of latrines.
- References and additional resources can be found in ***R4.6*** ***Latrines***.
- The ***EMI Latrine Design Template*** can be used to design the latrine blocks for a site.

4.6.3 DESIGN PROCEDURES

Step 1: Use ***A4.6.1 Description Of Types Of Latrines*** to determine the type of latrine best suited to the site and client's cultural background and preferences.

Step 2: Determine how many users of each latrine type are anticipated, how many latrines of which types will be required, and where latrines will be located on the site in conjunction with the architectural team. Observe required setback distances from the latrines and other structures.

Step 3: Use the ***EMI Latrine Design Template*** to determine solids storage depth and number of stalls required. Maximum vault depth is usually 2m. Shallower but wider vaults may be needed where shallow bedrock or groundwater is present or anticipated. These details are usually completed during detailed design, but the number of latrines and approximate size of each latrine block should be known during the Masterplan stage.

Step 4: Document all information, and sources of that information, used to complete the preliminary design of the latrines to aid in the dallied design process. Refer to the region specific details to ensure all information has been considered.

4.7 OTHER WASTEWATER TREATMENT

Wastewater collection and treatment is a critical element of nearly all EMI projects. Each project has its own challenges but ideally EMI should consider connecting to a local wastewater sewer system or designing a septic tanks, described in Section ***4.3* Septic Tanks**, and soil absorption systems consisting of soak pits, absorption trenches or absorption fields, described in Section ***4.5* On-Site Wastewater Disposal.** However, in some instances the site conditions or regulatory requirements do not permit such a treatment and disposal system. In such cases, alternate wastewater treatment system must be considered.

4.7.1 DESIGN STAGE

Frequency of Use: Rarely.

Conceptual Design: Preliminary determination of need for a special wastewater treatment system.

Detailed Design: Determine wastewater characteristics, evaluate treatment alternatives, and make the final determination of treatment technology. Conduct final process design, hydraulic design, and design details.

4.7.2 DESIGN CRITERIA

Site Conditions Requiring Alternative Wastewater Treatment

Site conditions or situations that do not permit the use of typical wastewater disposal systems include the following. These conditions are usually identified during Site Evaluation in Section ***1.4*** performed during the project trip or on subsequent site visits.

1. Seasonally high groundwater table elevation at the proposal location of the soil absorption system that is less than 2 meters below the ground surface (the bottom of absorption system must be at least 1m above the seasonally high groundwater elevation to function properly).
2. Uppermost limiting layer (layer of low-permeability or compacted soil or rock that interferes with the downward migration of treated wastewater) that is less than 1m below the bottom of the proposed soil absorption system.
3. Soil immediately below the bottom of the absorption system has a percolation rate that falls outside of the acceptable range of 1 min/25mm to 60 min/25mm. Less than 1 min/25mm means the soil is too coarse for adequate treatment of wastewater, result in groundwater contamination. A percolation rate greater than 60 min/25mm means the soil is not porous enough for the wastewater to migrate away from the disposal site quickly enough to handle the required wastewater volume. An excessively large and expensive absorption system would be required under such conditions. See Section ***3.3 Soil Absorption Capacity,*** ***A3.3.1*** ***Percolation Test Procedure*** and ***A3.3.2*** ***Application Rates*** for more information
4. The minimum setback distances between the wastewater disposal system and the nearest water supply, water pipes, property boundaries, and surface water cannot be

satisfied due to the size or configuration of the site. Refer to the ***Table 4.5-7 Setback Distance Between Absorption Systems and Nearby Features*** in Section ***4.3 Septic Tanks***.

5. The site contains unsuitable subsurface soil or surface water drainage conditions. Soil conditions that interfere with on-site wastewater disposal are very fine sands; heavy clays; expandable clays; organic soil, coarse sand; gravel or fractured rock; or limestone with solution cavities. Locations on a site that are not suitable for on-site wastewater disposal are depressions, the foot of slopes, concave slopes, floodplains, and wetlands.
6. Site topography is such that there is inadequate slope to allow for gravity flow of wastewater to, though, and away from the septic system, including any absorption systems. However, land slopes greater than 25% are unsuitable.
7. Site is densely wooded with trees or other vegetation with deep roots.
8. Local regulations prohibit on-site wastewater treatment systems that utilize disposal of wastewater to the soil column.
9. Site does not have enough suitable land area for the wastewater treatment and disposal system.

Note: Some of these situations can be mitigated with proper design, such as by installing curtain drains to depress groundwater depth, excavation of unsuitable soil layers, or use of shallow trenches and fields, or above-ground mound systems. These are discussed in Section ***4.5 On-Site Wastewater Disposal***. However, some of these mitigations could be costly.

Selecting an Alternative Wastewater Treatment

Almost all alternatives to septic system represent a significant increase in construction and operating cost, complexity, operator and maintenance personnel sophistication, special equipment or consumable chemicals, and the need for reliable electricity. Care is needed to adequately assess the available alternatives to ensure the system proposed is affordable, operable, sustainable, and will meet the necessary discharge limits.

Several alternative wastewater treatment systems used in resource-poor developing include:

- Wastewater treatment lagoons
- Constructed wetlands
- Evapotranspiration beds
- Oxidation ditches
- Membrane bioreactors
- Anaerobic treatment systems (anaerobic biological filters, anaerobic baffled reactors, up flow anaerobic sludge blanket systems)

- Combined treatment systems (DEWATS)
- Biogas generator

See ***https://akvopedia.org/wiki/Sanitation_Portal*** for descriptions, design considerations, advantages and disadvantages, and other helpful research. Note that the determination of which type of treatment systems is optimal for a given site is a complex process that requires significant amount of site specific information about the wastewater being treated; local environmental regulations; conditions of the site where the treatment system would be located; land area available; slope of available land; cost of electrical power, treatment chemicals, expendable materials, spare parts, and any specialty services required; any many other aspects.

Because of the rarity of such wastewater treatment systems for EMI projects, there are no standard design templates or AutoCAD details for these treatment systems. Design information for such systems will need to be obtained from published literature. Design of any of these systems requires significant experience and expertise and suitably qualified engineers who know local regulations and conditions should be consulted prior to selection and design. **It is strongly recommended that the design of wastewater treatment systems such as these be performed by professional engineers with considerable experience in their design, construction and operation rather than attempting a design based solely on published literature.** Consider both internal EMI design resources and external design engineers with experience in the region you are working in. Also consider the cost implications of using external design resources.

The following resources and tools are to be used in designing an alternative wastewater treatment system:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can help determine if an alternative wastewater treatment system is needed.
- References and additional resources can be found in ***R4.7 Other Wastewater Treatment***.
- An example matrix to compare treatment technologies can be created using the ***EMI General Treatment Matrix Template***. The following information should be researched for each treatment:
  - Methodology
  - Product Examples
  - Advantages and Disadvantages
  - Operational Requirements
  - Capital Cost
  - Life Cycle Cost

4.7.3 DESIGN PROCEDURE

Step 1: Evaluate the project site for the feasibility of utilizing a typical septic system for on-site wastewater treatment and disposal. Review Section ***4.3 Septic Tanks*** and the Site Evaluation in Section *1.4*. Also explore applicable regulatory requirements, if there are any.

Step 2: If the site is not suitable for a typical septic system, determine if an alternate special septic system design could be successful. These include shallow trenches, mound systems, curtain walls, removal of unsuitable soil layers, or other alternate approaches discussed in Section ***4.5 On-Site Wastewater Disposal***. The septic system section or other sources. These alternate design are not common in EMI, so exercise caution in proposing such a system. Ensure adequately trained and experienced personnel are available to complete the design properly.

Step 3: If an alternative system is not feasible, consider all appropriate wastewater treatment technologies to propose an alternate to septic system. Also consider recommending to the client that they look for an alternate location that allows for on-site wastewater disposal. Such a change could be the most cost effective and sustainable solution to unsuitable site conditions.

Step 4: Create a ***EMI General Treatment Matrix Template*** to help select the preferred treatment system. To complete the design, use local design professionals or system vendors if a manufactured system is being considered.

5 Site Design

5.1 GRADING AND STORMWATER DRAINAGE

Grading and stormwater evaluation ensures that the site design makes consideration for the effects of rainfall on the site as well as the impacts of existing and proposed topography on the buildings and vehicle/pedestrian paths. These investigations are important for preventing flooding, sizing rainwater harvesting equipment, and protecting against erosion. They also help to identify the need for stairs, retaining walls, and special grading on the site. There are several methods for estimating site runoff, but since many people can work on an EMI project at different times, it is recommended that a typical method be followed and assumptions documented clearly, so that others can follow the work that was done. Site grading will depend largely on locally recognized standards for slopes and the ability for local contractors to perform cut and fill operations on the site.

5.1.1 DESIGN STAGE

Frequency of Use: All EMI projects involving new or expanded buildings will include information on grading and stormwater drainage.

Conceptual Design: Perform an initial estimate of the expected rainfall for the site; set preliminary ground floor elevations for proposed structures; identify approximate wall and stair heights and locations on the site; determine expected drainage flow paths on the site; and perform preliminary sizing for rainwater storage.

Detailed Design: Review and refine the initial rainfall estimate along with the detailed design scope and any applicable masterplan changes to inform required site infrastructure and building plumbing design (gutters, roof downspouts, etc.). Specify the site stormwater drainage system; including conveyance (pipes, culverts) and any required attenuation measures (retention ponds, flow controls, etc.); determine slopes and spot elevations for site features (driveways, parking areas, walls, stairs, etc.).

5.1.2 DESIGN CRITERIA

Generally, building ground floor elevations should be set as closely as possible to existing grade to minimize cut and fill. The ground surface should slope away from buildings at a minimum grade of 1% to prevent rainwater from ponding at the foundation and undermining footings or causing other concerns. A well-designed site considers the effects of runoff and provides safe pathways for drainage to leave the site, with protections against erosion as needed. It is important to prevent ponding of storm water on the site to minimize the breeding of mosquitos, especially in malaria-prone areas. Special consideration must be taken to analyses grading both on steep sites and on flat sites to ensure that rain water does not become problematic or interfere with the expected site functions.

An accurate estimate of rainfall for the site will take into account many factors, such as:

- Desired design storm;

- Historic rainfall data for the region;
- Site characteristics (elevation, topography, proximity to oceans, prevailing winds, etc.);

The degree of detail selected for stormwater calculations depends on the needs of the site and expected purposes. For sites requiring only preliminary drainage paths and approximate water storage, and where storm runoff is not expected to be problematic, using regional monthly rainfall rates may be sufficient. Where harvested rainfall will be used for irrigation or to offset water use, or if a high erosion or flooding potential exists on the site, more detailed calculations to determine runoff should be undertaken.

Design Tips:

- Wherever possible, limit retaining wall height to 1m (use multiple staggered walls for bigger grade differences). As a general rule, the horizontal spacing between multiple staggered walls should not be less than two times the height of the lower wall. Where walls over 1m in height are unavoidable, seek input from a structural engineer and communicate to the owner the importance of adhering to design details in construction of site walls.
- In general, designed slopes should not exceed 3H:1V. Exceptions are made for reinforced slopes.
- Design for exceedance by considering the scenarios of extreme rain events that exceed the design storm, and also may consider additional risks from off site.
- International Standards for Accessible Construction and local accessibility standards should be consulted in identifying site layout and grading features such as widths and slopes for exterior pathways, ramp and stair standards, and building access. (Chapters 10 and 11 of the International Building Code (IBC) discuss requirements for accessibility and is free online ***https://codes.iccsafe.org/content/IBC2018***.)

The following resources and tools are to be used in developing the grading plan and stormwater runoff estimate:

- The Client Needs Assessment and Site Evaluation discussed in Section **1** include sample guiding questions and evaluation criteria that can inform important grading and drainage design components such as the selection of design storm, desirability of stairs in building access, and need for accessible design considerations.
- References and additional resources can be found in ***R5.1*** ***Grading and Stormwater Drainage***.
- Monthly average rainfall data for the nearest available location using a reputable website such as ***https://www.weather-atlas.com/en/climate***. Where possible, average results from multiple sources.
- The ***EMI IDF Analysis Template*** should be used to generate rainfall values where more detailed storm system sizing calculations are needed, or where EMI anticipates

moving into detailed design. The spreadsheet generates overall rainfall for multiple storm frequencies, as well as adjustments in intensity for each frequency based on typical storm durations.

- The ***EMI Stormwater Runoff Template*** can be used to estimate a drainage plan for the site.
- The International Building Code 2018 is available online for free: ***https://codes.iccsafe.org/content/IBC2018***

5.1.3 DESIGN PROCEDURE

Step 1: Review the information in Client Needs Assessment and Site Evaluation.

Step 2: Determine project lifecycle and phasing.

Step 3: Identify expected rainfall using monthly averages, or the ***EMI IDF Analysis Template***. Use office-specific detailed descriptions, Site Evaluation discussed in Section ***1*** and other observations from client meetings to determine which method to use, and (if using IDF) what design storm is appropriate.

Step 4: Determine building ground-floor elevations and general slopes around the site. Provide this information in a CAD file, or hand marked on the site plan. Include drainage arrows for expected flow directions, and dashed lines for locations of constructed channels.

Step 5: Evaluate topography of the surrounding area to determine locations of run-on from neighboring properties. Determine locations and types of systems to safely convey this water off-site using the ***EMI Stormwater Runoff Template.***

Step 6: Locate and size site storm water system.

Step 7: Provide all calculations related to rainfall in the report Appendices.

5.2 ROADWAYS

While much of the master planning layout of the site will be performed by the architecture team, the civil team should be involved in the process. Most EMI projects do not have a complicated vehicular circulation pattern, often there is a short access road leading to a parking lot. Most often, EMI designs involve onsite private roads and so EMI is not bound by design codes. Determining the road design and layout is an exercise in engineering judgment and will depend on the intended use of the road, the size and slope of the site. If designing a public road, consult with the local design codes to determine governing requirements.

5.2.1 DESIGN STAGE

Frequency of Use: During a master plan or any project that has a site layout.

Conceptual Design: An initial assessment of vehicular circulation through the site. This should include the layout of proposed and existing roadways, a preliminary typical road cross section with widths defined, and parking areas should be identified with approximate sizes needed.

Detailed Design: Roadways plans are further developed in close collaboration with grading and drainage plans. The typical cross sections should show widths, cross slopes, drainage swales or ditches and culverts should be designed based upon estimated peak flows from drainage areas as necessary. This should include a pavement section design in most cases.

5.2.2 DESIGN CRITERIA

There are several factors to consider such as:

- Vehicular access: determine from the Section ***1*** checklists which questions are relevant to the master plan;
- Roadway wearing course material see the recommendations below.
- Horizontal design— see the recommendations below;
- Vertical design—see the recommendations below;
- Drainage plan based on Section ***5.1 Grading and Stormwater Drainage***;
- Anticipated frequency and type of vehicles entering the site
- Facilities requiring access (kitchen, septic tanks for maintenance, etc.)
- Pavement subgrade consistency and uniformity
- Base and subbase material and compaction

Vehicular Circulation

- Any areas where special access is needed (i.e. Kitchen deliveries, maintenance trucks for septic tanks, water facilities, etc.)
- Any needs for multiple entrances

- Site conditions, soil types, grades, wet areas, drainage patterns which might make some areas unsuitable for roadways
- Parking and parking traffic

Roadway Wearing Course Material

Typical materials are listed below:

- Murram is gravel road with clay binder elsewhere (clay typically comprises about 3 to 12 percent of the material by weight), this term is common in sub-Saharan Africa.
- Tarmac is typically crushed rock mixed with tar (contraction of tarmacadam), and is a term commonly used for airport taxiways and parking areas (although most of these are concrete now).
- Macadam is a gravel road treated with either oil or tar to provide a hard surface for all-weather use.
- Gravel. A good quality gravel (or murram) for roads should have sound, angular gravel with a maximum size of 20 to 50 mm, with a silt-clay binder content of about 3 to 12 percent by weight.
- Asphalt: The local asphalt mix should be a fair recommendation.
- Paving stones.
- Concrete.

Most EMI projects specify the use of a compacted murram, or gravel, wearing course. On some sites, high-quality murram (a clay/gravel mixture) will be available onsite for harvesting, but on most sites, high-quality murram, or roadway gravel, should be imported. EMI typically recommends a compacted gravel surface of 150 mm thickness is sufficient if the subgrade is adequate. If subgrade is soft, or if heavy truck traffic is anticipated, then the gravel thickness might need to be 225 mm, or more. If asphalt, or concrete, is used for pavement, typically it has a sub-base layer over the subgrade, which is similar to a compacted gravel road material. This requires subgrade information such as CBR (California Bearing Ratio), or subgrade modulus etc. and requires more site geotechnical information to design. For a tarmac or macadam pavement, a sub-base layer is typically not used because such surfaces are just improved, or hardened, gravel roads. Some areas, such as Rwanda, have used paving stones which area a good option if local practices and materials allow. The designer can look at roads coming up to the site, checking for thickness of asphalt and if any sort of base course is under it.

The use of higher quality finishing materials (paving stones, tarmac, or asphalt) may be requested by the ministry. EMI currently does not have specific tarmac paving design standards and the engineer will have to evaluate materials and make a site-specific recommendation in cases where tarmac, asphalt or concrete is requested.

Note that site topography is very important, particularly if the access road, or site roads, are in a mountainous area and the road sections need to be constructed with cut and compacted fill with downslope stabilization or retaining walls.

Horizontal Design Considerations

- If the road is short, and there is not much likelihood of vehicles meeting each other head-to-head, then 3.0 meters is an acceptable road width. If the area adjacent to the roadway is flat and clear, it may be acceptable to expect vehicles to pull to the side of the road when passing is needed.
- If the road is long, and possibly busy, with a higher likelihood of vehicles meeting each other, consider a 6.0-meter-wide roadway. This would allow vehicles to pass each other without pulling off of the road, but would require them to slow down and pass carefully.
- If higher speed passing is necessary, the roadway should be a minimum of 7.5-m width for this type of roadway (two 12-ft, 3.65-m, wide lanes is standard in US and much of the world especially if two-way truck traffic is required).
- Most EMI-designed roads are not high-speed roads and do not require detailed consideration for other horizontal design parameters related to design speeds and site distances. Engineering judgment should be used when determining curve radii and if access roads to a site will have public traffic with speeds over 50 km/hr, regional codes should be consulted to determine horizontal curve radii. For site roads, passenger vehicles might only need curve radii of about 6m while trucks might require curve radii of 10m or more. If particularly tight corners are needed, or the roadway will serve large vehicles, some EMI offices may have access to software packaged with Civil 3D that will allow the designer to run various vehicles through a roadway and check for clearances.

Vertical Design Considerations

Vertical roadway design for private, onsite roads will be dependent on the engineering judgment of the designer.

- If possible, roadways should maintain a slope of 10% or less. Short reaches of access roads or driveways may be up to 12% if the surfacing is adequate. Steeper roadways may be acceptable, but will require special consideration based on the type of vehicle expected to use the road. (If any projects are in areas where it can be icy, then slopes should be flatter than 10%.
- Roadways of 10% or less may be finished with compacted clay/gravel mixture on steeper roadways, asphalt pavement or pavers should be considered to help avoid tire slipping.

Special consideration should be given in areas where the vertical design of the road experiences a large grade change – vertical curves may be needed in this area. For example, if a roadway is running flat, at 0.0%, and then suddenly transitions to a 12% climb, this transition should be achieved through either a vertical curve or a carefully laid out series of grade changes so that vehicles do not scrape bottom while navigating the grade change. Vertical curves may be needed on top of curbs to ensure sight distance, especially if pedestrians and vehicles share roads.

Drainage Considerations

Roadway layout should be considered in close collaboration with drainage design, see Section ***5.1 Grading and Stormwater Drainage***. Most gravel roads will function nicely if they are graded properly and drain. Thus, considering how water will flow across the site and road is important. Roadways often cut across the site and block drainage channels. If clear points are not identified for culverts or grated channels to allow water to cross the road, the road will either act as a dam or prevent water from flowing, or water will flow across the road and cause ruts and potholes. If the road is not crowned, the road may become the drainage channel.

Most roads on EMI projects are relatively narrow roads placed along a slope. In this scenario it is often advisable to have the cross slope of the road slope in a single direction, rather than crowning the road. The cross slope of the road should follow the slope of the site to limit the grading requirement. Asphalt or concrete pavements (or tarmac or macadam) should have a surface drainage slope, or crown slope, of 2% minimum, and gravel (or murram) roads should have a surface drainage slope of at least 3%.

If there is a significant area of land and development (either onsite or offsite) on the uphill side of the road or if the road has drainage from an adjacent hillside, a ditch should be placed along the uphill side of the road to collect this runoff and direct it to a crossing point and culverts should typically be designed to convey runoff from an uphill drainage ditch under the roadway to prevent washouts. This ditch will protect the road from the uphill runoff which would deteriorate the roadway surface. On the downhill side of the road, consideration should be given for how the runoff from the road will be handled. If there are buildings located near the road, on the downhill side, a roadside ditch may be needed to catch the roadway runoff and carry it to a discharge point. If there is sufficient landscaped area along the downhill side of the road, it may be appropriate to allow the runoff from the road to sheet-flow off of the road and flow into the landscaping. If this is the intention, care should be taken during construction to ensure that there is a flush connection between the roadway surface and the adjacent landscaping, it the contractor leave a berm of cut in this area, the water will not enter the landscaping and will run along the edge of the road, causing erosion.

The following resources and tools are to be used in developing the roadways for the site:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the roadway design.
- References and additional resources can be found in ***R5.2*** ***Roadways***.

5.2.3 DESIGN PROCEDURE

Step 1: Work with architecture team to develop a vehicle circulation plan for the site.

Step 2: Determine the width of each roadway on site. Deciding on road widths will require engineering judgment.

Step 3: Determine the material that will be used for the roadway surface based on the vertical design considerations.

Step 4: Develop a site drainage plan and ensure that the roadway layout fits in with this plan. Be sure to specify culvert crossings at key points.

Step 5: In coordination with the drainage plan, draw a roadway section for key portions of the road.

Step 6: Refine the horizontal layout of the road based on modeling software, if available.

Step 7: Consider the vertical layout of the road.

Step 8: Pavement section design, including drainage structures and embankment design as necessary.

5.3 RETAINING WALL DESIGN

Retaining walls are structures primarily used to hold soil to a slope it would not naturally keep. They may also be used to mitigate soil erosion, expand the useable area of a sloped site, protect facilities below a slope, and prevent soil collapse and settlement. In the developing world, retaining walls are typically constructed from reinforced concrete, timber logs, concrete blocks, brick, stone, reinforced earth or a combination of the above materials. Soldier pile walls with steel piles or lagging are also used in some areas. Soil nails or shotcrete walls are uncommon but available in some regions.

5.3.1 DESIGN STAGE

EMI typically recommends that sites are developed in a manner which avoids or minimizes the need for retaining walls. Walls less than 1m in height are typically recommended during conceptual design.

Frequency of Use: Varies depending on site topography.

Conceptual Design: If necessary, identify proposed retaining wall locations, type and perform initial calculations to estimate size based on preliminary soil data from the site investigation or geotechnical report if obtained. Defer to conservative standards of locally practiced methods if retaining walls are commonly used locally.

Detailed Design: Refine initial calculations and develop construction documents if using reinforced concrete. A site-specific geotechnical report should be obtained. Use the applicable regional and national codes and ensure proper licensing requirements are met.

5.3.2 DESIGN CRITERIA

Types of retaining walls include:

- **Gravity Retaining Wall:** Depends on self-weight, base interface friction, and passive earth pressure to resist lateral earth pressure; typically, economical up to a height of 3m. Can include stacked stone, masonry, or concrete blocks, and gabion basket system (wire meshes cages filled with rock).
- **Cantilever Retaining Wall:** Composed of a vertical stem wall, horizontal base slab, and sometimes a shear key to resist sliding. It requires a thinner section of concrete than a gravity wall but is more complex and expensive to construct, since it must resist the moment applied by active earth pressure. Typically, economical up to height of 8m.
- **Piled Retaining Wall:** Constructed by driving piles or drilling caissons along the length of the slope to be retained. Piles may be driven at close spacing, or have additional elements inserted between each pile to create a solid wall face. Sheet pile wall can also be used to protect adjoining structures or as a temporary measure. Typically, economical up to a height of 6m.

- **Mechanically Stabilized Earth (MSE) Retaining Wall:** A wall face is backfilled with select granular material layered with reinforcements (either metallic strips or plastic geogrids); economical where available, but not universally used or familiar.
- **Anchored Retaining Wall:** Deep cable rods or wires are installed deep into the earth and the ends are filled with concrete to provide an anchor. Suitable for loose soil over rocks and best employed when space is limited or a thin retaining wall is required.

Note that different types of retaining walls will require substantially different analysis, details, and construction methods. However, all retaining walls depend heavily on good drainage design. A majority of retaining wall failures can be attributed to poor drainage.

