Options for Sustainable Urban Drainage Strategies in Informal Settlements

This document is an adaptation of the guidebook created by a student group of Worcester Polytechnic Institute's Cape Town Project Centre while working with the informal settlement community of Langrug. The following contains a collection of viable urban drainage techniques that are viable for informal communities. Each technique is described in detail and includes a cost analysis, material list, and brief implementation instruction

Primary Authors: Lauren Harris, Andrea Kates, Timothy Momose, Christopher Overton

Secondary Authors: Kaylyn Button, Elisabeth Jeyaraj, Rodrigo Ma, Edwin Muniz

Editors: Macauley Kenney, Scott Jiusto

WPI

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Introduction

This document is meant to describe several ad hoc urban drainage strategies that could be applicable in informal settlements. Each informal settlement has its own set of greywater/stormwater issues and its topography, material availability, and funding. Thus, not every intervention described below is applicable to all informal settlements.

A large portion of the technical information and ideas for this chapter have been adapted from the *Urban Small Sites Best Management Practice Manual* developed for the Twin Cities Metro Council by Barr Engineering Company(Barr Engineering Company, 2001), and from a stormwater management manual developed by four WPI students as part of a 2010 IQP on adapting Sustainable Urban Drainage Systems for informal settlements(Button, Jeyaraj, Ma, & Muniz, 2010).

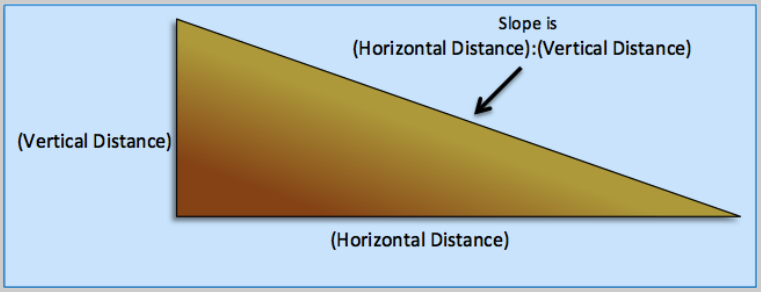


Figure 1: How to determine slope

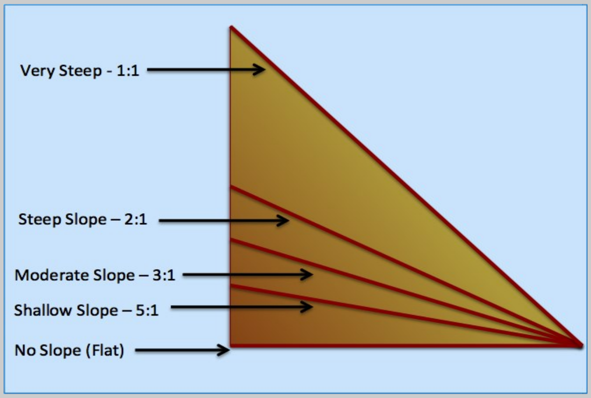


Figure 2: Comparison of different slopes

Notes on Cost

The costs of the different materials required for building these interventions will vary based on region and availability of materials. Costs can be extremely low if materials may be acquired readily from areas near the settlement. Keeping track of costs for other interventions will give further insight into the affordability of different options.

Notes on Slope

Some of the management systems discussed in this document have specifications regarding slopes. The notation used to depict slope shows the ratio of the horizontal distance along a hillside to the vertical distance. For example, if the slope is 3:1 (horizontal : vertical), then the slope is at such a steepness that if you walked up the slope far enough that you went 3 metres horizontally, you would have moved 1 metre up. Figure 1 shows various slopes defined according to the terminology introduced here. It can be used to estimate what the slope at a given location is.

1. Basins

Basins are designed to hold a large volume of water over an extended period of time in order to remove pollutants. Most basins are designed to remove major contaminants that include the following:

1. Sediment
2. Chemicals such as phosphorus and nitrogen (from waste or soaps)
3. Disease-causing bacteria

These contaminants are removed through a combination of methods.

- Sediment is removed through settling in the calm water
- Many chemicals are removed by plants growing in the basins
- Microbes growing in the basin can reduce levels of harmful bacteria

An additional benefit of basins is that they can store large volumes of stormwater, so that the stormwater systems downstream of the basin are not overwhelmed during heavy rains. The processes whereby basins remove pollutants from the water may not be fast enough to remove contaminants before standing greywater develops dangerous levels of bacteria. The basins described below were designed to deal with mildly contaminated stormwater, but not greywater, or greywater-contaminated stormwater.

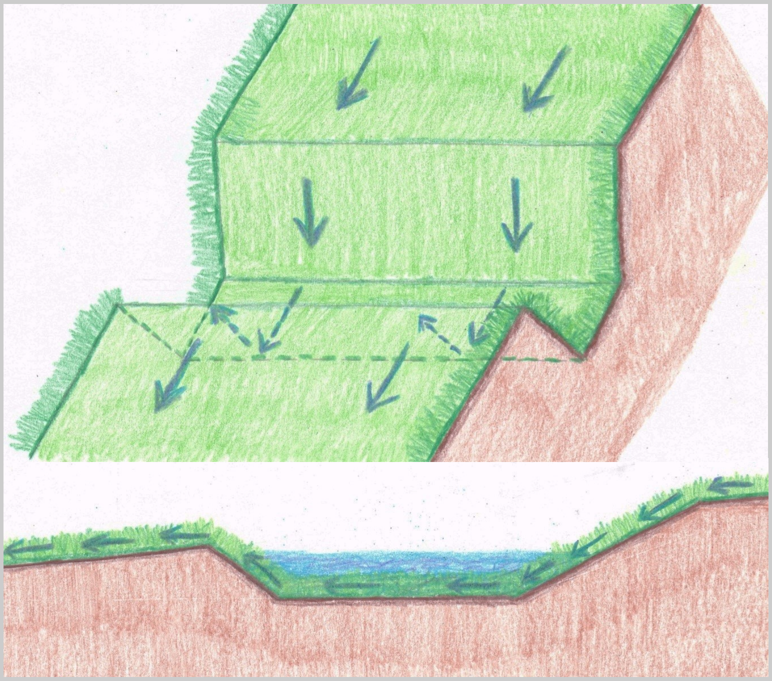


Figure 3: Wet swale, shown in three dimensions (top) and as a cross-section from the side (bottom)

1-1. Wet Swales

Description

Wet swales reduce runoff volume and flow by storing the water and using vegetation for infiltration. A wet swale is a shallow, vegetation-lined channel that runs across the slope so that it cuts off the water flowing down the slope.

Ideal Location

Wet swales need an open strip area of land that is:

1. ***Along a slope:*** The wet swale is designed to catch water that is running down a slope, so it requires an area where there is open land that cuts across the slope. The slope should be moderate – not too steep, or the wet swale will be hard to dig and unable to hold much water.

2. ***Able to support vegetation:*** The wet swale depends on grass to help to infiltrate and partially filter the water, so the land where it is made must be able to support vegetation. Sometimes, it may be necessary to fertilize the ground or use mulch for this purpose.

Wet swales are not good for flat areas or areas with steep slopes. Also, it can be hard to encourage proper plant growth in overly gravelly or sandy soil. Infiltration will be insufficient if the ground is overly packed or high in clay content and has difficulty draining, thus causing the swale to fail.

Pros:

✓ Reduces runoff

✓ Promotes infiltration

✓ Removes pollutants

✓ Inexpensive

✓ Creates biological habitats

Cons:

× Erosion in common when area floods

× Medium area requirement

How to Implement

1. Dig the swale

Dig the swale so that the bottom width is between 0.6 and 2.4 metres, the depth is between 0.15 and 0.5 metres, and the side slopes are no greater than 3:1 (horizontal:vertical).

Materials and Tools

1.Spades

2.Grass

a. Transplanted from in the settlement

b. Planted as seeds

c. Placed as sod

3. Mulch (optional)

2. Plant vegetation

The best approach for minimum erosion and best filtration is to plant grass so it will grow to completely cover the bottom of the swale and the ground leading to and from the swale.

Cost Considerations

If plants are available for transplant from within the settlement and spades can be obtained from community organizations or participating community members, this intervention can be implemented at a relatively low monetary cost. If mulch is necessary for plant growth (it may be necessary if the ground is infertile), the cost will be low to moderate.

