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CASE PROFILE COLLECTION No 5

< SUBSURFACE DAMS TO AUGMENT GROUNDWATER STORAGE IN BASEMENT TERRAIN FOR HUMAN SUBSISTENCE – BRAZILIAN EXPERIENCE >

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The objective of this initiative was to evaluate the technical strategy, social benefits and economic effectiveness of the construction of so-called underground dams to augment aquifer storage in semi-arid basement terrains with extremely limited natural groundwater resources and high drought propensity. This is considered a possible low-cost technology that could aid the rural poor in their battle for subsistence in such areas. The study was carried out, under the direction of GW-MATE, in northeastern Brazil by the UFPE, and this profile summarizes the field conditions and the principal findings, which are of broader geographical relevance, notably to various parts of Sub-Saharan Africa with similar hydrogeological conditions.

Hydrogeological Field Conditions

- The part of northeastern Brazil selected for this study was the *agreste* and *sertão* areas of the interior of Pernambuco State, where about 500 small underground dams were constructed during the 1990s. These represent the main national experience of this technology.
- This sub-region encompasses some 88,000 km^2 with a population density generally in the range 25-75 persons/km^2 Its climate is semi-arid with an average precipitation below 600 mm/a, with an extended dry season from August to December (Figure 1), high drought propensity and a potential evaporation of above 2,000 mm/a.
- Most of this extensive sub-region is underlain by crystalline basement rocks, which do not have preserved a deep weathered mantle and are of extremely low groundwater transmission and storage capacity. The terrain has a subdued but significant relief and the occurrence of groundwater is for the most part restricted to thin coalluvial and alluvial deposits in small valleys, whose streams flow only for limited periods after major rainfall episodes usually in March-May.
- Over parts of the sub-region saline soils are developed and their presence can lead to significant levels of groundwater salinisation, which can be further aggravated by direct evaporation when impoundment results in shallow water-table.

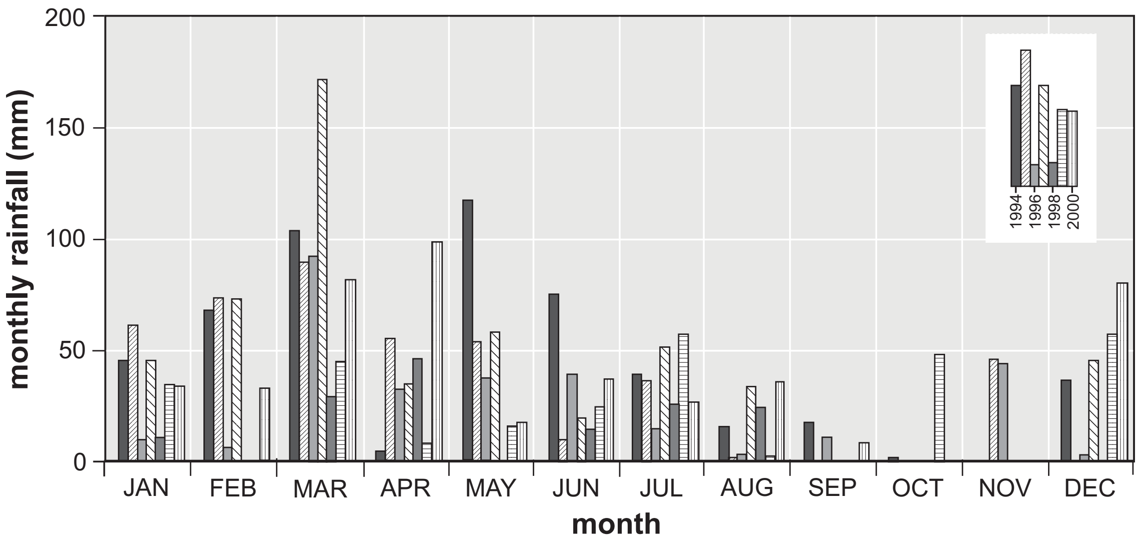

Figure 1: Variation of monthly rainfall over annual cycle for 1994 – 2000 at a typical site in the field area