Soil parameters required for design are:

- Soil Classification
- Unit Weight
- Wall & Base Interface Friction Angles
- Strength Parameters such as:
    - Soil Friction Angle and Cohesion
    - Undrained Shear Strength
    - Soil Layer Depth
- Site parameters required for design are:
    - Retained soil height
    - Location of water table (and seasonal variation)
    - Local stormwater runoff and drainage
    - Site seismic acceleration
    - Construction access to the slope
    - Material availability and properties
    - Site Slope (i.e. slope cross section)
    - Surcharge loads from adjacent structures or live loads

Types of Structural Failure:

<u>Sliding Failure:</u> evident when the wall moves away from the retained soil because the horizontal driving forces are greater than the resisting forces.

<u>Overturning Failure (eccentricity):</u> evident when the wall rotates about its front edge because the sum of the moments causing overturning is greater than the sum of the moments resisting overturning.

Bearing Failure: evident by soil failure below the wall caused by excessive vertical live loads, surcharge loads, and induced incremental seismic stresses.

Structural Failure: evident by excessive cracking or deflection in the vertical wall of the retaining structure. The wall is not adequately designed for the applied moment.

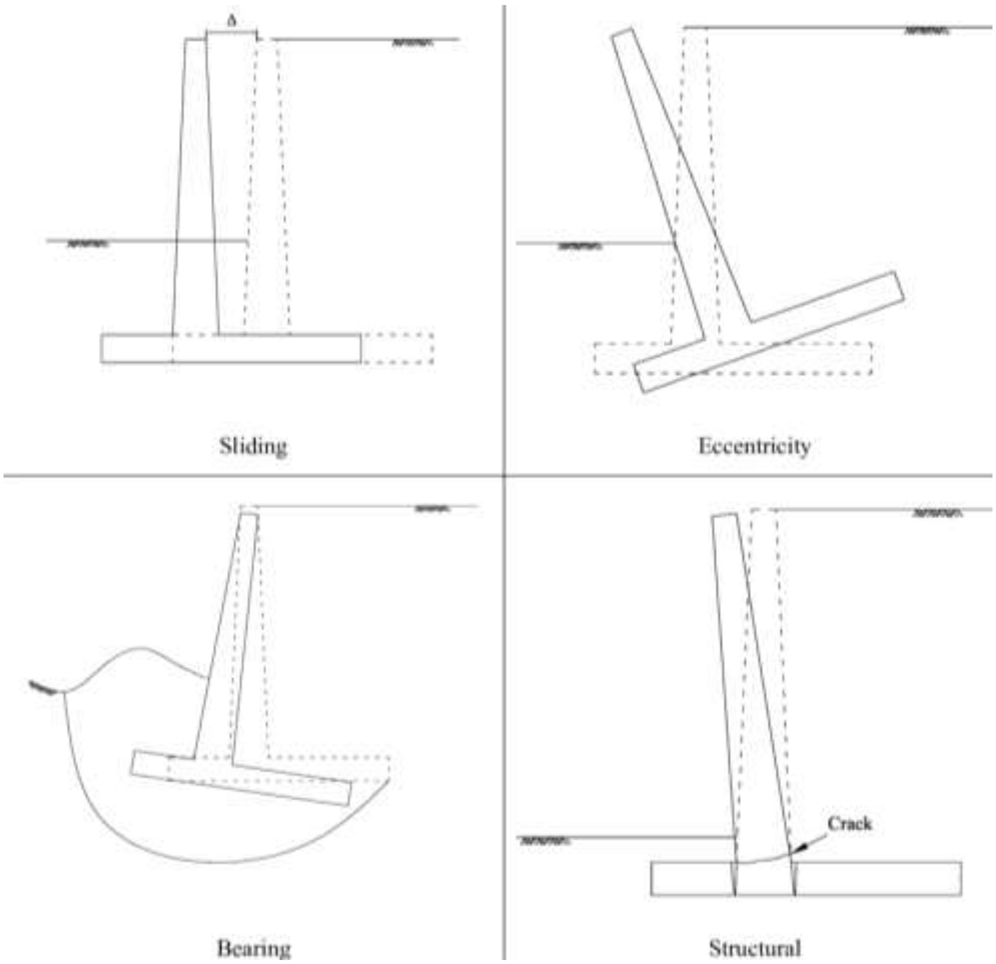


Figure 5.3-1 Types of Structural Failures

Global Failure: is evident by rotational movement (or failure) of the entire retaining wall system and all other reinforcing elements. This type of failure typically extends well below the retaining wall itself. Global failure occurs in unusually weak or soft soil, or when additional surcharge loads from the retaining wall and retained backfill induces failure on a steep slope.

Wall Drainage Details:

Drainage could include "weep holes" which are small openings that allow water to drain from behind the wall. An agricultural or French drain consisting of a perforated PVC or other suitable pipe surrounded by open-graded aggregate wrapped in separation geotextile on top of or behind the heel of the wall on retained earth side is required to drain the water unless a more sophisticated drainage system is utilized.

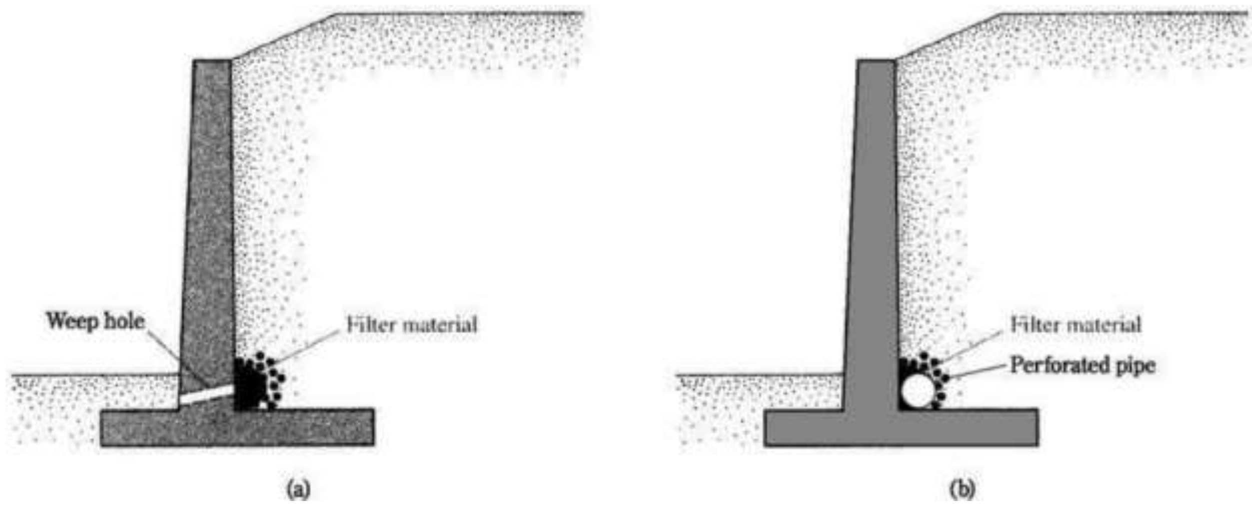


Figure 5.3-2 Diagram of Wall Drainage Details

The following resources and tools are to be used in developing the retaining wall design:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the retaining wall design.
- Appendix ***A5.3***
- ***Retaining Wall*** Types provides examples of retaining walls described above.
- Appendix ***A5.3.2*** ***Typical Retaining Wall Proportions*** provides typical dimensions for retaining wall design.
- Appendix ***A5.3.3*** ***Retaining Wall Design Parameters*** provides typical estimates of soil parameters and factors of safety (only to be used for conceptual design and estimation purposes)
- Appendix ***A5.3.4*** ***Forces on Retaining Walls*** provides the forces experienced by the retaining wall under normal conditions.
- References and additional resources can be found in ***R5.3*** ***Retaining Wall Design***.

5.3.3 CONCEPTUAL DESIGN PROCEDURE

Step 1: Perform a site assessment following Section ***1*** on site design.

Step 2: Select the retaining wall location. Best locations minimize soil excavation and backfill. Consider drainage patterns and existing site features.

Consider placing an adjacent retaining wall as opposed to designing the walls of buildings to retain soil to avoid possible rising damp and waterproofing issues in the building as well as other serviceability reasons.

Maintain spacing from roadways and foundations.

Step 3: Evaluate if surcharges due to vehicular traffic or adjacent structures will be applied to the wall. Where possible, avoid locations with heavy surcharge loads interacting with walls.

Step 4: Determine soil parameters, see ***Table A 5.3-35 Typical Soil Properties***.

Step 5: Determine the optimal type of retaining wall for the site based on local practices and site demands, Appendix ***A5.3***

Retaining Wall **Types**.

Step 6: Determine retaining wall geometry using Appendix ***A5.3.2*** ***Typical Retaining Wall Proportions*** for guidance.

Step 7: Check for failure modes see ***Figure 5.3-1 Types of Structural Failures***.

Step 8: Design site drainage and provide wall drainage details to minimize effects of water on wall stability, see ***Figure 5.3-2 Diagram of Wall Drainage Details***.

5.4 SITE LAYOUT, ACCESS AND PARKING

Although the architectural concept often drives the site layout, many important factors influence final placement of site features, and the civil team should provide input into the master plan early in the process to ensure important factors are not overlooked. Civil input will ensure that adequate space is reserved in appropriate locations for utility infrastructure, assess feasibility and appropriate placement of access point(s), and confirm that adequate parking is included to meet the needs of the program. The design guidance from the other Civil Sections (water, wastewater, grading, roadways, etc.) will inform this section.

5.4.1 DESIGN STAGE

Frequency of Use: All EMI projects should evaluate site layout, access and parking.

Conceptual Design: Evaluate placement and orientation of all site components in conjunction with architecture team; confirm setback, maximum building coverage, building height, or other local requirements are followed; coordinate locations and approximate sizing for site infrastructure (water, wastewater, solar, storm drainage, storage tanks, trash collection, etc.); evaluate or design vehicle and pedestrian access point(s); and locate and size parking areas.

Detailed Design: Review and refine the initial layout along with the detailed design scope and any applicable masterplan changes. Confirm locations and space requirements for site infrastructure based on detailed design of those systems; verify parking numbers and locations, and design parking lots (including maneuvering spaces); verify sight distance and vehicle maneuvering is achieved at all access points to and within the site; coordinate with site grading, utilities, waste management, and architecture as necessary.

Phasing Considerations: If the site is existing, and the ministry is expanding, phasing of proposed changes will need to be considered. Can construction happen when school is not in session, for example? If the ministry must remain open, access will need to be considered during the construction phases. In addition, staging areas for construction material storage should be considered. Final design may need to be adjusted to make construction easier.

5.4.2 DESIGN CRITERIA

Effective site layout should consider not only the buildings on the site, but also all of the supporting features required for the site to function as intended. This includes utility systems (water, wastewater, electrical, etc.), trash storage and collection, staging areas, vehicle types needing access to various parts of the site, required parking areas, security, etc.

Wind direction is an important factor to consider for site placement of features such as wastewater treatment facilities, trash storage or on-site refuse burning. Avoid placement or provide sufficient screening for locations that would direct odors or smoke towards ventilated or frequently populated areas. Coordinate with Section ***6.2 Solid Waste Disposal***.

Grading of the site should be taken into account when placing facilities that rely on gravity to perform their functions. Infiltration systems and stormwater ponds will usually be placed at the low end of the site, while water storage facilities will typically be placed at the higher end. It may be prudent to evaluate the surrounding watershed to determine stormwater runoff that occurs from upslope of the project site. Refer to Section ***5.1 Grading and Stormwater Drainage*** for grading and drainage considerations.

Existing access points on a site are typically maintained whenever feasible, but should always be assessed for safety and functionality. Where an access point has not been established (greenfield site) or when relocating or adding access points, consult local regulations to determine the approval process and location requirements (if any). Site access should at a minimum consider:

- Sight distance for vehicles on the adjacent roadway based on the design speed
- Need for bypass lanes or turning bays for concentrated high-volume arrivals such as school pickup/drop-off or church start/end
- Proximity to access points for adjacent properties
- Vehicle size that must be accommodated at each access point
- Need for separate entrances for visitors and/or staff/maintenance
- Security requirements of the access point

Where access to the site is controlled by a gate, the gate should be set back a sufficient distance to allow one or more vehicles to pull completely out of active traffic while waiting for the gate to be opened. Refer to Section ***5.2 Roadways*** for discussion on horizontal and vertical requirements for driveways on site.

Along with the primary site access, the following should also be considered:

- Access to trash collection for disposal off-site
- Access to septic tanks for periodic maintenance
- Access for drilling or maintenance of water supply well(s)
- Access to maintenance buildings (pump house, generator building, etc.)
- Access for deliveries (confirm vehicle type and turning requirements)
- Need for building access that accommodates special needs persons (wheelchair access, etc.) Refer to Section ***5.1 Grading and Stormwater Drainage*** for guidance on accessible design.

- Refer to local design standards for parking bay and access aisle design. Typical 90-degree parking bay dimensions are 2.5m x 5m, and a typical 2-way access aisle is 7m wide.

The following resources and tools are to be used in developing the site layout, access and parking design:

- The Client Needs Assessment and Site Evaluation discussed in Section 1 include sample guiding questions and evaluation criteria that can inform important access, layout and parking considerations.
- References and additional resources can be found in ***R5.4 Site Layout, Access and Parking***.

5.4.3 DESIGN PROCEDURE

Step 1: Review the information in Client Needs Assessment and Site Evaluation.

Step 2: Identify major site and surrounding features that influence layout (slope, wind direction, access location, views, existing vegetation, water features, existing facilities to remain, soil profile and suitability to support planned infrastructure, etc.). Document these features and their impact on the design in the report.

Step 3: Assess surrounding properties or potential developments to determine potential for impacts to/from any changes to the project site (drainage, waste management, etc.).

Step 4: Consider desired locations of infrastructure features (tanks, solar panels, soak away systems, trash collection, paths, pump house, etc.). Coordinate with Architectural team to designate approximate areas for these systems in the conceptual site layout.

Step 5: Determine access needs to various site features and design appropriate road/path and maneuvering spaces for these areas. Identify preferred location and desired amount of parking and lay out sufficient parking bays and access aisles.

Step 6: Once conceptual design for utility systems is complete, update these areas on the site layout to show actual expected footprints and access routes. If phasing is needed, provide sample phasing plan.

Step 7: Provide discussion on site layout, access and parking for the design report. Include recommendations on new site access location, or improvements to the current access or adjacent roadway to improve safety or function.

6 Solid Waste Management

6.1 SOLID WASTE COMPOSITION AND GENERATION

Identifying Solid Waste composition and estimating generation are important considerations for any EMI project but are crucial for medical facilities. The source and nature of Solid Waste depends on the nature of activities being conducted on-site, and an assessment of quality and quantity of waste generated at full build-out must be considered.

6.1.1 DESIGN STAGE

Solid waste composition and generation rates should be analyzed on every EMI project, and is of particular importance on hospital projects.

Frequency of Use: All hospital projects include a Solid Waste analysis. Other projects should assess whether any non-standard or hazardous waste is expected to be generated on-site, and complete an assessment accordingly. For most projects a simple discussion of solid waste generation is sufficient to include in the Master Plan report.

Conceptual Design: Identify potential sources of solid waste on the site and estimate the quantity produced on a regular basis.

Detailed Design: Compile a detailed list of expected normal and hazardous waste generated on-site, along with expected daily, weekly, monthly or annual disposal volumes.

6.1.2 DESIGN CRITERIA

Quantity and quality are the two major considerations in solid waste design. Quantity is the most important parameter required in the design of management and subsystems; it is given in terms of generation rate (i.e. the amount of waste generated by a person or a facility in one day). Solid waste quality encompasses not only the different types and sources, but also physical, chemical, and biological characteristics of the waste. Of particular importance are any hazardous characteristics. Materials suitable for recycling such as food processing waste, metal, glass or plastic suitable for recycling are also identified, however, recycling facilities in the area should be confirmed before proposing recycling.

Waste quantities are measured using either volume or weight measurement; however, the weight measurement is preferred as the most accurate. Worldwide, waste generated averages 0.74kg/person/day, but this ranges widely from 0.11 to 4.54 kg/person/day. The volume measurement uses the anticipated density of the waste as produced and is more applicable for facilities that do not have an on-site compactor. There is a positive correlation between waste generation and income levels; high-income countries account for 34% of waste generated, but only 16% of the world's population. Consult with local experts to determine the appropriate generation rate to use on each particular project.

Quality indicates the type of waste generated which may require special handling and disposal. Types of waste include medical waste, biohazard waste, chemically hazardous waste, organic waste, animal waste, recyclable materials, physically dangerous items (needles, broken glass, sharp metal debris), hazardous organic waste from wastewater disposal, etc.

Understanding of solid waste generated at health-care facilities, research centers and laboratories or any other facility related to medical procedures is particularly critical. Between 75% to 90% of the generated waste is comparable to domestic waste and considered "non-hazardous". The remaining 10-25% is considered hazardous and may pose a variety of environmental and health risks (WHO, 1986, pg. 3).

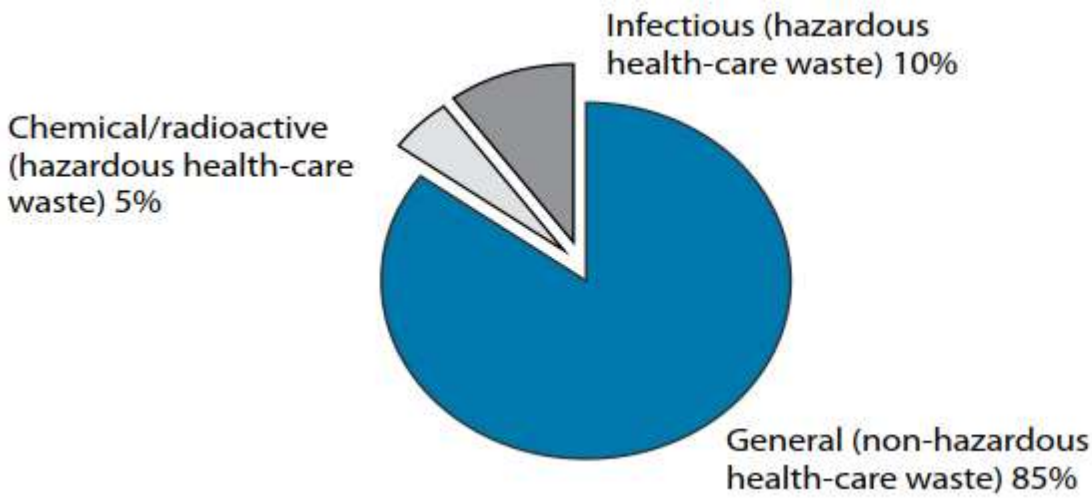


Figure 6.1-1 Types of Solid Wastes

Source: WHO, 1986

The following resources and tools are to be used in developing the site's solid waste generation:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the site's solid waste generation.
- ***Table A 6.1-39 Solid Waste Sources in Hospitals*** in Appendix ***A6.1*** outlines examples of health-care waste from different departments
- ***Table A 6.1-40 Average Waste Generation Rates*** in Appendix ***A6.1*** provides average waste generation estimates based on health-care facilities
- ***Table A 6.1-41 Bulk Densities of Solid Waste by Component*** in Appendix ***A6.1*** typical densities of solid waste

- ***Figure A 6.1-49 Example Waste Segregation Flowchart*** in_Appendix_***A6.1*** example waste segregation flow chart
- References and additional resources can be found in ***R6.1*** ***Solid Waste Composition***.
- ***EMI Solid Waste Field Packet*** can be used to evaluate and discuss with the ministry to understand anticipated or existing solid waste generation during a project trip.

6.1.3 DESIGN PROCEDURE

Step 1: Evaluate existing waste composition and generation using the provided ***EMI Solid Waste Field Packet***. If at a Greenfield site, skip to **Step 3**.

Step 2: At existing sites, verify the gathered information by observing waste collection locations and processes.

Step 3: Attempt to estimate the current volume of waste generated.

Step 4: Determine the rough percentages of waste composition and any unusual or hazardous waste.

Step 5: Estimate the average future amount of waste of each type to be generated (typically kilogram per occupied bed per day, or kilogram per person per day) based on responses from the ***EMI Solid Waste Field Packet***, Section *1* checklists, and provided tables in Appendix ***A6.1***.

Step 6: Determine if there are appropriate recommendations to minimize waste. These could include on-site organic waste composting, or separation and recycling of some waste.

6.2 SOLID WASTE DISPOSAL

Solid Waste Disposal encompasses the removal and destruction of typically solid or semi-solid materials that are useless, unwanted, or hazardous. Disposal typically means landfilling waste for the purpose of final burial/ destruction or placing it for future recovery as a form of pollution control. Isolating it minimizes the wastes environmental impact.

Structures to handle and dispose of solid waste for EMI projects are usually very simple, often consisting of sorting and storage facilities and simple burial or burn pits for waste that cannot be reused.

6.2.1 DESIGN STAGE

Solid Waste Disposal should be considered on every project and is essential for healthcare facilities.

Frequency of Use: All EMI projects should provide general recommendations regarding waste storage, handling and disposal. Healthcare projects always consider additional Solid Waste Disposal due to the hazardous nature of medical waste.

Conceptual Design: Evaluate existing solid waste disposal practices (if applicable) and make recommendations regarding future waste disposal based on the amounts and types of waste generated on the site. Ensure that adequate space is allocated on the site for solid waste disposal (if appropriate) and locate structures and facilities on plan.

Detailed Design: Depends on local or regional requirements. Typically, design any processing, storage, treatment and disposal facilities needed to safely handle and dispose of the solid waste on site in a manner consistent with requirements.

6.2.2 DESIGN CRITERIA

Solid Waste Disposal depends greatly on the available treatment methods and local conditions. Secondary considerations include waste characteristics, technology and requirements, environmental and safety factors, and cost.

Waste-treatment options include:

- **Thermal Processes:** rely on heat to destroy pathogens in the waste and is the most commonly used practice in facilities across the world.
- **Chemical Processes:** use of disinfectants.
- **Biological Processes:** use of enzymes to speed up the destruction of organic waste containing pathogens.

In the developing world, incineration is the most common waste-treatment system. Incinerators range from small-batch units to large, complex treatment plants and should have flue gas cleaning systems to minimize pollutant releases and meet national or international emission limits. Additional waste-treatment systems include:

- Autoclaves
- Integrated or hybrid steam-based treatment systems
- Microwave treatment technologies
- Dry-heat treatment technologies
- Chemical treatment technologies

Incineration requires limited pretreatment. Sorting solid waste to remove items such as pressurized, highly flammable, toxic or radioactive items, heavy metals, PVC, or explosives is necessary prior to incineration. If properly operated and maintained, the incinerator will eliminate pathogens from waste and reduce waste to a small volume of ash. Basic required waste characteristics include:

- Content of combustible matter above 60%
- Content of non-combustible solids below 5%
- Content of non-combustible fines below 20%
- Moisture content below 30%

Three generic kinds of incineration technology commonly used are

1. Dual-Chamber Starved-Air Incinerators: designed to burn infectious healthcare waste
2. Multiple Chamber Incinerators
3. Rotary Kilns: reach temperatures that break down genotoxic substances and heat-resistant chemicals

The treated waste is then disposed of in a landfill in a controlled fashion.

However, instead of disposing of waste, it is often allowed to accumulate at the facility where it is openly burnt or spread indiscriminately around the facility's grounds. This produces a far higher risk of transmission of infection than controlled disposal at a landfill site. Different communities have different customs for disposing of solid waste. Ensure you have an adequate understanding of how waste (i.e. anatomical waste) should be disposed of in a culturally or religiously acceptable way. Examples of this include placenta pits, hiding the morgue.

The following resources and tools are to be used in developing the solid waste disposal plan:

- The Client Needs Assessment and Site Evaluation discussed in Section ***1*** include sample guiding questions and evaluation criteria that can inform the solid waste disposal plan.
- Appendix ***A6.2***

- ***Solid Waste Disposal Minimum*** Requirements shows the minimum requirements for Solid Waste Disposal
- References and additional resources can be found in ***R6.2*** ***Solid Waste Disposal***.
- ***EMI Solid Waste Field Packet*** to share and discuss with ministry to develop and understanding of anticipated or existing solid waste generation.

6.2.3 DESIGN PROCEDURE

Step 1: Review ***EMI Solid Waste Field Packet*** with ministry. If on a Greenfield Site, skip to **Step 4**.

Step 2: Verify responses by observing disposal practices on site.

Step 3: Ensure the minimums as described in Appendix ***A6.2***

Solid Waste Disposal Minimum **Requirements** are met.

Step 4: Determine the quantity and composition of waste generated on-site using Section ***6.1 Solid Waste Composition and Generation***.

Note: every waste type must have a method for storage and disposal.

Step 5: Identify suitable treatment options prior to final disposal.

Note: most hazardous healthcare waste is potentially infectious, so waste-management technologies should focus on disinfection.

Step 6: Locate and size the on-site treatment and/or disposal practice(s) and provide guidance on frequency of use. Provide a sorting and storage area if solid waste requires some processing, such as separation of recyclable waste from the trash stream or burnable waste from non-burnable waste.