Figure 4: A wet swale filled with rainwater (River Engineering and Urban Drainage Research Centre)

Maintenance

·Inspect swale once or twice per week in the first few months for erosion and to ensure vegetation growth

·Remove trash and excess sediment found in the swale as necessary in order to prevent clogging

·It may also be necessary to cut the grass if it grows long enough to inhibit the flow of water

1-2. Stormwater Wetlands

Description

A wetland is a small, shallow pond surrounded by vegetation that is meant to temporarily store and remove pollutants in water before it reaches rivers and streams. There are various types of wetland, but the one most suitable for an informal settlement is the pocket wetland. A pocket wetland is a small marsh designed to hold stormwater during and after heavy rains. The wetland gradually drains after the rain, so normally, it is not flooded. The wetland is designed to support plants that will help to remove contaminants from the water.

Figure 5: Stormwater wetland (Kuh, 2009)

Ideal Location

Wetlands are best for the following conditions:

1. ***Large area:*** Wetlands need a fairly large area so that they can hold significant amounts of water and support many different types of plants, which will remove contaminants from the water.
2. ***Adequate water flow:*** Wetlands are designed to stay mostly covered with water, or at least moist, at all times so as to support plant life such as reeds. A wetland should be made in an area with a high enough water table to keep the ground somewhat moist even in the dry season. A continuous flow of water is also good for the wetland.
3. ***Land able to support diverse plant life:*** A wetland is designed to have many different types of plants growing in it. The land where a wetland is made should therefore be able to support various plants, even during the dry season.

Pros:

- ✓ Improves water quality
- ✓ Reduces water flow
- ✓ Low maintenance frequency

Cons:

- × Maintenance is extensive
- × Large land requirement
- × High implementation costs
- × Difficult to implement

How to Implement

1. Dig the basin

First, the basin for the wetland must be dug out. To keep the soil moist and allow vegetation to grow even during dry periods, the wetland should be dug down about to the natural groundwater level. The basin should cover around 4000 square metres or more – the wetland should be made with such a size that it deals with runoff from an area around 100 times its own area.

Materials and Tools

1. Spades
2. Picks
3. Plants – especially reeds and other water plants
4. Rocks
5. Mulch (optional)

The wetland should have a deep pool (around 1-2 metres deep) at its inlet to remove excessive sediment from incoming water and prevent sedimentation in the main wetland area.

2. Lay Rocks

To prevent erosion, lay rocks at the inlet and outlet of the wetland.

2. Plant vegetation in the wetland

Once the basin has been dug out, various plants can be planted in it. Species such as arum lilies, bulrushes, and reeds are suggested for the Cape Town area (Button, Jeyaraj, Ma, & Muniz, 2010) and might also be applicable for Langrug. Specific native species will vary depending on the location of the informal settlement, and the local native species should generally be used for constructed wetlands. Mulch can be used on the embankments to promote more plant growth.

Cost Considerations

Tools may be obtained from community members or community organisations, and plants and rocks can often be gathered from within the settlement. Plants should mostly be water plants, which can be gathered from the ponds and rivers in and around the settlement. Since these main materials and tools may be obtained with minimal cost, building a wetland can be quite cheap. Labour, however, will generally be substantial, due to the extensive digging required and careful maintenance of plants is important in the initial stages. Mulch may add a moderate cost if used in large amounts, so building a wetland on infertile soil may be more costly.

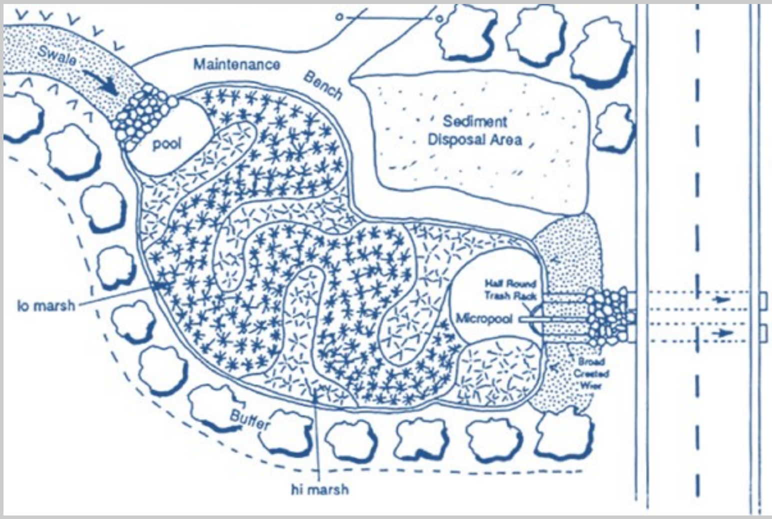


Figure 6: A top-view diagram of a pocket wetland (Barr Engineering Company, 2001)

Maintenance

Pocket wetlands, when compared to other wetlands, require maintenance regularly. The pool at the wetland inlet should be cleaned of sediment at least every two years, and the wetland itself should be monitored to ensure that the vegetation is doing well. It may be necessary to replant vegetation periodically, depending on species and wetland conditions.

1-3. Oversized Pipes

Description

An oversized pipe is a large pipe inserted into a smaller pipeline in order to reduce water flow by providing temporary storage of water runoff during heavy rains.

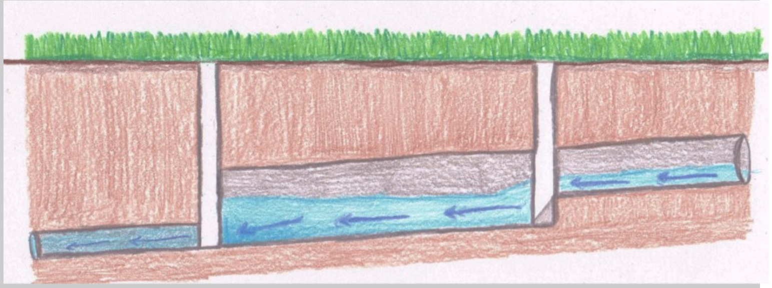


Figure 7: Oversized pipes

Ideal Location

Oversized pipes are usually used underground so as to minimize the amount of land area taken up, so ideal conditions include:

1. ***Areas with pipelines:*** Where there are already pipelines, an oversized pipe can easily be installed at one section for storage of excess rainwater.
2. ***Small slope:*** Oversized pipes are meant to temporarily store water, which can be done most effectively when the water does not flow through too quickly.
3. ***Easy to access:*** Over time, the oversized pipe can become filled with sediment, or even trash. Therefore, building this system so it is easy to access for maintenance and cleaning is helpful. Some ideas to expedite cleaning include:
    a. Bury the oversized pipe shallow.
    b. Use markers to clearly indicate the location of the oversized pipe.
    c. Bury the oversized pipe with attachments that will allow it to be lifted out easily.

Oversized pipes should not usually be installed on steep slopes or under structures that would limit access for maintenance.

Pros:

- ✓ Reduces runoff flows
- ✓ Can be used in small areas

Cons:

- × No water quality treatment
- × High material costs
- × Must be located in a place that can be easily accessed for maintenance
- × Slower water flow in the large pipe means it is easy for sedimentation to occurs

How to Implement

1. Dig a trench for the pipes

Dig a trench large enough that the pipes can be placed underground. Make sure that the pipes are placed on a shallow slope to ensure that the pipes can completely drain over time.

2. Place pipes in the ground

Place the pipes such that:

a. The medium sized pipe should be at the start of the system where the water will enter

b. The oversized pipe should be placed next

c. And finally the smallest pipe, restricting the outflow of the water

Materials and Tools

1. Spades
2. Picks
3. Large pipe
4. Rocks
5. Cement

Use the rocks and cement to create seals that can be placed over each and of the large pipe where it connects to the smaller pipes. The seals should prevent any sand from entering the large pipe through the gaps between it and the smaller pipes. Do not connect the cement onto the large pipe because the large pipe may need to be removed occasionally for cleaning.

3. Cover the pipes

Finally, bury the pipes, leaving some kind of marker to indicate where the largest pipe is, so it can be accessed later for maintenance.

