Report on a proposed dam with turbine powered pumps and electrical power for a sunflower seed press

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Scope

This proposal considers the technicalities and costs of building a dam on a farm in Mozambique for the purpose of supplying hydroelectricity and water for farming related activities.

Background

In order to stimulate development in the rural areas of Mozambique the government of that country has provided land to farmers with a proven track record in agriculture. There is a river flowing through one of these farms, situated near Chimoio, operated by Mr Braam Cronje. In order to increase the farming operation from 60 Ha to 300 Ha it is proposed that a storage dam be constructed in the river for two purposes (a) to improve the water supply for irrigation and (b) to drive a turbine that supplies torque to a number of irrigation pumps and a 20kVA generator. The generator powers a press that processes oil from sunflower seed. A proposed layout of this arrangement is shown below.

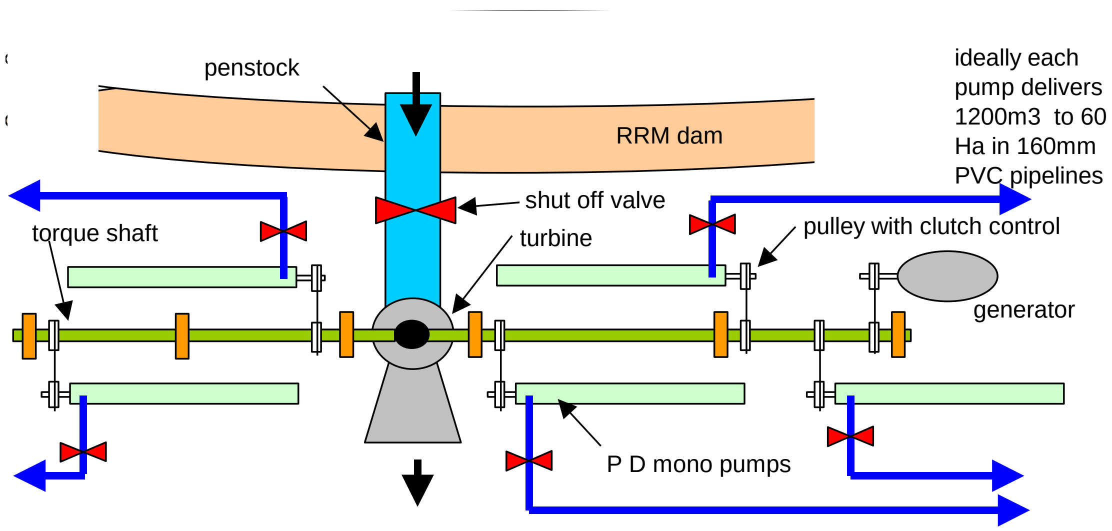


Figure 1 – Plan view of turbine immediately downstream of the RRM dam. It drives a torque shaft, which in turn drives five positive displacement mono pumps and a 20kVA generator. Water is taken to the coffee plantations via 160mm PVC pipelines.

Dam Design

Figures 2 and 3 are sketches of the proposed dam, which DFA have pieced together on the basis of a few readings taken with a GPS instrument by someone that visited the proposed site.

The different elements of the design are:

(a) On the left will be a 220m long **earth embankment**. The embankment is 13m high above ground level at its deepest point, and could be as much as 16m high from the base of the foundation. To construct this embankment a total of 69000m3 of earth must be excavated, transported, levelled and compacted. This can either be done using bulldozers if suitable material is close at hand, or with an excavator-loader and articulated-dump-trucks if the source of suitable earth is further away. The latter option still requires a bull dozer to level the material, and both options require a pad-foot roller for compaction.

A typical cross section of an earth embankment is shown in figure 4, indicating the various elements that typically are included, although the design will in the end be influenced by local conditions and will only be finalised after the investigative stage. In the absence of further imformation, these elements were assumed in arriving at a budget cost.

(b) Closing off the stream will be a **single arch,** probably a cantilever arch, made of Random-Rock Masonry (RRM) that has a pipe at the bottom that serves as the penstock to the turbine. The structure is entirely supported on exposed rock which appears to be minimally fractured, as is evident from figure 5. Figure 5 also gives an excellent view of the width of the gorge at the proposed site – which is estimated to be 75m.

(c) Interfacing between the RRM arch and the earth embankment there is to be a **buttress** that transfers the concentrated compressive load in the arch to the rock foundation.

