Report

Rehabilitation/Upgrading of Small Earth Embankment Dams

South Eastern Limpopo Province

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of

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for

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9-08-2003

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(Options 1A and 1B)

Increasing the Capacity of Earth Embankment Dams

Scope and Synopsis

Option 1 evaluates the technicalities and costs of upgrading/rehabilitating 50 small earth embankment dams in South Eastern Limpopo Province with a view to providing *an increased supply of water for the purpose of cultivating vegetables, and for providing drinking water for cattle.*

The increase in capacity can be achieved by increasing the depth of the reservoirs by bulldozing out the accumulated sediment and if need be some of the underlying earth, thereby increasing the depth of the dam's existing basin by approximately 2m (Option 1A). While this operation is a relatively simple bulldozing exercise, the volumes of earth to be removed are considerable. An alternative method of achieving increased storage capacity is to raise the height of the embankment (Option 1B). In this case the earth to be moved is an order of magnitude less, but clearly the supervisory input required to ensure a well engineered structure is substantially greater.

Nomenclature

The *earth embankment* is the structure that impounds the water.
The *crest* is the top of the earth embankment.
The *reservoir* is the body of water that is impounded by the earth embankment.
The *basin* is the floor of the reservoir.
The *spillway* is the structure on one of the side of the embankment that allows water to pass around the spillway.
The *freeboard* is the vertical distance of the embankment's crest above the maximum reservoir water elevation adopted for the spillway design flood.
The *dam* is the sum of all of the above components. This follows a terminology often used in South Africa, which in my view is more user friendly than the international understanding for the word dam, which restricts the meaning of the word to the embankment and the spillway structures and excludes the impounded reservoir and basin).
Full supply level, FSL is that level in the reservoir at which the spillway begins to discharge water downstream.

Background and Purpose

To safeguard the livelihood of many communities living in a zone on the western flank of the Kruger National Park, the NGO Ukwakhisana are leading a drive to increase the water storage capacity of approximately 50 small earth embankment dams in the area.

On 30-07-03 four earth embankment dams (see table 1) were inspected by Paul de Bruyn (Ukwakhisana), Dave du Toit (Barlows Equipment), Ian Johnstone (Consultant to Barlows), and Nicholas Papenfus (Dams for Africa).

The inspection confirmed that all the dams are relatively small structures intended to serve the local communities with water for their livestock, and in some cases there is also an intension to irrigate vegetable gardens.

By increasing the storage capacity of the dams, it is possible to use the dams to cultivate *vegetable gardens* on a far wider scale – which covers the bases of food security, poverty alleviation and skills development. At the same time the dams will continue to provide a source of *drinking water* for cattle, and the increased depth of the dams will mean a much more secure supply.

The Importance of Depth

In South Africa the rate of evaporation varies between 1m to 3m per year, depending on such factors as ambient temperature, wind, and humidity. For most parts of the country a figure of 2m per annum is a reasonable assumption. What this means is that if it does not rain for a full year, the level in the average rural livestock dam may be expected to drop by 2m. However, for any given dam the level will drop by 2m in less than a year depending on (1) how much is used for cultivation of vegetables, (2) how much water is consumed by livestock and (3) how much water seeps into the ground to replenish the surrounding water table. From this it is evident that a dam that has a depth of less than 2m is likely to dry up completely in a year if there are no significant inflows. This is illustrated by the dam in figure 1. It is now completely dry as it only has a maximum depth of 1,5m relative to its overflow or FSL level (full supply level). On the other hand the dam in figure 2, which has a depth of 2,6m relative to FSL, still has some water.

Figure 1 – A view of the Huntington community dam. The upstream embankment of this dam has noticeable erosion and there is evidence that it has been breached at one point, which implies an inadequate spillway. The reservoir is completely dry, which is not surprising given that it only has depth of 1.5m relative to the spillway.

Figure 2 – A view of the Newington C dam. This dam still has approximately 700mm water left in it. The photograph is taken from the start of the spillway, and the tripod represents the start of the embankment. This dam is estimated to have a depth of 2,6m when full, which explains why there is still some water left in it. (However, it is likely to be almost dry by the time the November rains arrive).

