A low cost approach for wadi flow diversion

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1. Introduction

A study of the land and water resources of the Wadi Rima coastal plain (YAR) was undertaken between 1974 and 1977 by the Land Resources Division (LRD) as part of the British Technical Assistance programme (Makin, 1977). One of the major proposals emanating from that study was for restructuring the traditional system of spate diversion and irrigation.

The Yemen coastal plain ('Tihamah') comprises extensive alluvial fans and terraces flanking the mountains of the interior. Lying close to sea level, the plain is hot and dry with a short, erratic summer rainy season, and evaporation exceeding 2 500 mm per year. Mean annual rainfall decreases from 350 mm at the foot of the mountains, to below 100 mm on the Red Sea coast. In general, only low yields of drought-tolerant crops are produced and water resources are intensively exploited for irrigation, the principal limitation to development.

Irrigation from Wadi Rima, over the past five centuries at least, has reached the extent that flows now rarely reach the sea. At the time of the LRD study, an estimated 60 percent of wadi water from the mountains was already being used for irrigation; any losses are mostly through bed seepage. However, these 'losses' are a major source of groundwater and, since pump extraction exceeds recharge, seepage may no longer be considered as a loss. The mean annual discharge of Wadi Rima onto the plain is estimated at about 80 million m³.

It should be emphasized that the LRD studies, upon which the following concepts are based, took place over ten years ago. Developments have since proceeded in an unforeseen way. Nevertheless, it is believed that the ideas from that study are generally applicable in similar situations outside the Arabian peninsular.

2. Traditional Spate Diversion

The intensive development in the wadi means there can be no planning for irrigation without considering existing patterns of land use. A high proportion of wadi water was already used for irrigation and extensive areas of the wadi were sculptured, for canals and field bunds, to make more effective use of that water. Complex patterns of land tenure and water distribution had evolved over the centuries and some effort was devoted to unravelling these, and understanding the basis for water allocation.

The whole system comprised 25 canals, fed by low rubble and brushwood deflectors, and some ten earth barrages (aqm) in the downstream reach where spates had generally lost momentum. Ideally, the canal intakes were set in the wadi bank on the outer side of bends to enhance the collection of flood recession and base flows, the intake heads being open and uncontrolled. The wadi is partially incised within an elevated alluvial fan, so each canal is capable of commanding extensive areas without heading-up.

The area irrigated in any one season with single to triple waterings averaged about 6 700 ha out of an estimated 8 000 ha; some distant fields might only be irrigated once or twice in a decade. Other areas have been deprived of water through the illegal development of new irrigation; here increasing numbers of people claim rights to wadi water. Rights to water feature strongly in the public consciousness and, indeed, have caused war on more than one occasion. Therefore we limited our approach to improving technology within the existing system, rather than introducing radical innovation such as large concrete weirs like those in a neighbouring wadi.

In Wadi Rima a single upstream deflector already existed, which was capable of diverting a significant proportion of the flood recession and base flows immediately on emergence from the mountains. This had important consequences for water rights because most of the discharge at this point in the wadi consisted of low flows (75 percent of the mean annual discharge comprised flows of under 5 m³/s) that could be diverted into canals. This single traditional deflector was capable of diverting about 30 percent of the total discharge. This accounts for the remarkably high level of abstraction by the traditional system; there was little scope for improved efficiency through further reducing wadi bed seepage. The diversion efficiency *per se* could be regarded as 100 percent since all flows are diverted, the only losses being wadi bed seepage and evaporation. Such diversion efficiency means that only limited benefit could be derived from structural improvement; consequently only limited economic investment could be justified.

There is, however, scope for improving the diversion mechanism. Shortcomings included:

- ❑ periodic destruction during high flows which, coinciding with peak demand for farm labour, was often left unrepaired until much of the wet season had passed;

- excessive wadi bed and bank erosion, concentrated on the outer bends of the wadi, could cause considerable damage to the canal headworks. Furthermore, excessive erosion of the wadi bed and/or the canal intake could leave the canal intake at a level higher than the wadi;
- differential wadi bed erosion leading to braided low flow channels in the middle of the wadi. Low flows, therefore, by-pass the inlet.