(d) On its right the earth embankment is to be confined by a RRM **retaining wall**. Note that the rock that will be used to construct the RRM arch, buttress, and retaining wall, will be sourced by blasting the rock flanks of the river some way upstream.

(e) A natural rock **spillway** exists that is estimated to be 30m wide. It requires some relatively minor blasting to achieve the required capacity. The existence of this natural off-stream spillway means that no water need go over the top of the RRM arch, thus preventing flooding of the turbine/pump/generator plant (see figure 1) from above during floods.

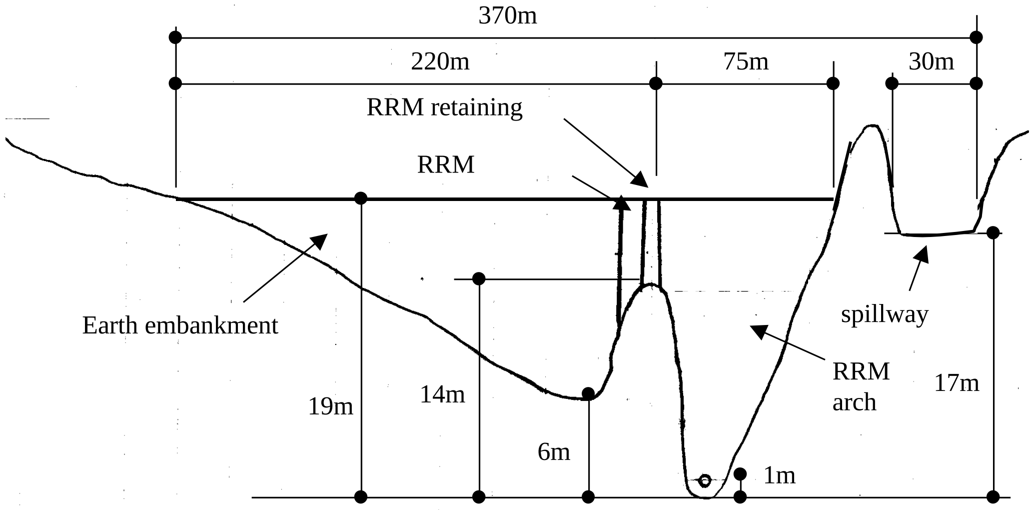
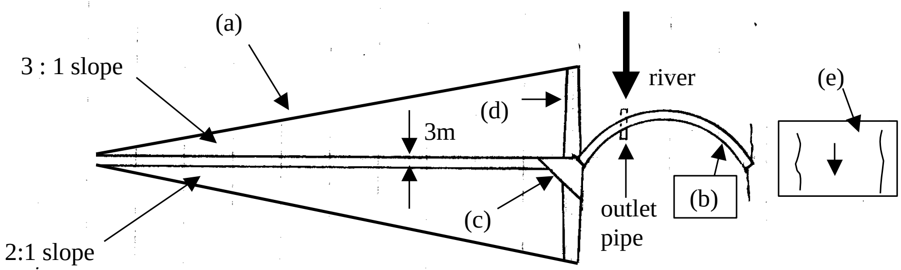


Figure 2 – Front Elevation of Dam. The vertical scale is exaggerated



(a) earth embankment (b) single arch RRM dam (c) RRM buttress (d) RRM retaining wall (e) spillway