*One variation on this method is to insert an oversized area into a channel. This area must be sloped, as the rest of the channel is sloped, so as to keep water flowing. However, it will be wider than other sections to slow water down and allow some water to be stored during heavy rains. The outlet of the wide section should be narrow to restrict flow. The further downhill the intervention is, the larger the wide section should be, since it will receive more water (See Figure 7).

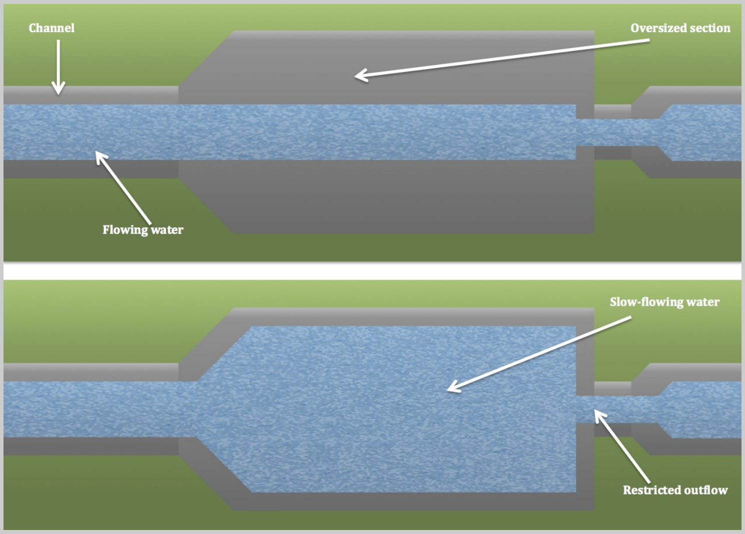


Figure 8: Oversized channel section with low waterflow (top), and high flow (bottom)

Cost Considerations

This is a high-cost implementation because the pipes and cement must be purchased. It also takes a fairly large amount of labour to install the pipes.

The oversized channel form is low-cost, since the channel simply involves the cost of material for the additional width of a short section of wide channel.

Maintenance

- Access points should be established at the ends of the oversized pipe as well as other intermediate locations (approximately every 30 metres)
- Sediment removal should be by mechanical means if possible
    - If flushing is the only option, take preventative measures so that the sediment is trapped and removed before moving further down the stream

2. Channels

Greywater and stormwater channels are designed to direct the water flow down a slope to a point where it will be gathered for treatment or for transportation to an offsite treatment centre. The simplest channels are trenches dug into the ground, following the downward slope. However, most permanent channels should be designed with protection to prevent erosion from the channel sides, so as to maximize channel life and reduce sedimentation downstream (see Strategies against Soil Erosion and Sedimentation page 40).

Figure 9: Grey water flowing down an informal stream in Langrug

To avoid flooding, channels should be built to be able to carry runoff water even from the most severe rain. Channels nearer to the bottom of the slope will need to carry more water than upstream channels, which receive runoff from a smaller area. The size of channel must take into account the amount of land area that drains into the channel. Stormwater and greywater stream mapping can provide valuable insight into the amount of runoff that a given channel will receive.

2-1. Vegetated Channel (Artificial Swale)

Description

A vegetated channel is a long, narrow trench lined with vegetation (usually short grass). The trench is situated so as to channel water down the hillside. A vegetated channel is typically dish shaped; around 25-50 centimetres deep and 1-2 metres wide.(Button, Jeyaraj, Ma, & Muniz, 2010)

Ideal Location

Vegetated channels are best when the following conditions are present:

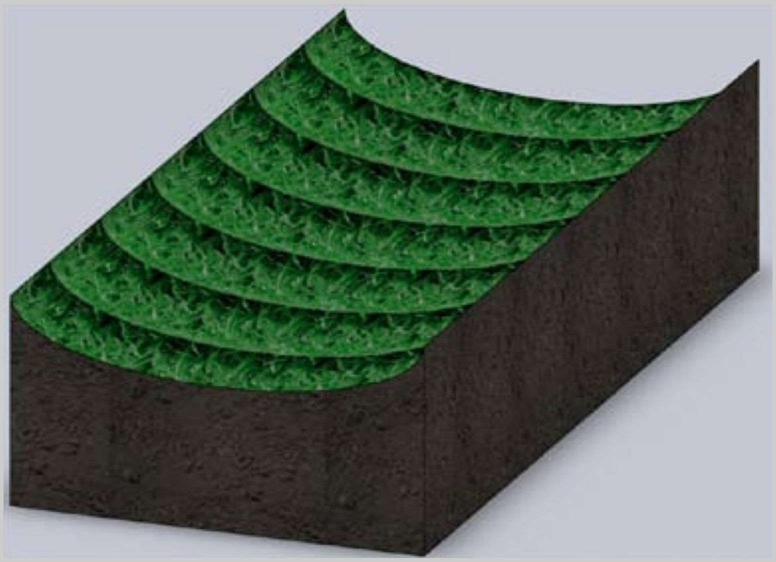


Figure 10: Computer-generated image of an artificial swale (Button, Jeyaraj, Ma, & Muniz, 2010)

·***Moderate slope:*** To ensure that water can be successfully directed down the channel without pooling, the vegetated channel must be constructed on a slope. Building the channel along a pre-existing stormwater gully ensures that the channel does indeed follow the natural slope. The slope should be steep enough that water can flow steadily through the channel, but it must not be too steep, as a steep slope will make it difficult for the swale to capture water.

·***Fertile soil with few rocks:*** Because the vegetated channel relies on plants to hold the channel's shape and prevent erosion, the channel should be built in ground that can support healthy plant growth. Vegetatation usually prefers fertile soil that is not excessively rocky. However, it will be possible to find grasses that can thrive in most soil conditions encountered in the settlement.

Pros:

- ✓ Low cost
- ✓ Easy to obtain vegetation around the settlement
- ✓ Easy to maintain
- ✓ Grass fosters good bacteria in its root system, helping to break down waste products in the grey water and reduce contamination and smells.
- ✓ Self-regenerating/repairing

Cons:

- × Takes time for grass to spead and take root
- × Require regular maintenance until grass is established
- × Some types of grass maybe aggressive and require regular trimming
- × May be difficult to implement at certain times of the year, when grass does not grow quickly
- × Not well known by community– may be difficult to gain support from the community

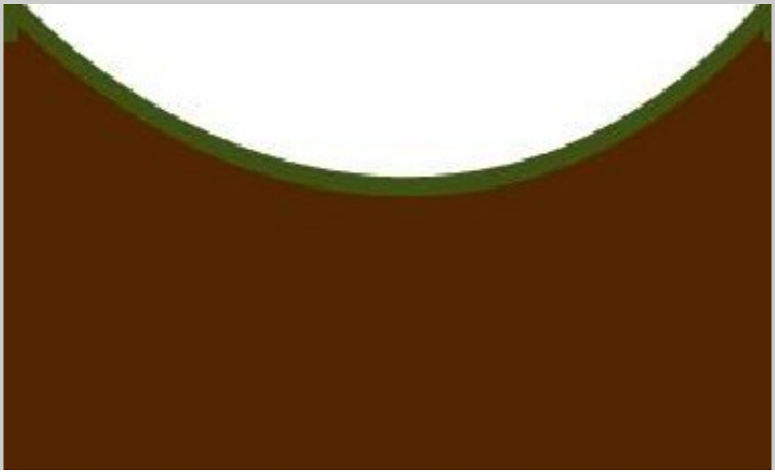
From these conditions, we determine that a vegetated channel is best suited to hillsides – especially along existing stormwater gullies

How to Implement

1.Dig the channel

First, the channel must be dug. Use spades, loosening the ground with picks if it is packed, rocky, or full of plastic. The channel should be around 25-50 centimetres deep at its middle, and around 1-2 metres wide. The ideal shape is dish-shaped, as seen in Figure 10. The channel must run down the slope of the hillside, and it

Figure 11: Cross-sectional view of dish-shaped vegetated channel (Button, Jeyaraj, Ma, & Muniz, 2010)



may be beneficial to follow the path of an existing stormwater gully, so as to ensure that the channel does not deviate from the mountain's natural slope.

2. Choose suitable grass species

Once the channel has been dug, a type of grass to plant in the channel should be chosen. The grass should meet the criteria for erosion-preventing vegetation. The criteria for plant decision are:

1.Dense, deep root systems

2.Preferably native species, already growing well in the settlement

3.Preferably not an overly aggressive, invasive species (to reduce maintenance requirement and minimize possibility of property damage)

In addition to these criteria, the plant must also be able to thrive even when in contact with the contaminants contained in grey water.

