Karamoja Productive Asset Program (KPAP)
Small Earth Dam Technical Assessment Report

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Summary:
A technical evaluation of small earth dams in Karamoja Productive Assets Programme (KPAP) was conducted in a 3 week period from Aug. 15 to Sept. 9, 2010 in the Karamoja region of Northeast Uganda. A total of 26 dams at varying stages of completion were visited. A general observation which applies to all dams was that very few were built with much forethought to the fundamental technical and siting criteria essential for a properly functioning earth dam. It was an extraordinarily fortunate scenario that a majority of the dams were able to hold water, albeit with significant rainfalls both before and throughout the duration of the field evaluation period.

There were frequent observed instances of communities wanting to build a longer and wider reservoir. This was understandable as a visually bigger reservoir area gives the impression of storing more water (at the expense of greatly increasing evaporative loss of water), in contrast to a deeper but visually smaller reservoir of the same volume which minimizes evaporative loss. This psychological bias was further reinforced by the division of reservoir excavation lots in 1m$^3$ portions which results in many reservoirs being exactly 1m deep and extending only in the horizontal direction due to easy organization of labor.

The poor construction quality of a majority of the embankments were made less apparent and critical by the fact that most of the water is stored below the ground level in excavated reservoirs. However, once water level reaches the constructed embankments above ground level, seepage and erosion may occur.

Conventionally earth dams are constructed during dry season, but in Karamoja the lack of large quantities of water needed for dampening soil for proper compaction of embankment means that construction will need to be carried out at the start of wet season, ideally finishing as quickly as possible to start immediately storing water for the rest of the wet season. It is essential to have diverting channels or earth bunds to divert water away from the partially excavated reservoir area during construction to avoid flooding delays. Constructions of many dams were delayed due to water flowing into reservoirs before completion. For many dams, small sections of embankments had to be temporarily removed to drain water away in order to continue excavation work. This presents a potential weak spot on the embankment in terms of structural homogeneity and seepage.

Local knowledge of both the catchment outflow and merging gullies on gentle sloping hillside proved to be invaluable in the likelihood of dam reservoirs being filled up with water. The lack of which usually results in reservoirs merely functioning as rain catchment basins where hardly any water flows in from external areas.

Without the availability of catchment outflow data and coupled with highly erratic rain events, the dams in Karamoja will have to be monitored and modified throughout its operational lifespan, especially the first few years. This includes deepening the reservoir, adding/modifying spillway and embankment, creating water diverting channels/earth bunds to increase inflow to the reservoir.

Culturally this is likely to be an invaluable experience for the dam project communities in strengthening cooperation, team organization, and sharing common goals. The numerous technical imperfections, mistakes may serve as excellent lessons. After all, we all learn more from our mistakes.
The most important lesson to be learned during this evaluation, to ensure a well-functioning small earth dam, is having the combination of good local knowledge of the catchment area - with clear signs of water outflow; and field staff who have the technical skills and fundamental knowledge of basic earthen dam structures to educate the community and to be always present during construction.
Introduction:

Basic earth dam siting, design, and construction considerations
Small earth dams are water storage dams with capacities up to about 10000 cubic meters and having embankments up to a height of about 5 meters. [Ref 1] Small earth dams can be built manually, using animal draught, a farm tractor, a crawler or bulldozer.

Conventional dam design follows a sequence of steps starting with the calculation of daily water use requirement, collecting monthly rainfall distribution data, estimating catchment area water outflow, estimating evaporation and seepage losses based on soil and laboratory tests, calculating required dam reservoir storage volume, and finally determining dimensions and height of embankment based on selected dam site topography.

In the KPAP context small earth dams are part of a food for work program using inexperienced manual labor with basic tools such as shovel, hoe, wheel barrow, plastic bucket, broken jerry can, and field made manual compactor. It is worth noting that in the unavailability of design data and basic earthworks construction tools such as levels and measuring tape, many conventional earth dam technical requirements will be partially simplified or ignored. Since all of the KPAP dams are relatively small hillside dams situated on gentle (<5%) slopes with small gullies feeding water to the reservoir, the dams will most likely function in a safe manner despite ignoring some of the conventional technical requirements more applicable to larger dams.

In the KPAP context, the quality of construction plays a bigger role than the conventional technical specifications. For safety margin and technical reasons small earth dams in Karamoja should be limited to storage capacities of no more than 5000 cubic meters and a height of 4 meters.

The first step in building a dam is to identify the best location. There will be many factors including cultural, political, and technical that affect this. Ultimately it is up to the judgment of the community and a knowledgeable construction supervisor to balance all the trade-offs involved in the site selection. The dam siting discussions in this report will be strictly focused on the most elementary and fundamental requirements necessary for a dam reservoir to stock water in the Karamoja context.

Dam site soil specific requirement:
We are primarily interested in two basic soil features when we are building an earth dam; soil permeability and soil strength. Soil permeability predicts the seepage rate of water stored in a dam reservoir, and soil strength indicates stability and strength of the dam embankment. The properties that effect both permeability and strength are numerous and complex. But, they do not have to be understood completely to perform some simple tests to determine if a soil is suitable for building dams.

There are many different ways to classify soil. The method presented here is a simplification of the Unified Soil Classification System (USCS). It has been reduced to the point that the tests can be performed in the field with little difficulty but the results are still useful. It is worth noting that the USCS is different from the methods agriculturists and soil scientists use to classify soils.
Soil can be broken down into two basic categories: organic soils (such as peat) and non-organic soils (sand, gravel, silt, and clay). Organic soils are formed from rotting and decomposing plant and animal matter and are characterized by high compressibility, dark color, and occasionally an organic smell. Because of their unstable nature and extreme variability, it is considered to be completely useless for foundations, embankments, and other forms or structures of engineering. Soils with small amounts of organic matter don't have to be discarded completely, but the amount should be as little as possible.

