TECHNICAL DRAWINGS - WATER INFRASTRUCTURE DESIGN FOR FLOOD MANAGEMENT

The tendency of the climate change analysis that has been carried out in the project, indicates an increase in annual monthly precipitation in Mtendeli and Nduta. Trends for Nyarugusu show more variability. The precipitation intensity (hourly rainfall rate) is increasing significantly in all three locations in all months in the analysis. Temperature is predicted to increase and lead to extreme events and increased occurence of heat waves. This leads to more runoff and increased risk of erosion. The risk and severity of floods also increases, and calls for improved stormwater management.

More unpredictable rainfall patterns combined with increased temperatures, and in turn evaporation, will increase the risk of drought for communities at risk in the region. Developing systems for rainwater harvesting can mitigate this risk, and using rainwater and runoff for agriculture and livestock will increase the resilience of these communities.

Overall, the suggested measures are developed with the objective of increasing water availability in the refugee camps and increasing the water use efficiency. Furthermore, the measures should improve flood and erosion control in the densely populated areas in Kigoma, and thereby reduce the exposure of the flood-prone ferralsol type soils with no or little vegetation cover. The measures are contributing to increased resilience of the refugee camps and associated host communities in the face of both current and future climate.

SYSTEM APPROACH AND PROPOSED INTERVENTIONS

There are different approaches to improve the situation in the areas for this study. The key to a well working system, is the interaction of the different technical installations in the catchment area. The form and aesthetic appearance of the facilities will depend on specific site characteristics, local public opinion and development design criteria.

To meet the challenges with the dry season, water can be collected and stored in ponds or dams. When water is recharged into the groundwater, the groundwater will serve as a reservoir throughout the year.

To transport water away from flood prone areas, the water can be led into micro scale stone pitched drainage channels, to transport the water away. The stones in the channel will slow the water down, prevent erosion in the bottom of the channel and might lead to groundwater recharge.

Water can be slowed down upstream in the catchment area. Weirs or stone filled gabions can be installed across the waterway. The weris or gabion installation might lead to some groundwater recharge - depending on the size of the installation. Check dams reduce the water speed, and accumulate sediments during floods. Gabions or weirs are typically installed in series along the waterway.

Rain water harvesting structures (Charco dams, water pans) are placed downstream from a catchment area, either on a natural run-off line, or at the end of a constructed channel. The installations collect water from the catchment, to be stored for later use.

The technical considerations for this drawing has to be seen as theoretical.
On site analysis or evaluation with modelling software has to be done to evaluate the catchment for the channels. Catchment size, slope and size of the river bed influence the size of the installation.

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Feasability study:
Climate resilient development in refugee camps and communities in Kigoma

INTRODUCTION

Infiltration trenches and infiltration basins are both feasible sustainable drainage systems (SuDS) that provide surface stormwater management based on infiltration to the sub-soils where the soils are of permeable characterization. Advantages include groundwater recharge and removal of suspended solids and heavy metals in the process. They are implemented in a treatment chain with other solutions, like drainage channels with weirs and stone filled gabions.

LIMITATIONS
To meet the different challenges with flooding and drought, the catchment areas must be thoroughly evaluated. In order to design the proposed stormwater management facilities, the run-off must be estimated to establish the natural drainage area characterizations, for safe design of hydraulic and flood protection structures.

Factors that should be considered when investigating specific catchment areas and the location of water infrastructure include rain intensity, size of catchment area, topography, slope, specific soil properties (permeability, stability etc.), water requirements, potential pollution sources, local stakeholders and cost/benefit of the proposed systems.

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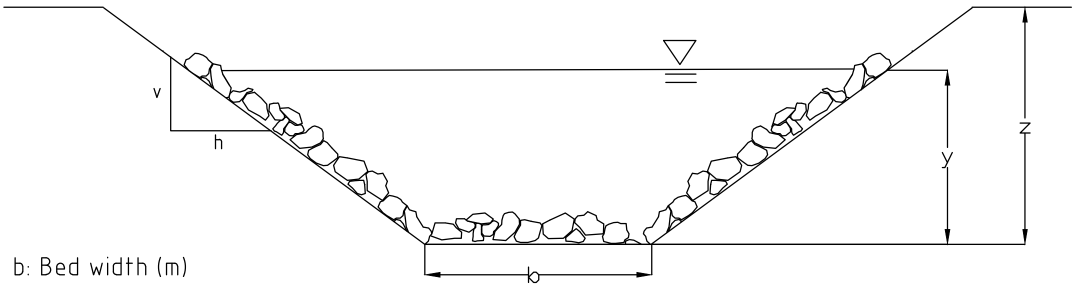
Feasability study:
Climate resilient development in refugee camps and communities in Kigoma

INTRODUCTION

TRAPEZOIDAL STONE-PITCHED DRAINAGE CHANNEL - CROSS SECTION



b: Bed width (m)
v:h: Bank slope
y:Water level at design discharge (m)
z:Channel depth (m)

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Technical drawing
STONE-PITCHED DRAINAGE CHANNEL

TRAPEZOIDAL STONE-PITCHED DRAINAGE CHANNEL - TECHNICAL SPECIFICATIONS

ABOUT

- Stone-pitched trapezoidal drainage channels are implemented for the removal of excess surface water in the rain season, where soil infiltration rates are low and the risk of flood is present.
- The drainage channel is to be constructed with a trapezoidal shaped cross section because it approximates closely natural channel sections and is easier to excavate and maintain than channels of other shapes.
- Because the banks of open drainage channels are especially sensitive to water erosion when not covered by natural vegetation, stone pitching is recommended in arid areas as a suitable soil conservation measure. The largest available stones should be used which permits pitching to be done effectively on the site. The stones used should have one large flat side, and should be of relatively equal size and angularity.
- As a result, safe discharge is ensured through erosion- and bank failure control, while sediment transport and gully formation is reduced, and stormwater flow velocities are increased.

DESIGN OF THE STRUCTURE

- A maximum channel depth (z) of 0.5 m is recommended for safety reasons.
- the vertical to horizontal side slope ratio (v:h) mainly depends on the soil type and its respective friction angle. Ferralsol soil texture typically ranges from sandy loam to clay. Steeper slopes save excavation costs and demand less land, but lead to bank failures if too steep. Table 1 summarizes recommended v:h ratios based on the dominating soil texture.
- The water depth (y) to bed width (b) ratio (y:b) should be kept within the limits of 1-2, as summarized in Table 1.
- The recommended maximum average flow velocities over the cross section in Table 1 are depending on soil texture and are stated to avoid erosion of bottom and banks. With stone pitching, the velocities can reside at the higher end of the velocities stated in Table 1.