3. Plant vegetation

The grass must be planted along the sides and bottom of the channel. The planting can be done either by seeding or by transplanting.

Transplanting involves moving the grass, including root systems, from one place where it was naturally growing, to the channel, where it is meant to be planted. Another kind of transplanting is sodding, which takes squares of sod (grass in a thin mat of dirt) and lays them over the ground. Sod is usually obtained from a retailer.

The second option for planting is seeding. This involves spreading grass seeds over the ground. Seeding is not usually a good option for vegetated channels because the seeds are easily washed away by water flow before they have taken root. For this reason, a newly seeded channel cannot be used for a few days or weeks after it has been seeded.

Cost Considerations

If transplanted grass is used, these channels can be made easily at no cost, assuming sufficient grass is available in the settlement for transplanting and tools can be borrowed from community members or organisations.

Materials and Tools

1. Grass or grass seeds

2. Spades

3. Picks if ground is especially hard or rocky

4. Fertilizer or mulch (if grass requires more fertile soil than the available soil)

Maintenance

Until the grass takes root firmly and becomes established in the soil, the transplants or seeds should be watered regularly - the ground should be kept relatively moist. Inspect the grass at least once a week to ensure that it is growing properly. Reseeding or additional transplanting may be necessary if the grass is not growing well.

After the grass has matured or established itself, it should be trimmed if it grows beyond the desired area. Most native grass species will not require regular watering beyond what is naturally received via rainfall. It may be necessary to occasionally remove trash that becomes caught in the grass.

To ensure that the channel continues to properly transport water without slowing it down too much or causing pooling, it may be necessary to trim the grass from time to time. If the grass becomes too tall, it can catch the water and cause pooling in parts of the channel that have mild slope.

2-2. Stone & Cement Channel

Description

The stone and cement channel is a basic channel that is lined with stones and held together by cement. The cement is meant to provide a smooth surface over which water can flow without pooling.

Figure 12: A stone and cement channel implemented in Langrug, South Africa

Ideal Location

Stone and cement channels are best for locations with:

1. ***Moderate slope:*** The slope will keep water flowing and prevent pooling, even if rocks are causing the channel to not be completely smooth.
2. ***Existing greywater / stormwater channels:*** Building along existing stormwater gully ensures that the channel does indeed follow the natural slope.

Pros:

- ✓ Stone is readily available and can be gathered from around the settlement
- ✓ Can be adapted to available materials
- ✓ Well known by community-readily accepted

Cons:

- × High cost of cement
- × Hard to repair if cement cracks
- × Can get pooling if built as a rock channel without cement, or if rock and cement are not laid down properly

How to Implement

1. Dig channel

First, dig a channel. Use spades and picks to loosen and remove soil. The channel must be large enough to deal with the waterflow expected during the most severe rainstorms experienced in the wintertime. To minimize the risk of erosion from the channel sides, do not make the sides overly steep. Avoid having sharp drops in the banks along the channel so there will not be collapsing. Dig the channel so that it goes down the natural slope of the mountain. Be careful to dig with a constant downward slope so as to prevent pooling in the finished channel

Materials and Tools

1. Spades
2. Picks
3. Stone
4. Sand
5. Cement
6. Wheelbarrow
7. Trowel
8. Brush

2. Lay stones

Next, line the channel with stones. This reduces the amount of cement required for the channel while also forming a solid base for the channel. Larger stones (up to about 30cm in diameter) should be applied along the sides of the channel to firmly hold the walls in place and prevent erosion and collapse. Smaller stones (up to about 15cm in diameter) should be used along the channel bottom to ensure that the base is smooth for minimal pooling.

3. Cement

When the stones are in place, cement must be put between and over them. The process of preparing the cement is as follows:

1. *Mix sand and cement powder*

   Use spades and rakes to mix fine sand with the cement powder. The ratio of sand to cement should be in the area of 2:1 or 3:1 (horizontal:verticle). Using the greater amount of cement will tend to yield a stronger cement, but at a higher cost.

2. *Add water*

   Once the cement powder and sand have been mixed, gather the mixture into a pile and create a bowl-like indentation in the center. Add water and mix in, gradually adding the water until the consistency of the cement is like damp sand.

The mixed cement must then be put into the channel, fitting in the gaps between the stones. Smooth it using the trowel. There must not be indentations or large bumps in the channel that could lead to pooling. Once the cement has been added and smoothed, brush it down using a wet brush to further smooth the cement.

Cost Considerations

Stone and cement channels are a moderate-cost intervention because of the need to buy cement and sand. Other materials and tools can usually be obtained within the settlement. If a pure stone channel is made, cement will not be needed, so cost will be significantly lower.

Example of rock and cement implementation

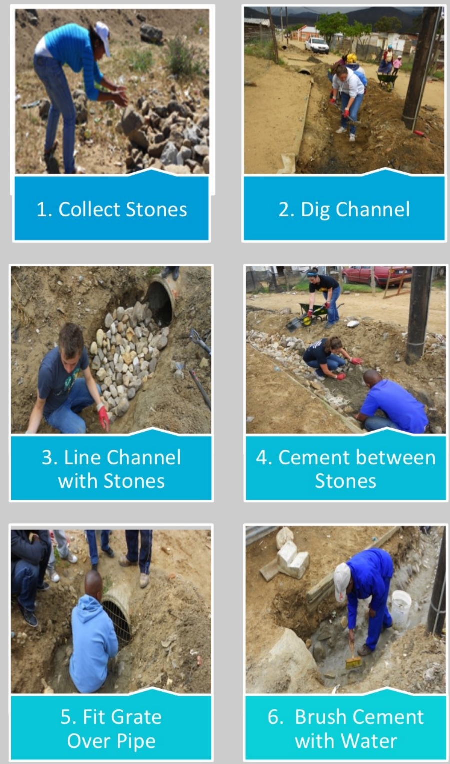


Figure 13: The building process used to implement a stone and cement channel in J-section, Langrug

Maintenance

Rock and cement channel maintenance will mainly involve removal of trash and sediment. Over time, any bumps or indentations in the channel will begin to fill with sediment, and sedimentation will occur naturally over the bottom of the channel. Additionally, trash will accumulate in the open channel, whether because people throw it directly into the channel or because it is blown in by wind or carried by water. The sediment and trash must be removed periodically to prevent pooling and blockages. The community must be involved with this cleaning and maintenance, as discussed in the Maintenance section of this guidebook (page 47). If the channel involves pipes, it will be helpful to place grates over both ends of the pipes to prevent trash from being washed or blown into the pipe from either end of the pipe.

Variations on the Stone and Cement Channel

The stone and cement channel can be adapted to make various types of channels by using or not using certain components. These variations are:

- ***Stone-lined channel:*** If funding or materials are not available, the channel may be made using only the stone lining. The result is a very quick, cheap alternative approach to making a greywater channel. This method comes with the risk of pooling between the rocks. To limit pooling, small gravel can be put in the gaps.

- ***Cement channel:*** For maximum smoothness, a channel can be made only out of cement. For such a channel, the cost will be relatively high due to the larger amount of cement required. If properly smoothed out, the cement can pass water very effectively, allowing the channel to operate with minimal pooling.

- ***Concrete channel:*** Channels where cement is mixed with gravel can provide a smooth surface, while also allowing the same amount of cement powder to cover a larger area.

3. Infiltration

Infiltration systems are used to encourage water to sink into the ground. They are often used to help store more water underground, reducing stormwater runoff to minimize the strain on drainage systems. When used solely for moving water underground, infiltration systems are most useful in areas with soils such as sand or loam that are highly permeable.

Infiltration is also applicable for various basic filtration systems. Filters are useful for improving the quality of greywater on-site. They can remove various contaminants from the greywater, reducing many of the problems caused by greywater, most significantly, smell and disease. Many modern filter options involve complicated membranes and machines, but the methods described below are simpler filters suited for implementation in informal settlements by informal settlement communities. These filters rely on natural materials including sand, rocks, and plants to remove contaminants from greywater. The filters described here are designed to encourage water to infiltrate into the ground, where layers of rocks and sand can work together with remove various contaminants.