To summarize, there are two principal means for generating benefits from wadi restructuring:

1. More efficient upstream diversion and canalization leading to a reduction in wadi bed seepage losses. The relatively high level of abstraction efficiency already reached here limits the savings to about 10 percent of the annual discharge.
2. Improved efficiency and stability of the wadi deflectors, enabling two waterings per crop. This would, in part, be at the expense of those areas receiving both single and multiple waterings.

The limited additional benefits gained by wadi restructuring meant any improvements had to be few in number and individually inexpensive; this in turn implied a need for several canals to be linked to a single structure insofar as social strictures permitted. The problem was, therefore, to devise an improved system of wadi diversion which would (a) ensure minimal social disruption, (b) increase the overall efficiency of water use within a system which was already remarkably efficient, and (c) keep capital and operating costs to a minimum. If (a) and (b) contradicted each other, a balance had to be struck.

3. Proposed Diversion Structure

The conventional form of diversion usually incorporates a raised weir. This has two advantages: (a) an increase in area commanded with commensurate reduction in the length of the canal headworks, and/or (b) an increase in diversion efficiency due to a greater difference in elevation between weir crest and canal invert. Prospective advantage (a) does not apply in the Wadi Rima context since the wadi and its associated canal head reaches are elevated on an alluvial cone and, as such, are already able to command extensive areas. Nor would advantage (b) be significant where water rights require a multiple diversion strategy. The sole benefit of raised weirs is from savings in wadi bed seepage—and even this 'gain' may be illusory since seepage 'losses' recharge groundwater which can be pumped onto high value cash crops elsewhere. In any event, the total cost of a series of reinforced concrete structures complete with stilling basins, or other energy dissipators, is likely to be out of all proportion to the benefit . A new concept has therefore been sought.

The idea was to improve the traditional deflector through bed stabilization, making it possible to intercept all low flows and direct them towards the canal intake. The structural configuration involves placing a permanent sill flush with the wadi bed with a sloping crossfall towards the intake. This can be achieved on the outer (convex) bends of the wadi where most existing offtakes are located. Considering the inherent mobility of the wadi bed, the key components of the proposed structure, namely the sill itself and its downstream protection mattress, need to be constructed of flexible materials. Choice of these was determined by a number of factors:

(i) employment of local labour;
(ii) use of locally available materials;
(iii) ability to sustain the effects of impact, abrasion and distortion; and
(iv) opportunity for local participation in construction, and development of a sense of responsibility for maintenance.

All these factors pointed to the selection of gabions. Design criteria were based more on the general flood regime of the wadi rather than on the incidence of extreme events (unknown but conjectured) upon which the design of orthodox raised weirs depends. Life expectancy would be considerably less than that of conventional concrete structures—but so would be the cost.

There were no guidelines or standards to follow for the hydraulic design of this structure. However, based on a flow diversion efficiency then estimated at 50 percent (compared with the 30 percent efficiency of the traditional upstream deflector), it seemed necessary to supplement an improved upstream gabion diversion structure with similar structures downstream, raising the overall abstraction efficiency while fulfilling the demands of traditional water rights. The proposed multiple diversion strategy involved replacement of the 25 deflectors by seven stabilized gabion weirs. The two uppermost structures would divert up to 80 percent of the annual flow (at rates less than 7.5 m^3/s) with the balance—mostly flood flows—diverted by the five downstream structures at flow rates up to 5 m^3/s. The 80 percent flow diverted upstream would enter the traditional distribution network via two linking main canals running close to the wadi, therefore facilitating water distribution while reducing seepage losses (see figure 1).

As in all such arangements, the heavy sediment load posed problems. Under the traditional system the heaviest material remains in the wadi while the finer sands and silt tend to be carried through the canal system (sometimes at scour velocities) to be deposited in the fields. Moreover, the bed load was distributed, along with the water, between 25 diversion sites. Any concentration into much fewer sites, especially if located further upstream, was likely to lead to a severely increased sediment flow in any new canal network. To carry this extra load, the canals might have to be graded at even steeper slopes than before; large linking canals built on such gradients (perhaps 1 percent) would be extremely unstable. Although, the compromise strategy of multiple diversion allows some spread of sediment at the expense of additional wadi seepage, the impact of these additional loads has yet to be tested under field conditions—perhaps incorporating such devices as control gates or silt excluders.