Non-organic soils are soils that have been produced through erosion and other geologic processes. The four basic types are: clay, silt, sand, and gravel. The differences between these types of soils are the size of the grains. Clay and silt also have chemical and shape properties that separate them, but since neither can be seen with the naked eye, they must be differentiated based on feel and other factors. Since almost all soils contain a combination of these grain sizes, soils can be classified based on how much of each type is present.

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>Size</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.0005-0.002 mm</td>
<td>Sticky and gooey when wet. Can be molded and rolled without breaking apart. Very hard when completely dried as in an oven.</td>
</tr>
<tr>
<td>Silt</td>
<td>0.002-0.06 mm</td>
<td>Very fine material, individual grains can't be seen with the naked eye. When dry silt feels like talcum powder. When wet, clumps break apart and disperse.</td>
</tr>
<tr>
<td>Sand</td>
<td>0.06-2 mm</td>
<td>Loose grains over a range of sizes. Even the smallest sand grains can be seen with the naked eye. The soil will feel gritty.</td>
</tr>
<tr>
<td>Gravel</td>
<td>2-64 mm</td>
<td>Large grains, easily distinguished.</td>
</tr>
</tbody>
</table>

Table 1: Description of basic non-organic soil grains

It is possible to get a rough idea of the distribution of the grain sizes using a straight glass jar. Take a narrow glass jar with a tight lid. Fill it half way up with a representative soil sample (gravel is easy to spot and can be removed and noted ahead of time). Fill to the top with water and then shake vigorously to put all particles into solution. Let sit for 24 hours or until the water is clear. The soil will sink to the bottom with the largest grains first. It is now possible to make a rough estimate of the percentages of each grain type and by measuring the height of each soil grain with respect to the total soil height as shown in Figure 2.
Soils with large amounts of clay are naturally impervious. To be suitable for the impervious embankment of the dam the soil will need at least 25-55% clay particles (USCS classification). A quick test for clay is to cut a lump of soil with a knife. If there is a bit of a shine to the soil it has a fair amount of clay in it. Also, a good clay soil will be able to roll into a “snake” about 1.5 mm thick and 40 mm long without breaking. Some experimenting with different amounts of water may be required. The wide range of clay content acceptable for dam embankment is due to the differing soil structure (how each grain type is arranged and attached to one another). A soil with lower clay content can be more impervious than a soil with higher clay content due to structural differences.

Once a potential suitable soil is found, a final check will be to perform the infiltration or permeability test, which can reveal the water retention abilities of a particular combination of soil type and structure. An onsite infiltration test is usually performed in conventional soil testing, using concentric metal rings of different standardized dimensions as shown in Figure 3.

In dry soil, water infiltrates rapidly. This is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate (when soil is completely water saturated). This is called the basic infiltration rate. We are interested in the basic infiltration rate for an earth dam reservoir.
The infiltration test is usually carried out in 1 hour interval with the results expressed in water level drop in mm per hour (mm/hr). To be suitable for an earth dam to store water we like to see less than 1-2mm/hour of infiltration rate at the dam reservoir site. In the KPAP context, there are no standardized metal testing rings available for onsite testing. Instead, a rough approximation of the test is to simply dig a hole about 20-30cm diameter and 20-30cm deep, filing the test hole with water making sure the soil is completely saturated, inserting a ruler, starting a timer (mobile phone) for 10 minutes and recording the starting and ending marks on the ruler to calculate the infiltration rate (see Figure 4). It is important to note that this test needs to be done at the bottom depth of the potential reservoir. This means that if the reservoir will be 3 meters deep, a working space/pit that is 3 meters deep at the potential dam reservoir site will have to be dug first, then the infiltration test hole can be dug at the bottom of the working pit. From field observations in Karamoja the dams can hold water with a tested infiltration rate as high as 4-5mm per hour. This is due to silt being washed into a new earthen reservoir, clogging up the pores in the soil, thus helping with the retention of water.

![Rough approximation of infiltration test](image)

**Figure 4: Rough approximation of infiltration test**

**Dam site catchment selection**
In general a dam should have the potential to fill completely with water runoff (most normal-rainfall years) or store sufficient water between runoff events. In Karamoja the purpose of a small earth dam is to store as much water as possible to last throughout the duration of a dry season, or at least minimize the effects of drought. Obviously, dam catchment area characteristics become critical in this scenario. We want to ensure that there is actually decent
amount of water flowing into a dam reservoir. In the absence of reliable local rain data and catchment area estimation, local knowledge becomes invaluable in terms of ensuring there will be water flowing out from the catchment area into the dam reservoir. For any potential dam catchment look for obvious signs of water runoff.

In cases where the rainfall data and catchment area are known, the water outflow (technically termed: catchment yield) can be approximated by:

**Catchment yield:**

\[ Rr = 10\% \text{ of the annual average rainfall in mm} \]

Catchment area \( A \) in \( \text{km}^2 \)

Catchment yield \( Y (\text{m}^3) = Rr \times A \times 1000 \)

The size of the dam reservoir would be built relative to the catchment yield. Dam catchment can include gentle sloping hillside, small converging gullies, seasonal gullies, small creeks, or diverting water channels. Figure 5, 6 and 7 shows examples of dam catchment.