It should further be noted that the depth of evaporation in a given dam is independent of its surface area. Thus the water level in large dams with large surface areas goes down at the same rate as in small dams (or even a small swimming pool) which have much smaller surface areas. Therefore *for a given increase in storage capacity* going deeper is always better than going wider and longer.

Another way of increasing the depth, *and* at the same time significantly increasing the storage capacity of a reservoir, is to increase the height of the dam's embankment. This will involve a lot less movement of earth compared to increasing the depth over the full basin, as the plan area and volume of an embankment is much less than that of the impounded reservoir, generally by one or two orders of magnitude. On the other hand raising the height of the embankment will require greater engineering input, which clearly has a cost implication.

Methodology

Altogether four dams were visited. The first two were completely dry, the last two still had small reserves of water, but their levels should be considered dangerously low, so low that the water may dry up before the November rains, with serious consequences to the stock farmers.

In addition to the visual impression gained, a few strategic measurements were taken of each dam using survey instruments. From this the present storage capacities of the various dams have been estimated, and the projected storage capacities after their basins have been lowered by 2m (option 1A) have also been calculated. (It is assumed that evaporation is 2m/yr). Alternatively the amount of earth required to raise the level of the respective embankments by 2m has also been determined (option 1B), as well as the corresponding storage capacities in the reservoirs. This information is recorded variously in appendices A through C, and is summarized in Table 1.

Appendix A gives the volume of *impounded water* in the respective reservoirs before and after bulldozing the basins 2m deeper (option 1A). The difference between these two amounts reflects the *earth* that has to be bulldozed, and is indicated in bold.

Appendix B gives the volume of *earth* required to raise the height of the dams by 2m (option 1B), and it is clear that this will require much less earthmoving compared to appendix A.

Appendix C is also related to raising the height of the wall by 2m (option 1B), but gives the corresponding volumes of *impounded water*. These volumes are substantially more than in appendix A because the reservoir's surface area is very much increased - note the increase in the dimensions 'b' and 'c' compared to appendix A. Although the values for 'b' and 'c' used here are estimates and require confirmation they are not considered unrealistic. The reservoir basins are assumed to be left untouched, although in practice the material used to raise the embankment will come from the respective basins, and will increase the capacity of the reservoir to that extent.

Table 1 - Lowering the Reservoir basin compared to Raising the height of the Dam

	Impounded Water m^3					
	option 1A lower basin m^3	**option 1B raise dam** m^3	factor			
Huntington Agricultural Dam	37238	105734	2.8	times more water at only only	12.9	% the earth
Huntington Community Dam	21556	79930	3.7	times more water at only only	16.0	% the earth
Newinton C dam	25841	87221	3.4	times more water at only only	14.7	% the earth
Dumphries Dam	33455	107612	3.2	times more water at only only	15.2	% the earth
Average	29523	95124.32	3.2	times more water at only only	14.5	% the earth

	Virgin Earth to be moved out of basin m^3			
	option 1A lower basin m^3	**option 1B raise dam** m^3	**catchment area km^2**	**% option 1B/option 1A** %
Huntington Agricultural Dam	19666	2535	0.40	12.9
Huntington Community Dam	13022	2090	0.50	16.0
Newinton C dam	12279	1810	0.25	14.7
Dumphries Dam	16784	2547	0.80	15.2
Average	15438	2245	0.49	14.5
Average m^3/ km^2 of catchment	31667	4606		

Table 1 summarises the information presented in the above appendices and gives certain ratios. The various volumes of the earth required to construct the dams both for option 1A and option 1B have been averaged for the 4 dams. Considering these averages, it may be seen that raising the height of the embankment (option 1B) relative to excavating the basin (option 1A) creates 3,2 times more stored water requiring the movement of only 14,5% as much earth. All other things being equal, this would imply that option 1B is 22 more times efficient than option 1A in terms of m^3 of stored water relative to m^3 of moved earth.