4. Results of Gabion Trials and Model Tests

Gabion trials were undertaken in Wadi Rima over two

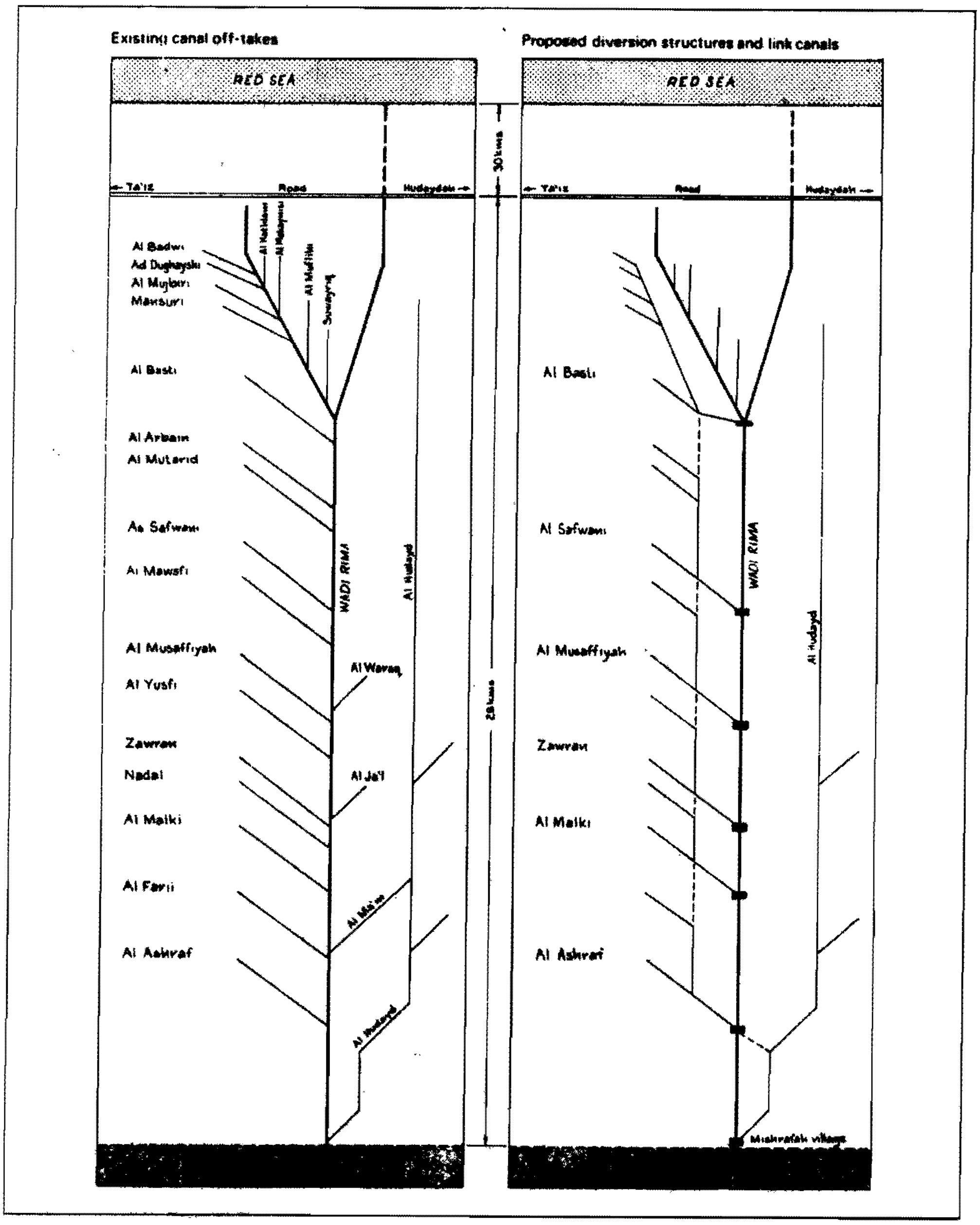

Figure 1 Existing canal off-takes and proposed diversion structures and link canals

years (1980-81) to test the durability and behaviour of the gabion material (Lawrence, 1982). These trials were conducted at two contrasting sites with rather different objectives.