Note: Treatment facilities could include a compost area for food waste, an incinerator for burnable waste, or special medical waste incinerator for infectious waste.

Note: Provide guidance on frequency of off-site disposal and ensure that the site design accommodates appropriate handling, storage, loading and transport needed.

Step 7: Identify if specific waste categories such as sharps, pharmaceutical, chemical, heavy metal, or similar are present and will require disposal.

Note: Storage areas and size will depend on the nature of waste. Hazardous waste must be stored under cover and in a controlled area; nonhazardous waste may be stored outdoors, but will be protected from human or animal contact. Combustible waste must be stored well away from other facilities.

Step 8: Determine location of final disposal. Desirable features include restricted access to prevent scavenging, daily soil cover to prevent odors, proximity to property line and buildings, regular compaction, an organized deposit of wastes to prevent contamination of groundwater and surrounding areas, and trained staff. Disposal facilities could include burial pits for non-burnable waste, ash, glass, infectious waste or tissue.

Appendix

A0 Introduction

Table 0- 3 List of Contributors

Report Sections	Author(s)	Editor(s)	Reviewers
Introduction	Jason Chandler	Natalie Thompson	Wil Kirchner, Larry Moos
1. Preparation and Site Evaluation			
1.1. Preliminary Research	Jason Chandler	Natalie Thompson	Kendra Hansen, Terry Fahey
1.2. Site Evaluation Equipment	Jason Chandler	Natalie Thompson	Kendra Hansen, Terry Fahey
1.3. Client Meetings	Jason Chandler	Natalie Thompson	Kendra Hansen, Terry Fahey
1.4. Site Evaluation	Jason Chandler	Natalie Thompson	Kendra Hansen, Terry Fahey
1.5. Site Survey	Terry Fahey	Riley Poynter	Bob Smith, Braden Swab, Chad Gamble, Patrick Cochrane, Solome Achan, Terry Fahey
2. Water			
2.1. Water Demand Estimate	Jaimee Sekanjako	Natalie Thompson	Jason Chandler, John Agee, Liz Wunderlich, Paul Berg
2.2. Water Supply Source Selection	Larry Moos, Hedina Angom	John Agee	Aileen Kondo, Mike Dirk, Mike Young, Paul Berg
2.3. Rainwater Harvesting	Hedina Angom	Natalie Thompson	John Rahe, Larry Moos
2.4. Greywater Separation and Reuse	Hedina Angom	Natalie Thompson	John Rahe, Larry Moos
2.5. Water Quality Testing	Jaimee Sekanjako	Natalie Thompson	Jeff Niemann, Larry Moos, Paul Berg
2.6. Water Treatment	Jaimee Sekanjako, Larry Moos	Natalie Thompson	Larry Moos, Mike Dirk, Mike Young, Paul Berg
2.7. Water Storage	Jaimee Sekanjako	Kyle Glidden	Aileen Kondo, John Rahe, Paul Berg, Wil Kirchner
2.8. Water Distribution	Andy Scheer	Natalie Thompson	John Rahe, Larry Moos, Mike Dirk, Paul Berg
2.9. Pump Selection	Andy Scheer	Kyle Glidden	Paul Berg, Wil Kirchner

Report Sections	**Author(s)**	**Editor(s)**	**Reviewers**
3. Geotechnical			
3.1. Soil Classification	Jennifer Laybourn	--	Josiah Baker, Kathleen Wassenaar, Terry Podmore
3.2. Soil Bearing Capacity	Jennifer Laybourn	BJ Elkins	Josiah Baker, Kathleen Wassenaar, Robert Bell
3.3. Soil Absorption Capacity	Jennifer Laybourn	--	Josiah Baker, Kathleen Wassenaar, Larry Moos, Mike Young
4. Wastewater			
4.1 Wastewater Composition and Quantity	John Agee	--	Larry Moos, Mike Young, Rachel Su
4.2. Wastewater Conveyance	Hedina Angom	Jennifer Laybourn	Jason Chandler, John Agee
4.3. Septic Tanks	Larry Moos	John Agee	Larry Moos, Mike Young
4.4. Grease Interceptors	Larry Moos	Kyle Glidden	John Agee, Larry Moos
4.5. On-Site Wastewater Disposal	Jennifer Laybourn	--	John Agee, Larry Moos
4.6. Latrines	Jaimee Sekanjako	Natalie Thompson	Larry Moos, Mike Young
4.7. Other Wastewater Treatment	Larry Moos	Natalie Thompson	Larry Moos, Mike Young
5. Site Design			
5.1. Grading and Stormwater Drainage	Andy Scheer	Kendra Hansen	David Burgess, Kyle Glidden
5.2. Roadways	Andy Scheer	Natalie Thompson	Josiah Baker, Kyle Glidden, Liz Wunderlich, Mike Dirk, Mike Young
5.3. Retaining Wall Design	Jennifer Laybourn	--	Anthony Cave, Ian Ebersole, Josiah Baker, Robert Bell, Tom Gruen
5.4. Site Layout, Access, and Parking	Kendra Hansen	--	Kyle Glidden, Liz Wunderlich, Wil Kirchner
6. Solid Waste Management			
6.1. Solid Waste Composition and Generation	Jennifer Laybourn	--	Kendra Hansen, Larry Moos, Rachel Su
6.2. Solid Waste Disposal	Jennifer Laybourn	--	Kendra Hansen, Larry Moos, Rachel Su

A1 Preparation and Site Evaluation

No appendices.

A2 Water

A2.1 WATER DEMAND ESTIMATE

Table A 2.1-1 Minimum water quantities required in the health-care setting

Health-Care Setting	Minimum Water Quantity Required
Outpatients	5 liters/consultation
Inpatients	40-60 liters/patient/day
Operating theater or maternity unit	100 liters/intervention
Dry or supplementary feeding center	0.5-5 liters/consultation (depending on wait time)
Wet supplementary feeding center	15 liters/consultation
Inpatient therapeutic feeding center	30 liters/patient/day
Cholera treatment center	60 liters/patient/day
Sever acute respiratory diseases isolation center	100 liters/patient/day
Viral hemorrhagic fever isolation center	300-400 liters/patient/day
Note: According to situations (e.g. for use of a flush toilet, the water requirement can be much higher) *Source: WHO, 2008*	

Table A 2.1-2 Water Requirements for Domestic Purposes in India

Description	Amount of water in liters per head per day
Bathing	55
Washing of clothes	20
Flushing of Water Closet	30
Washing the house	10
Washing of utensils	10
Cooking	5
Drinking	5
Total	**135 liters**
Source: Punmia, 1995	

Table A 2.1-3 Sphere Minimum Water Quantities

Surviving needs: water intake (drinking and food)	2.5–3 liters per person per day (depends on climate and individual physiology)
Basic hygiene practices	2–6 liters per person per day (depends on social and cultural norms)
Basic cooking needs	3–6 liters per person per day (depends on food type, social and cultural norms)
Health centers and hospitals	5 liters per outpatient 40–60 liters per in-patient per day 100 liters per surgical intervention and delivery Additional quantities may be needed for laundry equipment, flushing toilets and so on
Cholera centers	60 liters per patient per day 15 liters per caregiver per day
Viral hemorrhagic fever center	300–400 liters per patient per day
Therapeutic feeding centers	30 liters per in-patient per day 15 liters per caregiver per day
Mobile clinic with infrequent visits	1 liter per patient per day
Mobile clinic with frequent visits	5 liters per patient per day
Oral rehydration points (ORPs)	10 liters per patient per day
Reception/transit centers	15 liters per person per day if stay is more than one day 3 liters per person per day if stay is limited to day-time
Schools	3 liters per pupil per day for drinking and hand washing (Use for toilets not included: see Public toilets below)
Mosques	2–5 liters per person per day for washing and drinking
Public toilets	1–2 liters per user per day for hand washing 2–8 liters per cubicle per day for toilet cleaning
All flushing toilets	20–40 liters per user per day for conventional flushing toilets connected to a sewer 3–5 liters per user per day for pour-flush toilets
Anal washing	1–2 liters per person per day
Livestock	20–30 liters per large or medium animal per day 5 liters per small animal per day
Source: Sphere Handbook, 2018, Appendix 3	

Table A 2.1-4 Typical Non-Domestic Usage

Category	**Range** (liters/day)
Day School	15-45 per pupil
Boarding School	40-140 per pupil
Medical Clinic	15-30 per patient
Hospital without Laundry	120-220 per bed
Hospital with Laundry	200-350 per bed
Hostel/Hotel	80-135 per resident
Restaurant	60-90 per seat
Church/Mosque	25-40 per visitor
Office	25-45 per person
Rail/Bus Station	15-25 per user
Meeting House	10-15 per seat
Source: Punmia, 1995	

Table A 2.1-5 Water for Domestic and Non-Domestic Needs in India

Community Description	**Amount of water (liters per capita per day)**
Population up to 20,000: Supply through stand post	40 (minimum)
Population up to 20,000: Supply through house service connection	70 to 100
Population 20,000 to 100,000	100 to 150
Population above 100,000	150 to 200
Source: Punmia, 1995	

Table A 2.1-6 Consumption of Water for Domestic Animals and Livestock in India

Animals	**Water consumption in liters per animal per day**
Cow and buffalo	40 to 60
Horse	40 to 50
Dog	8 to 12
Sheep or goat	5 to 10
Source: Punmia, 1995	

Table A 2.1-7 Typical Livestock Usage

Type	Range (liters/day/head)
Cattle	25-60
Horses and Mule	20-50
Sheep or Goats	5-25
Pigs	10-15
Dogs	8-12
Chickens	0.15-0.25
Source: Punmia, 1995	

Table A 2.1-8 Water Usage for Domestic Purposes in Southern Asia

Purpose	Quantity (liters/capita/day)
Drinking	5
Cooking	3
Sanitary purposes	18
Bathing	20
Washing utilities	15
Clothes washing	20
Total (excluding water loss and wastage)	**81 liters**
Source: Smet, et al., 2002, Table 4.1, pg. 63	

Table A 2.1-9 Typical domestic water usage for different types of water supply

Type of water supply Typical water consumption	(liters/capita/day)	Range (liters/capita/day)
Communal water point (e.g. village well, public standpipe) At considerable distance (> 1000 m) At medium distance (500 – 1000 m)	 7 12	 5-10 10-15
Village well Walking distance < 250 m	 20	 15-25
Communal standpipe Walking distance < 250 m Yard connection Tap placed in house-yard	30 40	20-50 20-80
House connection Single tap Multiple tap	 50 150	 30-60 70-250
Source: Smet, et al., 2002, Table 4.2, pg. 63		

Table A 2.1-10 Various Water Requirements in Developing Countries

Category	Typical Water Use
School	
Day schools	15-30 l/day per pupil
Boarding schools	90-140 l/day per pupil
Hospitals (with laundry facilities)	220-300 l/day per bed
Hostels	80-120 l/day per resident
Restaurants	65-90 l/day per seat
Cinema houses, concert halls	10-15 l/day per seat
Offices	25-40 l/day per person
Railway and bus stations	15-20 l/day per users
Livestock	
Cattle	25-45 l/day per head
Horses and mules	20-35 l/day per head
Sheep	15-25 l/day per head
Pigs	10-15 l/day per head
Poultry	
Chicken	15-25 l/day per 100
Source: Smet, et al., 2002, Table 4.3, pg. 64	

A2.1.1 ESTIMATING WATER DEMAND FOR CROP IRRIGATION

Estimating Evapotranspiration (ET) solely from climatic variables gives potential ET (ET_O). This is the maximum ET that can occur according to the energy inputs for a given situation. This can be estimated from evaporation from an open water surface. The actual crop ET (ET_C) is given by a combination of the potential ET (ET_O) and a crop factor, K_C, which is dependent on the particular crop and its growth stage. There are ***published KC factors*** for crops under different conditions. The resulting actual crop ET, ET_C, is given by Equation A2.1-1:

Equation A2.1-1 Actual Crop Evapotranspiration (ET)

$$ET_C = K_C * ET_O$$

Estimates of ET_O are available from the United Nations Food and Agriculture Organization (FAO). The best known and most widely used is CLIMWAT, in which estimates of ET_O can be determined for locations around the world. Using weather data ***CLIMWAT*** develops a weather data file to be entered into another FAO program, ***CROPWAT***. This program calculates ET_C estimates for given crops in the chosen location.

If local weather data is unknown, a simplified approach may be necessary using Table A 2.1-11.

Table A 2.1-11 Approximate Max Crop Evapotranspiration (ET) Rates for Different Climatic Conditions

Climate	Max ET_C	
	in/day	mm/day
Cool Temperature	0.15	3.8
Warm Temperature	0.20	5.0
Warm Semi-Tropical	0.25	6.4
Hot Tropical	0.30	7.6
Hot Dry Desert	0.35	8.9
Note: These estimated values are derived from various sources and from Dr. Terry Podmore's experience. These estimates should only be used when more specific information is not available.		

References and additional resources can be found in ***R2.1*** ***Water Demand Estimate***.

A2.4 GREYWATER SEPARATION AND REUSE
A2.4.1 GREYWATER TREATMENT OPTIONS
A2.4.1.1 FILTRATION

This approach will remove solid material like hair, lint, and food particles from entering the greywater system. The simplest option for filtration would be a stocking filter. Stocking filters are only suitable for very small flows or relatively clean wastewater. Other options include a slow sand filter, similar to filters used to treat potable water, though such a system requires regular operation and maintenance. The appendix contains more information on sand filters and other treatment options for greywater.

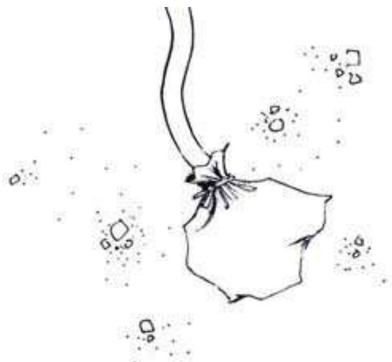


Figure A 2.4-1 Stocking Filter

Because greywater treatment is rarely used on EMI project, no detailed design information is provided in this manual. If a greywater treatment system is needed, specific design procedures for the type of system proposed will need to be determined at that time.

A2.4.1.2 SEDIMENTATION

This process removes solids and floating material from large quantities of greywater. Substances denser than water gradually settle to the bottom and those that are less dense like grease and oils among others form a scum layer which floats at the top. The liquid that forms the middle layer can then be sent to a storage tank or reused. A sedimentation tank may be required if greywater is hot so as to allow it cool down before reuse. Small sedimentation tanks could be designed similar to septic tanks. The sludge and scum storage volumes for such settling tanks could be much lower than those needed for a blackwater septic tank. As with blackwater septic tanks, settling tanks require ongoing maintenance.

A2.4.1.3 REED BED FILTRATION

This system uses an arrangement of reeds with dividers inside the bed to section off water flow, making the greywater weave back and forth across the planted reeds that remove contaminants from the greywater. A mulch pre-filter can be provided to remove all the solid matter prior to reaching the system to make the cleaning easier. The primary method of filtration in reed bed systems are from microorganisms developing on the roots of reeds, breaking down organic components and making conditions difficult for bacteria and viruses to survive. Excess nutrients within the greywater such as nitrogen are removed by the roots of the reeds.

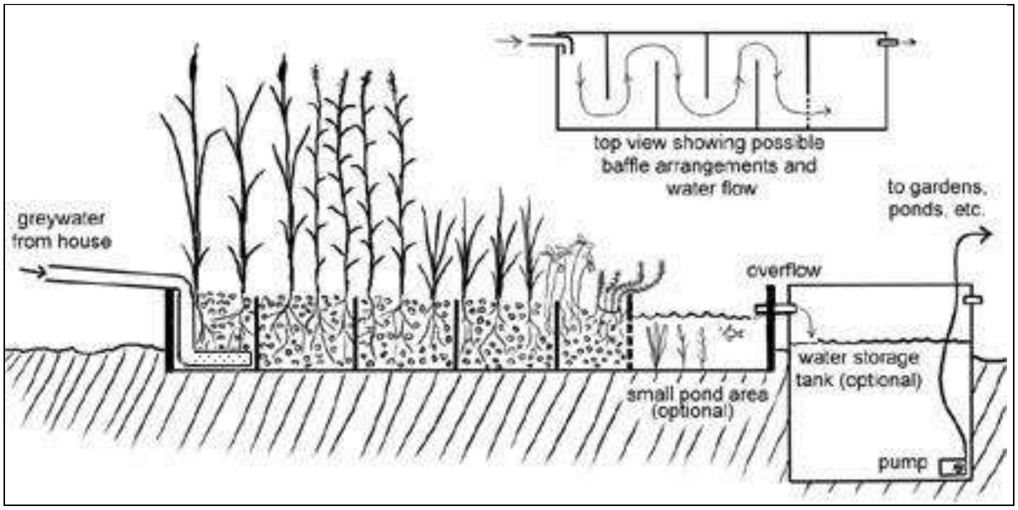


Figure A 2.4-2 Reed Bed Filtration System

Source: Bradley, 2012

Materials

- Wetland Reeds (like frankenia laevis, arundo donax, phragmites altissima, juncus acutus pointed, phoenix dactylifera, tamarix gallica)
- Gravel
- Plastic Liner
- Dividers
- Piping

Optional Materials

- Mulch - as a pre-filter
- Planter Box - for above ground

Table A 2.4-12 Reed Bed Strengths and Weaknesses

Strengths	Weaknesses
Can use indigenous plants to filter out pollutants	Water loss to evaporation
Can be used to remove harmful contaminants that would otherwise require special filters	Must have a constant supply of water
Reeds can rejuvenate	Industrial chemicals would kill reeds

Placement options

Reed beds need to be placed outdoors within a water tight system. They can either be placed in the ground with a plastic liner enclosure to prevent seepage of the wastewater in the ground or above ground with a suitable planter box.

Maintenance

Due to the presence of plants in the system that require an active water flow, considerations should be made for the times of the year where greywater generation is not enough to sustain the reeds.

A2.4.1.4 SAND FILTRATION

The system functions by passing contaminated water through three layers of sand. The top layer is usually fine sand, the middle coarse sand and gravel at the bottom. A bio-layer (made up of various microbes which fight pathogens and contaminants within the wastewater) usually forms on top of the fine sand after 10 days of consistent use. In order to ensure that the bio-layer is constantly wet, the outflow tubing should be positioned at the bottom of the unit and extending upwards to be parallel to the top of the fine sand. The system that encloses all these layers of sand is commonly made of either plastic or concrete. Flow rate for slow sand filters is between 0.1-0.4m/hour and that of rapid sand filters is 2-10gpm/sq. ft. Sand filters can be scaled up to treat large quantities of greywater, though maintenance requirements also increase with size.

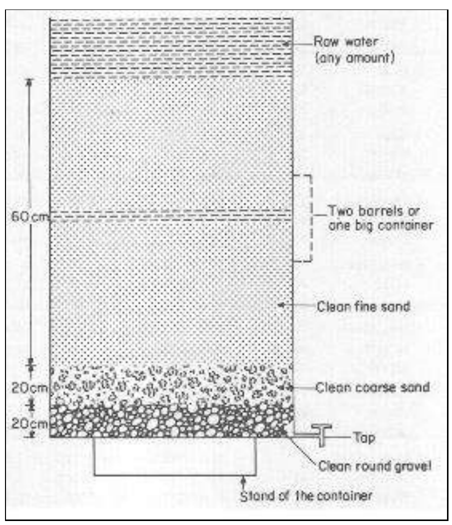


Figure A 2.4-3 Slow Sand Filtration System

Materials

- Gravel
- Coarse sand
- Fine sand

- Sealable tank or barrel
- Drip plate
- Piping

To make the sand filtration media more effective, a natural mulch basin filled with stones and organic mulch (leaves and tree bark among others) is recommended. The mulch basin provides for natural digestion of organic substances and removal of solid substances from greywater.

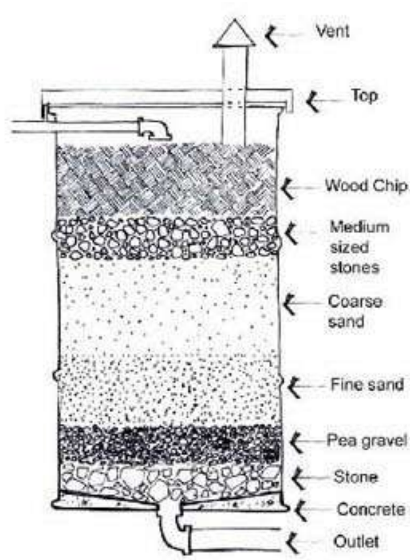


Figure A 2.4-4 Slow Sand Filtration System with Vent

Table A 2.4-13 Strengths and Weakness of Slow Sand Filtration System

Strengths	**Weaknesses**
Low costs to build	Large task to clean
Minimal regular maintenance	Susceptible to damage from chemicals
Versatile placement options	

Placement options

They can be placed either above or in-ground as long as space is available. The input and output of the system should be located near the top of the system.

Maintenance

The sand layer is cleaned by scraping off the top portion of the sand layer to a depth of 1-2cm. The layer of sand reduces as the bio-layer is scraped off to reduce its thickness. This would result into the need for an additional layer of the fine sand.

A2.4.1.5 AN OPEN EARTHEN LAGOON

Could be considered suitable for greywater treatment and storage if large amounts are available for reuse and a use for this much water exists. The presence of oxygen and sunlight will help treat the contaminants and kill pathogens present. Algae will grow rapidly in such a lagoon however, so it would need to be emptied on a regular basis and cleaned out.

A2.4.1.6 DISINFECTION

This can be done using chlorine or iodine. A chlorine concentration of 0.5 parts per million would be required to disinfect the greywater. Water disinfected with chlorine should be left to stand at least overnight so that the chlorine may evaporate since it may cause problems to plants and soil. UV light or ozone can also be used to reduce the amount of bacteria present in greywater. The reduction of bacterial content does not really have any advantage unless there is a risk of human contact. Achieving the desired residual chlorine in greywater is difficult because of the presence of soluble and insoluble organic material, which consumes the chlorine added. Since the concentrations of such chlorine-demanding material will vary significantly day to day, determining the correct chlorine dosage will be difficult.

A2.4.1.7 SOLAR DISTILLATION UNIT

These systems operate by evaporating the water at a lower temperature than the contaminants in the water would evaporate at. The water is then allowed to condense and captured for reuse. Typical solar distillation systems are a box or tray with a sloped piece of glass on top. The tray is colored black to absorb the most heat from the sun's radiation. The water is pumped into the tray where it will sit and heat up as the sun's energy bypasses the clear glass and heats the tray. The water then evaporates and the resulting water vapor collects on the glass above it. After the water has condensed on the glass, it beads up and rolls down the slope, where it drips into a small semi-circular tube where it is collected and ready for use.

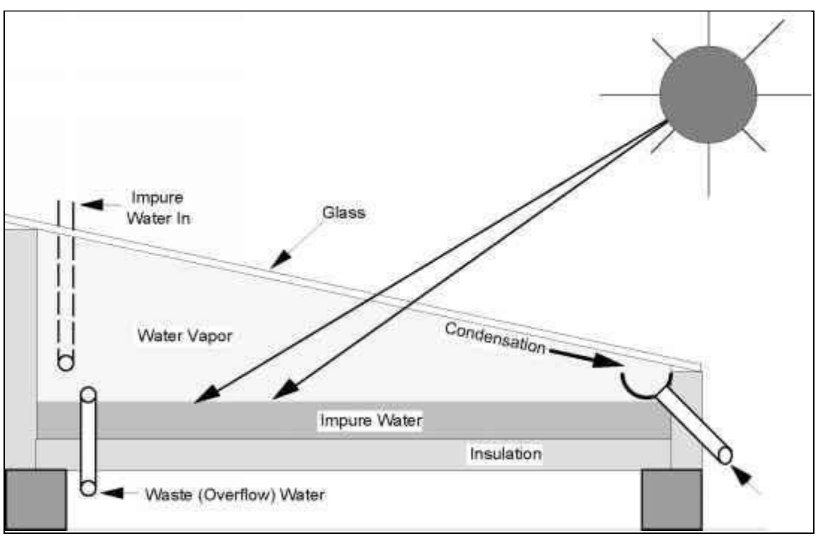


Figure A 2.4-5 Solar Distillation Unit

Materials

- Glass plane
- Black trough
- Piping
- Gutter tubing
- Waterproofing bonding agent
- Frame for the still to sit on

Placement options

The solar stills should be placed in an outdoor location with high exposure to sunlight. The units can vary in size depending on the desired outflow of distilled water.

Maintenance

Some greywater usually remains in the black trough after the solar distillation process. This needs to be emptied either manually and disposed or using a pipe that directs it to a black water disposal system.

Optimal conditions

This system would work best for a home with few people. Such a home should be located in a scarcely populated area to minimize shadows that could interfere with the distillation process.