Figure 3 – Schematic plan view of dam showing the five elements

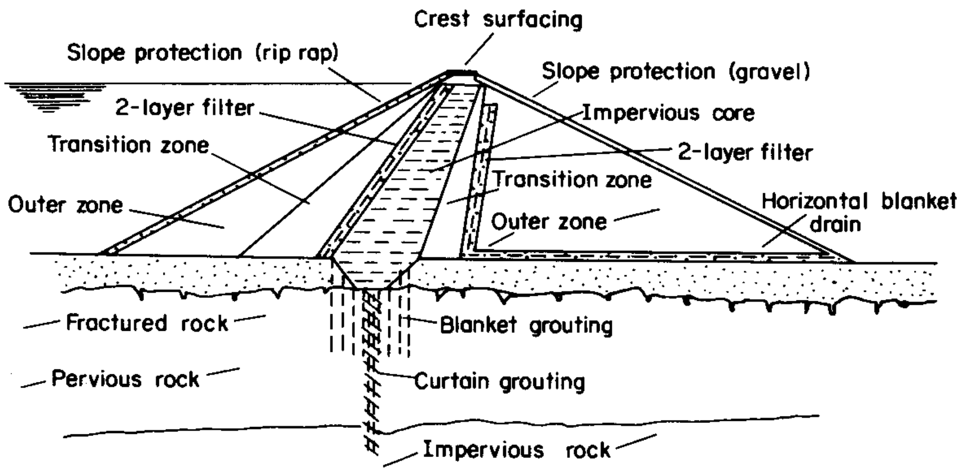


Figure 4 – Section through a typical earth embankment

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Figure 5 – Proposed site for RRM arch. The upstream end is on the left of the photo. The rock appears to be almost free from fractures, and the opposing abutments appear to be suitably angled for the construction of an arch dam.

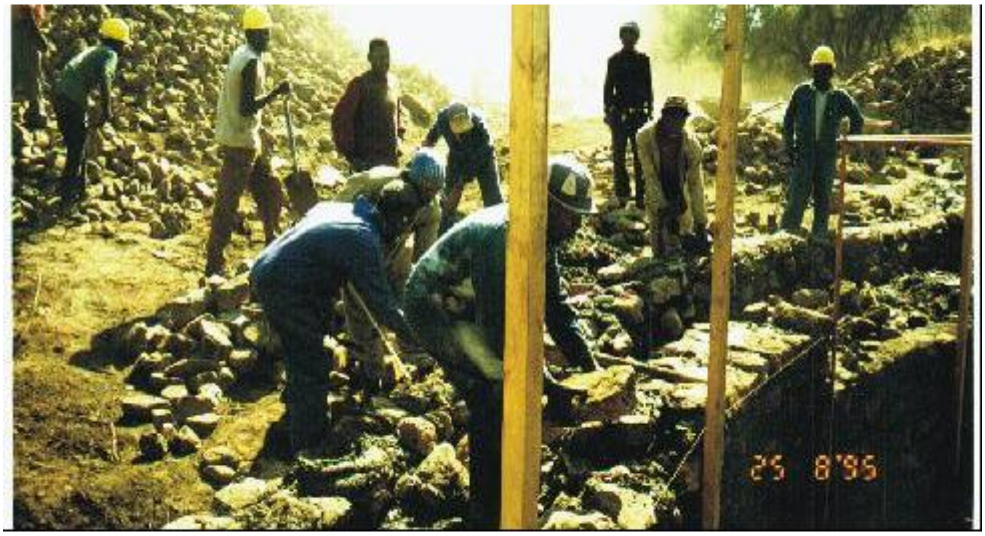

Figure 6 Example of a dam being constructed with RRC from rock that has been blasted. The tools are simple and the process is labour intensive.

Investigative phase

Prior to the final design of the earth embankment and the RRM structures, an investigation of the naturally occurring materials on site is essential.

1. **Earth embankment** : The design of an earth embankment dam largely depends on the characteristics of the ground that is available near the site. A number of trial pits will be required where the structure is to be founded, and at the sites where the clay for the impervious core is to come from, and at the sites where the granular material is sourced that is to make up the outer shoulders.

   From these exploratory holes samples should be taken and sent off for *laboratory testing*. Tests should be done to : (a) determine the porosity of the foundation, its density, shear strength, bearing capacity (b) classify the clay in terms of its plastic limit and liquid limit and pore pressure dissipation (c) determine the grading of the borrow pit materials & permeability (d) determine the shear strength of the material that makes up the outer shoulders (e) establish the consolidation properties of the foundation and embankment (f) determine the compactibility of the embankment material and the ideal moisture content for compaction.

   Insitu tests on the foundation material such as an insitu shear box test, vane tests and dynamic cone penetrometer tests will be very valuable in determining the founding depth. Insitu permeability testing should also be done.