3-1. Infiltration Trenches

Description

An infiltration trench is a shallow rock-filled trench designed to encourage water to sink through the rocks into the ground. It sometimes uses a buried perforated pipe to channel some or all of the infiltrated water to another area. Various sizes of rocks are used in layers to filter out some of the contaminants from the water as it infiltrates.

Figure 14: Rock-filled trench that encourages water to sink into the soil (Infiltration Trenches, 2007)

Ideal Location

If the infiltration trench is meant to merely let water sink down into the ground and stay there, it must be implemented in an area that allows for good infiltration of water. Some requirements include:

- ***Permeable soil:*** If the water is to effectively soak into the ground through the rocks, the ground must be made up of permeable soil (soil that is loose and allows water to pass through easily). This means that loose, sandy soils are ideal (as opposed to clays and compacted soils)

- ***Low water table:*** Infiltration will not occur if the ground is already saturated with water.

- ***Low amount of sediment in runoff:*** As the water infiltrates through the bed of rocks, it can deposit sediment that it is carrying. Over time, this sediment can clog the trench, so infiltration trenches should be implemented together with erosion prevention or sediment removal interventions.

If the infiltration trench will use a perforated pipe to remove the infiltrated water from the area, the requirements are the same, except that the soil no longer needs to be especially permeable, since the infiltrated water no longer needs to be stored in the ground. For the perforated pipe to effectively channel water, the trench must be implemented in ground with a slight slope.

Infiltration trenches can thus be implemented in areas such as:

- In loose soil at the bottoms of hills (to reduce runoff load)
- As part of a road, to carry runoff (using a perforated pipe)

Pros:

✓ Doesn't "waste" space because it's part of the ground

✓ Reduces runoff volume by moving water flow underground– aw a result, flooding is reduced

✓ Can remove sediment, some chemicals, and bacteria from stormwater

Cons:

× Can have clogging issues if runoff contains large amounts of sediment

× Can contaminate groundwater if polluted water infiltrates

× Can be hard to get enough rocks for a long trench

× Hard to maintain/clean

How to Implement

1. Dig the trench

Use the spades and picks to dig a trench around 1-2 metres deep and about 1 metre wide. If used for draining via a perforated pipe, the trench must be dug so as to follow a downward slope and must extend as far as an outlet from the pipe to a stormwater drain or channel. If the trench is meant to infiltrate stormwater into the groundwater, it can be placed perpendicular to the water flow along or at the bottom of the slope. The length of the trench can vary depending on the amount of runoff expected and the amount of space available.

2. Place the pipe (optional)

Once the channel has been dug, the perforated pipe can be put in. It must be laid so as to have a constant slope to keep water flowing through it.

3. Fill the trench with the rocks

Fill the trench until the rocks are about level with the surrounding ground. The lowest layer will be made up of the large rocks. If a pipe is to be placed in the trench, the large rocks should be layered at least up to the top of the pipe. The second layer is gravel, and the third is pebbles.

The pebbles serve to remove any trash or large objects from the water. The layers of larger rocks remove other contaminants.

Materials and Tools

1. Spades
2. Picks
3. Rocks
4. Perforated pipe (optional)

4. Implement sediment-reducing measures (recommended)

To prevent clogging of the channel by sediment, it is helpful to incorporate sediment removal/ erosion prevention interventions around the trench. One method that could be applicable is 4-2. Filter Strips on page 31.

Cost Considerations

Spades and picks have already been purchased for other projects, and many community members may be able to provide tools as well, so the cost of tools should be minimal. Rocks could be gathered around the settlement, but small rocks and pebbles such as those required for the trench may be difficult to gather in large amounts. For this reason, it may be necessary to purchase the gravel from an outside source. This could be a large cost if the trench is to be very long. The perforated pipe could be purchased or could be made by putting small holes in the upper half of a pipe, along its length.

Maintenance

Infiltration trenches are susceptible to clogging by sediment. When they become clogged, the trenches do not allow infiltration to occur as quickly as they are designed to, which can lead to an increase in runoff volume. To restore the infiltration trench's functionality, the sediment must be removed. This requires removal of the rock together with the sediment, followed by replacing the rock to the trench.

3-2. Soakaways

Description

A soakaway is a ditch in the ground that is filled with rocks and then covered with vegetation. The purpose of a soakaway is to allow runoff water to soak into the ground, after being filtered through the rocks and vegetation, and then redirected to a larger body of water.

Ideal Location

No specific area size necessary, but the soil should be able to support vegetation.

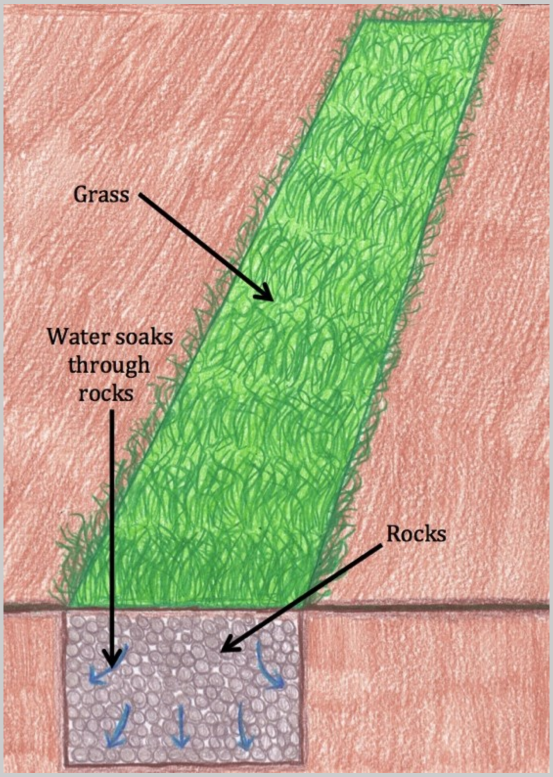


Figure 15: Soakaway illustration

How to Implement

1. Dig the ditch

Dig a ditch approximately 1 metre deep, 1.5 metres wide, and 4 to 6 metres long

2. Fill the ditch with stones

Fill the ditch with stones, until the stones are about level with the surrounding ground.

3. Plant vegetation

Plant grass over the ditch.

Pros:

✓ Filters water

✓ Encourages nutrient absorption

✓ Generally inexpensive

✓ Low maintenance

Cons:

× May not be effective if flooding occurs

× Vegetation must be managed

* One way that this could be implemented in many informal settlements would be to use the soakaway as a filtration point at the beginning of a greywater channel. Community members could dump their greywater on the soakaway grass strip, so the water could filter through the soakaway and emerge into the channel as cleaner water. This could reduce some of the issues associated with greywater.

Materials and Tools

1. Spades
2. Stones
3. Vegetation

Cost Considerations

If grass is transplanted from other areas of the informal settlement, this intervention can be implemented for little or no cost, since all materials and tools can come from within the settlement.

Maintenance

Soakaways require minor maintenance on a regular basis to control grass growth and prevent clogging.

- Vegetation must be controlled and cut on an as needed basis
- Removal of excess sediment or trash will be necessary to prevent blockages

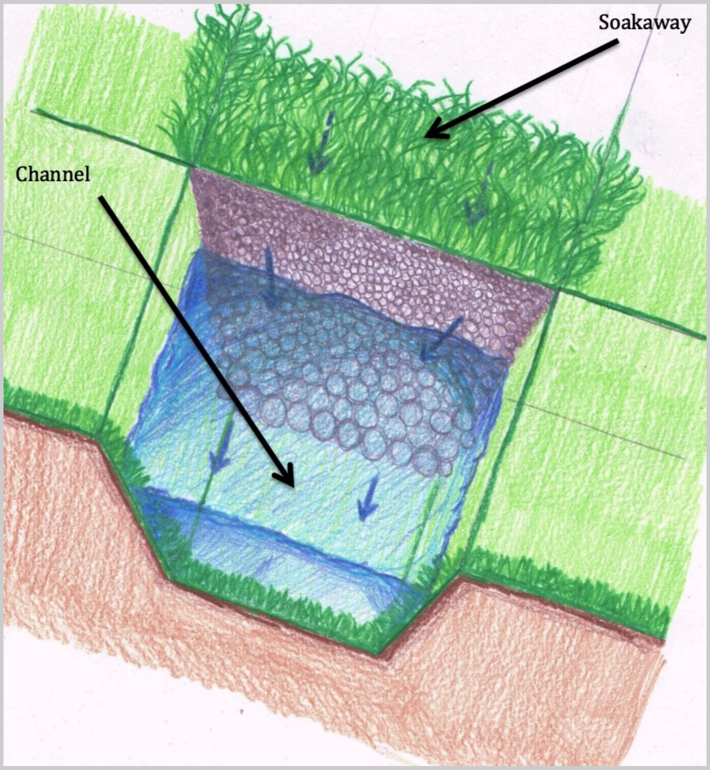


Figure 16: A soakaway used as a greywater filter at the

4. Combination

Some greywater and stormwater interventions use a combination of methods to move or treat water. The methods listed here use combinations of channeling, infiltration, and storage to deal with stormwater and greywater. When two or more types of intervention are required, these combined solutions can sometimes yield good results at a smaller total required area.