As well as presenting an average for the m^3 of earth for the two options, table 1 also indicates the km^2 average for the catchment areas of the four dams (i.e. 0,49km^2). It is thus possible to obtain a m^3/ km^2 average, which is shown to be 31667m^3 for option 1A and 4606m^3 for option 1B. This ratio is used in table 3 in section VIII to estimate the m^3 of earth for options 1A and 1B for the other 46 dams that were not visited. The m^3 for all 50 dams are also added in table VIII to give an appreciation of the size of the whole operation.

These quantities will be used by Barlows Equipment to determine the type, size and number of earthmoving machines required in order to execute the work before the rainy season sets in. It should be noted that there are definite economies of scale in having three machines employed simultaneously at different sites, firstly in terms of keeping a low bed employed, and secondly by keeping the essential on site engineering supervision fully occupied.

Option 2

(Options 2A and 2B)

Increasing the Capacity of Earth Embankment Dams to Sustain Cattle

Scope and Synopsis

Option 2 is a scaled down version of option 1 in terms of the quantities of earth to be moved. Here the emphasis is to upgrade/rehabilite the 50 small earth embankment dams with a view to providing a sustainable supply of *drinking water for cattle*, and not necessarily trying to substantially increase the storage capacity of the dam by excavating the whole basin (see option 1A) or raising the height of the earth embankment (see option 1B).

In option 2 sustainability is achieved by increasing the depth of the basin over a relatively small area, thus creating a ‘sink’, which has 1 in 3 sloping sides, manageable for cattle to walk down and up. The sink should be situated at the lowest point in the basin. The rationale for this is that depth in a dam is the best way of lengthening the period before it evaporates dry. The base and surface area of the sink need not be excessively large as cattle consume relatively small amounts water (especially when compared to the irrigation requirements for cultivating vegetables). The operation amounts to a relatively quick bulldozing exercise, which a D7 dozer should be able to complete in two days, given the correct engineering support regarding to levels, slopes and location.

Nomenclature

See option 1 for definitions of *earth embankment, crest, reservoir, basin, spillway, freeboard, dam.*

The *sink* is a relatively small excavated area situated somewhere in the basin of the reservoir, intended to preserve a strategic supply of drinking water for cattle to last through a drought.

Background and Purpose

The background is the same as for Option 1. There is however a shift in purpose. Here the primary objective is to ensure *drinking water for cattle*, and this is achieved by constructing a ‘sink’ at the lowest point in the reservoir’s basin. The community would be free to use the water in the dam for cultivation until such time as the basin is empty and the only remaining water is in the sink. Thereafter the water in the sink should only be used for cattle to drink as the sink does not have sufficient capacity for the relatively high demands of irrigation. At a depth of 2,5m below the floor of the basin the sink is sufficiently deep to withstand a drought for approximately one year.

The Importance of Depth

Refer to the general discussion in Option 1 for the importance of depth in a storage dam. However, whereas in option 1 the additional depth is achieved by increasing either the depth of the whole basin (1A), or alternatively raising the full length of the earth embankment (1B), in option 2 only a relatively small ‘sink’ is excavated in the basin for the exclusive purpose of sustaining cattle with drinking water.

Methodology

In option 2 the primary concern is to ensure that the sink has a sufficient volume of water (and especially depth) to sustain the cattle in the region through a drought. The number of cattle per square kilometer have been calculated in table 2 based on the assumption that there is one ox per 1,5 hectare. This is not sustainable in the long term and results in overgrazing, common in South Africa's rural areas. Normally a figure of one ox to seven hectares is recommended for preserving natural vegetation in relatively arid areas. However for the purpose of ensuring sufficient drinking water it is safer to use the highest known density of animals when determining the capacity of a sink. The higher figure also makes some provision for cattle who graze on other catchments to use the dam.

Having estimated the density of cattle per hectare or km^2, the total number of cattle on any given catchment may be estimated by multiplying the number of cattle per km^2 by the area of the catchment. Finally the water consumed by the cattle on the various catchments is determined by assuming that each of them drinks 60 litres daily (between 40 and 60 litres is normal).