Figure 5: Ideal gentle slope hillside dam catchment
Figure 6: Ideal gully leading to a dam reservoir

Very well defined gully, covering a big catchment area, which means lots of water flowing. Also grass cover is a natural silt trap.

Figure 7: Chaco dam inlet. Silt traps will have to be implemented for this inlet to prevent excessive siltation of the reservoir.
Small earth dam design:
A typical design of a small earth-fill dam is shown in Figure 8. For stability, the upstream slope must be a minimum of 3:1. Erosion protection is required to protect the dam from wave action. This protection can be achieved with a combination of smaller and larger rocks (or other suitable material). The downstream slope requires a minimum 2:1 slope, seeded with native grasses to prevent surface erosion. The top or crest of the dam should be a minimum of 2m feet wide for a stable embankment structure. The crest elevation should be a minimum of 0.5m above the Full Supply Level (FSL) of the reservoir. The dam should be fenced to prevent livestock traffic, as this traffic can be a major cause of slope and crest degradation. A textbook perfect dam embankment structure would look like the one in Figure 9. The crest width and the slope of embankments can be designed according the guidelines in Table 2 and 3.

Figure 8: Typical earth dam layout. (Ignore riparian pipe for our purpose)

<table>
<thead>
<tr>
<th>Height of Dam (H) (m)</th>
<th>Crest Width (B) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>2.1 to 3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>3.1 to 4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>4.1 to 5.0</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Table 2: Crest width based on different dam embankment height

<table>
<thead>
<tr>
<th>Dam Height (m)</th>
<th>Dam Face</th>
<th>Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&gt;50% Gravel &gt;15% Clay</td>
</tr>
<tr>
<td>3</td>
<td>Upstream</td>
<td>2.5:1</td>
</tr>
<tr>
<td></td>
<td>Downstream</td>
<td>2:1</td>
</tr>
<tr>
<td>3.1-6</td>
<td>Upstream</td>
<td>2.5:1</td>
</tr>
<tr>
<td></td>
<td>Downstream</td>
<td>2.5:1</td>
</tr>
</tbody>
</table>

Table 3: Embankment slope based on soil type
Spillway:

Spillway is a critical design feature of any dam. Spillway prevents overtopping of the dam and serious erosion during peak water runoff. Spillways in KPAP dams should only handle water flow once in a while during extremely heavy downpour events. They should not be handling water flow on a continuous basis. If this happens, the dam reservoir needs to be built bigger (deeper) to handle the normal catchment outflow. To prevent erosion of the spillway itself, riprap (a collection of loose stones) can be used. For most U-shaped hillside or chaco dams in KPAP (see Figure 10), spillways would be located at the tips of the U. Rocks and/or clay bricks would be piled on the edge of the embankment, compacted into the soil. The idea here is to prevent erosion of the U-tip edge and the downstream side of the embankment during overflow events. The height of the spillway will determine the full-supply-level (FSL) of the dam reservoir, which needs to be at least 0.5m from the top of the dam crest as previously indicated in Figure 8.
Construction:
In the Karamoja context we will strictly be working with homogeneous-fill earth dams. Diaphragm and zone type earth dams will not be discussed as they require careful technical supervision and semi-skilled labor. Homogeneous-fill type dam means that all of the embankment fill material has the same soil property. The fill materials should preferably be taken from the reservoir area or a borrow pit close by. The following materials should be avoided: organic material—including topsoil—decomposing material, material with high mica content, calcite clays, fine silts, schist’s and shale’s, cracking clays, and sodic soils. Avoid material with roots or stones. Normally dams are constructed during the dry season. In Karamoja because of the unavailability of large quantities of water necessary for dampening the soil for optimum compaction, the dam construction will need to be carried out at the start of wet
season, ideally finishing in a month to start immediately storing water for the duration of the rest of the wet season. It is essential to have diverting channels or earth bunds to divert water away from the partially excavated reservoir area during construction to avoid flooding delays.

At the foundation of the embankment topsoil will need to be stripped (note bottom of Figure 8) because it contains organic matter (such as roots) which prevents proper compaction and may provide seepage routes (piping) once the organic matter has decayed.

It doesn’t matter how good the dam design and siting is if the construction is subpar. This is especially true in the Karamoja context where constant technical supervision and skilled labor is usually not available. Ideally the dam will be built like a layer cake, one piece right on top of another. Once the soil is placed there is no sneaking back to work on something that was forgotten. Before any construction is started, thoroughly review the plans and make a list of what must be placed first, second, etc. Digging up soil and attempting to re-compact it will cause weak spots in the embankment.

The dam should be built roughly 10% taller than designed. Soil will settle and consolidate over time. The 10% allowance will help assure that it will still be the size it was designed for years in the future. 10% is a rough and safe estimate for embankment settlement. For un-compacted soil the dam will settle by 30% in height.

In order for the soil to act as predicted, it must be fully compacted. Compaction is the process of removing the voids from the soil and making it as dense as possible. The key to good compaction is; small lifts, good energy, and the right amount of water. Placing the soil in layers that are too big is a problem that plagues even professionals in developed countries. Even heavy equipment can’t make up for soil layers that are too thick. For hand compaction methods it is recommended to compact soil after every 20cm layer that has been laid. The greatest challenge to achieving the best compaction possible is getting the soil damp enough to pack, but not too wet. The optimum moisture content depends on soil type as shown in Table 4. It is very time consuming to ensure proper compaction, and it is a difficult concept for unskilled labor to understand. In earth dam construction the consequences of poorly compacted soil are far worse than falling behind schedule or other non-conforming technical specification. A simple test to evaluate proper compaction is to place the edge of the heel of a hard-soled boot on the fill and push down hard with all your weight. If only a mark is left, compaction is satisfactory. If the heel sinks in, compaction is poor.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Typical Value of Optimum Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>6-10%</td>
</tr>
<tr>
<td>Sand-Silt Mixture</td>
<td>8-12%</td>
</tr>
<tr>
<td>Silt</td>
<td>11-15%</td>
</tr>
<tr>
<td>Clay</td>
<td>13-21%</td>
</tr>
</tbody>
</table>