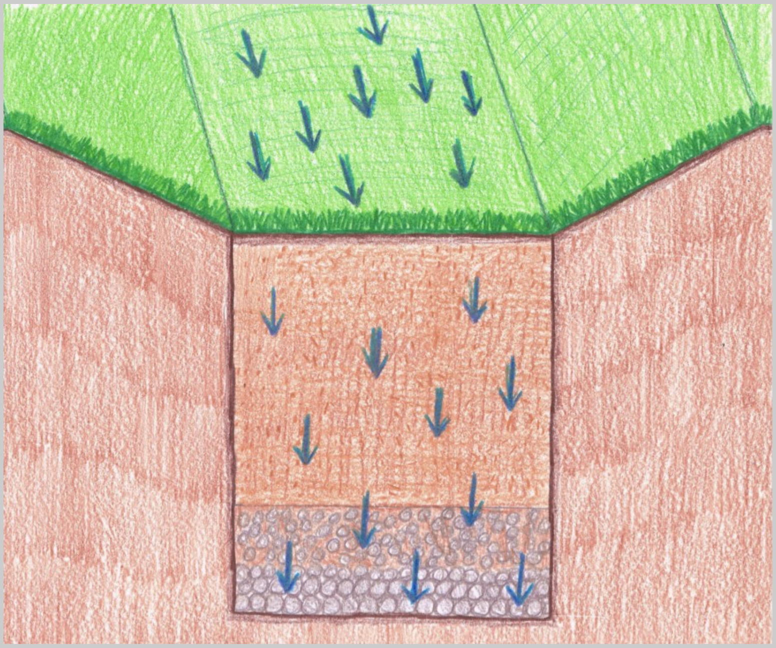


Figure 17: Dry swale with arrows showing water flow through channel and infiltration into ground

4-1. Dry Swales

Description

A dry swale is a vegetation-lined channel built over a filtering bed made up of layered rocks. It removes pollutants from runoff water as well as carrying excess water downstream and causing some of the water to soak into the ground. If the slope is steep, checkdams can be installed to temporarily pool the water, which provides more time for pollutants and sediment to settle and for water to infiltrate into the ground.

Ideal Location

Dry swales can be applied for areas that have:

1. **Shallow slope**: In order for water to properly flow through the dry swale, it must be build running down a slope. The slope should not be overly steep because the water must move somewhat slowly if it is to soak into the ground.
2. ***Soil that can support vegetation:*** Since a dry swale depends on grass to hold the channel walls in place and to filter out pollutants, the ground where it is made must support vegetation.
3. ***Permeable soil:*** The soil around the dry swale must be able to absorb the water that seep in through the rocks. Soil full of clay or highly compacted soil is not desirable.

Pros:

✓ Traps and filters sediment and other pollutants

✓ Reduces runoff flow speed

✓ Prevents erosion

✓ Inexpensive

Cons:

× Does not reduce bacteria levels in water

× Not effective with steep slopes

× High maintenance

How to Implement

1. Dig the channel

Dig the channel that will be covered with grass when the dry swale is complete. Make the channel with its banks sloped at a slope of about 2:1. The channel should be about 30 centimetres deep at the middle, and the flat base should be about 0.5-1 metre wide.

Materials and Tools

1. Spades
2. Stones and gravel
3. Grass or grass seeds
4. Wooden beam for checkdam (optional)

2. Dig the trench

Dig a trench that will contain the layered rocks. It should be around 50 centimetres deep beyond the base of the channel dug in step 1.

3. Lay rocks in the trench

The trench should be filled with rocks in the following order with the bottom two layers approximately the same thickness and the top layer about half the thickness of either of the other two. For a 50 centimetre deep trench, the layers and their thickness would be:

a. Bottom layer – Gravel – 20 centimetres thick

b. Middle layer – Soil/gravel mix – 20 centimetres thick

c. Top layer – Soil/sand mix – 10 centimetres thick

4. Plant grass

Once the filtering layers are in place, plant vegetation within the swale.

5. Build checkdams (optional)

If substantial infiltration is desired, checkdams can be built in the dry swale. A checkdam is a small structure built across the channel so as to cause water to slow down and pool. The pooled water will soak into the ground more effectively. To build:

1. Create a pile/ layer of rocks across the swale
2. Place a wooden beam on top of the rocks to break up the channel and insert the ends of the wood into the channel walls to hold it in place.

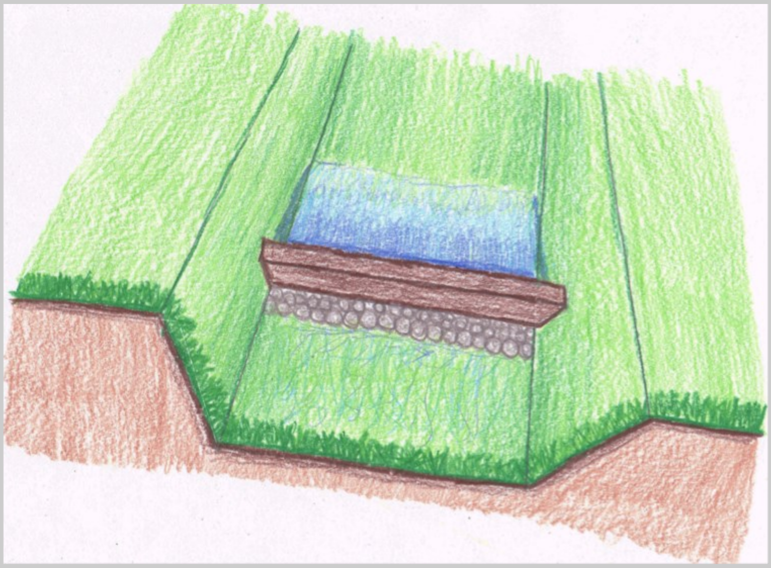


Figure 18: Stone and wood checkdam

Cost Considerations

Dry swales can be built at low cost if the necessary grass is available around the settlement for transplanting. Wood for checkdams may need to be purchased.

Maintenance

- Inspect swale once or twice per week in the first few months for erosion and to ensure vegetation growth
- Remove trash and excess sediment found in the swale as necessary in order to prevent clogging (also examine the checkdam)

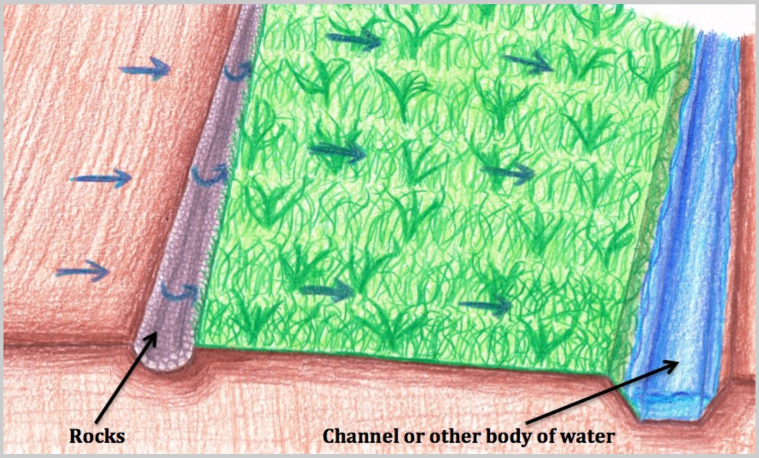


Figure 19: A grass filter strip with waterflow indicated by blue arrows

- Grass must be cut to a height of 0.1 metres, especially in the first year

4-2. Filter Strips

Description

A filter strip is a vegetated strip of shallow-sloped land that slows runoff water while also trapping sediment and other pollutants as well as providing some infiltration.