Dam Concept & Construction

- During the 1990s many underground dams were constructed in the sub-region and these fall into three main categories:
    - small structures up to 3 m deep constructed under 'government drought emergency job-generating programmes' (Figure 2) at sites selected by municipal committees without technical advice and follow-up; they were manually excavated, incorporated plastic membranes and a large-diameter concrete-ring waterwells
    - similar-sized structures constructed under local initiative by NGOs with specialist advice, but filled with only recompacted clay and without a well for water abstraction
    - much larger structures up to 10 m depth (in areas of thicker alluvial cover) located by technical criteria and constructed with the aim of supporting small-scale irrigated agriculture in areas with some existing irrigated cultivation; they benefited from the use mechanical excavators and incorporated impermeable plastic membranes, improved large-diameter waterwells and some technical monitoring.
- The climate of the study area is such that the practice of constructing small dams to impound surface water runoff results in very high evaporative losses, and the underground dam is thus an interesting alternative.
- The storage capacity of a typical subsurface dam and reservoir (say in average of 4 m depth, 50 m width and 500 m length) will be some 10,000 m^3, assuming a drainable storage coefficient of 0.10. This is not sufficient for these dams to provide multi-annual regulation, unless usage is only for human and animal consumption. However, intra-annual regulation makes possible the use of water for small-scale irrigation in the dry season, enabling the production of various crops.
- Sites with saline soils should be avoided for dam construction. While reduction in the salt levels through continuous water use is feasible, it requires operational procedures beyond those generally expected of small rural farmers. The periodic drying-out of subsurface reservoirs and/or maintaining there groundwater level well below surface are the best ways to mitigate salinisation tendencies.
- The principal construction problems encountered were :
    - errors in choice of location resulting in insufficient storage potential
    - insufficient depth to reach relatively impermeable bedrock
    - damage to plastic membrane during installation
    - location in a soil type with very low infiltration capacity
    - location in a soil type that could lead to severe groundwater salinization
    - low-yielding well due to poor construction.

Evaluation of Dam Performance

- The field survey work was carried out in two distinct phases. In the initial phase a widely-distributed set of 151 of the known 500 dams were examined, and a preliminary assessment made of their current status, construction problems, groundwater availability and quality, type of use, its benefits and beneficiaries,
- Using the results of the initial phase, a smaller set of dams was selected for more detailed study from the municipalities of São Caetano, Ouricuri and Mutuca (Figure 2), representative of the typical situations encountered. Amongst these 19 dams in the Mutuca area developed primarily for small-scale irrigated agriculture, were subjected to systematic socio-economic appraisal.

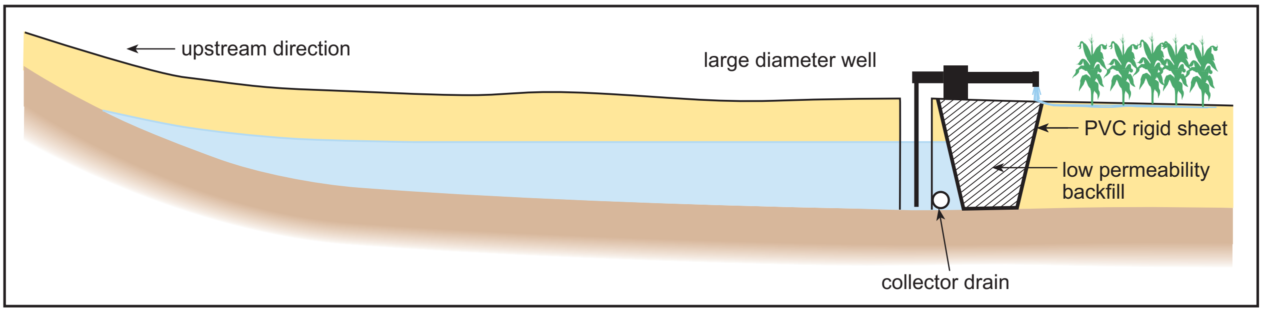

Figure 2: Underground dam construction in drought emergency job-generating program

(A) Basic Utilization

- Of the 151 dams visited in the first stage, 37% were essentially inactive, due to one or more of the above construction problems that made their use by the community impossible, and a further 13% were in good condition but little used by the local community as a result of availability of reliable surface water dams. The remaining 50% were in active use and the commonest types of use included domestic water-supply, livestock watering and small-scale manual irrigation (Figure 3).

(B) Socio-Economic Benefits

- The second phase of more detailed socio-economic survey led to a number of conclusions and observations. The benefit of the underground dam in terms of improving the community's quality of life can be very significant, as a result of the increased variety and quality of food that can be produced. The underground dams often have an important role in livestock watering and the production of dry-season animal forage, even where slightly brackish groundwater develops.