Table 4: Optimum moisture content for compaction
Limitations in implementing KPAP dams

There are important limitations and challenges in implementing small earth dams for the purpose of stocking water in any drought prone semi-arid region. The situation is made worse when very little data are readily available to aid in the design or the understanding of the critical limiting factors. The lack of basic elementary technical knowledge of the unskilled labor and social political issues of community mobilization and organizing labor further complicates what can realistically be constructed in the Karamoja context.

One of the critical dam design criteria; long term, reliable, measured local rainfall data was hard to come by in Karamoja. However, recent advances in climatology combining satellite imagining and limited rain gauge network enable the creation of rainfall data shown in Figure 10. (Famine Early Warning System – Network)

**NE Sorghum, Sisim, Maize and Livestock Zone**

![Graph of NE Karamoja regional rainfall distribution data](image)

**Figure 10**: NE Karamoja regional rainfall distribution data, adapted from USAID Karamoja Food Security assessment report 2010. Annual mean (12 yr Avg)= 698mm/yr with 219mm std dev.

Another key design criteria; the evaporation data was also not easily available. Two references in the Africa climatology literature were consulted [ref 2,3]. Potential evaporation (PET) for the NE Karamoja region where all the KPAP dams were built is estimated to be 1800-2200 mm/year, with roughly an even distribution of 5-7mm every day.

Based on the two important pieces of data above, the critical limiting factor in implementing a water stocking dam in KPAP becomes that of keeping the water from evaporating away. In
general all earth dams will suffer from a number of constraints common to Karamoja’s semi-arid environment. These include:

- High evaporation rates leading to significant losses from any water stored in open reservoirs.
- Low and erratic rainfall and prolonged droughts over several years of below average rainfall may lead to empty reservoirs.
- Siltation due to large amounts of sediment washed into reservoirs during severe storms, especially at the end of the dry season, which also makes the water turbid. Siltation can be avoided by trapping inflowing silt in silt traps and utilizing it for fertilizing garden plots.
- Contamination of water in open reservoirs can be caused by livestock entering reservoirs resulting in poor water quality. Clean water for domestic use can be drawn from a hand-dug well sunk in the immediate downstream slope area with seepage from the dam reservoir. (Assuming percolation rate isn’t too high and water spend 20+ days seeping through the soil to the well location.)
- The risk of small children and livestock falling into reservoirs. Small water reservoirs should therefore always be fenced. Ideally animals and people can only enter from the shallow sloping or stable rock/clay brick steps leading to the reservoir.
- The use of highly contaminated stagnant surface water stored in the dam for domestic purposes during severe drought when no other water sources are available.
- Dam reservoir becomes potential mosquito breeding ground. Critical health concerns if dam situated too close (<100m) to manyatta settlements.

**Prediction of water storage loss:**

The rainfall distribution in Figure 10 coupled with the evaporation data can be used to estimate the water storage loss in open reservoirs in Karamoja. According to Figure 10, there is very little chance for the months starting mid-November until April to have any useful rainwater runoff into the dam reservoirs, and at the same time daily evaporation rate exceeds the precipitation rate. The net vertical water level drop rate would be in the range of 4-6mm a day. Assuming a net 5mm drop a day, and 135 days from Mid-November to April, a total drop of 675mm will occur from evaporation alone. Adding in 25% of total drop from seepage losses, we will lose a total of roughly 850mm of water level during those drought months. It is assumed that the moderate duration rain events plus occasionally high intensity downpours starting from April and lasting until September would be enough to fill most properly sited dam reservoirs. The reservoirs will not be filled at the start of mid-November if the above assumed rain events do not occur. One reference cited any rain event less than 12mm/day in the Karamoja region is unlikely to produce meaningful runoff. This rough estimate of 850mm water loss during drought months highlights the importance of making the dam reservoir surface area smaller along with other measures to minimize evaporative losses. There is more to be discussed in the next section.
Overlooked technical and constructional aspects in KPAP dams

Evaporation:

Without a clear, irrefutable understanding on the effects and the mechanics of evaporation, KPAP beneficiary communities were all building dam reservoirs which are significantly longer and wider than it is deep (Figure 12). This was completely understandable as a visually bigger reservoir surface area gives the impression of storing more water. A larger surface area will greatly increase evaporative loss of water. No one can be expected to build a deeper but visually smaller reservoir of the same volume (which minimizes evaporative loss) when they do not fully understand how much water will be lost from evaporation.

A useful rule of thumb is that about 50% of the water in a reservoir is lost each year to evaporation, assuming that the reservoir is not build like an evaporation pond (long, wide, and shallow), in which case ALL of the water will be lost. Unfortunately many of the KPAP dam reservoirs were built like evaporation ponds, as a result some modifications will be required to enable the dams to prolong the storage of water.

Figure 12: Dam reservoir built like an evaporation pond.

Recommended actions for dams built like evaporation ponds include:

- Halt all horizontal direction excavations and continuing excavation only in the vertical direction to make the reservoir deeper. This means disregarding the size of the perimeter area of the currently finished dam embankment.