TABLE 1: Trapezoidal stone-pitched drainage channel specifications

Soil texture	Maximum recommended channel depth (z)	Bank slope (v:h)	Bottom width to water depth ratio (b:y)	Maximum average flow velocity (m/s)
Heavy clay	0.5	1:0.75 to 1:2	1-2	0.6 to 0.8
Loam		1:1.5 to 1:2.5		0.3 to 0.6
Fine sand		1:2 to 1:3		0.15 to 0.3
Coarse sand		1:1.5 to 1:3		0.2 to 0.5

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Technical drawing
STONE-PITCHED DRAINAGE CHANNEL

TRAPEZOIDAL STONE-PITCHED DRAINAGE CHANNEL - TECHNICAL SPECIFICATIONS

OPERATION AND MAINTENANCE

- Regular surveillance is recommended, especially before and during the rain period, because they are prone to clogging due to growth of aquatic plants and silting up by sediments introduced with uncontrolled runoff.
- Periodic maintenance is needed before the rain season, by mechanical desiliting and deweeding through manual labor. Measures should be taken to avoid steepening of side slopes to prevent bank failure.

ASSUMPTIONS AND LIMITATIONS

- The final design of the drainage channels requires detailed site information (incl. catchment area, annual rainfall patterns and landscape slopes) for the assumption of appropriate run-off characteristics (e.g. floods, flow volume and seasonal variability).

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CHECK DAMS OR WEIRS

- A weir is a small dam created across a valley or river channel that alters the flow characteristics of water. It often creates a reservoir. A weir placed across the water way as a barrier, often causes the water to pool behind the structure. The weir might be like a mini percolation tank, recharging the water into the water table.
- Height of the crest of a weir rarely exceed 3m. Weirs are designed to be over topped (the water is flowing over the dam top). The sedimentation of the reservoir is a major limitation.
- Check dams or gully plugs are structures built across a drainage ditch, swale or water way. They reduce flow velocity and accumulate sediments during flood.
- They are often introduced in areas where natural or agricultural vegetation cover was lost, or not capable of holding the topsoil.

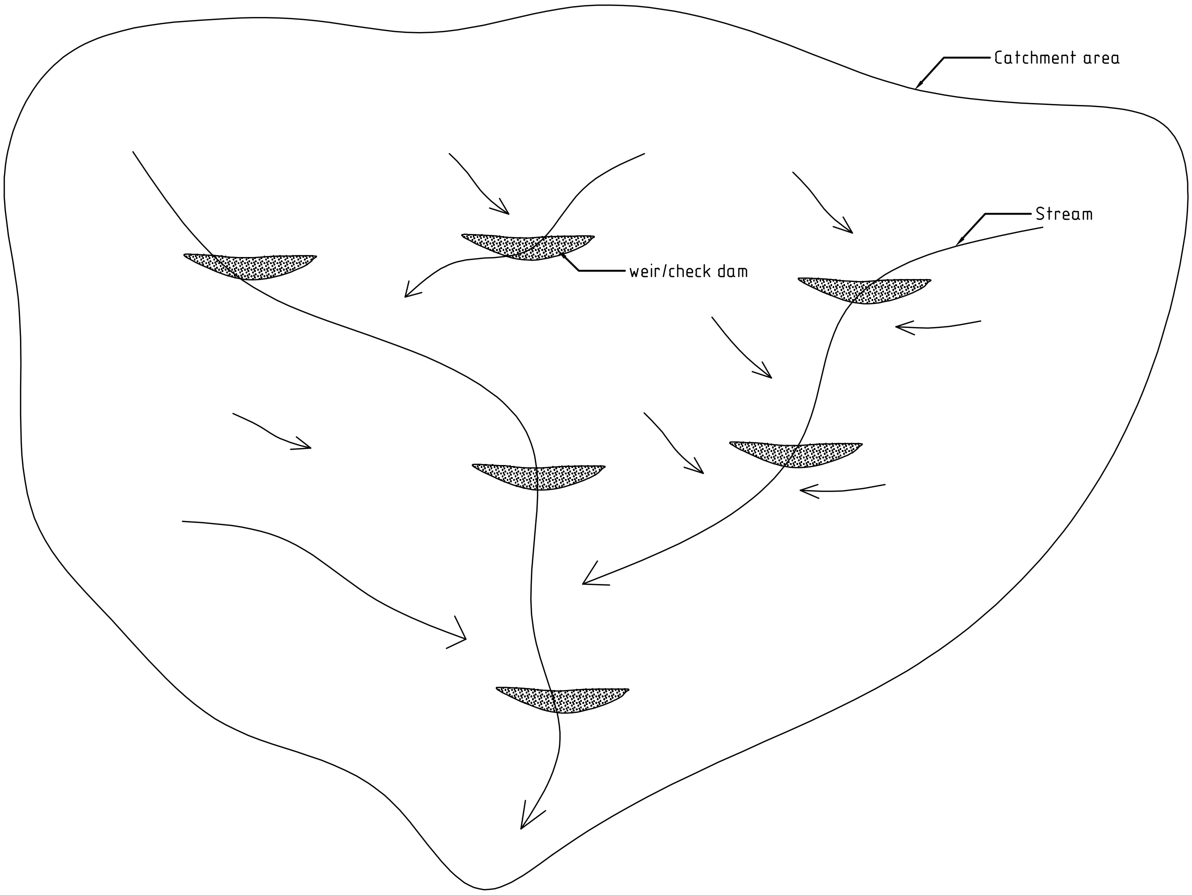

Illustration: A check dam is typically implemented as a system of several check dams in regular intervals.

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Technical drawing
CHECK DAMS, WERIS AND GABIONS

CHECK DAMS OR WEIRS

TEMPORARY vs. PERMANENT STRUCTURES

- Temporary structures are structures from small to medium size, designed to resist a few years.
- Permanent check dams are medium to large constructions, designed to last many decades and to resist massive flood events.

MATERIALS

Due to the variety of materials that can be used, this is one of the most used stabilization measures worldwide.
Check dams can be built with different materials:

- Brushwood
- Wooden posts
- Stones
- Fixing gabions
- Cement
- Piling sandbags

DESIGN OF THE STRUCTURE

- To provide stability and avoid underflow, the check dams should be firmly keyed to the bed and banks of the gully.
- The design of the structure varies from the materials used.