At the upstream site, the aim was to determine the relative performance of alternative materials when subject to the severest possible wadi conditions By siting this trial within a mountain gorge, the attrition suffered over two years would be equivalent to that over a much longer period at sites downstream on the Tihamah. Here the trial structure comprised a 0.5 m thick mattress laid across the gorge and divided into seven discrete panels each constructed of contrasting material specifications. These ranged from wire diameters of 2.5 to 4.0 mm, gabions welded or woven, and with an HDG or galvanized finish; in addition, one panel was surface-finished with a 150 mm concrete skim.

Over the two years, the structure was exposed twice to floods of 25 $m^3/s/m$ and 20 $m^3/s/m$ width, together with several floods of 10 $m^3/s/m$ width. Maccafferri 2.7 mm woven gabion proved most durable on balance. Although a concrete skim provided the best protection, the consequent lack of flexibility prevents its application where flexibility is required.

At the downstream site, the aim was to subject a full-scale structure to the less severe flood conditions experienced in the upper wadi reaches of the coastal plain, on a long-term basis, to assess actual durability and maintenance requirements. The majority of gabions forming the structure were found to be in excellent condition following two years of exposure. In some areas the stonefill had slumped and some re-packing was necessary if the gabions were forming part of a water diversion structure. This trial showed that welded gabion boxes and baskets could be used to construct a diversion structure of the type proposed, with a reasonable economic life, provided routine inspection and maintenance were assured (Lawrence, 1982). The continuing durability of the structure was confirmed, after six years *in situ* and notwithstanding lack of maintenance during this period.