- One way to reduce evaporation and conserve water towards the end of the dry season is to deepen 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. For
many KAPAP dam reservoirs, this will be working on deepening just the $\frac{1}{2}$ or the $\frac{1}{3}$ of the currently planned reservoir area.

- Trees should be planted all around downstream of the embankment, or on the side towards the prevailing wind to form a windbreak, which will reduce evaporation losses. Although this would take 10+ years to function as a truly effective wind break.

Seepage losses:
An undesirable feature of all earth dams is that some water will always seep through the embankment walls, even if it is constructed of good materials, and well-compacted. This seepage reduces water storage of the reservoir and the strength of the dam embankment. Seepage loss is difficult to estimate because dam reservoirs are built of various soil types which result in varying degrees of seepage. Nevertheless, another common rule of thumb states that seepage may account for about half that of evaporation (or 25% of the water in a reservoir). Proper preparation of dam site and compaction of the soil layers during construction will greatly reduce seepage losses. Unfortunately, this important and necessary dam construction practice was mostly unknown to the KPAP communities at the start of construction. Soil compaction during construction was only observed at 2 out of 26 dam sites. Many dam sites were missing the compaction tool or if the tool was available in the community it was not seen at the construction site. The compaction tool is very heavy and it is simply not practical to be carried
back and forth between the dam construction sites and the community. However, there might be theft concerns if the tool was left at the construction site. This was a difficult issue to resolve.

For most KPAP dams the poor quality construction of the embankments were made less apparent and critical by the fact that a majority of water is stored below the ground level in the excavated reservoirs. Very few dams had water levels extending over the ground level above to the embankments. For the few dams where water level has risen to the embankments, various degrees of seepage can be observed. For serious seepage problems at isolated spots of the embankment, there are two recommended remedies:

1. Opening up and digging into the downstream slope of the seepage spot of the embankment, look for roots, large rocks, and other potentially rotting organic material, remove them, and apply layers of clayey soil, and lastly compact well. This is sort of a band-aid solution and needs to be done very carefully when opening up and digging into the embankment since water level will be above the spot where the digging needs to take place. The embankment wall at the spot could potentially collapse and release all of the water from weakened wall structure.

2. Waiting until the water level recedes below the ground level. Then apply the above steps. In this case there will be no risk of wall collapsing since there won’t be water on the upstream side of the embankment.

For seepage problem of the entire dam reservoir due to improper site selection, a potential fix is to use plastic sheeting (1 mm polypropylene or 1.5 mm HDPE) blanket covering the entire wetted reservoir surface area. This involves digging an additional 0.5m soil depth on all wetted surfaces of the reservoir, laying down the plastic sheeting overlapping each sheet by at least 0.15m, and applying well compacted 0.5m soil above the plastic sheets to hold them in place. A material cost of roughly $3000 UGX per m² plastic sheeting can be used to calculate the total cost for the blanket. For a typical 30m x 30m x 4m rectangular dimensioned excavated reservoir, the wetted surface (not including embankment) is 2280m² and the cost of the impermeable plastic blanket would be $6,840,000 UGX. It is up to the KPAP project managers to decide if the cost benefits are worth the investment. This typical example demonstrates that it may be more cost effective to build a new dam at a new location than to patch up an existing dam site which was poorly chosen.

**Dam embankment not following proper contour:**

In many observed instances the bottom-section U embankment wall is build lower than the U sides or the tips (see Figure 11). It does not make sense for that part of the wall to be lower than the sides and the spillway as this means that the dam wall will be overtopped in cases of overflow. The positioning of some of the embankments is not ideal as they are in the way of the ground slope and blocking runoff water from entering the reservoir. Some of this oversight can be attributed to the lack of an onsite leveling tool or the lack of the understanding of the need to absolutely avoid overtopping earth dam walls. A basic field-made level can be made from a half-filled plastic water bottle tied to a piece of long-straight stick about 1m long. The half-filled water level in the bottle is used to indicate the horizontal ‘levelness’ of the stick. This simple tool will be able to correct most eye-sighting errors when used during construction.
Physical order of excavation lots:
There were many observed instances of the edges of the dam reservoirs being excavated first instead of the center part of the reservoir. This makes it easy to identify the size and the location of the embankments but that wouldn’t have been a concern in the first place if the location had been properly measured and marked. This also wouldn’t have been an issue if a suitable number of ‘construction work pathways’ for transporting excavated soil are reserved and designated. But the situation was that the majority of the reservoir perimeter excavation lots were dug, leaving a huge portion of the middle part of the reservoir to be excavated, but with a very narrow pathway where all workers must now use to transport soil out to the embankments. This became an extreme case of construction inefficiency in terms of queuing and unnecessary back and forth traffic. In some cases people were simply picking up the dirt from excavation lots with their hands, and throwing it over the completed excavation lots that’s now blocking their access to the outside of the embankments. It is recommended to carefully plan and communicate future reservoir excavations to minimize inefficient labor use and bottlenecking conditions.

Shape of a chaco dam inlet on hillside dams:
Many hillside dams had chaco dam style C-shaped inlets instead of a U-shaped inlet. For chaco dams the C-shape inlet is necessary because of the narrow gully inlet where it’s the only source of water entering the reservoir. For a hillside dam inlet it is wrong to use the C-shaped inlet and
works against the ideal situation where we want to catch as much water as we can from the wide, flat slope typical for a hillside dam catchment.