A2.5WATER QUALITY TESTING

Table A 2.5-14 Global Water Quality Standards

Parameters	2017 WHO Guidelines	USEPA NPDWR	Potential health effects or Reasoning Behind Guidelines
Alkalinity (mg/L)	NHS, depends on pH of system Soft waters <40 (pg. 175)	n/a	Definition: The buffering capacity of a water body; a measure of the ability of the water body to neutralize acids and bases and thus maintain a fairly stable pH level (USGS)
Ammonia (mg/L)	NHS, Odor at alkaline pH is 1.5 Taste threshold 35 (pg. 223, 313)	n/a	React with chlorine to reduce free chlorine and to form chloramines (WHO, pg. 223) NHS because occurs in drinking-water at concentrations well below those of health concern (WHO, pg. 313)
Arsenic (mg/L)	Guideline value: 0.01 (pg. 178, 315)	0.01	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer (NPDWR)
Chloride (mg/L)	NHS, Taste threshold 200-300 (223, 334)	2º: 250	Not of health concern at levels found in drinking-water, high levels impact taste (WHO, pg. 334)
Chlorine, total and free (mg/L)	Guideline 5 0.2-1 is normal for treated water (pg. 223, 334)	MCL: 4.0	Taste threshold is less than the health-based guideline value of 5 mg/L (WHO, pg. 223) Eye/nose irritation; stomach discomfort (NPDWR)
Fluoride (mg/L)	Guideline Values: 1.5 Added to water: 0.5-1 (pg. 178, 371)	MCL: 4.0 2º:2.0	Epidemiological evidence that concentrations above this value carry an increasing risk of dental fluorosis and that progressively higher concentrations lead to increasing risks of skeletal fluorosis (WHO, pg. 371)
Hardness (m/L)	NHS, Taste threshold 100-300 Scaling above 200 Corrosive less than 100 (pg. 225)	n/a	May impact taste, can cause precipitation of soap scum and the need for excess use of soap to achieve cleaning, cause scale deposition in treatment works, distribution system, and pipework and tanks within building (WHO, pg. 225)
Iron (mg/L)	NHS, Taste and staining threshold: <0.3 (pg. 226, 382)	2º: 0.3	Cause reddish-brown color to water and could form a slimy coating on the piping (WHO pg. 226)
Lead (mg/L)	0.01	0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure (NPDWR)

Parameters	2017 WHO Guidelines	USEPA NPDWR	Potential health effects or Reasoning Behind Guidelines
Manganese (mg/L)	Health Based: 0.4 Taste: 0.1 (pg. 226, 387)	2º: 0.05	May cause an undesirable taste in beverages and stains sanitary ware and laundry. At concentration of 0.2, coating can sluff off into the water as black precipitate (WHO, pg. 226)
Microbial *E. Coli* or Total Coliform (colonies per 100 mL)	No *E. Coli* detectable (pg. 149)	*E. Coli*: 0 Total: 5.0%	Fecal coliforms and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes may cause short term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, and people with severely compromised immune systems (NPDWR).
Nitrate/nitrite (mg/L))	50/3 (pg. 398)	10/1	Infants below the age of six months who drink water containing nitrate in excess of the guideline could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome (NPDWR, WHO pg. 398).
pH (standard units)	NHS, Suggested Range: 6.5-8.5 <8 chlorine is not effective >7 is corrosive to pipes (pg. 227)	2º: 6.5-8.8	Necessary to manage at all stage of water treatment to ensure satisfactory water clarification and disinfection, also important to maintain alkalinity and hardness to prevent corrosion or scaling of pipes (WHO pg. 227).
Total dissolved solids (TDS) (mg/L) or Conductivity (μS/cm)	NHS,<600 mg/L good >1000 mg/L unpalatable (pg. 228)	2º: 500	Causes unpalatable taste and causes excessive scaling in water pipes, heaters, boilers and household appliances (WHO pg. 228)
Turbidity (nephelometric turbidity units (NTU))	>4 is visible Chlorination requires <0.5 with average 0.2 or less (pg. 228)	Limit: 5 >0.3 95% of time	Turbidity is a measure of the cloudiness of 8water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria. These organisms can cause short term symptoms such as nausea, cramps, diarrhea, and associated headaches (NPDWR). Can impact the taste, sediments can cause damage to the distribution system, can cause staining and interfere with effectiveness of treatment processes (WHO pg. 228)

NHS—No health-based standard

Equation A2.5-2 Langelier Saturation Index

pH (Actual)+ Temperature (˚F)Factor + C.H. Factor + T.A. Factor – TDS Factor = S.I.

Temperature (˚F)	Temperature Factor
32	0.1
37	0.1
46	0.2
53	0.3
60	0.4
66	0.5
76	0.6
84	0.7
94	0.8
105	0.9
128	1.0

Total Alkalinity	T.A. Factor
5 ppm	0.7
25 ppm	1.4
50 ppm	1.7
75 ppm	1.9
100 ppm	2.0
125 ppm	2.1
150 ppm	2.2
200 ppm	2.3
250 ppm	2.4
300 ppm	2.5
400 ppm	2.6
800 ppm	2.9
1000 ppm	3.0

Calcium Hardness	C.H. Factor
5 ppm	0.3
25 ppm	1.0
50 ppm	1.3
75 ppm	1.5
100 ppm	1.6
125 ppm	1.7
150 ppm	1.8
200 ppm	1.9
250 ppm	2.0
300 ppm	2.1
400 ppm	2.2
800 ppm	2.5
1000 ppm	2.6

TDS	TDS Factor
TDS more than 1000 ppm	-12.2
TDS less than 1000 ppm	-12.1

Calculation Results	
S.I. > – 0.3	Corrosive Water
S.I. - 0.3 to +0.3	Balanced Water
S.I. < + 0.3	Carbonate Scale Formation

Source: Horizon CPO, 2021

Table A 2.5-15 EMI Water Testing Kits Contents

Parameter	Tests Available
Ammonia	AquaChek Water Quality Test Strips for Ammonia
Microbiological	ColiTag (Presence/Absence) Pathoscreen (Presence/Absence) 3M Petrifilm (Quantity) Coliscan Easygel (Quantity)
Chloride	Quantab Titrators for Chloride Low Range 30-600 ppm Cl-
Chlorine (Total and Free)	AquaChek Water Quality Test Strips for 5-in-1 Chlorine (Free & Total) Color Disc Test Kit, Model CN-66
Conductivity	Hach Pocket Pro+ Multi Meter
Iron	Permachem Iron Reducing Powder Pillows AquaChek Water Quality Test Strips for Total Iron Sample Vials
Nitrate/Nitrite	AquaChek Water Quality Test Strips for Total Nitrate Nitrite Hach 224000 Nitrate, Nitrite High Range Color Disc Test Kit
pH	Hach Pocket Pro+ Multi Meter AquaChek Water Quality Test Strips for 5-in-1
Salinity	Hach Pocket Pro+ Multi Meter
Total Alkalinity	AquaChek Water Quality Test Strips for 5-in-1
Total Dissolved Solids (TDS)	Hach Pocket Pro+ Multi Meter HM Digital TDS-4: Pocket-Size TDS Meter
Total Hardness	AquaChek Water Quality Test Strips for 5-in-1
Turbidity	2100Q Turbidity Meter Turbidity Tube

A2.6 WATER TREATMENT

A2.6.1 POINT OF USE TREATMENT FOR LOW TURBIDITY WATERS

A2.6.1.1 CERAMIC FILTERS

Removes most pathogens by filtering water through one or more ceramic filter elements.

Brands: Berkey, Katadyn, Doulton, CeraGrav by AquaCera, generic versions.

Pros – Effective against bacteria and protozoan cysts; easy to maintain, requires no power, can remove some chemicals with the correct filter element.

Cons – expensive, some are not effective against viruses (the Black Berkey claims to remove viruses), candle filters are fragile and can be easily damaged, slow production rate, no residual disinfectant, requires frequent cleaning.

Figure A 2.6-6 Ceramic Filter

A2.6.1.2 CARTRIDGE FILTERS

Uses hollow fiber ultrafiltration technology to remove pathogens.

Brands: Sawyer, Lifestraw, Aqua Clara, Lifesaver Systems, generic versions.

Pros – Lower cost than ceramic candle filters, units with smaller pore size (0.02 microns or less) can remove most viruses, can attach to a faucet for quicker filtering but will also work with gravity using a bucket system.

Cons – May be expensive, filters with larger pores (0.1 micron or more) do not remove all viruses, requires regular cleaning (backflushing), can be damaged easily, slow filtering rate, hard to find in some developing countries, two bucket systems (raw and treated) can be inconvenient and connecting/disconnecting may compromise safety of water.

Figure A 2.6-7 Cartridge Filter

A2.6.1.3 SOLAR DISINFECTION (SODIS)

Water is placed in clear plastic bottles and left in the sun for 6-8 hours (two days if cloudy).

Pros – Low cost, effective on all pathogens, does not change the taste of water, though it does raise the temperature.

Cons – Water must be clear, requires a full day to treat water so you must plan ahead, no residual disinfectant so it's easy for recontamination. Generally, this is not an accepted or desired method for sustained use.

Figure A 2.6-8 Solar Disinfection

A2.6.1.4 CHEMICAL DISINFECTANTS

Chlorine-containing materials kills pathogens.

Brands: Household bleach, solid chlorine (HTH), Aquatabs, Klorin, MadiDrop generic products.

Pros: Kills all pathogens although a long contact time is needed for protozoa, provides residual disinfectant to protect water in storage.

Cons: May give water an unpleasant taste, batch treatment – need to plan ahead, does not work as well with cloudy (turbid) water, requires supply of chemicals. In order to be effective on Giardia and Cryptosporidium, a higher dose and longer contact time is required. Some people groups may be reluctant to use water that tastes or smells like chlorine.

Figure A 2.6-9 Chemical Disinfectants

A2.6.1.5 UV DISINFECTION

Water flows past a UV light that kills microorganisms.

Brands: VIQUA, iSpring, HQUA, Watts, many generic versions.

Pros – Effective against all pathogens if properly operated and maintained, does not change the taste of water, treatment-on-demand – no waiting.

Cons – Requires reliable electricity, does not work well with turbidity of 10 NTU or higher, annual bulb replacement.

Figure A 2.6-10 UV Disinfection

A2.6.1.6 BOILING

Heat water to a rolling boil then let it cool. Store water in a closed container.

Pros – Easy, convenient process using equipment already on hand (cooker, tea kettle, pots, storage containers), kills all pathogens, easy to tell when treatment has been accomplished, works with turbid water, works well during emergencies.

Cons – Energy and fuel intensive, changes taste of water, dangerous, causes indoor air pollution, water is easily re-contaminated, high carbon emissions, fire safety issues, and smoke inhalation. It is not a sustainable solution due to limited supply of fuel.

A2.6.2 POINT OF USE TREATMENT FOR SURFACE WATER

A2.6.2.1 CERAMIC POT FILTERS WITH SILVER

Porous ceramic pots remove turbidity and larger pathogens (protozoa and some bacteria). Those impregnated with collodial silver can also be effective for inactivating smaller bacteria and viruses. It may be reasonable to combine a ceramic pot filter with a disinfectant, such as MadiDrops.

Brands: Potters for Peace, Spouts of Water, local brands.

Pros – Effective for protozoa and larger bacteria, low cost, locally made, no power needed, effective with turbid water.

Cons – Difficult to ensure quality control for locally made filters, result in uncertain treatment effectiveness, does not remove viruses although addition of colloidal silver can make them effective for virus inactivation, limited effective life since silver is depleted in about 6-12 months, fragile – cracks or chips can damage treatment efficiency.

Figure A 2.6-11 Ceramic Pot Filter with Silver

A2.6.2.2 BIOSAND FILTER

Water slowly passes through a deep column of fine sand (at least 55 cm deep) where solids are strained out and most pathogens removed. A biosand filter requires a lot of care and feeding. An understanding of the process and a commitment to operating them correctly is essential. A ripening time is required when first started, after a re-sanding, and after cleaning.

Brands: Generic concrete version (provided by many NGOs), plastic versions by TIVA (however, sand depth in the TIVA filter does not meet usual criteria for biosand filters), Bushproof, Hydraid, generic plastic versions.

Pros – Can be made from inexpensive local materials (sand, cement, plastic tubing) or purchased, requires no power, removes turbidity and pathogens.

Cons – Slow intermittent operation, so need to plan ahead, requires regular maintenance, additional disinfection (boiling, chlorine, UV treatment) is recommended to ensure all pathogens are killed. After producing 15-20 L in a day a reduction in quality is noticed in Biosand filters.

Figure A 2.6-12 Biosand Filter

A2.6.2.3 CHEMICAL TREATMENT AND DISINFECTION

Mixture of chemicals removes suspended solid matter and supplies chlorine for disinfection.

Brand – PuR packets (Procter and Gamble)

Pros: Effectively removes suspended solid material and turbidity from dirty water while disinfecting, treats all pathogens, works for highly contaminated water.

Cons – Batch process requires significant effort, requires continuous supply of packets, requires several large containers to treat and store water, high burden on users for correction application, some users may not like the idea of adding a chemical to their water, changes taste and smell of water.

Figure A 2.6-13 Chemical Treatment and Disinfection

A2.8 WATER DISTRIBUTION

A2.8.1 DETAILED DESCRIPTION OF METHODS FOR DETERMINING FLOW RATES

A2.8.1.1 PEAK FACTOR METHOD

The peak factor method is a simple method of estimating peak flow rates to each building on the site. The peak factor method requires that the designer calculate an average daily demand (ADD) estimate for each building on the site. Developing ADD estimates is a standard part of EMI master planning projects.

To estimate peak demands using the peak factor method, begin with the ADD estimate for each building and convert this value to a flow rate by dividing by the time over which the majority of the demand is expected to occur in that building. For example, if a building is expected to be in use only during business/school hours, then the use may be spread over 8 hours and the average flow in lps will be ADD / (8*3600). Note that choosing a shorter period of use (8 hours as opposed to 12 hours) produces a more conservative flow rate calculation. This calculation provides the designer with an average flow for each building.

A peak factor (PF) is used to convert average flow to peak flow, which is then used to design the distribution system. PFs are highly related to the number of consumers, the service areas, and the duration of the peak flow (δt) of a water distribution system. PFs generally tend to increase with a decrease in the number of consumers as well a decrease in δt. According to conclusions in Crous et al (2012), a peak factor based on a δt of 15min can be used for hydraulic design of water distribution systems.

Several sources suggest different PFs below;

Table A 2.8-16 Peaking Factors

Design flow conditions	Peaking factor
Maximum Hourly Flow rate	ADD x 2-4.5 [1]
Instantaneous Peak Flow	ADD x 5.2[2]
Sources: *1 – Uganda Ministry of Water and Environment, 2013* *2- Crous et al., 2012*	

If sufficient information is available to develop more accurate PFs for specific buildings (for example laundry facilities with a fixed operating schedule), use the specific factors for those buildings to determine peak flow rates. Document the basis for those factors in the design files.

The designer should use a reasonable PF that falls in the above range which can be different for different buildings on a site depending on water usage patterns and the number of people in that building.

The peak factor method is the quickest method for estimating peak flow rates to each building on the site. This method is useful during the preliminary master-planning stages when ADD has been estimated for each building, but the exact number of fixtures in each building has not yet been determined.

While the peak factor method is a widely used method and is useful for generating quick, conceptual designs, it should not be used as the sole basis for design on detailed design projects for the following reasons:

- The peak factor method relies on estimates of ADD for each building. ADD calculations require a large amount of engineering judgment and may not provide an accurate starting point for calculation of peak flow.
- Engineering judgment is required to estimate the number of hours of usage for each building.
- While research generally points toward using a peak factor of 2-5, this is a large range and it can be difficult to decide what peak factor to use for a given building.
- The peak factor method is based purely on ADD and assumptions about the usage patterns in the building and it does not take into account the number of fixtures which are present in the building. This can lead to peak flow estimates which are not grounded in the physical realities of the building plumbing design.

A2.8.1.2 FIXTURE COUNT METHOD

The fixture count method does not rely on the ADD but only on the number and types of fixtures present in each building.

This method assumes a flow rate per fixture (that may vary by type of fixture) and then multiplies this by the number of fixtures that are expected to be in operation during peak time.

EMI has typically assigned a flow rate of between 0.08 lps and 0.12 lps to each fixture. While there are tables which list recommended minimum flow rates for various types of fixtures, these tables are generally produced for countries which demand higher flow rates than typically expected on EMI projects.

Determining an appropriate flow rate to apply to each fixture is an area of ongoing research within EMI. The following are some justifications for the currently used rates of 0.08 lps to 0.12 lps:

- While a choice of 0.08 lps to 0.12 lps may seem a bit low, the designer should think of this as the minimum acceptable flow rate for each fixture. Throughout the majority of the day, fixtures will experience higher flow rates than this, but may drop down to 0.08 lps during peak times of water usage on the site.
- At 0.08 lps, it would take around 4 minutes to fill a 20-liter jerry can or about a minute to fill a typical toilet tank. This is slow, but may be acceptable during times of heavy water usage on the site.
- The designer must not only apply a flow rate to each fixture, but must decide how many fixtures are likely to be on at a given peak time. This determination requires engineering judgement and a strong understanding of water usage patterns. Some examples are below:
- In determining the peak flow to a school kitchen which has 10 taps for dish washing, it should be assumed that all 10 of these taps will be on at one time while the students queue up to wash dishes.
- In a residential bathroom that contains a sink, toilet, and shower; it should be assumed that only 2 of those fixtures will be in operation at a given time (toilet tank filling while hands are being washed).
- While the designer should consider various scenarios for each building, it is common practice to assume that 50% to 75% percent of fixtures will be on at peak time.

The fixture count method requires a strong understanding of the usage and fixtures of each building on the site. While the fixture count method requires engineering judgement in the determination of a flow rate for each fixture and an estimate of number of fixtures being used at a peak time, it is more grounded in actual project parameters than the peak factor method.

To demonstrate the advantage of the fixture, count method, imagine a school kitchen that cooks for hundreds of students but only has three fixtures in the building. Given the high number of students, the ADD will be high, and the peak factor method will produce a very high estimate of peak flows. It is possible that the peak factor method would produce a flow rate that is not physically possible given the presence of only three fixtures. The fixture count method would simply assume that all three fixtures will be on at a given time and therefore produce of flow rate estimate that is more grounded in the reality of the building design.

A2.8.1.3 WATER SERVICE FIXTURE UNIT METHOD

The water service fixture unit (WSFU) method is similar to the fixture count method and is adopted in most plumbing codes worldwide. The WSFU is an arbitrarily chosen measure that allows all types of plumbing fixtures to be expressed in common terms. The table below provides typical WSU load requirements for common plumbing fixtures as adopted in different model plumbing codes. EMI generally uses the WSFUs as specified in the 2018 International Plumbing Code.

Table A 2.8-17 WSFU Counts As Adopted In Various Plumbing Codes

Fixture	NBS – Hunter		IPC		UPC			NSPC[1]			
	Private	Public	Private	Public	Private	Public	Assembly	Single Family	Multifamily	Other	Assembly
One bathroom group	6	8	3.6	8	–	–	–	5	3.5	–	–
Bathtub	2	4	1.4	4	4	4	–	4	3.5	–	–
Combination fixture	3	–	3	–	–	–	–	–	–	–	–
Kitchen sink	2	4	1.4	4	1.5	1.5	–	1.5	1	1.5	–
Laundry tray	3	–	1.4	–	1.5	1.5	–	2	1	2	–
Lavatory	1	2	0.7	2	1	1	1	1	0.5	1	1
Service sink	–	3	–	3	1.5	3	–	–	–	3	–
Shower	2	4	1.4	4	2	2	–	2	2	2	–
Urinal, flush valve	–	5	–	5	*	*	*	–	–	5	6
Urinal, flush tank	–	3	–	3	2	2	3	–	–	–	–
Water closet, flush valve	6	10	6	10	*	*	*	5	5	5	8
Water closet, flush tank	3	5	2.2	5	2.5	2.5	3.5	2.5	2.5	2.5	4

[1] NSPC includes additional groupings. The FU selected are those for comparison purposes with the other codes.
*The UPC assigns accumulative fixture unit values beginning at 40 FU for WC flushometers and 20 FU for urinal flushometers.

The designer is tasked with identifying the type and number of fixtures in each building and consequently assigning respective WSFUs. Peak flow is then read from a published table (shown below) which relates WSFUs to peak flows.

Table A 2.8-18 Correlation Between WSFUs And Design Flows

TABLE 2.6 WATER SUPPLY FIXTURE UNIT (WSFU) LOAD AND RELATED DESIGN LOAD, IN GPM, L/MIN AND L/SEC, BASED UPON HUNTER'S WORK ON INSTANTANEOUS DOMESTIC WATER DEMAND.

	System with Predominantly Flush Tanks			System with Predominantly Flush Valves			
ater Supply Fixture Unit Load (WSFU)	gpm	L/min	L/sec	gpm	L/min	L/sec	Water Supply Fixture Unit Load (WSFU)
6	5.0	19	0.3	-	-	-	6
8	6.5	25	0.4	-	-	-	8
10	8.0	30	0.5	27.0	103	1.7	10
12	9.2	35	0.6	28.6	109	1.8	12
14	10.4	40	0.7	30.2	115	1.9	14
15	11.0	42	0.7	31.0	118	2.0	15
16	11.6	44	0.7	31.8	121	2.0	16
18	12.8	49	0.8	33.4	127	2.1	18
20	14.0	53	0.9	35	133	2.2	20
25	17.0	65	1.1	38	144	2.4	25
30	20.0	76	1.3	41	156	2.6	30
35	22.5	86	1.4	44	167	2.8	35
40	25	95	1.6	47	179	3.0	40
45	27	103	1.7	49	186	3.1	45
50	29	110	1.8	51	194	3.2	50
60	33	125	2.1	55	209	3.5	60
70	36	137	2.3	59	223	3.7	70
80	39	148	2.5	62	236	3.9	80
90	41	156	2.6	65	247	4.1	90
100	44	167	2.8	68	258	4.3	100
120	49	186	3.1	74	281	4.7	120
140	53	201	3.4	78	296	4.9	140
160	57	217	3.6	83	315	5.3	160
180	61	232	3.9	87	331	5.5	180
200	65	247	4.1	91	346	5.8	200
225	70	266	4.4	95	361	6.0	225
250	75	285	4.8	100	380	6.3	250
275	80	304	5.1	105	399	6.7	275
300	85	323	5.4	110	418	7.0	300
400	105	399	6.7	125	475	7.9	400
500	125	475	7.9	140	532	8.9	500
750	170	646	10.8	175	665	11.1	750
1000	210	798	13.3	218	828	13.8	1000
1250	240	912	15.2	240	912	15.2	1250
1500	270	1026	17.1	270	1026	17.1	1500
1750	300	1140	19.0	300	1140	19.0	1750
2000	325	1235	20.6	325	1235	20.6	2000
2250	348	1322	22.0	350	1330	22.2	2250
2500	380	1444	24.1	380	1444	24.1	2500
2750	402	1528	25.5	405	1539	25.7	2750
3000	435	1653	27.6	435	1653	27.6	3000
4000	525	1995	33.3	525	1995	33.3	4000
5000	600	2280	38.0	600	2280	38.0	5000
6000	650	2470	41.2	650	2470	41.2	6000
7000	700	2660	44.3	700	2660	44.3	7000
8000	730	2774	46.2	730	2774	46.2	8000
9000	760	2888	48.1	760	2888	48.1	9000
10 000	790	3002	50.0	790	3002	50.0	10 000

Source: International Code Counsel, 2017

Implementing the WSFU method does not involve the engineering judgement and guesswork that is inherent in the peak factor method and the fixture count method. In order to apply the WSFU method, the engineer only needs to know the types of fixtures in the building and can then read the appropriate design flow rates from published charts.

While the fixture count method requires the designer to estimate how many fixtures will be in use during peak time, the WSFU method automatically accounts for this factor. The relationship between the total number of WSFUs in a system and the design flow rate is not linear. The relationship was developed through research as well as statistical methods to determine an appropriate flow rate for a given number of WSFUs, taking into account the fact that not all fixture will be on at once. The example below demonstrates the value of this method:

Imagine that you are designing a small office building with only three fixtures. It would be logical to design assuming that all three of those fixtures will be on at one time. Now imagine that you are designing an airport with 500 fixtures. If you were to design assuming that all 500 fixtures were on, you would massively overdesign the piping in the building. The WSFU charts automatically account for the fact that the larger the number of WSFUs in the project, the smaller percentage of fixtures will be on at one time. The WSFU method can be used to calculate a peak flow rate for a small building with a few fixtures all the way to the peak flow rate for a city with thousands of fixtures – automatically accounting for the ratio of fixtures that are likely to be on at one time.

While the WSFU method eliminates some of the guesswork inherent in the other methods, it still requires engineering judgement in its application to water distribution modelling. Imagine a site with 10 dormitories. If the WSFU method is used to determine the peak flow to a single dorm, and then that number is multiplied by 10, the resulting flow rate will be significantly higher than if the WSFUs for all 10 dorms are added together, and then the flow rate is read from the chart. Again, this is because the relationship between WSFUs and peak flow is not linear. If the WSFU method is used to calculate a peak flow for each building on a site and then that peak flow is applied to the model, the model will be overly conservative.