2. **RRM structures** : The single span arch, the buttress and the retaining wall are all to be built by a form of construction that may be referred to as Random Rock Masonry. As the name implies, the primary material in this form of construction is rock of random size and orientation. It is placed with mortar in much the same way as other forms of masonry, but with a degree of care to pack the voids between larger rocks with smaller rocks and mortar, so as to ensure that no passages are created for water to go through. In the absence of an abundant supply of small rocks in the river bed, which appears to be the situation at this site, rocks may be obtained by blasting from the river bed or banks some distance upstream. Figure 6 shows a dam being constructed from RRM using rocks that were obtained in this way. By using correct blasting techniques it is possible to ensure that the majority of the rock fragments are a manageable size for a RRM structure, i.e. between 100m and 250 mm. It is essential that an experienced blasting specialist inspects the nature of the rock, its density, the spacing and orientation of joints and fractures, blastibility factor, ultimate compressive strength etc.), and with the aid of specialized software determine the diameter and depth of the holes, the burden, the spacing of the holes, the type of explosive, packing density, stemming length, the sequence of detonating, safety measures, etc.

   The blasting specialist and an experienced civil engineer should also assess the site where the dam is to be founded in regard to the bearing and shear strength of the material, and especially the degree that cracks and fissures may allow uplift pressure to develop. The visual *impression* gained from figure 5 is that the rock is very sound and that the jointing structure is unlikely to allow the development of uplift forces. Clearly a close examination of the exposed rock in the river bed and abutments is required to confirm this, and to determine the ideal position and angle for the arch, or (cantilever arch).

A suitable mortar sand should be sourced. This may be a blend of river sand and suitable pit sand sourced in the vicinity.

Finally the quality, availability and cost of cement should be investigated.

3. **Hydrological Investigation :** The residual (minimum) flow in the stream should be established, as well as the high flow. The number of months that low flow and high occur should also be determined. The size of the catchment area (in km2) should be measured, and the potential storage capacity of the dam should be established using survey instruments.

4. **Cost** : Table 2 shows that an amount of R150000 has been allowed for the initial investigation to cover the costs relating to laboratory testing, travelling costs and professional fees of specialists.

Turbine, Pumps, Pipelines, Generator, Press and Irrigable Land

1. **Turbine**

Table 1 shows how the turbine, pumps, generator (for the oil press), and pipelines to irrigable land are related to one another.

Two turbine models of the cross flow design are considered, CF315 and CF 395. From line 7 it may be seen that CF 315 is adjustable in terms of its flow rate, while model CF395 has the greater capacity.

From figure 2 it is evident that the full supply level of the dam is 17m, i.e. the height of the spillway above the base of the dam. A drop in the level of 1,0m is selected as the maximum allowable drop before a level control switch shuts down a motorised valve that allows water into the turbine. This done the level of the water will steadily rise again. The following day the turbine operation may be restarted.

Table 1 shows that the presumed minimum flow in the river of 0,08 m3/s, is much less than the flow requirement of any of the turbines. On the other hand, during high flow (see table 1), there is more than sufficient flow to operate any of the turbine models continuously without depleting the level of the dam. In fact excess flow will make its way over the spillway.

The output shaft of the turbine drives a differential that is connected to a shaft mounted on plumber blocks. Pulleys are mounted to the shaft connected to other pulleys mounted on the corresponding output shafts of 5 positive displacement mono pumps. A sixth pulley is connected to a generator, that supplies the sunflower oil press.

The concept of driving the pumps directly from the turbine without first converting its output torque into electrical energy (via a generator), and then back into mechanical energy (via an electrical motor) significantly improves the efficiency of the system. Only in the case of the remote sunflower oil press is it necessary to generate power, but clearly the generator can be much smaller and cheaper.

2. Pumps

The arrangement of the five mono pumps is shown in figure 1. They have the capability of pumping up to heads of 100m, and when pumping against the design head of 60m , a flow of 54m3/hour/pump may be expected, absorbing 12.54kW of power. Water discharged into a pool below the turbine's tailrace is piped to the suction side of each pump, while 160mm pvc pipes are connected to the delivery side. A clutch arrangement engages each pump as required, as well as the generator.

Note that the heavy duty monopump selected is the largest in the range, and to achieve a flow rate that will allow 300 Ha to be irrigated, five pumps are required. However, there are distinct advantages to using five pumps:

- it allows five independent pipelines, each with its own pump, to be routed to different parts of the 300Ha plantation.
- if one pump breaks down, only 20% of the irrigation is affected.
- the pumps are relatively inexpensive
- they are relatively light and therefore simple to install and exchange

Finally it should be noted that the output of a positive displacement pump (e.g. monopumps) is directly related to its rotational speed, only losing performance in direct proportion to its loss of speed. On the other hand the performance of a centrifugal pump reduces drastically if its revolutions are reduced, as may happen if the dam is say only half full.