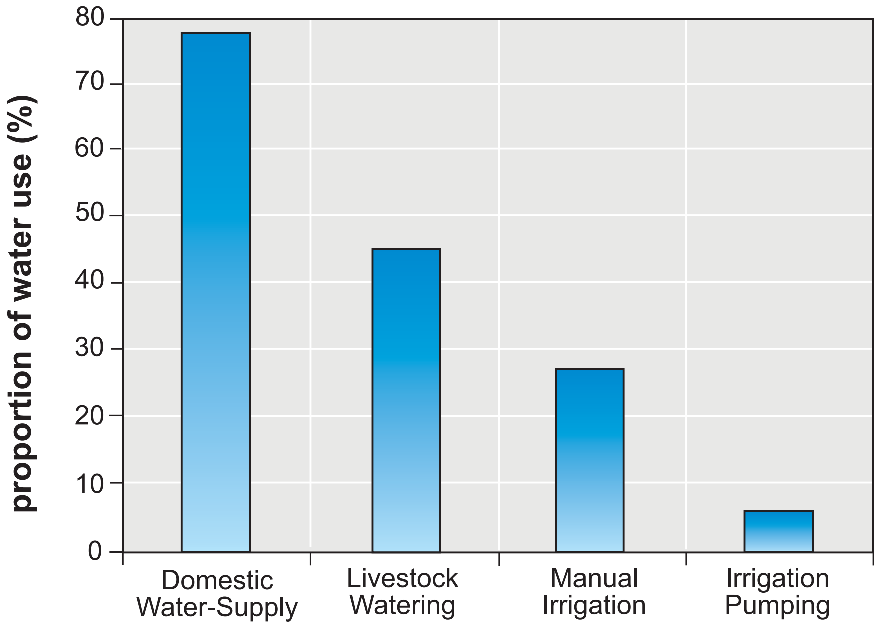

Figure 3: Classification of use of groundwater supplies from underground dams (note: some dams are multipurpose)

- Larger scale underground dams, such as those constructed around Mutuca, can sustain small-scale irrigation in the dry season and generate income for land owners and the community. The cultivation of 3 crops per annum was possible locally in this area. It is important to point out that the Mutaca area has a tradition in small-scale irrigated agriculture, and in the Ouricuri area it was possible to stimulate one, whereas elsewhere (for example in São Caetano) this was not the case. The access to markets is an important consideration, and if this is difficult then crop prices and income generation will be much lower.
- Construction of underground dams in localities experiencing a near-total rural economic stagnation is not alone likely to transform the socio-economic condition. To obtain a positive impact, other factors need to be addressed, such as energy provision, investment capital and technical assistance. It is important to take this into consideration, since in the case of São Caetano and of all those municipalities that experienced underground dam construction as part of an emergency drought relief programme, the first criterion for site selection was community need and other factors were not adequately considered.
- The cost breakdown for a typical dam is given in Table 1, but costs vary considerably with the scale and function of the structure (Table 2).

Table 1 : Cost analysis (in US $) for construction of underground dams*

COST COMPONENT	REPRESENTATIVE COST**
Feasibility Study	210
Construction	1410^^
Technical Support	275
TOTAL	**1895^^**

* *based on a typical dam of 4m maximum depth and 40m maximum length*
** *prices under local conditions in March 2001 (converted from Brasil Rs at rate of 2.0)*
^ *includes cost of a large-diameter well to abstract stored water*
^^ *US $410 less if manual (not mechanical) excavation used for underground dam and waterwell*

- The more detailed socio-economic analysis of dams constructed to support small-scale dry-season irrigated agriculture in the Mutuca area (Table 2) suggested that the capital investment cost could generally be recovered within a few years of operation (in some cases after the first year). It, however, should be noted that in the case of this appraisal:
    - on the one hand, Mutaca is an area of somewhat more favorable conditions for the construction of deeper dams with larger storage and also has more tradition in irrigated agriculture
    - but on the other hand, the appraisal had to be restricted (because of the lack of long-term reliable data) to the situation in a 'normal hydrological year', when 6 out of the 19 dams evaluated were not in use.

Table 2: Cost-benefit analysis (in US $) for underground dams in the Mutuca area

PARAMETER	INVESTMENT COST*	BREAKDOWN OF ANNUAL BENEFITS*			TOTAL ANNUAL BENEFIT*
		Economy Of Time	Value of Animal Production	Value of Crop Production	
average for 19 dams in area	3,413	70	702	3,216	3,987
average for 13 dams active in study year	4,410	102	1,025	4,701	5,828
average for 8 dams with irrigated cropping	5,034	83	877	7,614	8,598
maximum values for individual dam	-	644	3,760	20,550	-

* *prices for local conditions in March 2001 (converted from Brazil Rs at rate of 2.0)*

Strategy for Improving Success

- The use of underground dams would appear applicable to other states of regions of northeastern Brazil with similar soil and climatic conditions, and equally unfavorable hydrogeological conditions. Likewise, it could be of utility in various of the more arid parts of Sub-Saharan Africa with broadly equivalent conditions. It is important to remember that the presence of little weathered and relatively impermeable bedrock at shallow depth is necessary in order for the dams to augment groundwater storage, and that careful attention needs to be paid to the risk of build-up of soil and groundwater salinity.
- The human factor is essential for the success of underground dams. If there is no cooperative effort with, and subsequent ownership by the community, effective operation and adequate maintenance is unlikely to follow. Furthermore, continuing technical assistance in irrigated agriculture diversification and dam/well maintenance will be required.

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