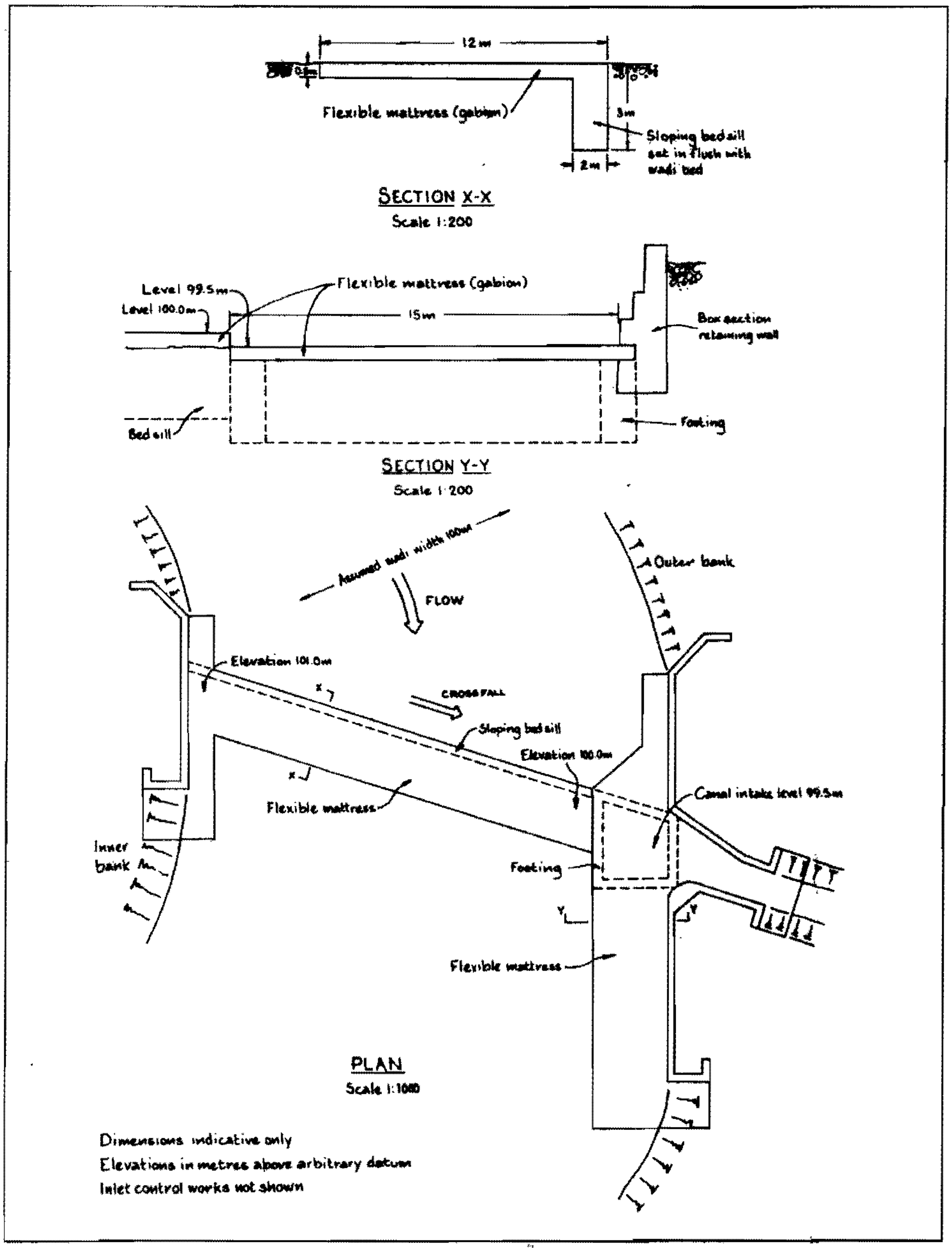

Figure 2 Proposed wadi diversion structure (bed stabilization)

Hydraulic model tests by the Hydraulics Research Station, UK, showed that a bed stabilization diversion arrangement, of the type shown in figure 2 and located near the mountain front, would be capable of diverting up to 78 percent of the flow at rates of 2 m^3/s or less (Lawrence, 1983). A second structure, located 5 km downstream, would divert about 10 percent of the flow by-passing the first.

Meanwhile the YAR Government, with World Bank support, decided to proceed with wadi restructuring based on a more orthodox strategy of a single, raised weir aiming to divert up to 90 percent of the flow at rates up to 15 m^3/s (DHV, 1979). Nevertheless, the gabion trials, outlined above, provide valuable information on labour inputs and productivity, construction duration, structural problems and actual costs of construction, all of which data can still be applied to comparable sites elsewhere.

5. Comparative costing

Although a gabion stabilisation structure requires a greater outlay in maintenance and periodic replacement, its capital cost is less than 20 percent of that of a comparable concrete raised weir (Table 1). Despite limited economic benefits and life expectancy, as well as the emphasis placed on local participation and maintenance of long

Table 1 Cost comparison of main gabion structure and a concrete raised weir, Yemen trials (1980)

	cost YR (1000)
Gabion and other materials	693
Plant hire	250
Transport, repairs and fuel	240
Local labour (wages)	918
Total (gabion structure)	2101
DHV Estimate for one raised weir and intake	12 100

established water rights, the advantage rests firmly with a flexible diversion strategy using gabion wadi bed stabilization structures, utilizing local materials and labour.

Non-quantifiable advantages of gabion over conventional structures may be summarized as:

- inexpensive materials allow the siting of several down-stream diversions to accommodate local water rights;
- materials with a relatively short life-span injects a degree of flexibility into the system, to accommodate subsequent changes in water rights;
- the technology is readily adopted locally and, once mastered, can be applied to neighbouring wadis;
- low foreign exchange component; and
- high level of local labour involvement.

6. Conclusion

Evaluation of various alternatives for improved spate irrigation in Wadi Rima (YAR) showed most approaches to be uneconomic (Makim, 1977). Traditional irrigation is already highly efficient and only limited benefits would accrue from any improvement. The most economic approach proved to be a low cost strategy using local materials and direct labour to build gabion structures at just a few off-takes. The aim was to stabilize the wadi bed, thereby directing low flows into the canal heads. Subsequent field trials and model tests demonstrated the feasibility of this approach with regards both hydraulic design and material durability.

Significant economic saving could only be achieved by severely curtailing canalization and restricting irrigation to a significantly smaller upstream area. This would result in greater inequality in water distribution and probable social disruption. Legal rights to water in Wadi Rima had been embodied in customary law. Water rights had evolved through compromise and conciliation in response to the increased pressure of population. Any attempt at radical innovation would upset the delicate, if ever-changing, balance of water allocation developed over the centuries. An approach based on multiple diversion and link canals goes some way to minimizing disruption.

In Wadi Rima, this solution is no longer applicable because a more conventional option was selected. However, wadi bed stabilization has the particular advantages of being based on traditional operation, is labour-intensive and involves a form of intermediate technology which means it can be constructed, sustained and operated largely through the efforts of local people. As such, the approach could have wide application beyond th : shores of Yemen.

References

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