ASSUMPTIONS AND LIMITATIONS

Weirs and check dams are usually implemented in regular intervals. The type of weir or check dam is dependant on the materials used, the catchment size, slope and geotechnical considerations.

MAINTENANCE AND OPERATION

- Sedimentation in the reservoir is a major limitation. The sediments accumulate upstream of the weir.
- Check dams needs constant and intense maintenance.
- Improper maintenance can lead to structural damages over time.

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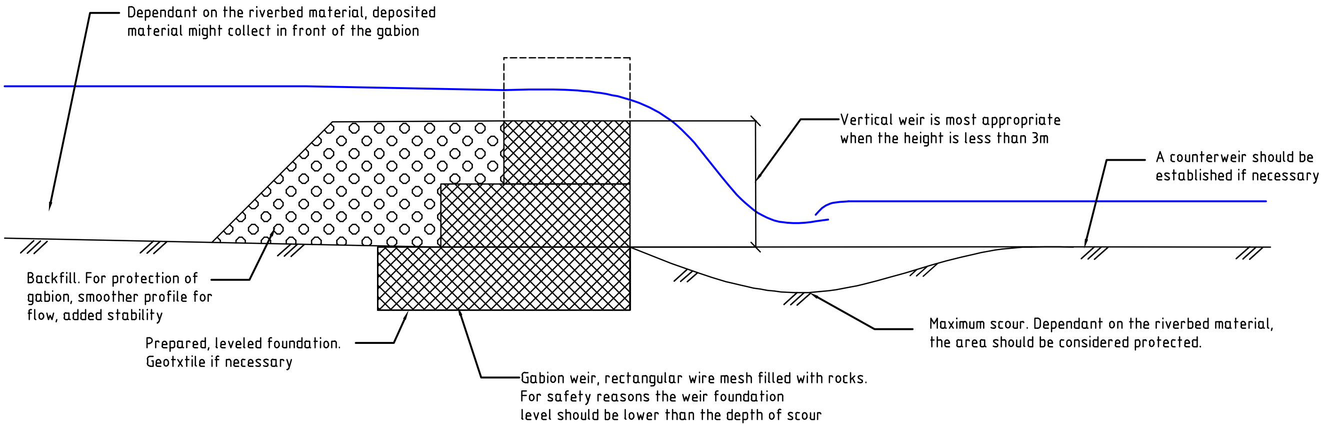
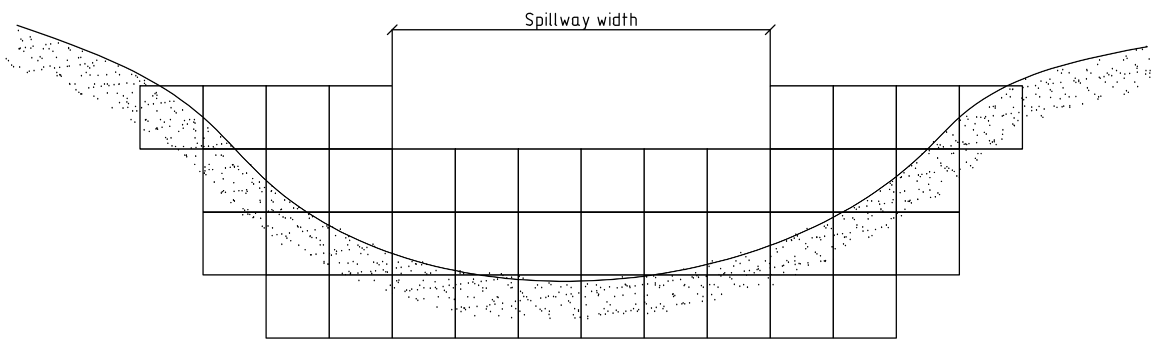
Technical drawing
CHECK DAMS, WEIRS AND GABIONS

STONE FILLED GABION
PROFILE ALONG THE RIVER

ABOUT
- Gabion weirs are structures built across the streambed for flood regulation and river training purposes.
- Gabions are built using rectangular wire mesh or wooden baskets filled with rocks.



STONE FILLED GABION
PROFILE ACROSS THE RIVER BED



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Technical drawing
CHECK DAMS, WEIRS AND GABIONS

STONE FILLED GABION
TECHNICAL SPECIFICATIONS

DESIGN OF THE STRUCTURE

- Vertical profile is most appropriate when the gabion structure is less than 3m.
- Height is limited to between 2-4m to prevent erosion damage immediately downstream. Calculations can be substituted by practical rules if the height does not exceed 3-4 meters.
- Gabion baskets should not have stones sizing less than the mesh openings. Gabion baskets can be manufactured at village level. The mesh in the gabion baskets and mattresses is double twisted.
- Construction can be placed directly on the soil - however it is preferable to avoid direct contact with the soil. The best option is geotextile weighing 500-700g/m2, an option is bags made of thin interwoven plastic strips sewn together.
- The gabion can be made impervious to keep the water level above the weir with geotextile and compact earth fill.
- The foundation needs to be leveled and prepared before the gabion is placed on the soil.

MATERIALS

Minimum materials needed to build a stone filled gabion:

- Stones (sizing larger than the mesh openings).
- Gabion baskets made of wire. Baskets can be produced locally.
- Geotextile or interwoven plastic bags (placed between the soil and gabion structure)

ASSUMPTIONS AND LIMITATIONS

- A relatively straight longitudinal stream condition should be obtained to avoid bank erosion.
- Potential of establishing a series of gabion weirs (check dams) along the stream.
- The gabion structure is less than 3m high
- The installation needs to be properly designed on a later stage regards to the local site conditions and runoff characteristics (catchment size rainfall pattern and slope, floods, flow volume, seasonal variability)
- Geotechnical assessments and calculations to prevent sliding and overturning should be done for larger structures.
- The runoff speed in the drainage channels depends to a large extent upon channel size and land slope.
- The spillway must be designed according to the calculated design flow.

MAINTENANCE AND OPERATION COST

- The most common damage is opening of the gabions. The baskets should be repaired and filled with new material when broken. It is necessary to repair the damage as soon as possible.
- A project in Haiti, funded by UNDP/UNCDF and FAO showed that damage to structures mostly happened within the first 2-3 years (Berney et al., 2001).
- Based on the project in Haiti, it was estimated that the cost of the repairs were about 10-12% of the initial total cost (Berney et al., 2001).