**Importance of educating communities by building a mini-model earth dam**

The author had several opportunities to interact with the communities during the construction. There were a few instances where the community feels strongly about the way they would like their dam to be built and would not readily accept some of the technical recommendations made by the author. This was a revealing experience and coupled with many other overlooked dam constructional aspects underscored the need to educate the communities before implementing a dam project. The author had excellent feedback from conducting a dam construction workshop where a 50cm x 40 cm long mini hillside earth dam complete with spillway, proper embankment slopes and scaled dimensions were used to demonstrate various technical operating criteria of an earth dam. Water was poured into the mini-catchment and into the model dam, showing what happens when the dam overflows and the importance of proper spillway design/location/construction. Every aspect of the technical specification and construction can be demonstrated with the mini-model dam. Such a model can be constructed at potential dam sites in less than 30 minutes by field staff. This presents the communities a live, visual presentation of what a finished dam should look like and how it should operate. It is the author’s belief that this kind of onsite training will have the utmost positive impact and lasting effect, more so than any printed field guides or manuals.

**Upstream and downstream impact**

Before constructing a dam, the environmental impact must be evaluated. Small earth dams do not have a major impact, except if many small dams are constructed in the same catchment, in which case their combined effect could be significant. This has not been observed in KPAP dams as none are sharing the same catchment area. In terms of downstream impact it is critical for any earth dam design to take into account the consequences in case of a catastrophic dam failure. None of the KPAP small earth dams are built big enough or situated in a location where possible loss of life could occur should the dam fail. Most KPAP dams are located on wide/gentle sloping hillside, with most of the water stored under ground in excavated reservoirs. There is no upstream impact and the only downstream impact is the slightly wetted soil downstream of the embankment from the water seepage. We would actually like to take advantage of the wetted soil by planting tree lots or orchards or other crops that likes to grow in a high moisture content soil. There is only one KPAP dam (Toroi West) utilizing a seasonal gully way/small creek. In this case the upstream impact is the higher than normal flood water line along the upstream gully and the downstream impact is the dryer gully bed due to most of the water trapped in the reservoir and in the upstream gully way. In cases of dam failure there will be slight amounts of rushing flood water into the otherwise dry downstream gully way, flood water should be no more than a meter deep. There are no communities situated close to the upstream or the downstream part of this isolated gully way which drains into a nearby bigger
water way and eventually into a river. There is minimum ecological impact for this chaco dam location.

**Work norm, monitoring, and follow-up**

A work norm was implemented for KPAP dam construction. 1m³ of earthworks is assigned to each person per 5 hour work day, with 8 total work days per month. 1m³ is what each person are expected to complete in one work day. This work norm looks to be very reasonable. Assuming 100 people were to build a 30m x 30m x 3m reservoir for a hillside dam. We have 2700m³ of excavation needed plus additional earth bunds/channels for water diversion during construction, and soil from borrow pits nearby for properly compacted embankments. Factor in 20% of extra soil volume required in addition to the actual excavation, we have a total of 3240m³ of earthworks to be divided among 100 people. Each person will be responsible for roughly 32m³ of earthworks, and if we use 8 total work days per month, the total dam construction time will be exactly 4 month. If there were 200 people working on the same dam, it does not mean that the construction time will be halved. There is a limit on how many people can be in a 30m x 30m work area at the same time.

There is an un-intended negative consequence by assigning 1m³ per worker, when most communities understood it as a 1m x 1m x 1m lot. When many workers are present (usually the case), excavation work can only be expanded in the horizontal direction due to labor organization and work space availability. This result in many dam reservoirs being exactly 1m deep while being very long and wide (built like an evaporation pond). It is recommended that the 1m³ excavation lot be redefined as 0.5m wide by 1m long by 2m deep. Chipping away a 0.5m section of soil is also more natural with regard to using the hoe. In addition, for any site with more than 150 workers, it is recommended to split up the total number of workers into work groups that work on different days to avoid overcrowding of the construction site. It is further recommended to split up each work group into three sub-groups; one for excavation, one for hauling soil, and another group dedicated to compacting soil, and all the groups would rotate their work every 10-15 minutes or so. The rotation of work is important as manual excavating and compacting work is incredibly physically demanding. It would not be unusual to have equal duration work time and breaks due to the extreme physical demand.

There were some discussions and concerns as to whether a work-hour based or a result based work norm would be more appropriate. This concern came up when some communities seem to take much longer to complete their dams compared to other communities. Many dams were seemingly behind schedule due to a variety of factors. It was difficult to establish a standardized work-progress norm when every dam site has different soil and other environmental conditions. On a sandier soil with lower clay content when the soil is slightly moist, it is relatively easy to excavate a 1m³ area. Conversely, on a high clay content soil when completely dry, it becomes more time consuming (by a factor of two or more) to excavate the same volume of soil. For some dams the onsite inefficiencies and bottlenecking issue were seriously delaying the construction progress. While others had flooding issues that also caused significant delays with extra work needed.
In consideration of the vastly different situations at most dam sites, coupled with community mobilization issues, monitoring of the work norm and construction progress becomes the responsibility of the field staff or the construction supervisor. It is up to the judgment of the onsite supervisors to determine whether a proper work norm has been followed and whether a dam's construction progress is satisfactory.

Without the availability of catchment outflow data and coupled with highly erratic rain events, any newly constructed dams in Karamoja will have to be monitored and modified throughout its operational lifespan, especially the first few years. This includes deepening the reservoir, adding/modifying spillway and embankment, creating water diverting channels/earth bunds to increase inflow to the reservoir. The success of the crucial future monitoring and maintenance tasks will depend on the strength of the leadership of each dam project's management committees.