A2.8.1.4 RECOMMENDED PROCESS FOR WATER DISTRIBUTION

Different methods of calculating peak flows and different assumption about timing of water usage onsite can produce dramatically differing results and engineering judgment is always needed in the design of water distribution systems. The designer must have a very thorough understand of the fixtures and usage patterns on the site as well as a strong understanding of the benefits and downfalls of each of the peak flow calculation methods discussed above.

The following process is recommended in designing site distribution systems:

- Calculate the peak flow to each building using the peak factor method
- Calculate the peak flow to each building using the fixture count method
- Compare the two methods and determine which to use for each building. If there are dramatic differences between the results from the two methods, try to understand where the differences come from.
- On most EMI projects, the pressure in the system is provided by the elevation of the storage tank. Model the system under the scenario where the tank is nearly empty. Do this by setting the elevation of the tank 0.50M above the height of the stand. This ensures that you are modelling the limiting scenario; when the tank is full, pressures will be higher.
- When building the water distribution model, it is usually acceptable to create one node per building and apply the peak flow for the entire building at that single node. Set the elevation of this node at the elevation of the highest fixture in the building.
- Run the model under several different scenarios, remembering that it is not likely for all the buildings on the site to experience their peak flows at the same time of day.
- Once you have a “worst case scenario” that you feel is representative for the design of the distribution system, calculate the total flow in the system by summing all of the flows to the buildings.
- Use the WSFU method to determine a peak flow for the entire site.
- If the WSFU method yields a peak flow that is dramatically higher than your model; you may have underestimated some flow rates. If the WSFU method yields a peak flow that is lower that your model; you are likely overestimating the peak flow rates.
- Adjust peak flow rates as needed based on engineering judgment and a comparison of the three peak flow calculation methods.
- Run the model under several different scenarios and ensure that minimum acceptable pressures are maintained. The goal is to have a minimum of 2.0 meters of residual head at each fixture within the building. If you have modeled the entire

building as a single node, make sure that the node has a minimum residual pressure of 2.3 meters. Experience on past projects leads to the estimate that about 0.30 meters of head will be lost to friction within the interior building piping system.

- If the model is producing unacceptably low pressures the following are some ways to increase the pressure in the system:
    - Increase sizes of critical pipes. In EPAnet you can view the unit head loss in each pipe and quickly see which pipes might be undersized.
    - Add extra loops/connecting pipes into the system.
    - Branch the system as early as possible. The pipe coming out of the tank will have the highest flow rate and likely high friction losses. Branch the system early to shorten the distance in which the flow for the entire site is contained in a single pipe.
    - Increase the height of the tank stand.

A2.8.2 EMI EPANET GUIDELINES

Introduction

EPAnet is a modeling software that runs a simulation of hydraulic and water quality behavior within pressurized pipe networks. EMI uses EPAnet to model and design water distribution systems. This guide is not intended to be comprehensive, but simply to give some guidance on how to set up an EPAnet model. Consult the EPAnet user manual for further guidance on using the program.

Further EPAnet Guidance can be found: ***R2.8*** ***Water Distribution***

Downloading EPAnet Program

EPAnet is a free resource provided by the United States Environmental Protection Agency (EPA) and can be found at this website: ***https://www.epa.gov/water-research/epanet***.

Setting up the Model

Dimensions (View >> Dimensions) enable user to set map units (in EMI, we will be using meters)

The **title** can be set in the Summary menu, found in the Project tab (this title will be the label for the printed document)

EMI Standards

I. **Defaults** (Projects >> Defaults) enable the user to set different properties of the model

Properties – set physical parameters of the model.

Pipe Roughness: coefficient for the model. Use 140 for HDPE/PP-R pipe (double check is using different pipe material).

Hydraulics – Other hydraulic parameters.

Flow Units: Use Liters per second (LPS).

Headloss Formula: Use Hazen Williams (H-W).

For gravity-flow pipe applications, such as irrigation delivery pipelines or water-supply pipelines from reservoirs or diversion points higher in elevation than the site, Manning's Equation is typically used.

II. Junction Settings

Elevation

Type	Guideline
Underground	0.5 m below ground
Tank	Outlet elevation + 0.5 m

Sinks & Toilets	1m above finished floor
Showers	2m above finished floor
Ceiling	Check architectural sections

Base Demand

Type	Demand
Non-fixture junctions	0
Fixture modelled as "off"	0
Fixture modelled as "on"	Peak flow – adjust for various times of day

III. Pipe Settings

Length / Auto-length

If auto-length is "on," lengths will be automatically set based on how the pipe is drawn. (Will need to scale – check section below for instructions). Generally easier to use this setting, but need to double check values to ensure they match. *Auto-Length may turn off automatically when closing a drawing, so verify that it is on before starting again.

If auto-length is "off," enter all lengths manually as measured from drawings.

Diameter

Always use pipe internal diameters (not the same as the nominal diameter) – check table below:

HDPE - PN6 Internal Diameters	
HDPE Pipe Size OD (mm)	Inside diameter (mm)
20	16.4
25	21.4
32	28.2
40	35.4
50	44.2
63	55.8
75	66.4
90	79.8
110	97.4

Roughness

Use <u>140 for HDPE/PP-R pipe</u> (double check is using different pipe material) – see previous section for instructions.

Loss Coefficient (K)

The loss coefficient field is how we account for minor friction losses through bends and valves.

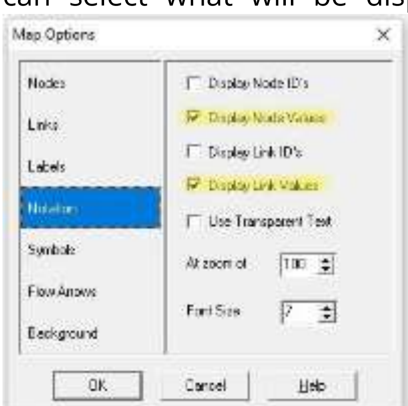
Apply the appropriate loss coefficient to the pipe downstream of the fitting

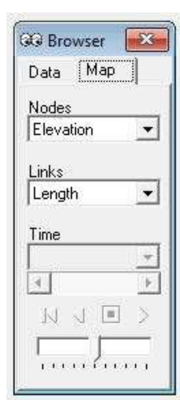
The final run of pipe from the ceiling to the fixture should be modelled as a straight vertical pipe, but should have a loss coefficient applied to it as listed which accounts for the bends and valves that are typical of building fixtures

EPANET2 Fittings	**K (Total)**
Globe valve, fully open	10.00
Angle valve, fully open	5.00
Swing check valve, fully open	2.50
Gate valve, fully open	0.20
Short-radius elbow	0.90
Medium-radius elbow	0.80
Long-radius elbow	0.60
45 degree elbow	0.40
Closed return bend	2.20
Standard tee - flow through run	0.60
Standard tee - flow through branch	1.80
Square entrance	0.50
Exit	1.00
Valve, Float for water tank (ball valve in Africa)	5.00

<u>Useful Tools</u>

<u>Setting Notation Labels:</u> Open **Options** (View >> Options…) and check 'Display Node Values' and 'Display Link Values' under the Notation tab. In the Browser window, you can select what will be displayed in the drop down menus in the 'Map' tab.





<u>Group Edit:</u> Allows multiple objects to be edited at one time. Click on **Select All** (Edit >> Select All) and all objects in the current Network Map window will be selected. Once the objects are selected, click on **Group Edit** (Edit >> Group Edit…). In the pop up window, various options for editing are given. Choose desired options and then click "OK"

<u>Loading a Backdrop Map (from AutoCAD)</u>

In AutoCAD file, select all the objects desired to be in the EPAnet model.

Under the 'A' menu, select Export → other formats.

Save the WMF file in the folder were EPAnet file is located.

In EPAnet model, load file in the **backdrop** menu (View >> Backdrop >> Load)

Select desired file in the pop-up window.

<u>Scaling a Backdrop Map</u>

To scale an object, you will need the [1] distance of a particular object in the AutoCAD file and [2] measurements of the same object in the EPAnet model. Under the **Dimensions** menu (View >> Dimensions), adjust the 'Upper Right' coordinates by multiplying the default number by the ratio of [1] / [2].

To find the measurements of an object in the EPAnet model:

1. Ensure that the auto-length option is turned on
2. Create a node at each endpoint of the object ( )
3. Create a pipe between the nodes created ( )
4. Select the "edit" button in the Browser window ( )
5. The resultant pop-up window will show the length value.

<u>Step by Step guide for Project models</u>

1. Draw a proposed pipe layout in CAD. Usually this is a looped network with a centralized water storage system.
2. Set up the EPAnet model – adjust default settings, Load & scale CAD as a Backdrop Map, turn on auto-length. Look to previous sections for guidance.
3. Add reservoir (not tank) in the appropriate locations to represent water storage tank(s). In the reservoir dialog box, input the elevation as total head.

4. Add junctions at every building and at major pipe branches. Set elevations and base demand as described above. For most models, it is appropriate to model an entire building as a single node. Set the elevation of the building node as the elevation of the highest fixture in that building.
5. Connect adjacent junctions by adding pipes to form the network proposed in 1) above. Estimate pipe diameters to start.
6. Run the model. The run will either be successful or return some errors.
7. Adjust the system (pipe layout, pipe diameters, height of tank stands) until he pressures in the system are acceptable.
8. Run the model under various peak flow assumptions. Think through various times of day and the varying water use patterns that the site might experience. You can run various flow scenarios either by using the demand pattern function in EPAnet or by save several copies of the model, each with different flow inputs.

A2.8.3 PICTURES OF DIFFERENT PIPE FITTINGS

Figure A 2.8-14 90 Degree Short Radius Elbow

Figure A 2.8-15 90 Degree Long Radius Elbow

Figure A 2.8-16 180 Degree Elbow

Figure A 2.8-17 45 Degree Short Radius Elbow

Figure A 2.8-18 Poly Propylene Compression Fittings

Figure A 2.8-19 PCV Pipe Fittings

A3 Geotechnical

A3.1 SOIL CLASSIFICATION

A3.1.1 TEST PROCEDURES MANUAL TESTS

A3.1.1.1 SOIL PAT IN HAND

Distinguish between fine sand and fines (silt and clay):

- Take soil and rub in the palm of your hand
- Turn palms down and shake
- Sand grains will fall off; silt and clay will stick.

Distinguish between clay and silt:

- Place soil in hand with palm facing upward.
- Mix soil with some water until the soil is moldable and form into pat (see figure below)
- Firmly tap edge of hand for 5 to 10 seconds
- Silt: surface of the soil starts shining and the water rises to the surface;
- Clay: water does not rise to the surface.
    - Clay will also feel stickier than silt when wet.

Figure A 3.1-20 *Soil Pat in Hand*

A3.1.1.2 FEEL TEST

Rub some moist soil between fingers

- Sand feels gritty
- Silt feels smooth (or soapy)
- Clay feels sticky (or greasy)

A3.1.1.3 BALL SQUEEZE TEST

Squeeze a moistened ball of soil in the hand

- Coarse texture soils (sand or loamy sands) break with slight pressure
- Medium texture soils (sandy loams and silt loams) stay together but change shape easily
- Fine texture soils (clayey or clayey loam) resist breaking

A3.1.1.4 RIBBON TEST

Squeeze a moistened ball of soil out between thumb and finger

- Ribbons less than 1 inch
  - Feels gritty – coarse texture (sandy) soil
  - Not gritty feeling – medium texture soil high in silt
- Ribbons 1 to 2 inches
  - Feels gritty – medium texture soil
  - Not gritty feeling – fine texture soil
- Ribbons greater than 2 inches – fine texture (clayey) soil

A3.1.1.5 JAR TEST

Source: Oregon State University, 2018

Step 1: Spread soil on a newspaper to dry. Remove all rocks, inorganics, roots, and anything that is not considered a soil particle.

Step 2: Finely pulverize the soil to ensure lumps and clods of particles have been broken up, but do not crush individual particles

Step 3: Fill a tall slender jar one-quarter full of soil

Step 4: Add water to fill the jar

Step 5: Put on a tight-fitting lid and shake hard for 10 to 15 minutes. This shaking breaks apart the soil aggregates and separates the soil into individual mineral particles.

Step 6: Set the jar where it will not be disturbed for 2 to 3 days.

Step 7: Soil particles settle out according to size. After 1 minute, mark on the jar the depth of the sand

Step 8: After 2 hours, mark on the jar the depth of the silt.

Step 9: When the water clears, mark on the jar the clay level. This typically takes 1 to 3 days, but may take weeks with soils having high clay content.

Step 10: Measure thickness of sand, silt, and clay**.**

Common results

- Sandy soil: sand particles sink and form a layer on the bottom of the jar. Water will appear fairly clear, quickly.
- Clayey soil: water remains cloudy with a thin layer of particles on the bottom. Water stays murky longer, because clay particles settle slowly.
- Silty soil: behaves similarly to clay, so it is difficult to determine the difference between clay and silt.
- Loamy soil: clear water with a layer of sediment on the bottom and fine particles on the top.
- Organic matter: floats on the surface

A3.1.1.6 WASH TEST

Step 1: Collect and moisten enough minus No. 40 sieve size material (fine sand) to form a 25 mm cube of soil.

Step 2: Cut the cube in half and set one half aside.

Step 3: Place one half of the cube in a cup and cover with water.

Step 4: Agitate the mixture to ensure all fine particles are suspended.

Step 5: Carefully pour out the water and suspended fines without losing any sand particles.

Step 6: Repeat the wetting, agitating, and pouring process until all fines have been washed out and the water is clear. Again, take care not to lose any sand particles.

Step 7: Compare the two samples (the half of the cube set aside and the half of the cube with the fines washed out) to roughly estimate the percentage of sand and fines.

Step 8: Use percentages to determine if the soil is fine or coarse grained.

Note: fines include both silt and clay, therefore, this test will only be able to narrow down the type of soil to a few different classifications. Take note of any of the possible classifications.

A3.1.2 ADDITIONAL INFORMATION

A3.1.2.1 SOIL CLASSIFICATION PYRAMID

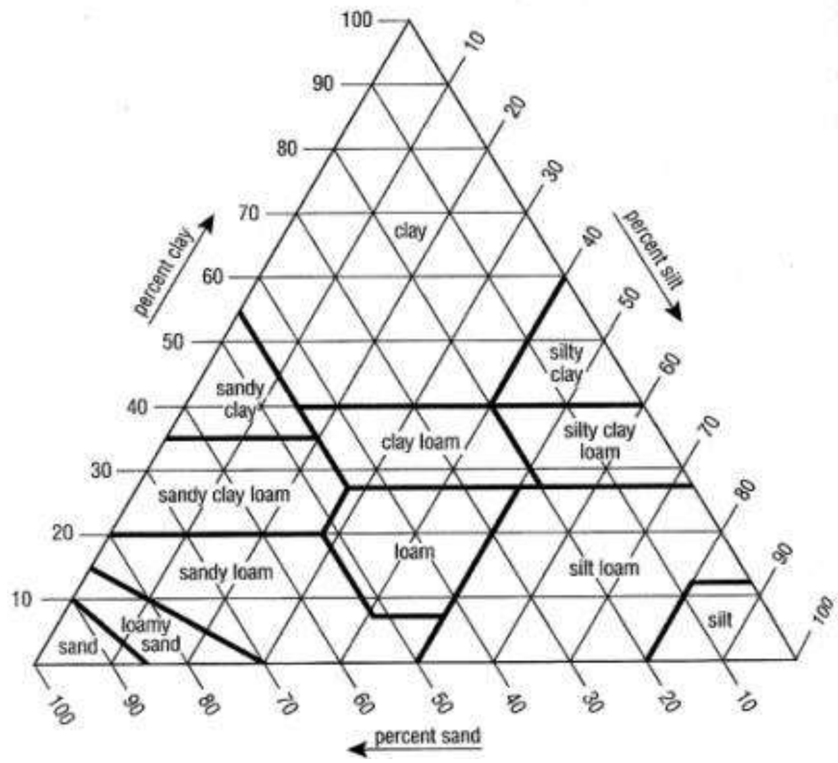


Figure A 3.1-21 Classification Pyramid

Source: USDA, 2020

A3.1.2.2 SOIL COLOR

- **Black:** associated with concentration of organic matter; the blacker the soil, the higher concentration of organic matters; typically found in wetlands
- **Red/Yellow:** related to soils with alteration of clay minerals; weathering of minerals releases aluminum and iron oxides
- **Grey:** found in wetlands that have been submerged for long periods of time
- **Green:** possible but certain minerals (glauconite an melanterite) must be present
- **Light Brown or White:** usually located in coastal zones with weathered quartz

A3.1.2.3 MOISTURE

Table A 3.1-19 Moisture Content Based on Field Test

Description	Field Test
Dry	Absence of moisture, dry to the touch, dusty
Damp	Apparent moisture
Moist	Grains appear darkened, but no visible water
Wet	Saturated, visible free water

A3.1.2.4 ANGULARITY

- **Rounded particles** can be spherical or ellipsoidal and have smoothly curved sides and edges
- **Subrounded particles** have generally plane sides and well-rounded corners and edges. Some sharp edges are present if particles have been broken
- **Angular particles** have sharp corners, edges, and relatively plane sides with unpolished surfaces (freshly crushed rock)
- **Subangular particles** have slightly rounded edges and slightly curved sides, but in general have sharp corners and edges with relatively plane sides and unpolished surfaces

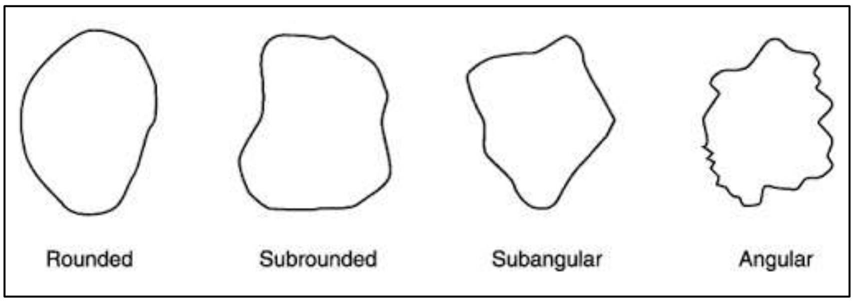


Figure A 3.1-22 Angularity of Particles

A3.1.2.5 GRADATION

- **Well-graded** materials have particles representing a range of sizes between large and small
- **Uniformly graded** materials have a limited range of particle sizes (i.e. all particles are the same size)
- **Gap graded materials** have some intermediate sizes, but are lacking sizes in the middle (i.e. there are gaps in the particle gradation)

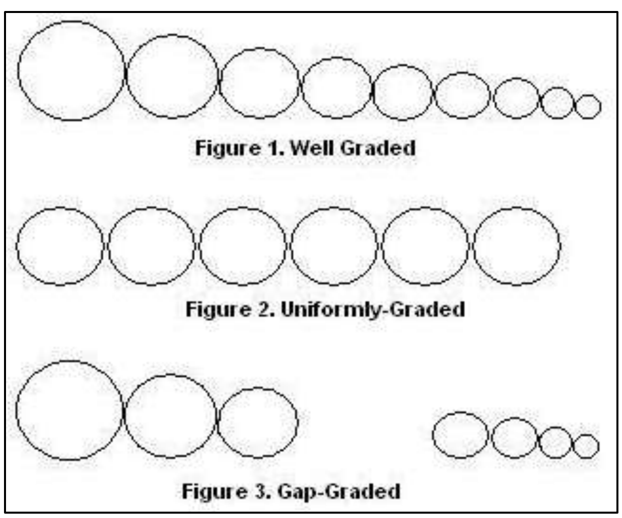


Figure A 3.1-23 Examples of Grading

Table A 3.1-20 Grain Size

Term	Diameter (mm) [in/sieve size]	Description
Boulder	305 [12”] or larger	Larger than a basketball
Cobble	76 [3”] – 305 [12”]	Lemon to grapefruit
Coarse Gravel	19 [3/4”] – 76 [3”]	Grape to lemon
Fine Gravel	4.75 [#4] – 19 [3/4”]	Uncrushed pepper to grape
Coarse Sand	2 [#10] – 4.75 [#4]	Salt to uncrushed pepper
Medium Sand	0.420 [#40] – 2 [#10]	Powdered sugar to salt
Fine Sand	0.075 [#200] – 0.420 [#40]	Powdered sugar
Fines (Silt / Clay)	< 0.075 [#200]	Ground flour

Based on USCS, ASTM D2487

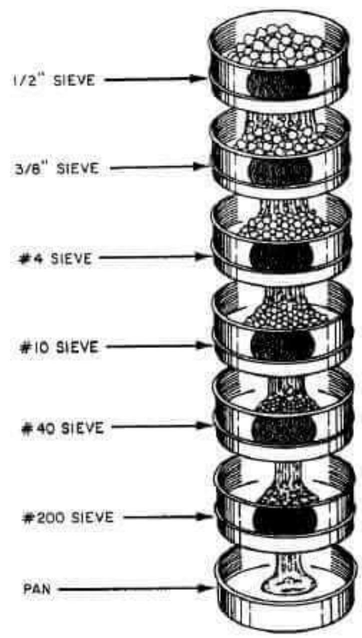


Figure A 3.1-24 Sieve Sizes

Table A 3.1-21 Plasticity

Description	Field Test
Non-Plastic	Soil falls apart at any water content
Low Plasticity	Soil is easily crushed with fingers; thread is rolled with difficulty
Medium Plasticity	Soil is difficult to crush with fingers; readily rolled into a 3mm thread
High Plasticity	Soil is impossible to crush with fingers; easily rolled smaller than a 3mm thread

Table A 3.1-22 Soil Consistency (Coarse Grained Soils)

Field Description Term	Consistency Description Definition	Relative Density (%)
Very Loose	Particles loosely packed and can be easily dislodged by hand. Easy to penetrate with shovel handle.	0 – 15
Loose	Particles loosely packed, but some resistance to being dislodged by hand. Easy to penetrate with hand shovel.	15 – 35
Medium (moderately) Dense	Particles closely packed, and difficult to excavate with a hand shovel. Resistant to penetration by point of geologic pick.	35 – 65
Dense	Particles very closely packed and occasionally weakly cemented. Cannot dislodge individual particles by hand. Requires many blows of geologic pick to dislodge.	65 – 85
Very Dense	Particles very densely packed and usually cemented together. Requires power tools to excavate.	85 – 100

Table A 3.1-23 Soil Consistency (Fine Grained Soils)

Field Description Term	Consistency Description Definition	Undrained Shear Strength (kPa)
Very Soft	Finger easily pushed in up to 25 mm	<12
Soft	Exudes between fingers Finger pushed in up to 25 mm	12 – 25
Medium Stiff	Molded by light finger pressure Thumb makes impression easily Penetrated by thumb with moderate effort. Cannot readily be molded by fingers,	25 – 50
Stiff	Can be indented slightly by thumb (up to 8mm)	50 – 100
	Thumb will not indent Readily indented by thumb nail	100 – 200
Hard	Indented by thumbnail with difficulty or cannot be indented.	>200

A3.1.2.6 ADDITIONAL TERMS

Stratified – alternating layers of varying material or color with layers at least 6 mm thick (thickness should be noted).

Figure A 3.1-25 Stratified Soil Layers

Laminated—alternating layers of varying material or color with layers less than 6 mm thick (thickness should be noted).

Fissured—breaks along definite planes of fracture with little resistance to fracturing

Figure A 3.1-26 Fissured Breaks

- **Slickensided—**fractured planes appearing polished or glossy. Can be an indication of a small fault as two blocks shear past each other smoothing the surface. Can also be an indication of soil with significant amounts of shrink-swell clays (clay expands and contracts along cracks and the sides are rubbed smooth)

Figure A 3.1-27 Slickensided

- **Lensed—**inclusions of small pockets of different soils. i.e. small lenses of sand scattered throughout a mass of clay (thickness should be noted).