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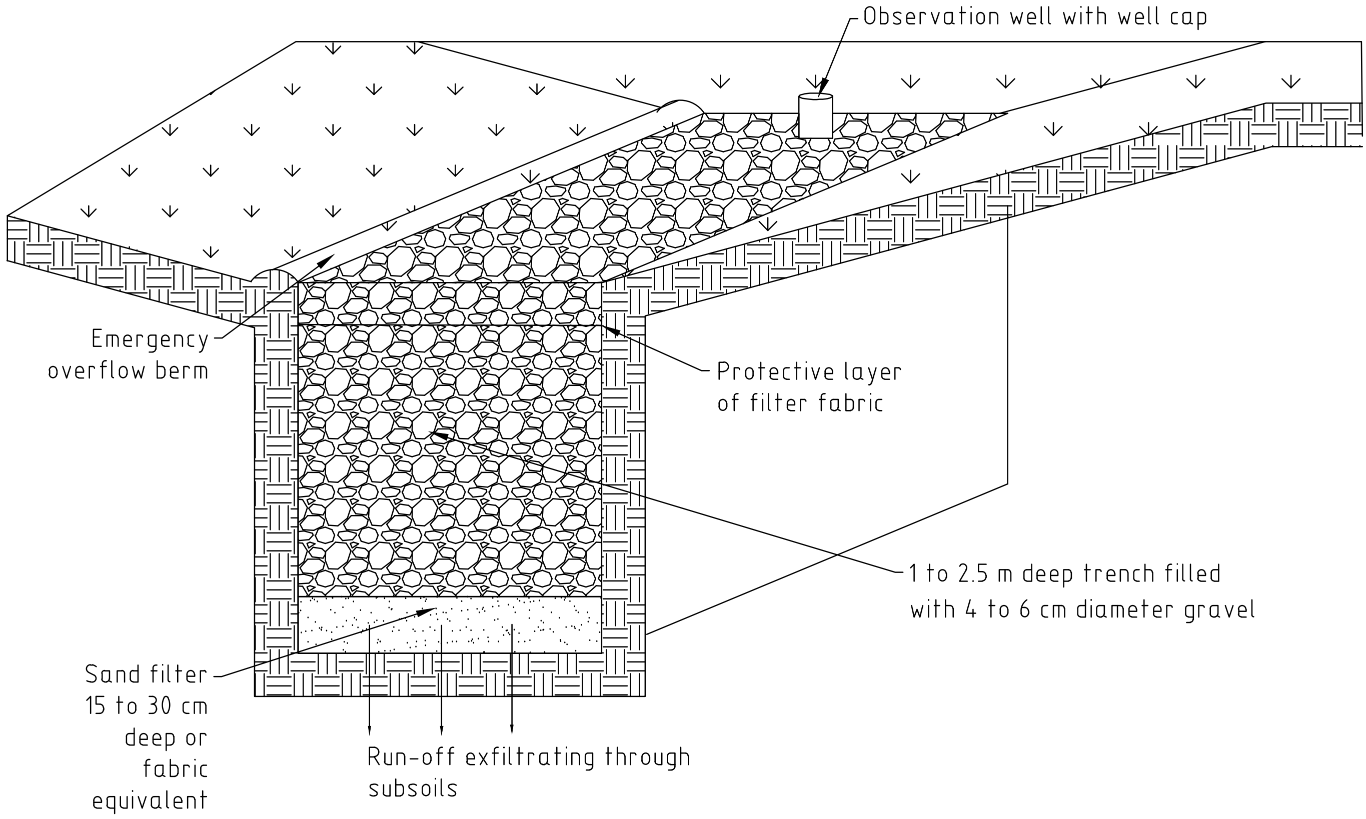
INFILTRATION TRENCH
SIDE VIEW



The technical considerations for this drawing are theoretical. On-site analysis or evaluation with modelling software must be conducted for evaluation of the catchments of the trenches. Catchment area, slope and soul texture influence the dimensions of the installation.

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Feasibility study:
Climate resilient development in refugee camps and host communities in Kigoma.

Technical drawing
INFILTRATION TRENCH

INFILTRATION TRENCH
TECHNICAL SPECIFICATIONS

ABOUT

- Infiltration trenches are excavations filled with coarse rubble or stone aggregate. Stormwater runoff is temporarily stored in the pore space of the aggregate material, reducing the overall runoff rates and volumes. The stored runoff will gradually infiltrate through the sides and bottom of the trench in the surrounding soil and recharge the groundwater reservoirs, thereby contributing to increased water security through natural water balance preservation, groundwater replenishment and baseflow preservation.
- Trenches can be used to capture sheet or point flow from a drainage area or can function as an off-line device.
- Removal of total suspended solids and heavy metals is high, while the nutrient removal is low to medium.
- Trenches reach their highest functionality when they are applied in conjunction with other techniques and should not be used as end-of-pipe systems due to the risk of too high flow rates.

DESIGN OF THE STRUCTURE

- Infiltration trenches are usually 1-2 m deep and at least 0.5 m wide. The design performance must be known for 10, 30 and 100 year events, and design to cope with the standards of service required.
- The sediment input with the water inflow should be limited by implementing pre-treatment (e.g. sedimentation basins or traps). Including a vegetative cover as a filter strip and adding a geotextile layer are appropriate preventive measures for sediment clogging.
- The slope of the trench bottom should be near 0 to evenly distribute the exfiltration.
- An observation well of 100-150 mm diameter perforated PVC should be included to measure the trench water level after a storm event. If it has not been fully drained after 3 days, remedial work may need to be conducted.
- The overflow berm on the downstream side of the trench helps detaining surface runoff and allows it to pond and infiltrate to the trench. The berm also promotes uniform sheet flow for runoff overflow.
- The backfill material should have a diameter of 40 to 80 mm and the clay content should be limited to less than 30%, while the porosity should be 0.3 to 0.4.
- The drainage time should reside between 2 to 3 days. The minimum drain time from full volume to half volume should be 24 h.
- The groundwater table should be at least 0.6 to 1.2 m below the trench bottom.
- Trenches should be implemented minimum 30 m from any drinking water supply well and at least 3 m downgrading and 30 m upgrading from building foundations.