**Dam projects technical info and specific recommendations**
A total of 26 dam project sites were visited by the author. Table in the following pages lists some of the technical information and specific notes and recommendations for each dam project.
<table>
<thead>
<tr>
<th>Dam project Village</th>
<th>workers</th>
<th>Reservoir Volume (m³)</th>
<th>Infiltration (mm/10 min)</th>
<th>Soil Composition</th>
<th>Holding water at time of site visit?</th>
<th>Catchment area/inlet</th>
<th>Action (C=compact soil, D = deepen reservoir, S=spillway, IH=increase wall height)</th>
<th>Comments and critical concern (if any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir</td>
<td>46</td>
<td>1800</td>
<td>1mm</td>
<td>dark clay</td>
<td>full of water</td>
<td>natural gully inlet, chaco dam style</td>
<td>C, D, S, IH</td>
<td>currently trying to drain standing water so construction can continue</td>
</tr>
<tr>
<td>Moruangisigiria</td>
<td>36</td>
<td>1000</td>
<td>2mm</td>
<td>dark clay sand, hard to determine ratio</td>
<td>yes</td>
<td>plenty of water flow signs</td>
<td>C, D, S, IH and move 1 tip of U so it's not blocking water from entering</td>
<td>there is a natural bank on one side of the dam, advised to remove one of the U legs and make natural bank be part of dam.</td>
</tr>
<tr>
<td>Nalebeny D12</td>
<td>38</td>
<td>1250</td>
<td>Couldn’t do test bec of standing water</td>
<td>dark clay</td>
<td>full of water</td>
<td>locals say plenty of water flow from the &lt;3% slope</td>
<td>C, D, IH and move both tip of U so it’s not blocking water from entering</td>
<td>currently trying to drain standing water so construction can continue</td>
</tr>
<tr>
<td>Lemugete</td>
<td>49</td>
<td>1000</td>
<td>Couldn’t do test bec of standing water</td>
<td>dark clay</td>
<td>full of water</td>
<td>&lt;2% slope, signs of good water flow</td>
<td>C, D, S, IH</td>
<td>currently trying to drain standing water so construction can continue</td>
</tr>
<tr>
<td>Natipem</td>
<td>45</td>
<td>600</td>
<td>Couldn’t do test bec of standing water</td>
<td>dark clay</td>
<td>full of water</td>
<td>natural gully inlet, chaco dam style</td>
<td>C, D, S, IH</td>
<td>currently trying to drain standing water so construction can continue</td>
</tr>
<tr>
<td>Toroi Central</td>
<td>123</td>
<td>1287</td>
<td>&gt;20mm, second test 2mm (total saturated soil)</td>
<td>fine sandy soil, small amount of clay</td>
<td>yes but a small shallow area only (after recent big rainfall)</td>
<td>decent sized catchment, but not much signs of water flowing</td>
<td>Deepen reservoir when there is no standing water.</td>
<td>This reservoir is made like an evaporation pond...and the main problem is that there are no signs of water flowing in.</td>
</tr>
<tr>
<td>Location</td>
<td>Code</td>
<td>Level (m)</td>
<td>Basin Size (m)</td>
<td>Water Size (m)</td>
<td>Condition</td>
<td>Findings</td>
<td></td>
<td></td>
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<tr>
<td>Toroi West</td>
<td>88</td>
<td>1144.53</td>
<td>&gt;20mm, couldn't do second test</td>
<td>couldn't get sample due to full reservoir</td>
<td>yes, almost full level</td>
<td>good natural gully inlet, chaco dam style, spillway needed, nicely capturing all water flow from a seasonal gully way.</td>
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<tr>
<td>Leleokot D23</td>
<td>154</td>
<td>1221</td>
<td>3mm</td>
<td>sandy clay</td>
<td>yes</td>
<td>rock catchment from steep hillside one significant rock, compacting, spillway, increase bank height, locals do a good job of compacting. First observed instance of it.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ligot</td>
<td>120</td>
<td>600</td>
<td>4mm</td>
<td>reddish 50% sandy soil</td>
<td>few spots</td>
<td>catchment area very wide, C, D, S, IH, and move U tips so they don't block water from entering, slight concern with infiltration rate, worth a revisit to see if holding water after recent heavy rain</td>
<td></td>
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</tr>
<tr>
<td>Nariwose</td>
<td>181</td>
<td>1250</td>
<td>3mm</td>
<td>40% sand 60% silt+clay</td>
<td>few spots</td>
<td>good catchment, with good water flow, C, D, S, IH, recently overtopped by heavy rainfall. Locals repairing washed away dam wall</td>
<td></td>
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<tr>
<td>Nariwore</td>
<td>94</td>
<td></td>
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<tr>
<td>Kalapata</td>
<td>95</td>
<td>750</td>
<td>&gt;20mm</td>
<td>82% sand</td>
<td>tiny spots</td>
<td>very steep foothill, After revisits confirmed no water holding due to high sand content. Unfortunately this dam is a wasted effort</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locherep</td>
<td>181</td>
<td>3150</td>
<td>1mm</td>
<td>30% silt + sand, 70% silt + clay</td>
<td>standing water at the deeper end</td>
<td>huge catchment area, Move tips of U so they aren't blocking water from entering. Dig only half of the reservoir deeper, standing water may prevent construction progress, dam is way too big. Built like evaporation basin.</td>
<td></td>
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</tr>
<tr>
<td>Location</td>
<td>Code</td>
<td>Depth</td>
<td>Soil Type</td>
<td>Water Presence</td>
<td>Slope Conditions</td>
<td>Measures to Consider</td>
<td>Notes</td>
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<tr>
<td>Lochom</td>
<td>154</td>
<td>1250</td>
<td>dry, clay</td>
<td>yes, decent size pool of standing water</td>
<td>&lt;5% slope, natural grass silt trap, signs of water flowing</td>
<td>compacting, spillway, increase bank height</td>