Generally the quantity of water used by cattle is negligible in relation to evaporation, except for the smallest of reservoirs. (In this exercise evaporation is assumed to be 2,0m annually). Hence the rationale of using a small 'sink' of sufficient depth and plan area to overcome evaporation losses. It should be excavated near the deepest point in the basin. (Note that the stated dimensions 'b' and 'c' in table 2 refer to the bottom plan area of the sink, and from this perimeter it will have a gradual 1 in 3 upward slope to ensure that the animals can walk down to the water. This also makes the bulldozer operation practical.

Two different approaches may be considered in deciding on the base area and the depth of the sink, and these will be referred to as Option 2A and Option 2B:

In Option 2A the depth of the sink is determined by the sum of the annual evaporation and the drop in the level in the sink as a result of cattle drinking. In table 2 these figures are 2m and 0,5m respectively, giving a total of 2,5m. The base area has been adjusted to ensure that the quantity of water consumed by the cattle is 0,5m. In Option 2A the top of the sink coincides with the basin of the reservoir. This means that 2,5m of earth will need to be excavated to get to the base of the sink.

In Option 2B the base level of the sink is situated 2,5m below the reservoir's FSL. This in effect means that a sink will only be required if the reservoir is less than 2,5m deep. (Strictly this level could be reduced slightly further as the influence that the cattle have on the level will be negligible until such time as the basin is reduced to the area of the sink, and this length of time will vary depending of the FSL of the dam. However, in the interests of simplicity this refinement will be ignored, and the effect of ignoring this is to slightly increase the length of time before the dam/sink will be empty).

In shallow dams Option 2B is only sustainable if the dam is a dedicated cattle dam, since the sink depths in option 2B are reduced according to degree that the FSL is less than 2,5m above the floor of the basin. On the other hand for deeper dams where the FSL exceeds 2,5m, no sink will be built. This is the case for dams 1 and 13 in option 2B of table 2. The negative figures for the 'total depth of the sink' indicate the extent that the depth of the dam exceeds 2,5.

Table 2 - Earth to Remove for Sink Excavation

Identity Number of Dam	units	1	4	12	13	average
Option 2A - Base of sink to be 2,5 m below reservoir basin						
ha/ox	ha/ox	1.5	1.5	1.5	1.5	
maximum oxen density	oxen/ha	0.67	0.67	0.67	0.67	
max oxen / km2	oxen / km^2	67	67	67	67	
Catchment Area	km^2	0.4	0.5	0.25	0.8	0.49
total max oxen in catchment	oxen	27	33	17	53	
litres/ox/day	lt/ox/d	60	60	60	60	
total water consumed per day	m^3/day	1.6	2.0	1.0	3.2	
water consumed per yr	m^3/yr	584	730	365	1168	
length and breadth of sink at its base	m	34	38	27	48	
equivalent drop in sink level from drinking/yr	m	0.51	0.51	0.50	0.51	
add evaporation/yr	m	2	2	2	2	
Total depth required for sink	m	2.5	2.5	2.5	2.5	
earth to remove for sink excavation	m^3	3323	4095	2161	6379	3989
earth to remove for sink excavation per km2 of catchment	m^3/km^2					8184
Option 2B - Base of sink to be 2,5 m below FSL						
ha/ox	ha/ox	1.5	1.5	1.5	1.5	
maximum oxen density	oxen/ha	0.67	0.67	0.67	0.67	
max oxen / km2	oxen / km^2	67	67	67	67	
Catchment Area	km^2	0.4	0.5	0.25	0.8	0.49
total max oxen in catchment	oxen	27	33	17	53	
litres/ox/day	lt/ox/d	60	60	60	60	
total water consumed per day	m^3/day	1.6	2.0	1.0	3.2	
water consumed per yr	m^3/yr	584	730	365	1168	
length and breadth of sink at its base	m	34	38	27	48	
equivalent drop in sink level from drinking/yr	m	0.51	0.51	0.50	0.51	
add evaporation/yr	m	2.00	2	2	2	
subtract depth to botm of basin	m	3.30	1.50	2.07	4.4	
Total depth required for sink	m	-0.8	1.0	0.4	-1.9	
earth to remove for sink excavation	m^3		2337	1740		1019
earth to remove for sink excavation per km2 of catchment	m^3/km^2					2091

In table 2 the various volumes of the earth required to bulldoze the sinks have been added for the 4 dams for both options2A and 2B (3989m^3 and 1019m^3 respectively). These figures may be manipulated to obtain the average m^3 to be excavated per km^2 of catchment for both options (i.e. 8184m^3 and 2091m^3 respectively). Next these values are used to obtain the m^3 to be bulldozed for all the other dams that were not visited nor surveyed, but for which the size of the catchments have been determined from 1:50000 maps, for both options 2A and 2B. These values are recorded in Table 3 (see section VIII) for each dam and the total m^3 of bulldozed earth for the entire operation is also shown.