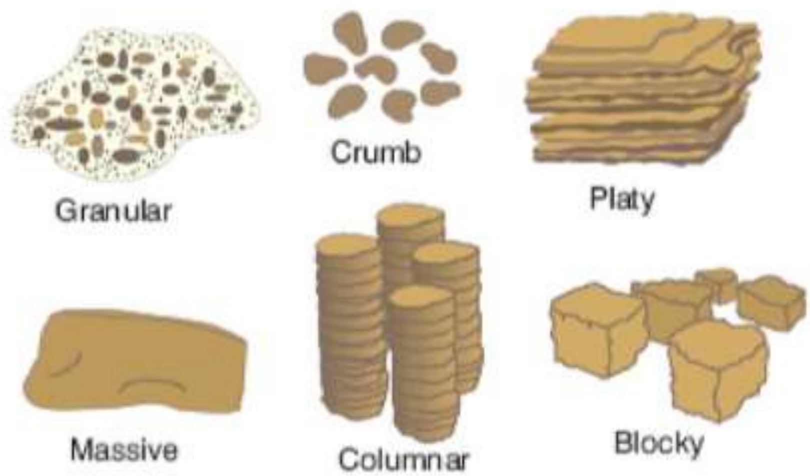


Figure A 3.1-28 Soil Types

- **Granular—**single grains connected to other grains forming what appears to be larger particles resembling single grains
- **Platy—**soil particles aggregated in think plates or sheets piled horizontally on one another
- **Massive—**no discernable structure
- **Blocky—**cohesive soil that can be broken down into smaller angular lumps which resist further breakdown.
- **Homogeneous—**same color and appearance throughout
- **Deleterious material—**harmful or injurious substances prohibited for use in a project. This could be due to reliability, health and safety, structural

stability, performance, physical integrity, susceptible to change or deterioration, and non-compliance with regulations

- **Saprolitic soils—**chemically weathered rock

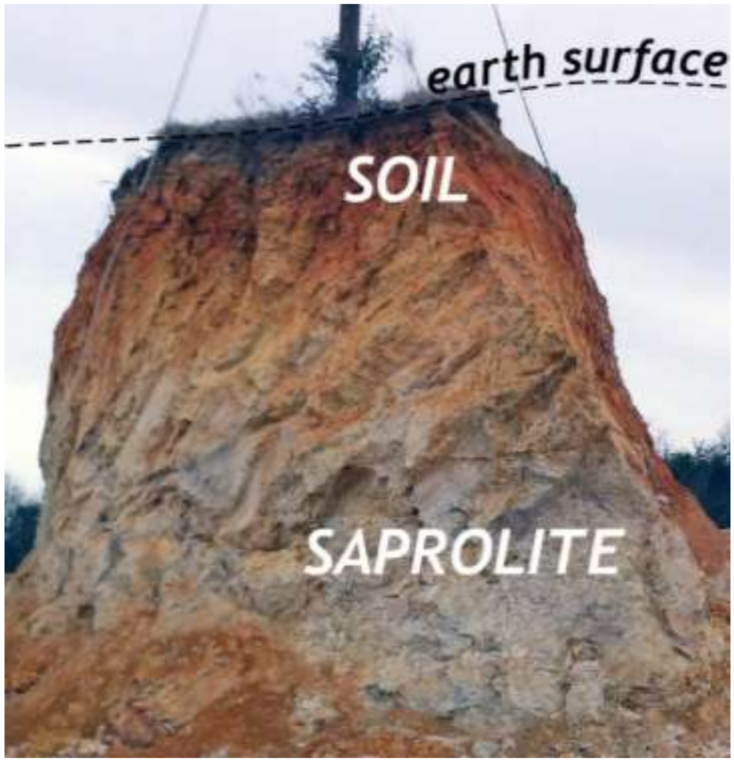


Figure A 3.1-29 Saprolitic Soils

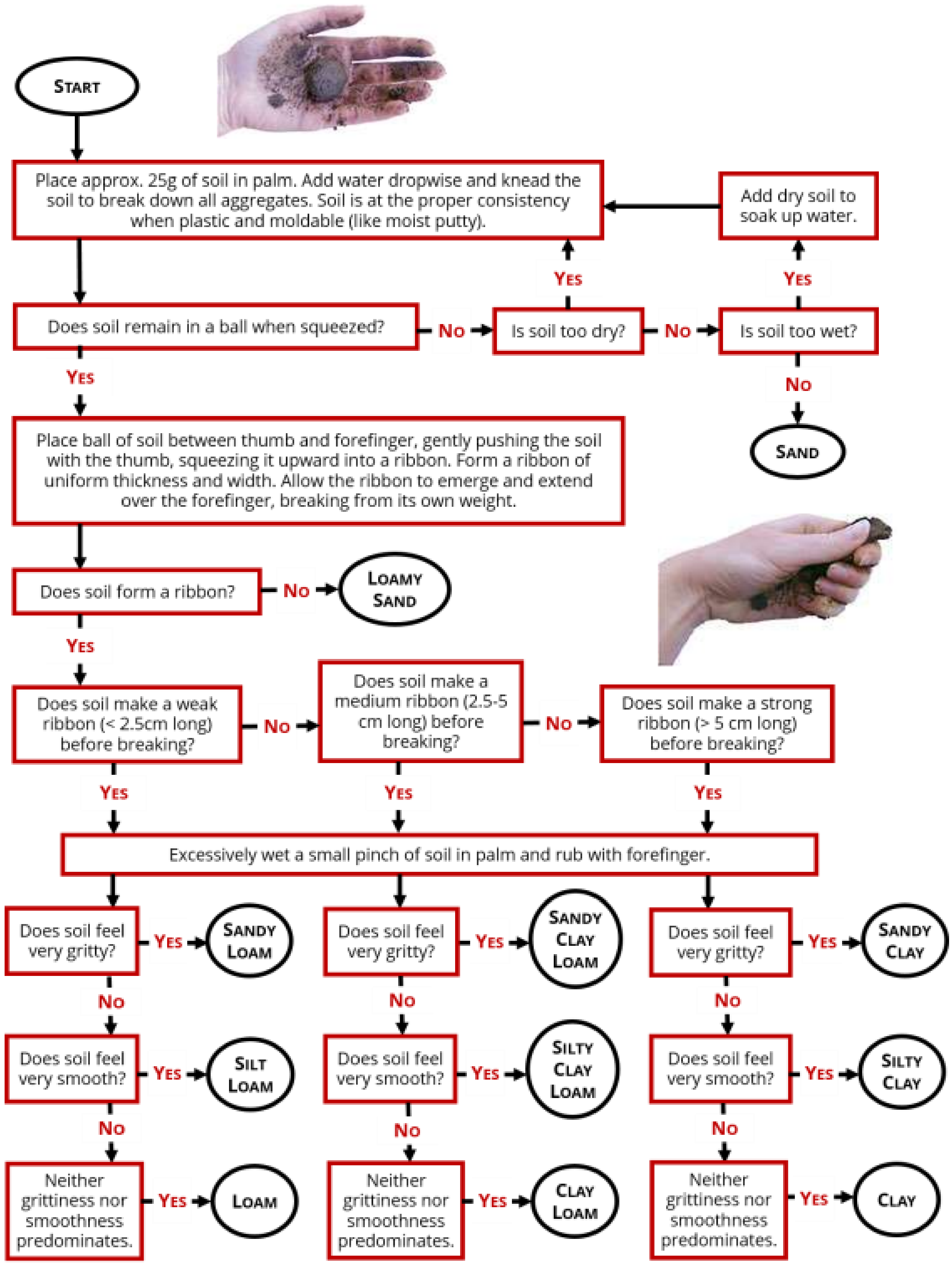


Figure A 3.1-30 Guide to Texture by Feel

Source: Thein, 1979

A3.1.3 CLASSIFICATION COMPARISON

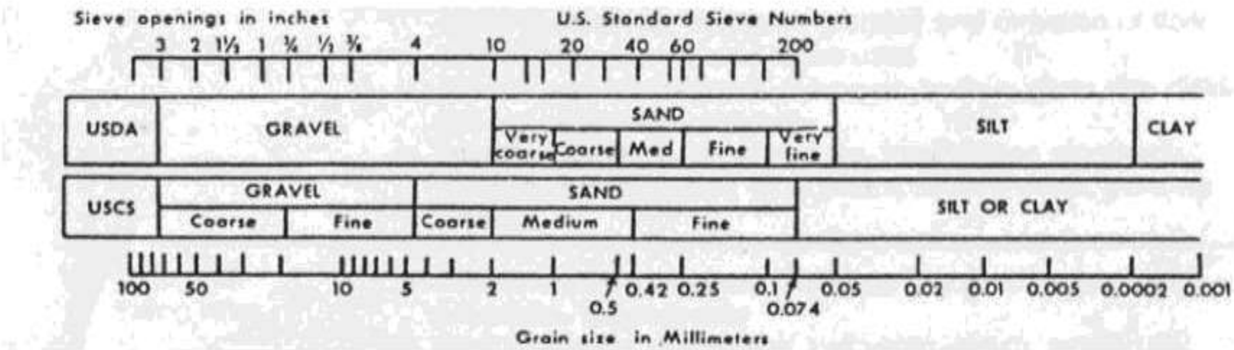


Figure A 3.1-31 Sieve Opening and Grain Size

Table A 3.1-24 USDA and USCS Classifications

USDA Classification	Possible USCS Classification
Clay	Clay, Clay with Sand, Sandy Clay, Silty Clay, Silty Clay with Sand, Sandy Silty Clay
Silty Clay	Silty Clay, Silty Clay with Sand
Silty Clay Loam	Silty Clay, Silt, Silty Clay with Sand
Silt Loam	Silt, Silt with Sand, Sandy Silt, Silty Clay with Sand, Sandy Silty Clay
Silt	Silt, Silt with Sand
Clay Loam	Sandy Silty Clay, Silty Clay with Sand
Loam	Sandy Silty Clay, Silty Clay with Sand, Silty Sand
Sandy Clay	Clayey Sand, Sandy Clay, Sandy Silty Clay
Sandy Clay Loam	Clayey Sand, Sandy Silty Clay, Silty Sand
Sandy Loam	Silty Sand, Clayey Sand, Sandy Silty Clay
Loamy Sand	Silty Sand, Clayey Sand, Sand
Sand	Sand, Silty Sand

Table A 3.1-25 USCS and USDA Classifications

USCS Classification	Possible USDA Classification
Clay	Clay
Clay with Sand	Clay
Sandy Clay	Clay, Sandy Clay
Silty Clay	Silty Clay, Silty Clay Loam, Clay
Silty Clay with Sand	Clay Loam, Silty Clay Loam, Silt Loam, Loam, Clay
Sandy Silty Clay	Loam, Clay Loam, Clay, Sandy Clay, Silt Loam, Sandy Loam
Silt	Silt, Silt Loam, Silty Clay Loam
Silt with Sand	Silt Loam, Silt
Sandy Silt	Silt Loam
Sand	Sand, Loamy Sand
Clayey Sand	Sandy Clay Loam, Sandy Clay, Sandy Loam, Loamy Sand
Silty Sand	Sandy Loam, Loamy Sand, Loam, Sandy Clay Loam, Sand

NOTES:

1. In general, the USDA soil classification is more concerned with soil texture and grain size whereas USCS classification is more concerned with soil behavior, especially as it pertains to fine-grained soils
2. The above tables ignore sand particle coarseness, gravel sized particles, gradations, and plasticity
3. There is some discrepancy between the USDA and USCS methods concerning the particle size at which a soil is classified as fine-grained or coarse-grained. This distinction was ignored in the above tables, but there is a remote possibility that materials classified as very fine sand according to the USDA method may be classified as low plasticity silt with the USCS method
4. The USCS method uses soil behavior rather than particle size to classify fine-grained soils. For the purpose of this comparison, it was assumed that soil behavior was synonymous with particle size. Some liberties were made in comparing fine-grained materials between USDA and USCS, especially for silty clay and loam materials
5. This chart is for comparative purposes only and is not a substitute for soil testing.

A3.1.4 HAND AUGERING/BORING LOCATION

A hand auger may be used for subsurface exploration and is suitable for sand, silt and soft clay. Stiff clays, hard materials and gravels are difficult or impossible to drill through or remove. Augers can be used up to a depth of about 15-25 meters, depending on geology. Above the water table, the borehole generally stays open without the need for support, but a temporary PVC casing may be used below the water table to prevent the hole from collapsing. Hand augers are rotated into the ground until they are filled, then lifted out of the hole and emptied. Parts include extendable steel rods, a handle, and steel auger bits. Hand augers are widely used in parts of Africa, Central America, and western countries.

Using a Hand Auger

1. Follow equipment instructions to assemble auger. Typically, connect the auger to the handle and secure with pin.
2. Make a starter hole by turning the handle in a clockwise direction until it has drilled approximately 30cm into the soil.
3. Once the auger is filled with soil, lift the auger out of the borehole and shake auger away from the hole to remove the cuttings
4. Place the auger back into the hole and repeat the process: turn handle until auger is filled, lift auger out of hole, shake auger away from hole to remove cuttings
5. Continue process until the completion depth or handle has almost reached the ground
6. Once handle has almost reached the ground, remove pin and handle, add extension rod and replace handle and pin.
7. Repeat turn, lift, shake process until completion depth or an additional rod must be added

Tips:

- If drilling in dry sand and cuttings fall out of the auger or sides cave in, add water to make the sand stickier if not performing in situ moisture testing
- Ensure a straight trajectory when drilling the borehole, especially in the first few meters
- Ensure extensions and handles are securely fastened to prevent losing equipment in the hole.

- Take care when drilling below the groundwater table if temporary casing is not used.

Borehole Location Suggestions

The objective of subsurface exploration is to distributed borings to determine foundation soil layering. Boreholes should be located near foundations or other structures especially in locations and depths where surface soils are obviously different. Do not locate borings further than 10 meters from the proposed structure. The number of borings depends on cost, size of structure, availability of equipment and labor. However, a greater number of borings will give greater soil information and reduce the possibility of encountering unexpected soil conditions during construction. The depth of boring can vary between one to three times the shorter foundation or structure side length. If the stiffness and strength are known and bedrock is located at a depth that matches the base of the structure, 2 m depth is sufficient. If small foundations or structures are designed, a depth of 1.5 the shorter side length can be used.

Notes:

1. Consider the possibility of buried objects when choosing locations

A3.2 BEARING CAPACITY

A3.2.1 ALLOWABLE BEARING CAPACITY TABLES

Table A 3.2-26 Typical Bearing Capacity based on Soil Type[1]

	Soil Type	**Safe Bearing Capacity (kN/m^2)**
Cohesionless	Gravel, sand and gravel, compact soil with high resistance to penetration when removed with tools	440
	Coarse sand, compact and dry	440
	Medium sand, compact and dry	245
	Fine sand, silt	150
	Loose gravel or sand gravel moisture, loose coarse to medium sand, dry	245
	Fine sand, loose and dry	100
Cohesive	Soft shale, hard or stiff clay in deep bed, dry	440
	Medium clay easily indented with a thumb nail	245
	Moist clay and sand clay mixture indented with strong thumb pressure	150
	Soft clay indented with moderate thumb pressure	100
	Very soft clay penetrated several centimeters with thumb pressure	50
	Black cotton soil or other shrinkable or expansive clay in a dry condition (~50% saturation)	Determine from detailed Investigation
Organics	Peat	Determine from Investigation
Man-made	Fills or man-made ground	Determine from Investigation

Source: Dutta, 2017

[1] NOTE: Allowable bearing capacities are negatively affected by the presence of a water table within the foundation zone of influence.

Table A 3.2-27 Factors of Safety for Various Structures

Retaining	Walls	3
	Temporary Braced Excavation	> 2
Buildings	Silos	2.5
	Warehouses	2.5
	Apartments, offices	3
	Light industrial, public	3.5
Footing		3

Source: US Army Corps of Engineers, 1992, Table 1-2

A3.2.2 IN-SITU SOIL STRENGTH TEST PROCEDURES

Pocket Penetrometer

- Used to determine unconfined compressive strength of **saturated, cohesive soils**
- Gives direct reading calibrated in tsf or kPa (error ±20-40%)
- Spring-operated instrument

To use: push into soil and read indicator sleeve.

Shear Vane

To use: press vane into **level section** of **undisturbed** soil. Slowly turn torsional knob until soil failure occurs. Multiply the reading by 2 for results in kPa.

Dynamic Cone Penetrometer (DCP) Test

- An 8 kg free fall hammer lifted and dropped from a height of 575mm
- Correlation of DCP and Bearing Capacity (Paige-Green 2009)
    - Bearing capacity = $3426DN^{-1.014}$
        - Where DN = Cone penetration rate (mm/blow)

To use: Record the distance of cone tip penetration after every 5 blows.

A3.2.3 ULTIMATE BEARING CAPACITY

Equation A3.2-3 Simplified Ultimate Bearing Capacity

$$q_u = c * N_c + \frac{1}{2} * B * \gamma_H{}' * N_\gamma + \gamma_D' * D * N_q$$

q_u = ultimate bearing capacity pressure

c = soil cohesion (undrained shear strength)

B = foundation width

D = foundation depth

γ_H' = effective unit weight beneath foundation base within failure zone

γ_D' = effective unit weight of surcharge soil within the foundation depth (D)

$N_{c,\gamma,\sigma}$ = dimensionless bearing capacity factors

Equation used for continuous footings only.

Assumption: soil below foundation along the critical plane of failure is on the verge of failure. Additional factors added for general applicability.

Refer to FHWA Circular No. 6, Chapter 5; NAVFAC DM6-02; or Eurocode 7 for additional information.

A3.3 SOIL ABSORPTION CAPACITY

A3.3.1 PERCOLATION TEST PROCEDURE

1. Dig or drill a 150mm dia. hole to the intended depth of the absorption system (usually 1-2m deep, 3-5m for seepage pits).
2. Scrape the inside surface of the hole with a sharp implement to remove any smearing or plugging of the surface caused by the digging process.
3. Place a 50mm thick fine gravel layer in the bottom of the hole.
4. Fill the hole to 300mm above the top of the gravel layer with clean water and keep the water level at this depth for at least 4 hours, 24 hours if swelling clay is present. If the hole drains two times within 10 min, no further saturation is needed.
5. Refill the hole to 150mm and measure the distance from a fixed reference point to the water surface multiple times over a sufficiently long interval between measurements (1-30 min between measurements) to accurately measure the rate of water surfaced drop. Continue making measurements until the rate stabilizes (at least two consecutive tests where the water level drop does not vary by more than 2mm for the same time interval). When the water depth drops to less than 50mm, stop the test.
6. Refill the test hole to 150mm above the gravel and repeat the test at least two more times for greater accuracy.
7. Calculate the percolation value (in units of min/25mm) as the time in minutes for the water surface to drop 1” (25mm) after the rate has stabilized. Only the last few measurements should be used to calculate the percolation test value.
8. Perform at minimum 2 tests per site. Perform additional for large sites.

A3.3.2 APPLICATION RATES

Table A 3.3-28 Recommended Rates of Wastewater Application

Soil Texture	Percolation Rate (min/25mm)	Application Rate (lpd/m^2)
Gravel, Coarse Sand	<1	Not Suitable
Coarse to Medium Sand	1-5	49
Fine Sand, Loamy Sand	6-15	33
Sandy Loam, Loam	16-30	25
Loam, Porous Silt Loam	31-60	18
Silty Clay Loam, Clay Loam	61-120	8

Source: EPA, 1980, Table 7-2

Table A 3.3-29 Accepted Application Rate for Conventional Soils

Soil Group	Soil Texture Class	Application Rate (gal/ft^2-day)	Application Rate (lpd/m^2)
I	Sands Sand Loamy Sand	1.2 – 0.8	50 – 33
II	Coarse Loam Sandy Loam Loam	0.8 – 0.6	33 – 24
III	Fine Loams Sandy Clay Loam Silt Loam Clay Loam Silty Clay Loam Silt	0.6 – 0.3	24 – 12
IV	Clays Sandy Clay Silty Clay Clay	0.4 – 0.1	16 – 4

Source: NCEHS, 1996, Table 4.6.1

Table A 3.3-30 Accepted Application Rate for Saprolitic Soil

Soil Group	Saprolite Textural Class	Application Rate (gal/ft^2-day)	Application Rate (lpd/m^2)
I	Sands		
	Sand	0.8 – 0.6	33 – 25
	Loamy Sand	0.7 – 0.5	29 – 20
II	Loams		
	Sandy Loam	0.6 – 0.4	25 – 16
	Loam	0.4 – 0.2	16 – 8
	Silt Loam	0.3 – 0.1	12 – 4

Note: Saprolite is a chemically weathered rock and form in the lowest zones of soil profiles.

Source: NCEHS, 1996, Table 4.6.2

Table A 3.3-31 Influence of Site and Soil Evaluation Factors on Application Rate

Site Evaluation	Higher Application Rate	Average Application Rate	Lower Application Rate
Landscape Position	Ridges or interfluve, shoulder and nose or convex slopes	Linear Side Slope	Head, foot and toe slopes, concave slopes
Soil Structure	Granular, single-grained soils		Blocky
Clay Mineralogy	No clay or some non- expansive clay	Non-expansive clay	Expansive clay
Organic Matter	0%	2-5%	High organic matter
Soil Wetness	> 1.2 m	Between 0.9 m to 1.2 m	Between 0.6 to 0.9 m
Soil Depth	> 1.2 m	Between 0.9 m to 1.2 m	Between 0.6 to 0.9 m

Source: NCEHS, 1996, Table 4.6.4

Table A 3.3-32 Suggested hydraulic and organic loading

Texture	Structure		Hydraulic loading (gal/ft²-day)		Organic loading (lb BOD/1000ft²-day)	
	Shape	Grade	BOD=150	BOD=30	BOD=150	BOD=30
Coarse sand, sand, loamy coarse sand, loamy sand	Single grain	Structureless	0.8	1.6	1.00	0.40
Fine sand, very fine sand, loamy fine sand, loamy very fine sand	Single grain	Structureless	0.4	1.0	0.50	0.25
Coarse sandy loam, sandy loam	Massive	Structureless	0.2	0.6	0.25	0.15
	Platy	Weak	0.2	0.5	0.25	0.13
		Moderate, strong				
	Prismatic, blocky, granular	Weak	0.4	0.7	0.50	0.18
		Moderate, strong	0.6	1.0	0.75	0.25
Fine sandy loam, very fine sandy loam	Massive	Structureless	0.2	0.5	0.25	0.13
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.2	0.6	0.25	0.15
		Moderate, strong	0.4	0.8	0.50	0.20
Loam	Massive	Structureless	0.2	0.5	0.25	0.13
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.4	0.6	0.50	0.15
		Moderate, strong	0.6	0.8	0.75	0.20
Silt loam	Massive	Structureless		0.2	0.00	0.05
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.4	0.6	0.50	0.15
		Moderate, strong	0.6	0.8	0.75	0.20
Sandy clay loam, clay loam, silty clay loam	Massive	Structureless				
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.2	0.3	0.25	0.08
		Moderate, strong	0.4	0.6	0.50	0.15
Sandy clay, clay, silty clay	Massive	Structureless				
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak				
		Moderate, strong	0.2	0.3	0.25	0.08

Source: EPA, 2002, Table 4-3

A4 Wastewater

A4.2 WASTEWATER CONVEYANCE

A4.2.1 PEAK FACTOR FOR DOMESTIC WASTEWATER

This is the ratio of maximum to average flows. Peak factor (P_f) for domestic wastewater can be calculated using different formulae depending on the condition of flow. The table below shows some methods that can be used to calculate peak factor.

Table A 4.2-33 Peak Factor Methods

Method	Peaking factor formula	Sustained duration	Conditions of application
Harmon	$P_f = 1 + \frac{14}{4+\sqrt{p}}$	Hourly	P: population in thousands
Babbit and Baumann	$P_f = \frac{5}{p^{0\cdot 2}}$	Instantaneous	$1 \le P \le 1000$ P: population in thousands
Munksgaard and Young	$\frac{2\cdot 97}{Q_m^{0.0907}}$	Extreme annual peak 4hrs	Q_m, in m^3/s
	$\frac{2\cdot 9}{Q_m^{0.0902}}$	Extreme annual peak 8hrs	Q_m, in m^3/s
	$\frac{1\cdot 75}{Q_m^{0.036}}$	Extreme annual peak day	Q_m, in m^3/s
Metcalf and Eddy	$PF = \begin{cases} 5, & P \le 5 \\ \frac{4.8}{P^{0.121}}, & P > 5 \end{cases}$	Hourly	$1 \le P \le 1000$
Gifft, H.M.	$PF = \frac{5}{P^{0.167}}$	Instantaneous	$1 \le P \le 200$
Johnson, C.F.	$PF = \frac{5.2}{P^{0.15}}$	Instantaneous	$1 \le P \le 200$

Flow variation in sewers usually reduces as population increases. Therefore, P_f values are usually higher for smaller populations than the larger populations. Flow into the sewers of small communities results from the quasi-random usage of a range of home appliances with the frequency of use being related to the time of the day, living and work style of the residents. This statement is true for most EMI project that involve design of boarding schools or living homes. The students usually leave the dormitories early morning for class and they may come back for lunch in the dorms or have from the dining hall. After lunch they go for their afternoon classes and get back to the dorms in the evening. All this going back and forth results in variation of wastewater flows with maximums and minimums.

Poisson Rectangular Pulse (PRP) – Gumble Approach (Zhang, 2005)

As mentioned in the first draft of the design manual, no derivation or theoretical justification for the peaking factor formula used had been offered. A parent formula for peaking factor that accounts for both indoor and outdoor water demands was derived by use of basic principles from the Poisson Rectangular Pulse model of residential water use and extreme value frequency analysis. Estimates were used in the derivation and not actual data.