ASSUMPTIONS AND LIMITATIONS

- A comprehensive hydrogeological and geotechnical evaluation must be conducted to determine the site of implemetation. This includes determining the lowest soil infiltration rates for the design calculations.
- Not suitable for sites with fine particled soils like clays and silts in the upstream catchments, as may be the case in the ferralsol landscape. They are applicable in impervious areas where the particle concentrations and sediment load of the runoff are low.
- Prone to failure if maintenance is poor, inappropriate siting or high debris input.
- Trenches are not recommended when the contributing slopes are greater than 5 % as low velocites are required for appropriate pollutant removal from infiltration.

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Feasibility study:
Climate resilient development in refugee camps and communities in Kigoma

Technical drawing
INFILTRATION TRENCH

OPERATION AND MAINTENANCE

- Key maintenance requirements are regular inspection for signs of clogging, sediment removal and cleaning or replacement of stone. Access for maintenance purpose should be considered when designing and locating the trenches.
- Regular maintenance includes monthly litter and debris removal, annual weed and root management if the surface is vegetated and annual removal and washing of exposed stones on the surface. Occasional maintenance includes half yearly or annual removal of sediments.
- Replacement of filter material should take place every 10-25 years, depending on its performance.
- The inlets, trench surface and silt accumulation should be monitored half yearly.
- The annual maintenance costs is estimated to 0,3-1,3 $ /m^2 of filter surface area.

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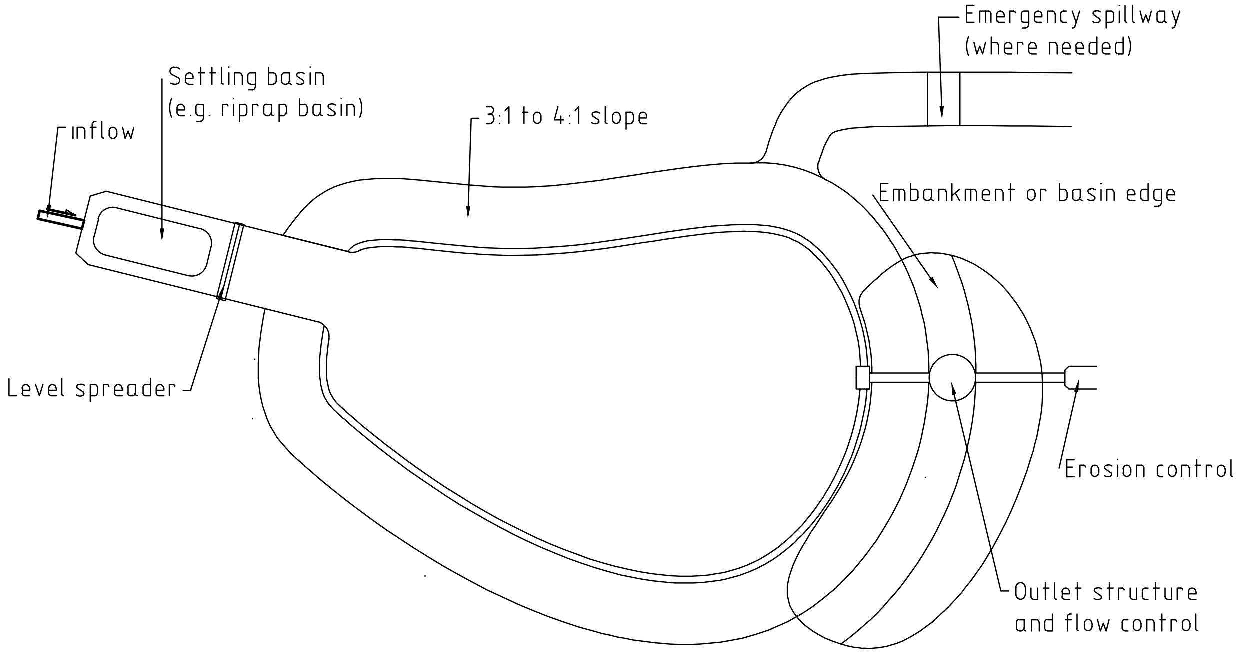
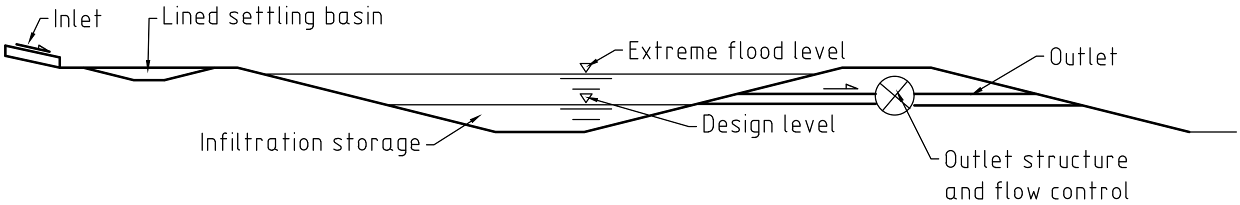
Technical drawing
INFILTRATION TRENCH

INFILTRATION BASIN
TOP VIEW



INFILTRATION BASIN
SIDE VIEW



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Feasibility study:
Climate resilient development in refugee camps and host communities in Kigoma.

Technical drawing
INFILTRATION BASIN

INFILTRATION BASIN TECHNICAL SPECIFICATIONS

ABOUT

- Infiltration basins are cost-effective excavations designed to store runoff from stormwater events and rainy seasons, for infiltration. As such runoff volumes are reduced from the respective drainage area while the groundwater reservoirs are recharged, surface water baseflows are replenished and pollutants are removed through filtration. They can also be designed to provide aesthetic value.

DESIGN OF THE STRUCTURE

- The infiltration basins are ideally designed to be off-line using a diversion structure upstream.
- Infiltration basins are susceptible to clogging, and therefore require pre-treatment in a settling pond for removal of suspended solids and silt.
- Erosion control of the inlet can consist of e.g. stone rip-rap and a level spreader to promote a even sheet flow into the basin.
- The basin floor should be as leveled as possible to maximize the infiltration surface and reduce erosion risk. This provides uniform ponding and infiltration of the runoff across the surface area of the floor.
- The basins must be located stable grounds, as verified by soil and groundwater conditions.
- The groundwater level must be more than 1 m below the basin floor.
- The basin should be designed so that it is half empty within the first 24 h of a storm event to ensure storage space for subsequent or multiple storm events.
- The side slopes should be no more than 1:4 steep. Shallow side slopes mitigate safety risk as bank collapses and allow for vegetative stabilization, easy access for maintenance and the public.
- If an embankment is required, the embankment fill material should be uncontaminated natural soils. The embankment must be stable and watertight.
- If the infiltration basins are part of the main drainage system, they must include emergency spillways capable of passing excess runoff to prevent structure damage.