3. Generator

With the pumps being driven directly from the turbine via a torque shaft, only a relatively small 25kVA generator is required to produce sun flower oil from a press. (While the press only uses 20kW, allowance must be made for losses in the cable, given that the press is remote to the generator). As shown in figure 1, the generator is also driven by the torque shaft connected to the turbine.

The model C395 turbine generates sufficient torque for all five pumps and generator to operate – continuously in full flow conditions, but less than two hours each day when 'residual flow' conditions prevail. On the other hand the C315 model has less torque and requires that one of five pumps must be declutched before the generator is engaged. In practice this is not likely to be a serious draw back as it is unlikely that irrigation can take everywhere simultaneously. In residual flow conditions the system can operate between three to four hours depending on how much water is being used.

4. Pipelines

Each of the mono pumps has a class 6 x 160mm diameter pvc pipeline connected to its delivery port, as shown in figure 1. Each pipeline supplies 60 Ha, and is assumed to be 1km long. Therefore the total length of the pipeline used to estimate the cost of bringing water to 300 Ha is 5000m. The cost of this is reflected in table 2.

5. Press

The 20kW press is remote to the turbine/generator and should be supplied with an electrical cable that limits losses.

6. Irrigated land

The total number of irrigable hectares may now be calculated, once it is known how many m^3 of water is required daily to irrigate one hectare. Clearly this will depend on the crop selection, and it is understood that for coffee, the proposed crop, this figure is 20m3/day/ha.

In table 1 the inter-relation of the various components of the complete system of turbine-pump-pipeline is shown relative to the target irrigable quantity of land of 300Ha.

Construction Period

The investigative phase is likely to take two weeks, and the various tests and reports and designs another one to two months. The duration of the construction/commissioning phase is likely to be four to six months.

1	**Table1 - Relationship between Turbine, Pump, Pipelines, Press and Irrigable Land**								
		Residual flow				**High flow**			
3	**Turbine**								
5	Model of Turbine	*CF315*	*CF315*	*CF395*		*CF315*	*CF315*	*CF395*	
6	Characteristic head on turbine	*9*	*9*	*9*	*m*	*9*	*9*	*9*	*m*
7	Corresponding characteristic flow in turbine	*0.360*	*0.530*	*0.840*	*m^3/s*	*0.360*	*0.530*	*0.840*	*m^3/s*
8	Full supply level of dam relative to base of dam	*17*	*17*	*17*	*m*	*17*	*17*	*17*	*m*
9	Allowable drop in FSL before closing down turbine	*1*	*1*	*1*	*m*	*1*	*1*	*1*	*m*
10	Minimum supply level for turbine to operate	16	16	16	m	16	16	16	m
11	Turbine height above base of dam	*1*	*1*	*1*	*m*	*1*	*1*	*1*	*m*
12	Net head on turbine	*15*	*15*	*15*	*m*	*15*	*15*	*15*	*m*
13	Corresponding flow in turbine	0.465	0.684	1.084	m^3/s	0.465	0.684	1.084	m^3/s
14	*Assumed Minimum Flow in the river*	*0.08*	*0.08*	*0.08*	*m^3/s*	*0.465*	*0.684*	*1.084*	m^3/s
15	Volume of river inflow into dam per day	6912	6912	6912	m^3/day	40155	59117	93695	m^3/day
16	Turbine hrs to deplete daily river inflow	4.13	2.81	1.77	hrs/day	24.0	24.0	24.0	hrs/day
17	Estimated Turbine efficiency	*75*	*75*	*75*	*%*	*75*	*75*	*75*	*%*
18	Turbine power	51.3	75.5	119.7	kW	51.3	75.5	119.7	kW
20	**Pumps**								
22	**Number of pumps**	3	5	5		3	5	5	
23	Total head to be pumped	*60*	*60*	*60*	*m*	*60*	*60*	*60*	*m*
24	Power absorbed by pumps - Howden	37.6	62.7	62.7	kW	37.6	62.7	62.7	kW
25	Pump efficiency - Howden	*70.4*	*70.4*	*70.4*	*%*	*70.4*	*70.4*	*70.4*	*%*
26	Delivery of pumps at 939 rpm - Howden	0.045	0.075	0.075	m^3/s	0.045	0.075	0.075	m^3/s
27	Duration of pumping (governed by turbine)	4.13	2.81	1.77	hrs/day	24.00	24.00	24.00	hrs/day
28	Total water pumped	669	758	478	m^3/day	3888	6480	6480	m^3/day
30	**Irrigated Land**								
32	Water required per hectare (20m^3/ha for coffee)	*20*	*20*	*20*	*m^3/Ha/day*	*20*	*20*	*20*	*m^3/Ha/day*
33	Irrigable hectares pumped	33.5	37.9	23.9	Ha/day	194.4	324.0	324.0	Ha/day
34	Target hectares to be irrigated	*300*	*300*	*300*	*Ha*	*300*	*300*	*300*	*Ha*
35	Capacity of system wrt demand	11.2	12.6	8.0	%	64.8	108.0	108.0	%
37	**Sunflower Seed Press**								
39	Surplus power available after pump's consumption	13.7	12.8	57.0	kW	13.7	12.8	57.0	kW
40	Additional power if not starting 1 pump	12.54	12.54	12.54	kW	12.54	12.54	12.54	kW
41	Corresponding available power for generator/press	26.2	25.4	69.5	kW	26.2	25.4	69.5	kW
43	**Frictional losses/km/pipeline**								
45	number of pipelines	3	5	5		3	5	5	
46	frictional loss in 125mm diameter pvc	13.4	13.4	13.4	m	13.4	13.4	13.4	m
47	frictional loss in 160mm diameter pvc	4.2	4.2	4.2	m	4.2	4.2	4.2	m
48	frictional loss in 200mm diameter pvc	1.4	1.4	1.4	m	1.4	1.4	1.4	m
49	frictional loss in 250mm diameter pvc	0.5	0.5	0.5	m	0.5	0.5	0.5	m
50	frictional loss in 300mm diameter pvc	0.2	0.2	0.2	m	0.2	0.2	0.2	m