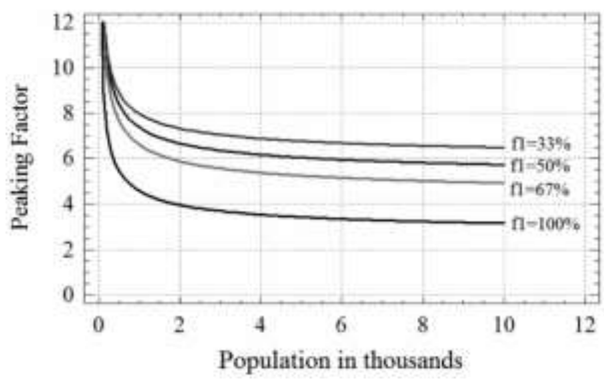


Figure A 4.2-32 ***PRP model for residential water use***

The lower PF curve in the figure above corresponds to indoor water use only. Since virtually all indoor water use is returned as domestic sewage, this curve could be used for sizing sanitary wastewater systems. However, this approach does not account for infiltration and inflows that depend on wet weather and system defects.

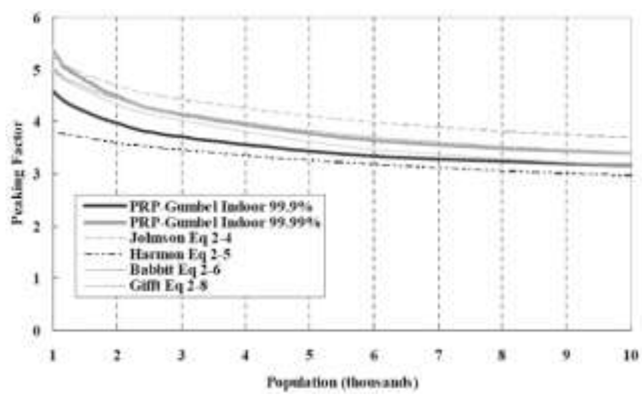


Figure A 4.2-33 ***Comparison between PRP-Gumbel approach and other empirical methods***

The PF expression for indoor water use only was;

$$2.50 + \frac{2.07}{\sqrt{P}}$$

This expression is very similar to the empirical formulae currently used to estimate the PF for domestic wastewater as shown in the figure above. The PRP-Gumbel (99.9%) curve gives PF values that are comparable to those adopted in wastewater design applications. As shown in the figure above, most of the peaking factor estimated using the wastewater empirical method lie above the PRP-Gumbel (99.9%) curve. This suggests that the conventional practice for estimating wastewater peaking factors is quite conservative, giving values with a relatively low risk of exceedance.

Fixture Unit Method

This method is used for sizing purposes in the absence of documented information such as existing meter records or reported values for analogous system. Hunter (1940) showed that peak water demands are related to the number and type of indoor fixtures being served by the tap using the Hunter curve. AWWA M-22 (1975) found out that the estimates from Hunter's curve tended to overestimate demands and so a modified version of fixture unit values was provided which are based on a system of empirical measurements. The AWWA M-22 (2004) modified version is commonly used for commercial developments like office buildings, hotels and schools among others.

A4.2.2 CALCULATING JUNCTION BOX ELEVATIONS

The following simple steps can be used to guide the ***EMI Wastewater Junction Box Design Template*** process.

Step 1: Elevation of the building

Step 2: Furthest fixture on the building sewer line

Step 3: Calculate junction box elevation by,

$$Building\ elevation - Slab\ thickness - Hardcore\ and\ sand\ blinding - Road\ thickness - Pipe\ size$$

Table A 4.2-1 Typical Thicknesses And Size

	Typical size (mm)
Slab thickness	100
Hardcore	200
Sand blinding	50
Murram (Dirt Road)	50
Pipe size	110

Note: The slab thickness, hardcore, sand blinding and compacted Murram (dirt road) thicknesses should be verified from the structural details.

Step 4: Calculate pipe invert into the junction box.

$$Elevation\ obtained\ in\ step\ 3 - Slope\ x\ Pipe\ length\ from\ the\ fixture$$

Note: The slope above is usually 2%.

Step 5: Calculate pipe invert out of the junction box

$$Invert\ in - Slope$$

Note: The slope above is usually 3%.

Step 6: Calculate pipe invert into the next junction box.

$$Invert\ out\ of\ the\ previous\ JB - Slope\ x\ Pipe\ length\ from\ the\ previous\ junction\ box$$

Step 7: Calculate the pipe invert out of the junction box.

$$Invert\ in - Slope$$

Step 8: Apply steps 6 and 7 for the remaining junction boxes.

Note: After the above calculations, check the elevation differences for the junction boxes to ensure that the pipes are not very steep. Very steeply sloped inverts into junction boxes can lead to sewage fall into the junction box which results into turbulence and eventually smell.

Table A 4.2-2 Sewer Diameter, Minimum and Maximum Slopes

Sewer Diameter (inch)	Minimum Slope (ft./100 feet)	Minimum Slope (%)	Maximum Slope (ft./100 feet)
4 (100mm)	1.05	2.00	
6 (150mm)	0.60	1.00	
8 (200mm)	0.40	0.50	1.8
10 (250mm)	0.28	0.40	1.2
12 (300mm)	0.22	0.35	1.0
14 (350mm)	0.17		
15 (375mm)	0.15	0.30	0.8
16 (400mm)	0.14		
18 (450mm)	0.12	0.25	0.9
21 (525mm)	0.10	0.20	
24 (600mm)	0.08	0.15	
27 (675mm)	0.067	0.15	
30 (750mm)	0.058	0.15	
36 (900mm)	0.046	0.15	

A4.3 SEPTIC TANKS

A4.3.1 ALTERNATIVE SEPTIC TANK CALCULATIONS

A second, slightly more accurate method can be used where wastewater generation patterns are not similar to typical residential usage and if the required information is available. Use this method if sludge and scum generation rates can be accurately estimated.

Calculate storage volume for sludge and scum separately from the water volume needed for a 24-hour retention time and add them together (from WHO, WEDC)

Equation A4.3-4 Alternative Septic Tank Calculations

$$\boldsymbol{V} = \boldsymbol{Q} + (\boldsymbol{P}\, x\, \boldsymbol{N}\, x\, \boldsymbol{F}\, x\, \boldsymbol{S})$$

V = Water volume in liters

Q = Average wastewater flow (L/day)

P = persons using system

N = Years between desludging

F = Decomposition factor (1.0-1.3 depending on temperature, lower temperatures use higher values)

S = Rate of sludge accumulation (25L/year/person, blackwater only, 40L/year/person combined)

A4.3.2 MAINTAINING SEPTIC TANK AND ABSORPTION FIELD SYSTEM

Do

- Do obtain necessary permits from the appropriate local agency before doing any construction or repairs.
- Do use professional certified installers when needed.
- Do keep your septic tank and distribution box accessible for pumping and adjustment. Install risers if necessary. The covers should be locked or of sufficient weight to prevent a child from lifting them.
- Do have your septic system inspected annually and tank pumped out every 2 to 5 years by a professional contractor.
- Do keep a detailed record of repairs, pumping, inspections, permits issued and other maintenance activities.
- Do conserve water to avoid overloading the system. Repair dripping faucets and leaking toilets, avoid long showers and run washing machines and dishwashers only when full. Use water-saving features in faucets, shower heads and toilets.
- Do divert other sources of water, such as roof drains, house footing drains, sump pump outlets, and driveway and hillside runoff away from the septic system. Use curtain drains, surface diversions, downspout extensions, retaining walls, etc. to divert water.
- Do take leftover hazardous household chemicals to an approved hazardous waste collection center for disposal. Use bleach, disinfectants and drain and toilet bowl cleaners sparingly and in accordance with product labels.

Don't

- Don't go down into a septic tank for any reason. Toxic gases in the tank can be explosive and can cause asphyxiation.
- Don't allow anyone to drive or park over any part of the system.
- Don't cover the absorption field with a hard surface, such as concrete or asphalt. Grass is the best cover for promoting proper functioning of the field. The grass will not only prevent erosion but will help remove excess water.
- Don't plant a garden, trees or shrubbery over or near the absorption field area. Tillage may cut absorption trenches. The roots can clog and damage the drain lines.
- Don't make or allow repairs to your septic system without obtaining the necessary permits.

- Don't pour into drains any grease, cooking fats, chemical drain openers, paint, varnishes, solvents, fuels, waste oil, photographic solutions, pesticides or other organic chemicals. They can upset the bacterial action in the tank and pollute groundwater.
- Don't use your toilet as a trash can. Keep out coffee grounds, bones, cigarette butts, disposable diapers, feminine hygiene products, paper towels, facial tissues and other materials that decompose very slowly.
- Don't add enzyme or yeast additives to the septic tank in hopes of improving bacterial action. None have been proven beneficial and some actually cause damage to soil and vegetation and may pollute groundwater.

Source: Schultheies, 2001

A4.4 GREASE INTERCEPTORS

Table A 4.4-34 Grease Interceptor Design Parameters

Parameter	Value	Comments
Hydraulic retention time	Minimum 30 min at max flow	Retention times of an hour or longer are common for commercial systems. If water is hot, longer HRTs are required to allow water to cool and FOG to separate.
Reserve volume for FOG and solids storage	25% of liquid volume	Multiply water volume by 1.25 to provide volume for FOG storage.
Depth	800-2000mm	Most are 1000-1500mm deep.
Width	500mm minimum	Minimum buildable width using brick and mortar is 500mm. Other construction methods may allow for a smaller tank.
Length	Minimum 2 times width	Add thickness of interior wall and plaster to determine overall length.
Drop in pipe inverts from inlet to outlet	50-75mm	Accounts for head loss through tanks.
Inlet baffle tee	Minimum 110mm dia. inlet baffle tee extends downward at least 0.5 times the water depth and extends 100mm above water surface and 300 mm above the tank bottom.	PVC pipe tees form the baffles. Tees prevent floating FOG or solids from blocking the inlet or outlet pipes and permit removal of this material.
Interior wall	Extend top of interior wall 150mm above water surface. Leave 75mm air gap between the top of wall and ceiling of tank. Two 110mm dia. crossover pipes are located 300mm above the tank bottom. Upstream ends of pipes consist of tees with vertical risers extending 150mm above the water surface.	Interior wall retains FOG and helps reduce turbulence in the tank. Tees on the crossover pipe prevent plugging of these pipes and allows for easier removal of floating material.

Parameter	Value	Comments
Outlet baffle	Minimum 110mm dia. outlet tee extends to within 300mm of floor and 100mm above water surface.	Outlet baffle inlet end should be near the tank floor to allow food solids to exit tank.
Cleanouts	Provide access hatches above inlet and outlet baffles and interior wall tee. Provide pipe clean-out ports on the inlet and outlet pipes unless junction boxes are close enough to allow cleaning of the pipes.	Cleanout hatches should be placed directly above the tee baffles so the interior of the tees can be inspected and cleaned as needed.

A4.6 LATRINES

A4.6.1 DESCRIPTION OF TYPES OF LATRINES

A4.6.1.1 VENTILATED IMPROVED PIT (VIP) LATRINE

A VIP latrine consists of a small building constructed over a pit or vault (Figure 6) that employs a straight vent pipe from the pit, fitted with an insect screen, to allow gas to escape while preventing flies from exiting the pits. They are designed to minimize the light level in the latrine structure so flies will be attracted to the light at the end of the vent pipe rather than the interior of the structure. They should be positioned such that the predominant wind direction directs fresh air into the structure and out the vent pipe, located on the back side of the building. Properly vented and situated VIP latrines will result in lower odor than a conventional latrine, if properly maintained.

Standard VIP latrines employ a single deep pit. These have a limited design life, because when full, the structure must be emptied, or abandoned and relocated. Latrine pit excavations can reach up to 20m or more, depending on the depth to groundwater or rock. There is no realistic way to recover the resources in human waste with such a pit: it is a disposal method only. The land used for such a pit will not be usable for any other purpose after the pit is filled. It is difficult to construct a conventional latrine block that has more than one stance due to the need to have separate deep pits.

Advantages: Simplicity, low cost, water-less operation, low maintenance, common and well understood method of waste disposal.

Disadvantages: Odor, flies, shallow groundwater or rock layers limit the depth of the pit, pit has limited lifespan, and waste material cannot be used for agricultural purposes.

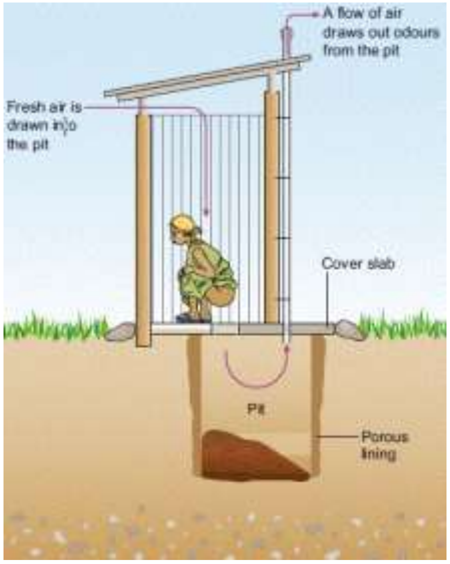


Figure A 4.6-34 Ventilated Improved Pit Latrine (VIP)

Source: www.open.edu

A4.6.1.2 DOUBLE VAULT LATRINES

Double vault latrines are dry vault latrines with two chambers, constructed side by side, for each stance. Each vault is designed to hold the amount of waste generated in a span of at least 2 years. Only one vault is in use at a time and it is used until it is full. The other vault is idle and sealed so it is not used. When the first vault becomes full (level of solids is less than 0.5m below the floor of the latrine) it is sealed and the second vault is put into use. The first vault is left to rest and the waste is slowly allowed to compost in place. After two years of inactivity, the access hatch to the vault is opened and the composted, pathogen-free waste is extracted and may be disposed of or used as a soil conditioner on gardens or agricultural fields. Once cleaned out, the first vault is again available for use and the process continues. Double vault latrines have an advantage over single vault latrines because the use of the latrine is not interrupted by the need to store the waste for two years while it becomes stabilized. Double vault latrines are often built as VIP latrines with the necessary ventilation elements. Separate vent pipes for each vault are usually specified. See Figure 7.

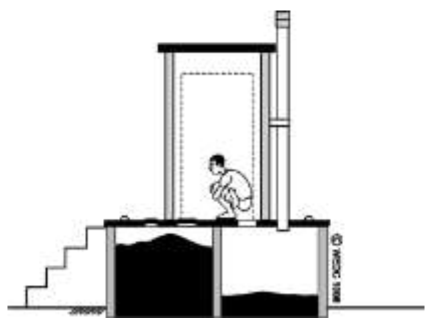


Figure A 4.6-35 Double Vault Latrine (WEDC)

Advantages: Same as the single vault VIP latrine but with less interruption of service when the vault fills with waste.

Disadvantages: Same as the single VIP latrine. Cost of the double vault is higher than a single vault due to the more complex structure and need. Training of users and maintenance personnel is more important due to added complexity.

A4.6.1.3 DRY VAULT LATRINE WITH URINE DIVERSION (URINE-DIVERTING DRY TOILET, UDDT)

In a dry vault latrine, the waste is placed in a sealed concrete or stone vault built under the latrine structure. Stances are constructed by casting a hole in the concrete slab covering the vault, or placing a plastic or ceramic toilet pan in the slab during construction. When not in use, the hole can be covered by a removable metal cover for safety and to prevent trash from entering the vault. Toilet pans with gravity operated door that claim to reduce odors and flies are also available, but can be a maintenance problem. Anal cleaning is performed using toilet paper, plant material, newspaper or other dry material. Water for washing hands is disposed of separately and is not directed to the vault. Dry vault latrines can be built in latrine block with multiple stances. Most dry vault latrines are constructed as VIP latrines with the requisite ventilation pipe and other features.

To reduce moisture in the vaults, urine if often separated from fecal matter. Separating the urine will reduce odors, decrease fly and mosquito propagation, increases the rate of composting of the solids, and may increases the ability of the latrine to inactivate pathogens. Urine is also a low-hazard source of nitrogen that can be used as a fertilizer with little processing besides dilution. To separate urine from feces, a special urine separator toilet pan is installed at each stance and separate piping is installed to transport the urine to storage containers, if it will be used for fertilizer, or to a soak pit, if it will not be used (see Figure 8). In toilet facilities for men and boys, a urinal can be installed, connected directly the urine collection system.

Advantages: The use of reusable dry pits eliminates the need for deep pits that must be abandoned when full and the structure relocated. Shallow excavation could also reduce construction cost and make construction safer. Shallow excavation allows these latrines to be used in areas with high groundwater tables (at least 1m below the bottom of the vault) and shallow bedrock which makes deep pits unsuitable. Dry waste may have less odor and flies than a conventional latrine. After a period of time (approximately two years after the last use and the vault is sealed) the composted waste may be considered pathogen free and can be removed from the vault and used as fertilizer. The vaults can be filled, cleaned and reused many times, eliminating the cost of digging a new vault each time one fills up. Urine diversion reduces odors and flies in the latrine. Improves the quality of the compost generated.

Disadvantages: Additional cost of constructing the concrete or masonry vault walls and floor, training of latrine users is required to ensure it is used properly. Poorly designed, built or operated units will generate odors and flies. Urine diversion may not be familiar to users and therefore could be used improperly. Urine diversion requires more diligent cleaning to minimize odors. The small diameter urine piping is easily plugged and difficult to clean, particularly if the urine-diverting toilet pan is not used properly.

For the reasons outlined above, EMI typically specifies double-vault improved dry pit VIP latrines. Urine separation is sometimes included, but this decision must be made on a case-by-case basis with the client's concurrence. This design provides a low-odor, long-term, and relatively safe solution to excreta disposal and resource recovery, though it does require training on how to properly use and maintain the system.

A4.6.1.4 COMPOSTING TOILET

This form of latrine allows waste to be collected in dry form and converted to compost over about a 12-month period after the vault is filled and removed from service. Fecal matter is deposited into the vault and covered with dry material such as ash, soil, dry grass, or plant matter. Most composting toilets also divert urine to improve the composing process since moisture and nitrogen in urine interfere with composting. The entire unit can be built above grade, instead of utilizing an in-ground pit, to improve ventilation and ease of removal of waste. Compost toilets can be an acceptable option if groundwater or the presence of shallow rock limits the use of pits. However, experience has shown that these units are difficult to operate properly, often resulting in flies and odors. EMI does not typically recommend use of compost toilets because, in many communities, they are not culturally appropriate or sustainable and the units are often unsanitary and unpleasant if not carefully cleaned and maintained.

Advantages: No water is needed to operate the toilets (though water is still needed for hand washing and cleaning), no leach pit or adsorption field is required, compost is produced for agricultural use, units have a longer design life than standard pits because there is no need to dig a new pit and relocate the structure when the pit fills up.

Disadvantages: Many users are often unfamiliar with these units and they may not be desirable in some cultures because of their aversion to handling human waste. Operation and maintenance are more complex, and adherence to special procedures to use, clean, and maintain the latrine is required for success. The compost may still contain pathogens and restrictions on its use as a fertilizer should be followed to avoid disease.

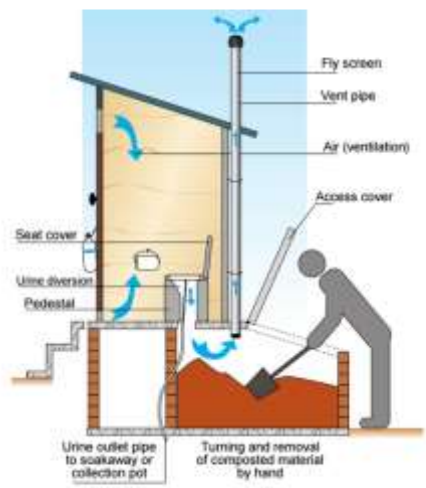


Figure A 4.6-36 Compost Latrine

Source: www.open.edu

A4.6.1.5 POUR-FLUSH AND AQUA PRIVY

An aqua privy is a version of a water-flushed toilet connected to a septic tank and soak pit system. Is some designs, the toilets are constructed directly above the septic tank with the waste pipe extending below the water surface to form a water trap. Other designs have a “P” trap to form a water seal. Pour-flush toilets are similar to standard flush toilets except special low-water-use squat toilet pans are often used and only 2-3 liters of water is used per flush, versus 5-10 liters for a flush toilet. The pan is emptied of waste by manually pouring water into the pan. The toilets often discharge directly into a nearby septic tank. Water from both types of toilets is disposed of in a leach pit or adsorption field. In some cases, the septic tank may have a porous bottom and side walls to allow for draining of the wastewater. The design process is similar to that used for standard septic tanks and soak pits. Water is often used for anal cleaning with these devices. Since toilets incorporate a water seal between the septic tank and the interior of the latrine, preventing the release of odors and flies into the building, they can be placed near, or even inside buildings. They can be considered an incremental improvement to pit latrines, though water use is greater.

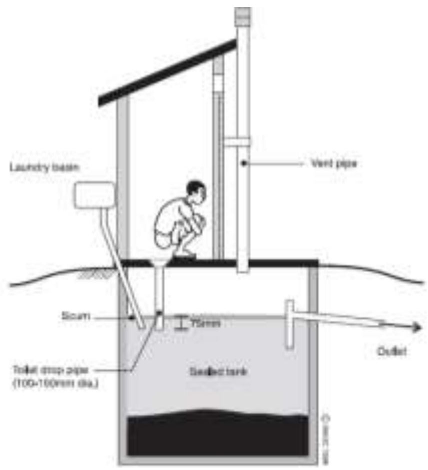


Figure A 4.6-37 Aqua Privy (WEDC)

Figure A 4.6-38 Pour Flush Latrine

Source: www.open.edu

Advantages: Lower water requirements than standard flush toilets. A piped water supply is not required. Less odor and flies due to the water seal. May be installed near or inside a structure.

Disadvantages: Requires a consistent, reliable water supply near the latrine. Not commonly used in East Africa due to water scarcity. Requires education on the use of the system. Can only be used in areas with porous soil and groundwater over 5m deep.