ASSUMPTIONS AND LIMITATIONS

- They are appropriate when the drainage area is greater than 0.02 km^2. When the drainage areas are smaller, infiltration trenches are recommended.
- Infiltration basins require a relatively large and flat land area with permeable soils.
- Should not be constructed in locations where the slope stability is low or in e.g. areas prone to landslides, close to building foundations and at the top of embankment slopes.

OPERATION AND MAINTENANCE

- The design should allow for appropriate maintenance access, including the 1:4 slope steepness.
- Regular maintenance include monthly to half-yearly litter, debris and trash removal as well as grass cutting and vegetation management.
- Remedial actions include erosion repair, rip-rap realignment, rehabilitation of inlets, outlets and overflows, evening of the basin floor and re-seeding or re-planting.
- Monitoring efforts include monthly inspections of inlets, outflows, bank sides and the infiltration surface. The focus should be put on physical damage of different compartments, surface compaction and ponding, as well as blockages due to silt accumulation.
- The maintenance costs are estimated to 0.1 to 0.4 \$/m^2 of detention basin area or 0.3 to 1.3 \$/m^3 of detention volume.

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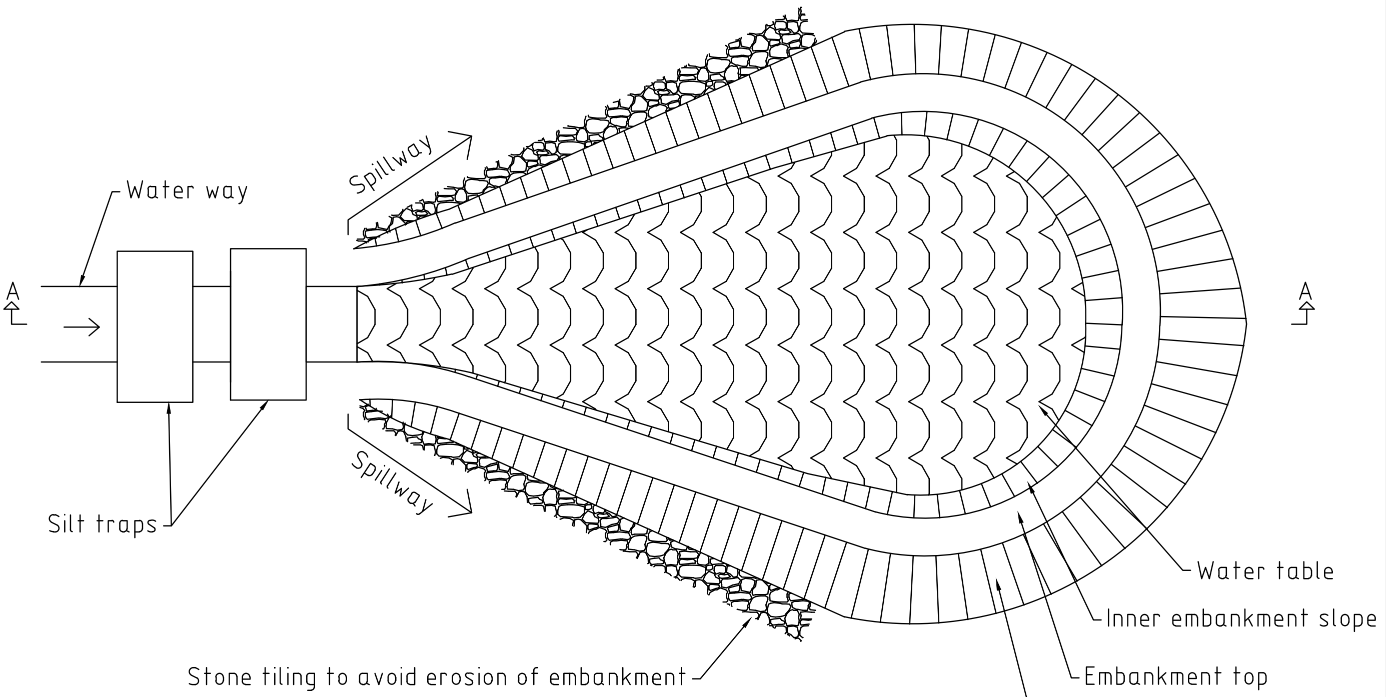
Technical drawing