Provisional Cost Estimate

A considerable amount of effort has been put into obtaining a realistic price estimate for the construction of the dam. From Table 2 it may be seen that the various components of investigation, establishment, design, construction, installation and commissioning are estimated at R 4 407 351. However, if suitable ground is not found within bulldozer range and an excavator and ADT haulage trucks must be used instead, then an additional cost of R 543 254 may be incurred – based on a haulage distance of 500m. Clearly however, these figures will be revised after the site investigation, currently they represent a very approximate analysis of costs, for fundraising purposes.

Table 2 - Provisional Cost of Chimoio Dam

Description	unit	unit cost	option 3 qty	cost	
Investigative phase					100000
Site Establishment in Mozambique					150000
Dam Walls					
Foundations - provision to grout cracks	lot			75950	
Steel reinforcing for cantilever arch	lot			84248	
RRM buttress/retaining wall	m3	710	174	123540	
RRM single span cantilever arch wall	m3	710	1329	943576	1227315
Earth embankment					
Earth embankment	embankmt	1	1200000	1200000	
Strip drains - 150mm pvc pipe	m	26.99	2000	53980	
Strip drains - sealmac geofabric	m	5.14	2000	10280	
Strip drains - filter sand	m3	50	825	41250	
Chimney drain - 400mm filter sand	m3	50	1408	70400	
Rock protection - 500mm	m3	50	2200	110000	1485910
Spillway	m3	750	25	18750	18750
Consulting fees on dam	%	15	2981975	447296	447296
Hydro Electricity - CF315 turbine and generator complete installed and commissioned	ea	532500	1	532500	532500
Outlet pipe					
Outlet pipe - 4m x 1m steel pipe	ea	8000	1	8000	
Outlet pipe - Valves	various	40000	1	40000	
Outlet pipe - blanking plate	ea	2000	1	2000	50000
250 HD Mono pumps incl clutches	ea	18000	5	90000	90000
160mm Pipelines	m	5000	61.116	305580	305580
Grand total excl VAT					4407351
Additional for Excavator/Hauler option if no suitable ground is available within bulldozer range					543254

Conclusion

This report has discussed the costs and technicalities of building a dam to provide storage water for irrigation, mechanical turbine power to drive irrigation pumps and a generator (for a sunflower oil press). It recommends that an investigative study be undertaken to enable the design of the dam and to establish local conditions with greater certainty.