A5 Site Design

A5.3 RETAINING WALL DESIGN

A5.3.1 RETAINING WALL TYPES

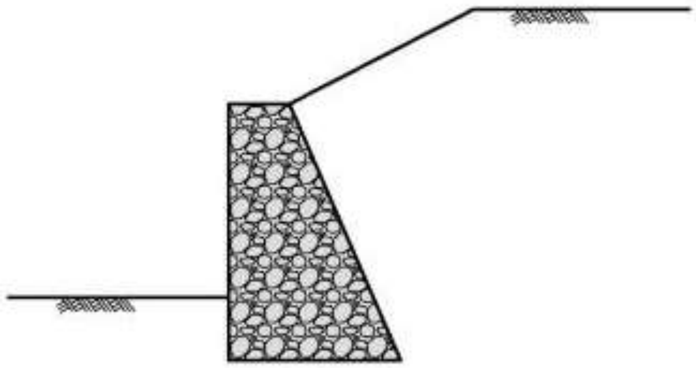


Figure A 5.3-39 Gravity Wall

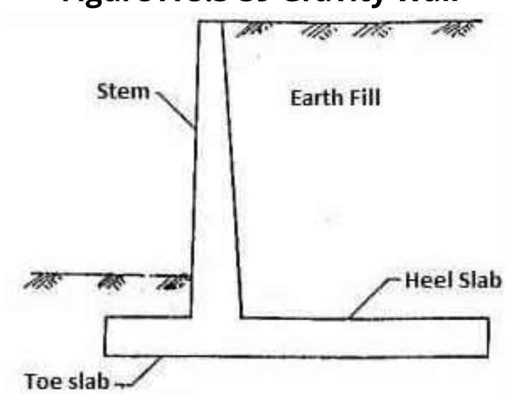


Figure A 5.3-40 Cantilever Wall

Figure A 5.3-41 Sheet Pile Wall

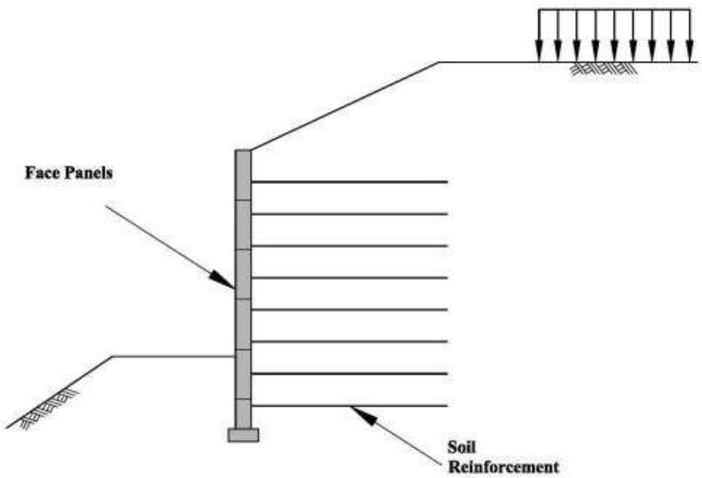


Figure A 5.3-42 MSE Wall

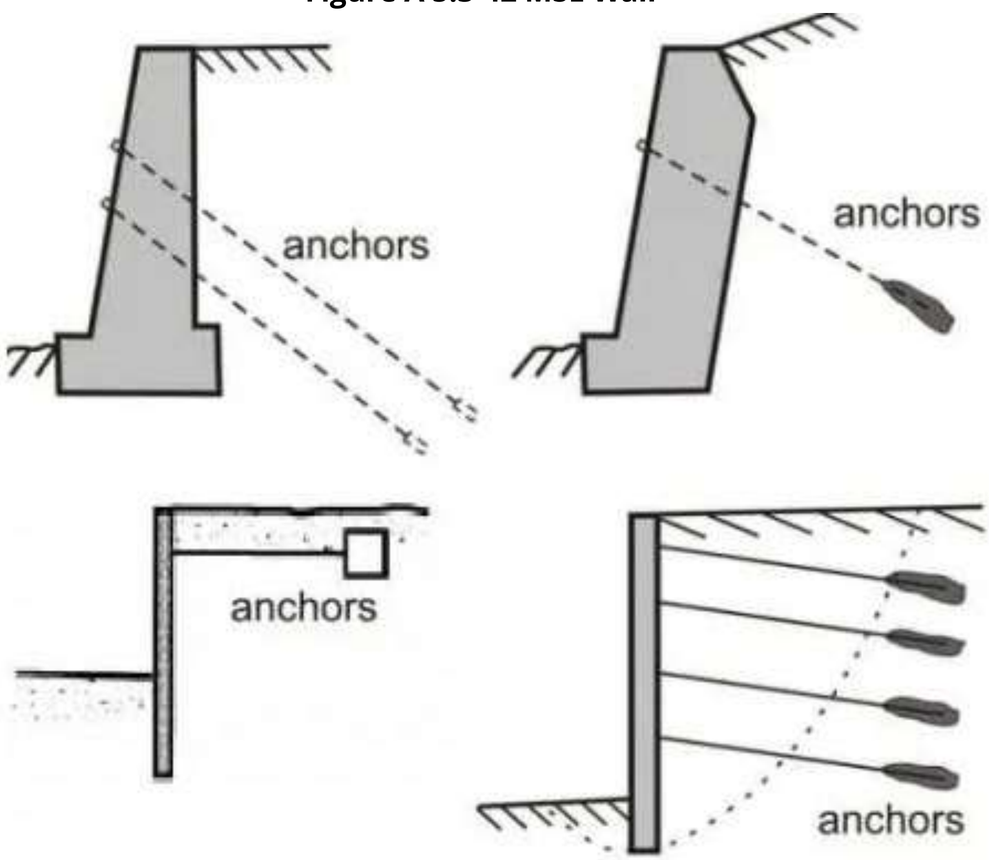


Figure A 5.3-43 Anchored Retaining Wall

A5.3.2 TYPICAL RETAINING WALL PROPORTIONS

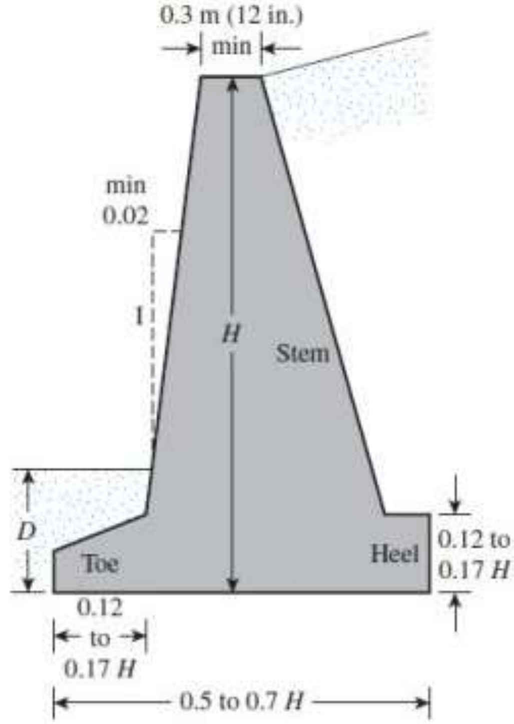


Figure A 5.3-44 Gravity Wall

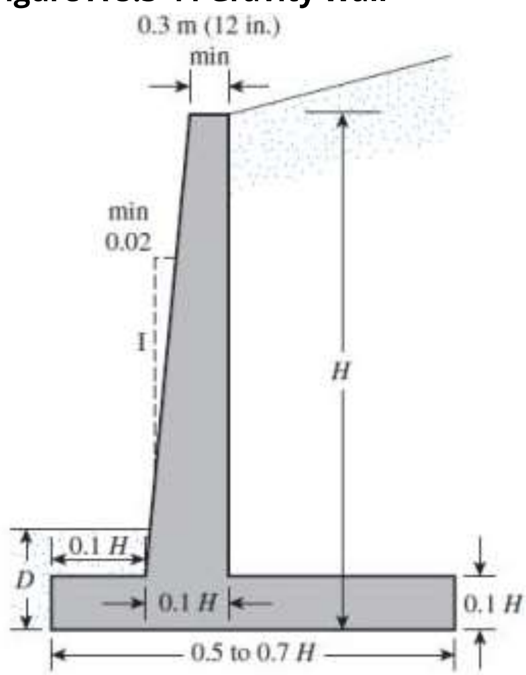


Figure A 5.3-45 Cantilever Wall

Source: Murthy, 2006

A5.3.3 RETAINING WALL DESIGN PARAMETERS

Table A 5.3-35 Typical Soil Properties

Soil Type	Porosity	Void Ratio	Water Content	Dry Unit Weight (kN/m^3)	Saturated Unit Weight (kN/m^3)
Uniform Sand (loose)	0.46	0.85	32%	14.1	18.5
Uniform Sand (dense)	0.34	0.51	19%	17.1	20.4
Well-graded Sand (loose)	0.40	0.67	25%	15.6	19.5
Well-graded Sand (dense)	0.30	0.43	16%	18.2	21.2
Windblown Silt (loose)	0.50	0.99	21%	13.4	18.2
Glacial till	0.20	0.25	9%	20.7	22.8
Soft clay	0.55	1.20	45%	11.9	17.3
Stiff clay	0.37	0.60	22%	16.7	20.3
Soft slightly organic clay	0.66	1.90	70%	9.1	15.4
Soft very organic clay	0.75	3.00	110%	6.8	14.0

Source: Christopher et al, 2006, Table 5-9

Note: Precautions needs to be taken when using the given typical water content of any soil type. The water content of soil is affected by different soil depth, rock fragment content, and other soil properties. Therefore, values given in table are not absolute. Additional data from the Naval Facilities Engineering Command could be used as reference as provided in Table A 5.3-36.

Table A 5.3-36 Typical Properties of Compacted Soils (NAVFAC)

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Moisture, Percent	Typical Value of Compression (Percent of Original Height)		Typical Strength Characteristics				Typical Coefficient of Permea-bility ft./min.	Range of CBR Values	Range of Subgrade Modulus k lbs/cu in.
				At 20 psi	At 50 psi	Cohesion (as com-pacted) psf	Cohesion (saturated) psf	φ (Effective Stress Envelope Degrees)	τ			
GW	Well graded clean gravels, gravel-sand mixtures.	125 - 135	11 - 8	0.3	0.6	0	0	>38	>0.79	5×10^{-2}	40 - 80	300 - 500
GP	Poorly graded clean gravels, gravel-sand mix.	115 - 125	14 - 11	0.4	0.9	0	0	>37	>0.74	10^{-1}	30 - 60	250 - 400
GM	Silty gravels, poorly graded gravel-sand-silt.	120 - 135	12 - 8	0.5	1.1	.....	.....	>34	>0.67	$>10^{-6}$	20 - 60	100 - 400
GC	Clayey gravels, poorly graded gravel-sand-clay.	115 - 130	14 - 9	0.7	1.6	.....	.....	>31	>0.60	$>10^{-7}$	20 - 40	100 - 300
SW	Well-graded clean sands, gravelly sands.	110 - 130	16 -9	0-6	1.2	0	0	38	0.79	$>10^{-3}$	20 - 40	200 - 300
SP	Poorly graded clean sands, sand-gravel mix.	100 - 120	21 - 12	0.8	1.4	0	0	37	0.74	$>10^{-3}$	10 - 40	200 - 300
SM	Silty sands, poorly graded sand-silt mix.	110 - 125	16 - 11	0.8	1.6	1050	420	34	0.67	$5 \times >10^{-5}$	10 - 40	100 - 300
SM-SC	Sand-silt clay mix with slightly plastic fines	110 - 130	15 - 11	0.8	1.4	1050	300	33	0.66	$2 \times >10^{-6}$	5 - 30	100 - 300
SC	Clayey sands, poorly graded sand-clay-mix.	105 - 125	19 - 11	1.1	2.2	1550	230	31	0.60	$5 \times >10^{-7}$	5 - 20	100 - 300
ML	Inorganic silts and clayey silts.	95 - 120	24 - 12	0.9	1.7	1400	190	32	0.62	$>10^{-5}$	15 or less	100 - 200
ML-CL	Mixture of inorganic silt and clay.	100 - 120	22 - 12	1.0	2.2	1350	460	32	0.62	$5 \times >10^{-7}$	.....	.....
CL	Inorganic clays of low to medium plasticity.	95 - 120	24 - 12	1.3	2.5	1800	270	28	0.54	$>10^{-7}$	15 or less	50 - 200
OL	Organic silts and silt-clays, low plasticity.	50 - 100	33 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	50 - 100
MH	Inorganic clayey silts, elastic silts	70 - 95	40 - 24	2.0	3.8	1500	420	25	0.47	$5 x >10^{-7}$	10 or less	50 - 100
CH	Inorganic clays of high plasticity	75 - 105	36 - 19	2.6	3.9	2150	230	19	0.35	$>10^{-7}$	15 or less	50 - 150
OH	Organic clays and silty clays	65 - 100	45 - 21	.....	.....	.....	.....	.....	.....	.....	5 or less	25 - 100

Notes:
I. All properties are for Condition of "Standard Proctor" maximum density, except values of k and CBR which are for "modified Proctor" maximum density.
2. Typical strength characteristics are for effective strength envelope.; and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property la greater than the valve shown.
(..) indicates insufficient data available for an estimate.

Source: Naval Facilities Engineering Command (NAVFAC), 1986, Table 1

Table A 5.3-37 Failure Modes

Failure Mode	**Factor of Safety**
Sliding	1.5
Overturning	1.5-2.0
Bearing Capacity	3.0

Table A 5.3-38 Ultimate Friction Factors and Adhesion for Dissimilar Materials

Interface Materials	Friction factor, tan δ	Friction angle, δ degrees
Mass concrete on the following foundation materials:		
Clean sound rock	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		
Steel sheet piles against the following soils:		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls	0.40	22
Clean sand, silty sand-gravel mixture, single size hard rock fill	0.30	17
Silty sand, gravel or sand mixed with silt or clay	0.25	14
Fine sandy silt, nonplastic silt	0.20	11
Formed concrete or concrete sheet piling against the following soils:		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	0.40 to 0.50	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill	0.30 to 0.40	17 to 22
Silty sand, gravel or sand mixed with silt or clay	0.30	17
Fine sandy silt, nonplastic silt	0.25	14
Various structural materials:		
Masonry on masonry, igneous and metamorphic rocks:		
Dressed soft rock on dressed soft rock	0.70	35
Dressed hard rock on dressed soft rock	0.65	33
Dressed hard rock on dressed hard rock	0.55	29
Masonry on wood (cross grain)	0.50	26
Steel on steel at sheet pile interlocks	0.30	17

Interface Materials (Cohesion)	Adhesion C_a (psf)
Very soft cohesive soil (0 - 250 psf)	0 - 250
Soft cohesive soil (250 - 500 psf)	250 - 500
Medium stiff cohesive soil (500 - 1000 psf)	500 - 750
Stiff cohesive soil (1000 - 2000 psf)	750 - 950
Very stiff cohesive soil (2000 - 4000 psf)	950 - 1,300

Source: Naval Facilities Engineering Command (NFEC), 1986, Table 1, p. 7.2-63

A5.3.4 FORCES ON RETAINING WALLS

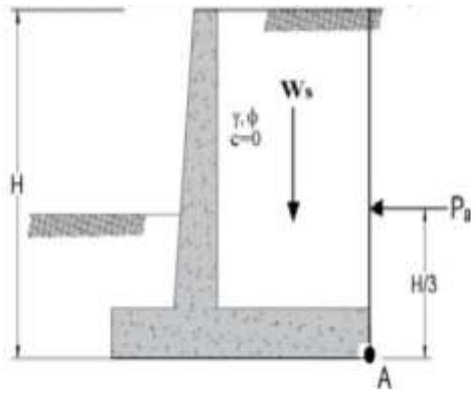


Figure A 5.3-46 Case 1: Vertical Backface and Horizontal Granular Backfill

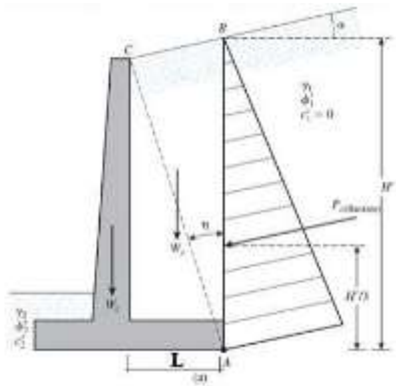


Figure A 5.3-47 Case 2: Vertical Backface and Inclined Granular Backfill

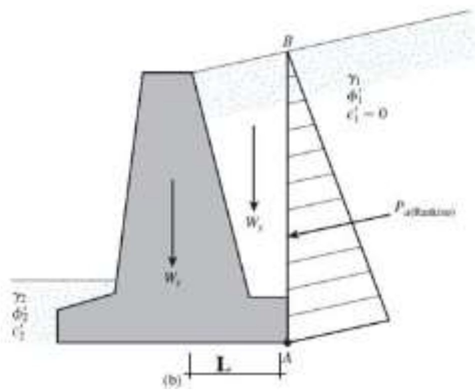


Figure A 5.3-48 Case 3: Inclined Backface and Inclined Granular Backfill

Forces opposing movement are divided into two groups:

- Forces causing wall to move
  - Weight of soil and surcharge on the backfill
- Forces opposing movement

o Frictional resistance to sliding due to the weight of the wall and passive resistance of the soil in front of the wall (typically ignored)

A6 Solid Waste Management

A6.1 SOLID WASTE COMPOSITION AND GENERATION

Table A 6.1-39 Solid Waste Sources in Hospitals

Dept.	Sharps	Infectious and Pathological Waste	Chemical, Pharmaceutical and Cytotoxic Waste	Non-Hazardous or General Waste
Medical Ward	Hypodermic needles, intravenous set needles, broken vitals, ampoules	Dressings, bandages, gauze, cotton, gloves, masks contaminated with blood or bodily fluids	Broken thermometers and blood pressure gauges, split medicines, spent disinfectants	Packaging, food scraps, paper, flowers, empty saline bottles, non-bloody diapers or intravenous tubing and bags
Operating Theatre	Needs, intravenous sets, scalpels, blades, saws	Blood and other body fluids, suction canisters, gowns, gloves, masks, gauze and other waste contaminated with blood, bodily fluids, tissue, etc.	Spent disinfectants, Waste anesthetic gases	Packaging, uncontaminated gowns, gloves, masks, hats and shoe covers
Laboratory	Needles, broken glass, Petri dishes, slides, cover slips, broken pipettes	Blood and body fluids, microbiological cultures, stocks, tissue, infected animal carcasses, tubes and containers contaminated with bloody and body fluids	Fixatives, solvents, broken lab thermometers	Packaging, paper, plastic containers
Pharmacy Store			Expired drugs, split drugs	Packaging, paper, plastic containers
Radiology			Silver, fixing and developing solutions, acetic acid	Packaging, paper
Chemotherapy	Needles, syringes		Bulk chemotherapeutic waste, vials, gloves, other material contaminated with cytotoxic agents, excreta and/or urine	Packaging, paper
Vaccinations	Needles and syringes		Bulk vaccine waste, vials, gloves	Packaging

Dept.	Sharps	Infectious and Pathological Waste	Chemical, Pharmaceutical and Cytotoxic Waste	Non-Hazardous or General Waste
Environmental Services	Broken glass		Disinfectants, cleaners, split mercury, pesticide	Packaging, flowers, newspapers, magazines, cardboard, plastic and glass containers, yard and plant waste
Engineering			Cleaning solvents, oils, lubricants, thinners, asbestos, broken mercury devices, batteries	Packaging, construction/demolition waste, wood, metal
Food Services				Food scraps, plastic, metal/glass containers, packaging
Physicians' Offices	Needles and syringes, broken ampoules and vials	Cotton, gauze, dressings, gloves, masks, other materials contaminate with blood/body fluids	Broken thermometers, blood pressure gauges, expired drugs, spent disinfectants	Packaging, office paper, newspapers, magazines, uncontaminated gloves and masks
Dental Offices	Needles and syringes, broken ampoules	Cotton, gauze, gloves, masks and other materials contaminated with blood/body fluids	Dental amalgam, spent disinfectants	Packaging, office paper, newspapers, magazines, uncontaminated gloves and masks
Home health care	Lancets and insulin injection needles	Bandages and other material contaminated with blood or other body fluids	Broken thermometers	Domestic waste

Table A 6.1-40 Average Waste Generation Rates

	Type of Health-Care Facility	Total Waste Generation (kg/patient-day)	Infectious Waste Generation (kg/patient-day)
Pakistan	Hospital	1.28-3.47 (2.07 typ.)	
	Clinics and Dispensary	0.075	0.06
	Basic Health Unit	0.04	0.03
	Consulting Clinics	0.025	0.002
	Nursing Homes	0.3	
	Maternity Homes	4.1	2.9
Tanzania	Hospitals	0.14	0.08
	Health Centers (urban)	0.01	0.007
	Rural Dispensaries	0.04	0.02
	Urban Dispensaries	0.02	0.01
South Africa	National Central Hospitals		1.24
	Provincial Tertiary Hospitals		1.53
	Regional Hospitals		1.05
	District Hospital		0.65
	Specialized Hospital		0.17
	Public Clinic		0.008
	Public Community Health Centre		0.024
	Private day-surgery Clinic		0.39
	Private Community Health Centre		0.07
Tibet	Household Wastes	0.25	
	Commercial Sources	2.36	
	Office Sources	0.21	
	Weekly Veg. Markets	0.3	
	Schools & Institutions	0.1	

[1] From four hospital and other facilities in Karachi; Peseod et Saw (1998).

[2] Data based on survey of facilities in Dar es Salaam; Christen (1996).

[3] Data from a survey of 13 hospitals and 39 clinics in Gauteng and Kwa Zulu Natal; clinics have no beds and may not be open all week; community health centers have up to 30 beds and operate 7 days per week; DEAT (2006).

[4] Data from *Studying Municipal Solid Waste Generation and Composition in the Urban Areas of Bhutan,* Phuntsho, Herat, Shon, Vigneswaran, Dulal, Yangden, Tenzin, 2009.

Source: WHO, 2014 pg. 18.

Table A 6.1-41 Bulk Densities of Solid Waste by Component

	Component	Density (kg/m^3)
Canada	Human Anatomical	800-1200
	Plastics	80-2300
	Swabs, absorbents	80-1000
	Alcohol, disinfectants	800-1000
	Animal infected anatomical	500-1300
	Glass	2800-3600
	Bedding, shavings, paper, fecal matter	320-730
	Gauze, pads, swabs, garments, paper, cellulose	80-1000
	Plastics, polyvinyl chloride (PVC), syringes	80-2300
	Sharps, needles	7200-8000
	Fluid, residuals	990-1010
Ecuador	General wastes	596
	Kitchen wastes	322
	Yard wastes	126
	Paper/cardboard	65
	Plastic/rubber	85
	Textiles	120
	Sharps	429
	Food wastes	580
	Medicines	959
General	Food wastes	290
	Paper	89
	Cardboard	50
	Plastics	65
	Textiles	65
	Rubber	130
	Leather	160
	Yard wastes	100
	Wood	237
	Glass	195
	Tin cans	89
	Aluminum	160
	Other metals	320
	Dirt, ashes, etc.	480
	Ashes	745
	Rubbish	130

Source: WHO, 2014 pg. 18

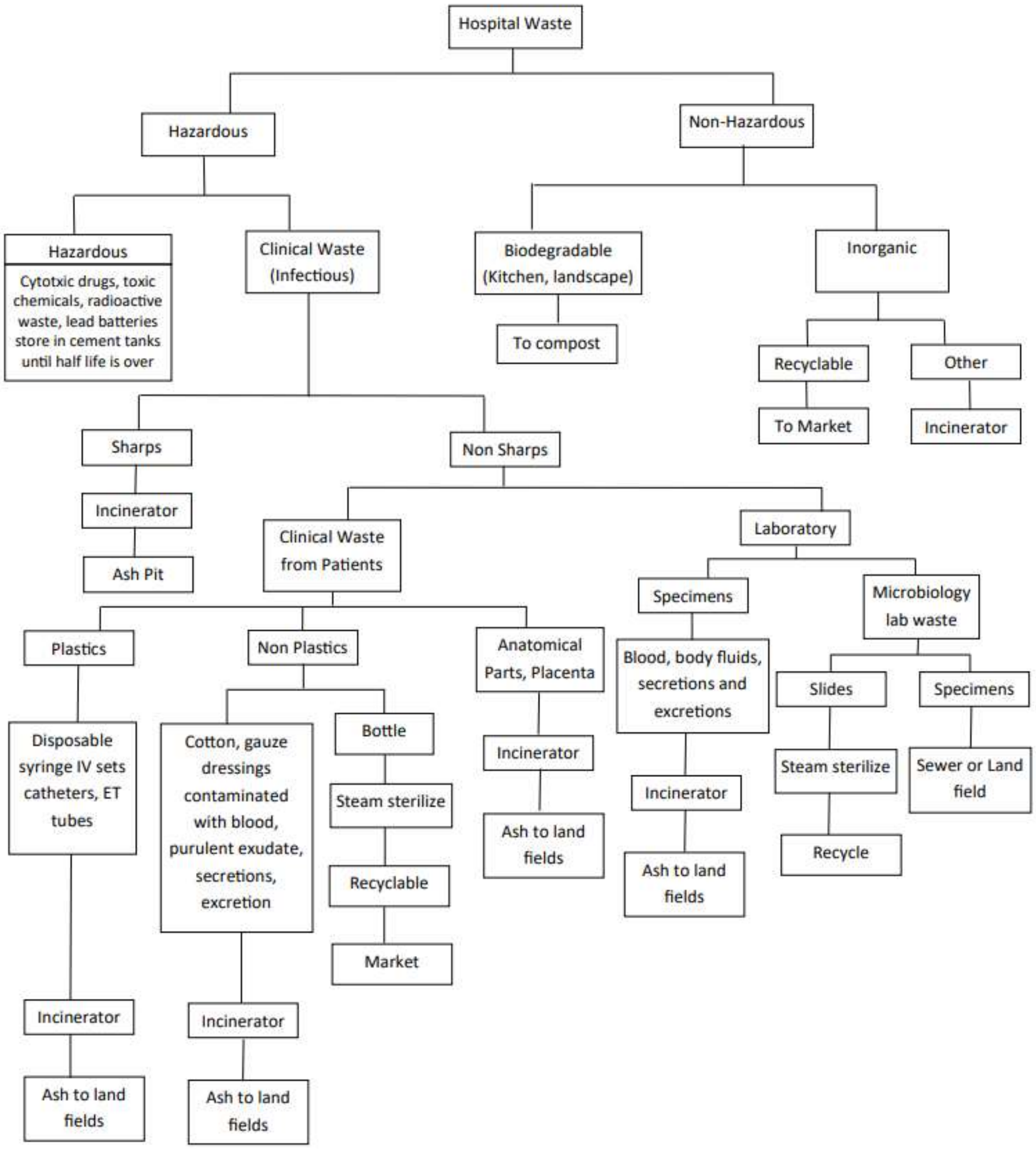


Figure A 6.1-49 Example Waste Segregation Flowchart

Source: US-0720 Tenwek Project

A6.2 SOLID WASTE DISPOSAL

A6.2.1 SOLID WASTE DISPOSAL MINIMUM REQUIREMENTS

1. Reduce waste and segregate to minimize the amount of waste requiring treatment
2. Choose a treatment process that achieves at least the minimum required disinfection level
   a. Treatment can be done on the premises or at a centralized treatment facility.
   b. Use appropriate technology when treating waste based on characteristics, technology capacity and requirements, environment and safety factors, and cost.
3. Dispose of waste safely

In extreme circumstances, where no treatment is possible, hazardous healthcare waste from small facilities can be buried on the premises where public access can be restricted. Larger healthcare facilities should arrange with local landfills to provide a special area and restricted access.

A7 Region Specific Guidelines

Regional specific guidelines are available for the following EMI office locations. They are available within the EMI Civil Design Guide File Structure in the ***Region Specific Guidelines*** subfolder.

A7.1 UGANDA REGIONAL GUIDELINES

PDF

A7.2 INDIA REGIONAL GUIDELINES

PDF

A7.3 MENA REGIONAL GUIDELINES

PDF

Reference

R2 WATER

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