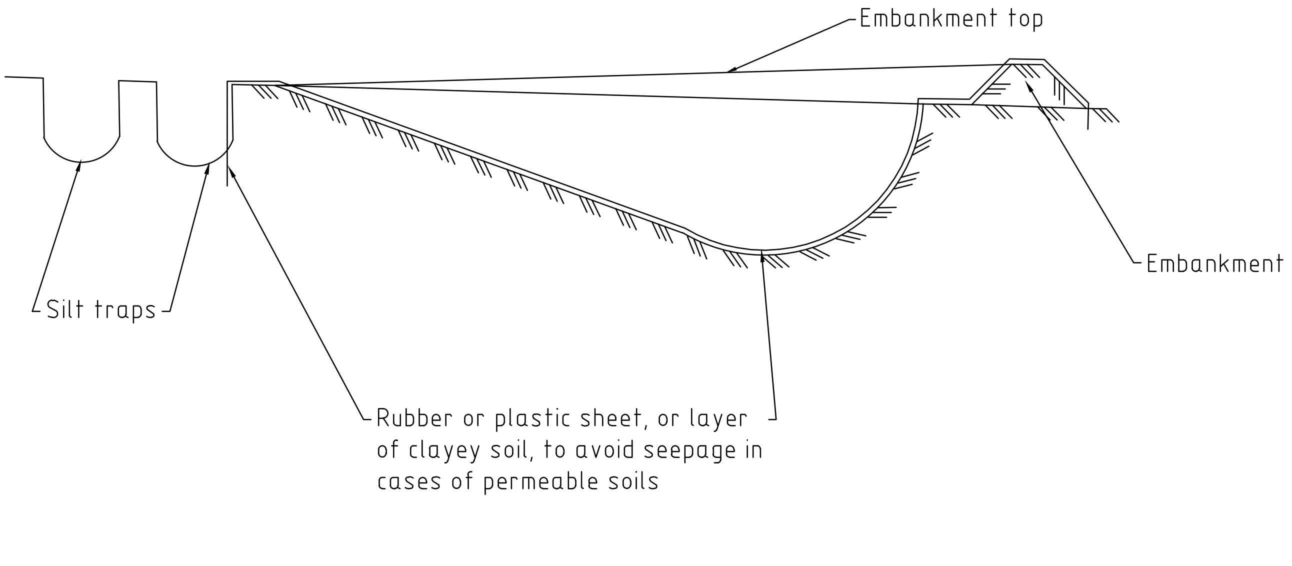
INFILTRATION BASIN

CHARCO DAMS AND WATER PONDS/PANS
PLAN VIEW

Water pans are dug out depressions in soil constructed to harvest and store rainwater. Charco dams is a East African variety of the water pan. Similar structures also fed by groundwater are called water ponds.



SECTION A-A



The technical considerations for this drawing has to be seen as theoretical.
On site analysis of catchment area, optimal siting, water needs, soil properties, cost/benefit nalysis and other influencing factors should be carried out in each case.

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Feasibility study:
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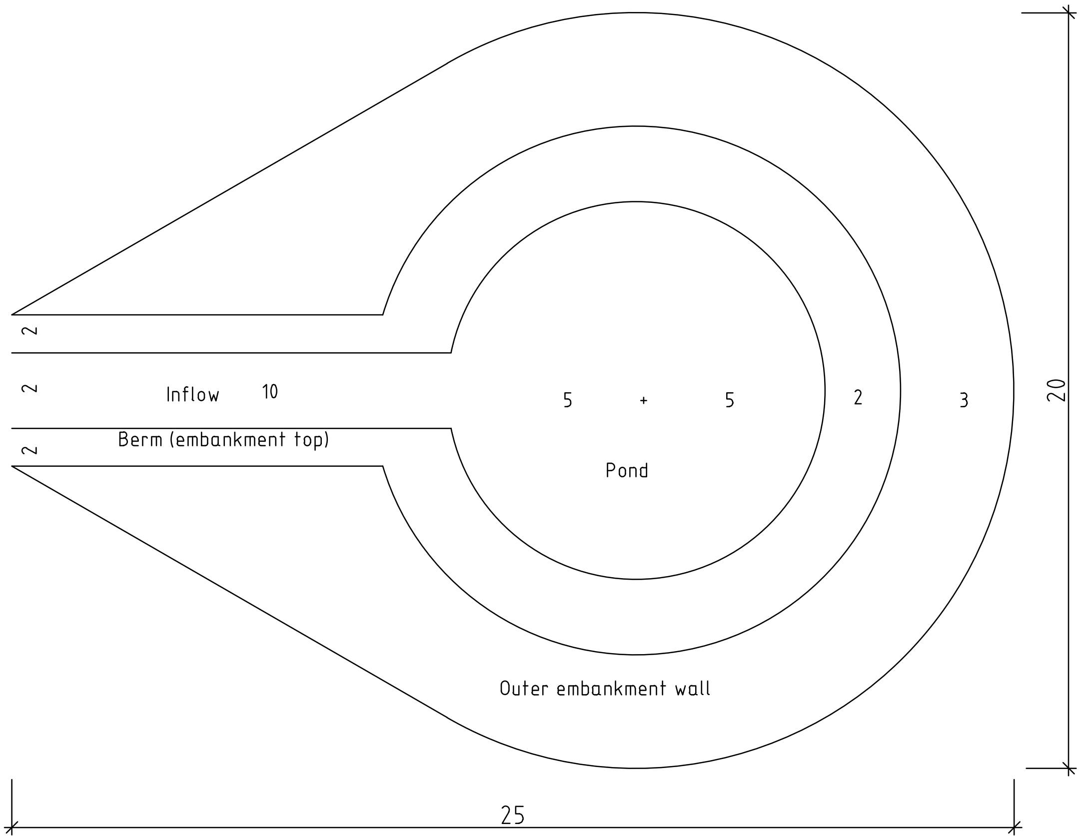
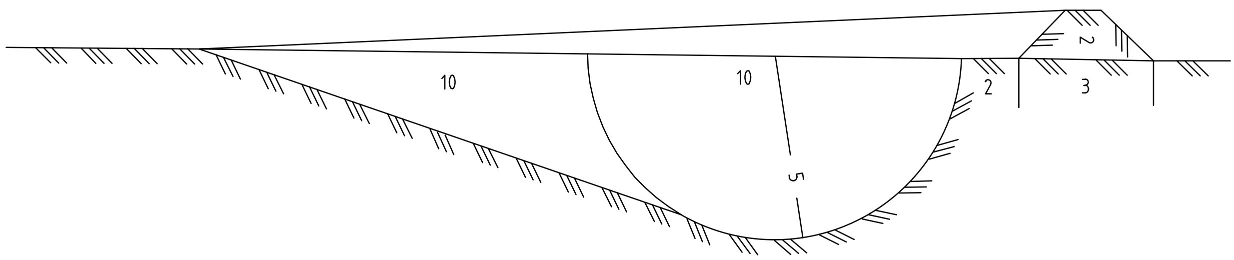
Technical drawing
CHARCO DAMS AND WATER PANS/PONDS

CHARCO DAMS AND WATER PONDS/PANS
STANDARD LAYOUT

Measurements in meters.





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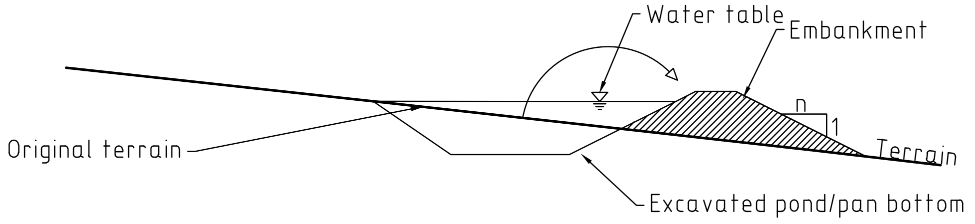
Technical drawing
CHARCO DAMS AND WATER PANS/PONDS