Pros:

✓ Helps remove sediment and pollutants from runoff

✓ They are simple and inexpensive to install

✓ Low maintenance

Cons:

× Difficult to maintain sheet flow

× Need a lot of space

Materials and Tools

1. Rakes
2. Grass or grass seeds
3. rocks
4. much or fertilizer (optional)

Ideal Location

Filter strips are most applicable for areas that have:

1. ***Large area:*** Filter strips use shallow water flow spread over a wide area. The slope on which the filter strip is I mplemented should be at least 4 metres across.
2. ***Shallow, uniform slope:*** For water to flow slowly over the filter strip without pooling, a constant but shallow slope is needed.
3. ***Soil that supports vegetation:*** Since filter strips de pend on grass for filtration, choose an area with fertile soil that can support plenty of grass, or use fertilizer.

How to Implement

1. Loosen the topsoil

Use the rakes to loosen the top layer of soil along the slope. If necessary, make the slope more uniform as well.

2. Lay rocks along the top of the slope

To slow the water flowing onto the filter strip and prevent too much sand from flowing onto it, put rocks along the top of the hill at the start of the filter strip.

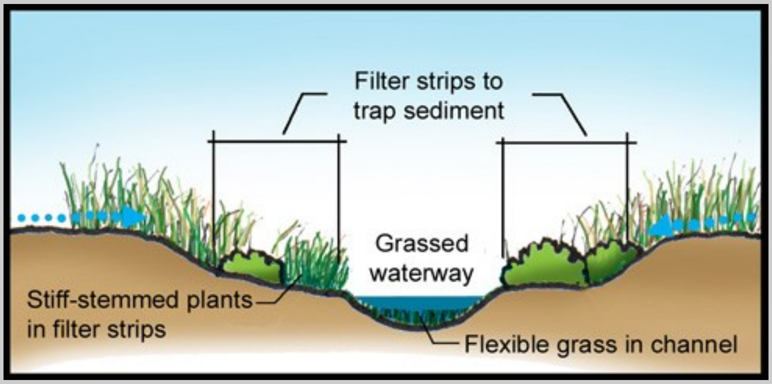


Figure 20: A setup for filter strips along a vegetated channel (2-1) (National Agroforestry Center)

3. Plant grass

Either transplant grass to the slope or spread grass seeds over it. Lay down mulch or fertilize the ground if the soil is not fertile enough to support the grass growth.

Cost Considerations

If the soil does not need to be fertilized or mulched, all materials and tools can be obtained from within the settlement at little to no cost.

Maintenance

The filter strip should be checked at least once a week to monitor vegetation growth. Transplanted grass may also need to be watered to encourage it to spread. Ideally, divert water away from the filter strip until vegetation is established. Every month or so, check the filter strip for sedimentation and trash and clean as necessary.

4-3. Sand Filters

Description

A sand filter is a stormwater and greywater management intervention that causes water to infiltrate through sand in order to filter out fine sediment particles and various chemicals, as well as some bacteria. It is made up of a pretreatment basin (5-1 Sediment Basins page 36, or 4-2. Filter Strips page 28) to remove large sediment particles

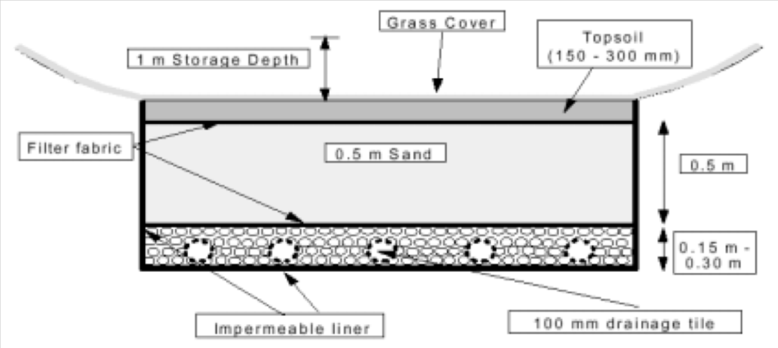


Figure 21: Cross-sectional diagram of a sand filter (Barr Engineering Company, 2001)

from the incoming water, as well as a sand-filled basin that filters the water after large sediment has been removed.

Sand filters are designed to hold water in a pool after large rain events, draining over the course of no more than 24 hours.

Pros:

- ✓ Can be applied in a variety of situations
- ✓ Requires little space
- ✓ Very effective at removing fine sediment, with some capability for removing chemicals and bacteria as well
- ✓ Relatively simple to install

Cons:

- × Pretreatment basin required ahead of filter to prevent clogging
- × Requires maintenance, especially when filtering a large amount of runoff
- × Relatively expensive to build if higher quality sand must be purchased
- × Hard to use effectively where there is a lot of sediment in the incoming water

Ideal Location

Sand filters have few limitations on where they can be installed, and they can even be used in areas with:

- Steep slopes
- Small area

Ideally, sand filters should not be used to service runoff from very large areas. Aim to apply one sand filter to deal with runoff from around 20,000 square metres of upstream watershed land. With this in mind, sand filters may be most applicable partway down the slope in the settlement, where they can serve to remove some contaminants from the water before it reaches the lower parts of the settlement. This will help to reduce health risks. Building the sand filter midway on the slope rather than at the bottom will also ensure that the filter is not overwhelmed by dealing with too much runoff, since only the part of the slope upstream from the implementation site will drain through the sand filter.

Materials and Tools

1. Spades
2. Picks
3. Clay or liner which will not let water pass
4. Fine sand
5. Stone or gravel
6. Geotextile or fine shadechloth
7. Perforated pipes
8. Grass (optional)

Figure 22: A formal sand filter with rocks over

How to Implement

1. Dig the sand filter basin and pretreatment basin.

The basin must be dug using the spades and picks. It should be about 1-1.5 metres deep. A trench must also be extended from the base of the filter for installation of drainage pipes leading out from the filter. The sand filter should be around 2 square metres in area. The banks surrounding the filter should be sloped down to the basin at a slop of up to 3:1 and laid so that 50 centimetres or more of water can temporarily pool over the filter.

A settling basin should also be dug ahead of the sand filter. This basin should be around 1-2 metres deep to allow proper settling of sand from the incoming water. Use implementation instructions as described on page 36, 5-1 Sediment Basins.

2. Line the basin

The basin must be lined with a plastic lining or with a layer of clay to reduce leakage of water into the surrounding ground. The clay should be around 30 centimetres thick, and should cover the base and walls of the sand filter basin.

3. Lay pipes and gravel

Next, lay the outlet pipes and surround them with gravel to a depth of about 30 centimetres. The pipes must be perforated pipes, and should be of a material that will not crack under the pressure of the rock and sand above the pipes. Once the pipe are in place so as to drain into a downstream channel, cover the part of the pipes in the trench leading out of the filtration basin and line the wall of the relayed ground with clay, as in step 2.

4. Lay the sand

Lay the geotextile or fine-holed shade cloth over the gravel before laying the sand in the filter, up to about 20 centimetres below the upper edge of the filter basin. Do not pack the sand. It must be loose to properly pass water through.

5. Cover with rocks

Cover the sand with rocks and gravel to prevent incoming water from washing the sand away as it enters the basin.

6. Plant grass (optional)

In some cases, it may be beneficial to plant grass over the filter, or at the very least, along the banks around the basin, to improve filtration and prevent erosion

Cost Considerations

If fine sand can be obtained from in the settlement, this intervention can be implement for a rather low cost, with all materials except for the gravel and pipes (possibly the geotextile/shadecloth as well) being obtained from in the settlement.

Figure 23: A clogged greywater channel in Langrug, South Africa

Maintenance

Sand filters require regular maintenance for proper operation. They should be inspected a couple times in the first few months after installation and at least after every major storm during that period. After the first few months, inspect at least twice a year to ensure that the filter is operating and draining properly without long-term pooling.

Trash and surface sediment must be removed from the filter surface and the pretreatment basin regularly to prevent clogging.