Quantities for Earthmoving

The amount of earth that is to be moved in each dam as well as the total for all 50 dams is shown under the headings of ‘option1A’ ‘option 1B’ ‘option 2A’ and option 2B in Table 3. As may be expected, option 1A requires the movement of the most earth, followed respectively by options 1B, 2A, and finally 2B. It must always be kept in mind that the figures for the respective dams are based on extrapolations from the m^3 / km^2 averages of the dams that were surveyed (i.e. dams 1, 4, 12, 13), so that the respective totals are only approximations of the total extent of the work.

These figures will be used by Barlows Equipment to determine the type, size and number of machine required, in order to execute the work before the rainy season sets in. (There are definite economies of scale in having three machines employed simultaneously, firstly in terms of keeping a low bed employed, and secondly by keeping the essential on-site engineering supervision fully occupied). Barlows will determine the number of hours required to complete the work for the various m^3 corresponding to the various options, and this will allow them to apply a R/hours rate to give the total cost. This exercise is done in the next chapter.

Table 3 Volume of Earth to be Moved

dam #	Area of	option 1A	option 1B	option 2A	option 2A
see	catchment	avg m3 from table 1		avg m3 from table 2	
appndx D		31667	4606	8184	2091
	km^2	m^3	m^3	m^3	m^3
1	0.4	12667	1842	3274	836
2	0.3	9500	1382	2455	627
3	1.5	47501	6909	12276	3137
4	0.5	15834	2303	4092	1046
5	1.4	44334	6448	11458	2927
6	1.3	41167	5988	10639	2718
7	0.75	23750	3455	6138	1568
8	3.9	123501	17963	31918	8155
9	1.1	34834	5067	9002	2300
10	2.2	69667	10133	18005	4600
11	1.7	53834	7830	13913	3555
12	0.25	7917	1152	2046	523
13	0.8	25334	3685	6547	1673
14	1.5	47501	6909	12276	3137
15	2.6	82334	11976	21278	5437
16	0.6	19000	2764	4910	1255
17	64.8	2052022	298469	530323	135497
18	1.1	34834	5067	9002	2300
19	2.6	82334	11976	21278	5437
20	2.3	72834	10594	18823	4809
21	8.7	275503	40072	71201	18192
22	1.2	38000	5527	9821	2509
23	12.5	395838	57575	102300	26138
24	2.4	76001	11054	19642	5018
25	2.3	72834	10594	18823	4809
26	0.4	12667	1842	3274	836
27	2.8	88668	12897	22915	5855
28	0.6	19000	2764	4910	1255
29	3.1	98168	14279	25370	6482
30	8.1	256503	37309	66290	16937
31	3.8	120335	17503	31099	7946
32	9.9	313503	45599	81022	20701
33	0.8	25334	3685	6547	1673
34	1.1	34834	5067	9002	2300
35	0.3	9500	1382	2455	627
36	1.7	53834	7830	13913	3555
37	1.1	34834	5067	9002	2300
38	1.8	57001	8291	14731	3764
39	0.3	9500	1382	2455	627
40	0.7	22167	3224	5729	1464
41	0.6	19000	2764	4910	1255
42	2.3	72834	10594	18823	4809
43	1.9	60167	8751	15550	3973
44	19.1	604840	87975	156314	39938
45	6.6	209002	30400	54014	13801
46	0.4	12667	1842	3274	836
47	0.5	15834	2303	4092	1046
48	0.1	3167	461	818	209
49	1.1	34834	5067	9002	2300
50	1.7	53834	7830	13913	3555
Average		**120018**	**17457**	**31017**	**7925**