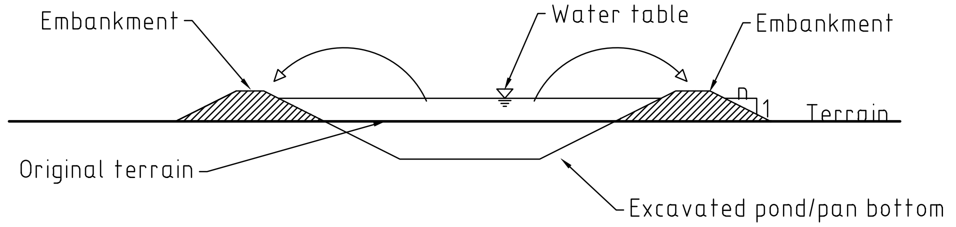
CHARCO DAMS AND WATER PONDS/PANS
CONSTRUCTION METHODS FOR EARTHEN DAMS

Cut-and-fill pond



- Placed in a sloping terrain
- Soil is excavated and parts or all of the soil excavated is used for constructing an embankment on the sides and on the downstream side of the pond/pan.
- Slope of embankment depends on soil conditions, and should be adapted to local soil stability

Dug-out pond



- Placed in flat terrain
- Soil is excavated to construct an embankment surrounding the pond/pan.
- Slope of embankment depends on soil conditions, and should be adapted to local soil stability, see table below.

Embankment stability			
Height of dam	Position	Clayey gravel	Clayey sand
Below 3 meters	Upstream slope	2.5:1	2.5:1
	Downstream slope	2:1	2:1
3m to 6m	Upstream slope	2.5:1	2.5:1
	Downstream slope	2.5:1	2.5:1
Above 6 meters	Upstream slope	3:1	3:1
	Downstream slope	2.5:1	3:1
Source: Nelson, K.D. 1985			

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Technical drawing
CHARCO DAMS AND WATER PANS/PONDS

CHARCO DAMS AND WATER PONDS/PANS
TECHNICAL SPECIFICATION 1/2

DESIGN OF THE STRUCTURE

Dimensioning

- Typical volume 100-5000 m^3
- Typical depth: 1-3 m
- Dimensions for silt trap is guiding, and will depend on size of waterway, water inflow and amount of sediments in water.
- The capacity/catchment area ratio should be such that the pond can fill up in about 2-3 months of rainfall.
- When dimensioning the dam, the following questions shouuld be answered:
  - Will the dam provide clean enough water for its wanted purpose
  - How much water is needed?
  - What will the dam cost to provide this amount of water?
- When estimating water losses from the dam, a rule of thumb is 50% of the stored water lost to evaporation and 25% lost to seepage.
- Evaporation losses can be reduced by deepening one end of the dam reservoir. As the pond dries out, the remaining water will accumulate in the deeper section and minimize the area of water exposed to evaporation.

Placement

- Must be placed downstream from a catchment area, across the flow path of natural drainage, or with a connecting water way from a catchment area.
- Should be situated at the lowest point in the locality, so rainwater runoff flows naturally towards the water reservoir by gravity.
- Water collected in water pans is not protected from pollution, and therefore not safe for human consumption.
- The bund should be located where maximum storage volume is obtained for minimum volume of earthfill. This condition, generally, can be met at a site where the stream or drainage channel is narrow and steep, the side slopes are steep and stable, and the stream bed is of consolidated and nearly impervious formation. Such sites also minimizes the pond area to water storage ratio.
- Water reservoirs should be fenced or covered to prevent people and livestock from falling into the water.

Construction

- Dams can be constructed gradually by starting with a small dam, and later enlarging the dam the following dry seasons. This gives a smaller initial cost for constructing the dam.
- Trees and grass should be planted on the dam wall to protect it from erosion and create a windbreak. More trees should be planted outside the embankment on the side towards the prevailing wind to form a windbreak, which will reduce evaporation losses and provide firewood, poles and timber.
- The embankments walls should be compacted regularly during construction, to make a firmer, and less permeable wall. After digging out the pond, the bottom should be compacted to reduce seepage losses.

The technical considerations for this drawing has to be seen as theoretical.
On site analysis of catchment area, optimal siting, water needs, soil properties, cost/benefit nalysis and other influencing factors should be carried out in each case.

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CHARCO DAMS AND WATER PANS/PONDS

CHARCO DAMS AND WATER PONDS/PANS TECHNICAL SPECIFICATION 2/2

Silt traps

- Silt traps slow down the water entering the dam, enabling sediments to settle in the silt traps instead of in the dam. This keeps the dam from being filled with sediments, reducing the stored water volume.
- Dimensioning and maintenance of the silt traps depend on how much sediments is transported through the waterway leading to the dam. Sediments accumulated in the silt traps should be dug up after rain showers, to minimize the amount of sediments reaching the dam. These sediments can be used for fertilizing garden plots.

DESIGN OF THE STRUCTURE (CONTINUED FROM PAGE 4)

Spillway

- A huge volume of rainwater runs off a large catchment during heavy rains. If a smaller dam is built with a large catchment, the reservoir will fill up with water quickly and a huge surplus of water will pass over the spillway, where it may cause erosion.
- Spillways must be constructed with this in mind, to avoid eroding the top or sides of the embankments.
- This can be achived by diverting the spillway away from the embankments, and/or
  - Planting the spillways with drought resistant perennial grasses in contour lines spaced 30 cm apart
  - Covering the spillways with stones packed together and planted with grasses
  - Constructing low masonry-walls in a staircase pattern 30 cm deep and 2 m apart along the spillway
  - Keeping the slope of the spillway floor at below 3 cm per 100 cm

MATERIALS

- Water pans are constructed from digging out soil and forming embankments from the dug out soil.
- The suitability of the local soil must be determined in each case.
- Rocks are used for lining the embankments along the spillways, to avoid erosion.
- In cases of very permeable soil, e.g. sandy soils, a plastic or rubber sheet, or a layer of clayey soil can be used as lining to minimize infiltration.

OPERATION AND MAINTENANCE

- Silt traps require regular emptying of sediments, ideally after rain showers. Well-maintained silt traps reduce sedimentation in the pond
- The pond also has to be emptied of sediments as it fills up. This should be done at the end of the dry season, when the water level is at its lowest.
- Garbage and other floating materials collecting in the pond should be removed on a regular basis, the frequency of which depends on how fast such debris accumulate.

The technical considerations for this drawing has to be seen as theoretical.
On site analysis of catchment area, optimal siting, water needs, soil properties, cost/benefit nalysis and other influencing factors should be carried out in each case.

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