5. Strategies against Soil Erosion and Sedimentation

Figure 24: Bank erosion along a greywater channel in Langrug, South Africa

A major threat to the effective operation of greywater and stormwater management systems is the buildup of sand and silt - known as sedimentation. This leads to reduced capacity for channel flow. In extreme cases, sedimentation can lead to complete blockage of a channel or pipe, causing overflow and flooding. Even mild sedimentation can lead to problems with pooling. Figure 22 shows a greywater channel clogged with sand to the point that water cannot flow through. At the time that this picture was taken, the pooled water ahead of the pipe had begun to give off a strong odour, and was probably contaminated with bacteria.

The process by which wind or water removes sand from the ground and carries it away is known as erosion. This sand can come from all over the settlement, settling in various channels around the settlement. Rainwater erodes sand from exposed ground throughout the settlement and carries it downstream into channels. Wind can erode sand from the unpaved roads and yards near a channel and deposit it in the channel.

In addition to causing gradual sedimentation in channels, erosion can lead channel walls to suddenly collapse into the channel, quickly causing pooling or clogging. This problem usually occurs when heavy rainfall results in large amounts of runoff water flowing into the channel over its banks. As the water erodes sand from the sides of the channel, it can weaken the banks to the point that they cave in, filling the channel with sand. Figure 23 shows a channel whose banks have collapsed on a small scale, leading to significant sedimentation in the channel, the banks have eroded away in the circled areas, and preventative measures will be required to keep the banks from collapsing further in the future

Ideal Location

Sediment traps are best used in the following conditions:

- ***Directly before a pipe:*** Because sediment traps are designed to remove sediment from the flow, they are most useful for preventing sedimentation from occurring in places that are hard to clean, such as pipes. Putting a sediment trap right before a pipe can keep the pipe from becoming clogged with silt and sand, reducing the need for cleaning.

Pros:

✓ Helps prevent sedimentation in pipes

✓ Easy to construct

Cons:

× Medium space requirement

× Involves pooling-cannot be used with raw greywater streams

× Requires regular cleaning, especially after heavy rain

× Cost of cement

× Labor-intensive implementation

- ***Clean water streams:*** Because they inherently involve pooling, sediment traps are not the ideal option for dirty grey water streams, unless if there is a steady flow of relatively high volume, such that the pooled water is constantly being replaced and pushed out of the pool. To prevent the growth of bacteria in the pooled water, the incoming water must be clean of food particles and grease before it comes to the sediment trap.

Materials and Tools

1. Spades
2. Picks
3. Rocks

Cement (for gully pot)

Based on these conditions, we see that locations where mulch is a viable option include the following:

- At the inlet to a stormwater drain (e.g., the drains by the relocated shacks in Langrug's J-section) *if* the stream can be controlled so as to be clean enough that pooling is safe.
- At the inlet to a drain or pipe in a seasonal stormwater stream *not* used for greywater.

Figure 25: A typical sedimentation basin (left) and gully pot (right) (St. Mary's Soil Conservation District, 2011) (CPM Group Ltd.)

How to Implement

1. Dig the basin

First, dig out the basin using the picks and spades. A basin will be about a metre deep and 10 metres square. Because this takes a large amount of space, it may be more feasible in informal settlements to construct a simplified gully pot type basin, as shown on the next page

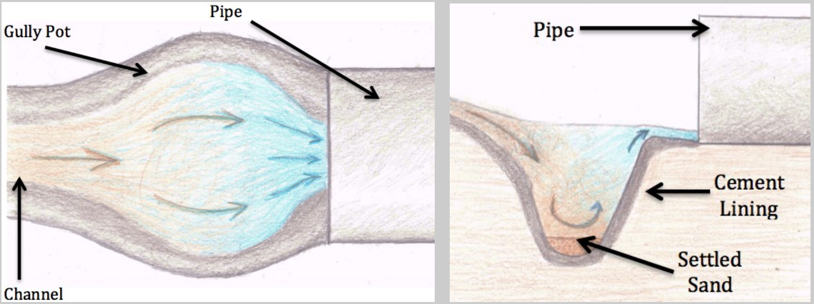


Figure 26: Simplified gully pot design from top (left) and side (cross-section) (right)

The simplified gully pot will first require that a round hole about 1-1.5 metres deep and 1 metre in diameter be dug about 30 centimetres ahead of the pipe. The sides of the hole should be sloped very steeply (around 60-90 degrees). The hole should have an outlet channel leading to the pipe and an inlet channel that starts narrow and widens up to the diameter of the hole as it enters. The inlet channel should empty into the hole at a depth of about 30 centimetres and the outlet should begin at a depth of about 20 centimetres (Figure 25).

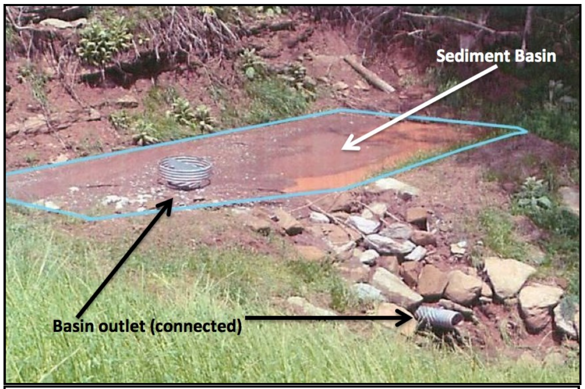


Figure 27: A sediment basin filled with sediment. Basins must be cleaned out before they reach this level of sedimentation (The Charleston Gazette, 2010)

2. Line with rocks

If making a sediment basin (pond type), optionally line it with rocks. To make a gully pot, line with rocks and cement. Try to make cement as smooth as possible so sediment can be removed from the pot easily using spades.

Cost Considerations

This is a low to moderate cost intervention, since it requires cement. Small gully pots can be implemented using a limited amount of cement.

Maintenance

Inspect at least once a month to monitor sediment deposits. Remove sediment when basin or gully pot is 1/3 or 1/2 full. Place removed sediment where it will not re-erode back into the basin.

Figure 28: Cement channel base extended up the channel walls to prevent erosion

Pros:

✓ Can be easily implemented along with the channel

✓ Very effective at preventing erosion

Cons:

× Requires large number of materials to build the channel

× Can be hard to retrofit

Materials and Tools

1. Same as for corresponding channel

5-2 Channel Base Extension

Description

This intervention involves extending the channel base (rocks, cement, or vegetation) along the sides of the channel so as to cover the sand and prevent it from eroding into the channel. The result will be vegetative stabilization if the original channel is vegetated, or a rock/cement retaining wall lying over the channel walls, if the original channel was a rock/cement channel.

Ideal Location

Channel base extension can generally be applied wherever the corresponding channel can be applied. It is, however, necessary to consider foot traffic and vehicle traffic along the channel. The extended base must be strong enough to withstand the traffic. More specifically, vegetation used must be able to survive the trampling, or cement must be strong enough to resist cracking.

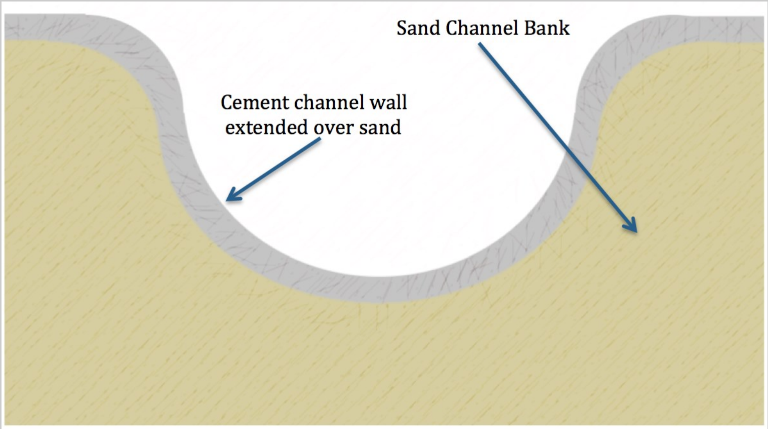


Figure 29: Cross-sectional schematic of extended channel walls

How to Implement

1. Extend channel walls

Using whatever materials were being use for the base of the channel, extend the base along the banks of the channel, covering the banks so as to prevent erosion.

Cost Considerations

Consult the costs for the type of channel to which this intervention will be applied.

Maintenance

Maintain as the corresponding channel is maintained.

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