<td>standing water may prevent construction progress</td>
<td></td>
</tr>
<tr>
<td>Longaro D3</td>
<td>3750</td>
<td>1mm</td>
<td>50% silt + clay, 50% sand</td>
<td>standing water at isolated dug outs</td>
<td>decent sized catchment</td>
<td>current planned reservoir far too large. Advised digging only half of the undug planned area. Tip of U maybe blocking water from flowing in.</td>
<td>standing water in dugouts prevent construction progress</td>
<td></td>
</tr>
<tr>
<td>Usake D10</td>
<td>300</td>
<td>10mm</td>
<td>sandy soil</td>
<td>no</td>
<td>tiny, no signs of water flowing</td>
<td>advised not to carry out further work due to wasted efforts. Unsuitable site with sandy soil, tiny catchment, no signs of water flow</td>
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<tr>
<td>Narube D11</td>
<td>1500</td>
<td>1mm</td>
<td>clayey</td>
<td>yes</td>
<td>decent with standing water on shallow depressions</td>
<td>move tips of U so they aren't blocking water from entering. Also dig only half of the reservoir deeper</td>
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<tr>
<td>Nariamaoi D12</td>
<td>648</td>
<td>clayey full of water</td>
<td>Good</td>
<td>C, D, S, IH</td>
<td>standing water may prevent construction progress</td>
<td>Standing water may prevent construction progress</td>
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<tr>
<td>Tulelo D14</td>
<td>800</td>
<td>clayey full of water</td>
<td>Good</td>
<td>C, D, S, IH and move 1 tip of U so it's not blocking water from entering</td>
<td>standing water may prevent construction progress</td>
<td>Standing water may prevent construction progress</td>
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<tr>
<td>Nariwose D18 (sidok)</td>
<td>1400</td>
<td>clayey full of water</td>
<td>good, signs of water flow</td>
<td>C, D, S, IH</td>
<td>currently trying to drain standing water so construction can continue</td>
<td>Existing dam rehabilitation, advised to dig a 20m semi circle 1.5m deeper within the current huge reservoir. Locals claim dam was filled before. In process of digging a diversion ditch to catch water runoff from road side channel. Locals has very strong opinion on wanting a big dam, does not want to listen to consultant’s advise of making just a 3rd of the current reservoir deeper. This will be</td>
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<tr>
<td>Loroyo (in Kaped) D19</td>
<td>3522.4</td>
<td>sandy clay</td>
<td>no, signs of water evaporation</td>
<td>one water diverting channel</td>
<td></td>
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<tr>
<td>Location</td>
<td>Test Date</td>
<td>Depth</td>
<td>Test Result</td>
<td>Water Description</td>
<td>Notes</td>
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<tr>
<td>Narionomoru D20</td>
<td>1903.5</td>
<td></td>
<td>Couldn't do test bec of standing water</td>
<td>clayey, full of water, clear signs of water flow</td>
<td>C,D,S,IH, very good local knowledge. Claims water always filling up</td>
<td></td>
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<tr>
<td>Loit D21</td>
<td>1440</td>
<td>5mm</td>
<td>standing water</td>
<td>somewhat sandy reddish silt/clay, Anecdotal evidence suggests reddish sand/clay mixture does not hold water well in karamoja region, some standing water in the natural shallow pond/depression</td>
<td>C,D,S,IH, very hilly hillside, some signs of water flow. No easy way to increase runoff to pond. Try to make a deep, small reservoir next to the existing pond, drain shallow water over, then dig deeper the existing shallow pond. This is a natural depression that’s very shallow and filled with water. The rain has been heavy but the locals say the water level hasn’t risen above the current level or in past years’ observation (never overflowing). A natural pond’s water level will not increase assuming normal rainfall. Best thing community can do is deepen existing natural depression to minimize evaporation losses. Building a huge dam around it is a complete wasted effort!</td>
<td></td>
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<tr>
<td>Locali east D22</td>
<td>1150</td>
<td></td>
<td>Couldn’t do test bec of standing water</td>
<td>29% sand, 71% silt + clay, standing water</td>
<td>C,D,S,IH, and move U tips so they are not blocking water, currently trying to drain standing water so construction can continue</td>
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<tr>
<td>Dangasil D24</td>
<td>1470</td>
<td>3mm</td>
<td>standing water</td>
<td>10% fine sand, 90% silt + clay, big &gt;5% sloping catchment</td>
<td>C, D, S, IH, Field staff claims too much water flow, inlet being blocked so construction can continue</td>
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<tr>
<td>Moriunyang D25</td>
<td>980</td>
<td>2mm</td>
<td>little pools of water</td>
<td>red soil, 46% sand, 54% silt + clay, decent catchment</td>
<td>C, D, S, IH, field staff claims small puddles of water been standing for 3 weeks</td>
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<tr>
<td>Napangimoe D26</td>
<td>1750</td>
<td>Couldn’t do test bec of standing water</td>
<td>41% sand, 59% dark silt + clay</td>
<td>standing water</td>
<td>gully way going into reservoir</td>
<td>C,D,S, IH</td>
<td>sinking ground near dam inlet is a concern, field staff instructed on moving dam wall and sloping current eroded sinking ground to minimize effects. One section of dam visibly seeping, likely due to piping of uneven material buried under un-compacted embankment</td>
<td></td>
</tr>
</tbody>
</table>
References:

1. Erik Nissen-Petersen, Water From Small Dams, Danish international development assistance (Danida), 2006.