Flood protection works and low cost diversion structures

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1. Introduction and background

The potential for agricultural development in the Southern Arabian Peninsula is very limited. Rainfall is low and unreliable, and insufficient for large scale rainfed crop production. Agriculture is therefore almost exclusively dependent on spate irrigation from the occasional wadi flows originating from local rainstorms in the mountainous catchment areas.

Substantial investments have been made in improving the construction or rehabilitation of weirs, wadi training and protection works, and water distribution systems. However, these strategies have not always led to the anticipated increase of production and rates of return on investments have often been disappointing.

2. Flood protection works

Protection works can be subdivided into two main categories, namely:

i. *bank protection*—the armouring of wadi banks to resist erosion and subsequent loss of land; and
ii. *wadi training* engineering works which aims at encouraging wadi flow to follow a designated course.

The very high investments for these type of works require a thorough analysis of functions, costs and anticipated benefits, which should be made in the planning stage. In most spate areas land with good soil properties for agriculture is not a scarce resource, but water is the major limiting factor in agricultural production. Therefore, from the economic point of view, protection works only seem justified if the irrigation capability of the spate system can be enhanced or when high value works such as settlements, roads, canals and structures are to be protected.

In practice, however, the planner has to take into account socio-political factors, which may play an important role in the selection of sites and the establishment of priority levels of works.

2.1 Basic design principles and approach

It will be impractical, if not impossible, to provide effective protection against damage from all flood events. A choice has to be made as to what level of security is required or feasible, related to the value of works or lands to be protected and costs of the actual protection works.

Usually bank protection and training works are designed to withstand floods with a return period of about 10 years. At weir sites a higher level of security is often required to safeguard the high cost structures against damage, concurrent with the selected design flood, which may have a return period in the order of 20 to 50 years for large concrete weirs but obviously lower for smaller gabion weirs (see 3.1.4).

It is not said that floods exceeding the design flood will subsequently destroy all protection works. In that case the level of damage will strongly depend on the flood intensity and duration.

Although works will be overtopped and possibly outflanked, they are still likely to be effective in confining the main wadi flow within the boundaries of the designated channel since overbank flow will, in most conditions

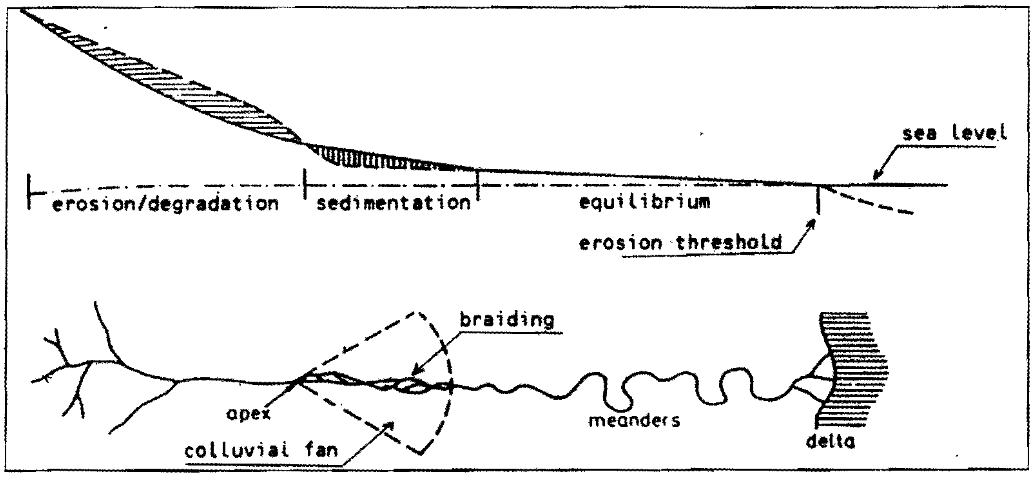

Figure 1 Long section of wadi

(except for floods of extremely high magnitude), be restricted by vegetation and form roughness.

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2.1.1 *Surveys*
Before a decision can be taken on precise location and type of wadi protection works, it is necessary to study the peculiarities of the wadi system and assess what effects the works will or may have on wadi behaviour. Semi-detailed maps of 1:75 000 to 1:25 000 should be available or otherwise be compiled, for the feasibility study, and 1:10000 for detailed planning.

2.1.2 *Wadi morphology*
It is imperative that the most important features of wadi behaviour are recognised, before design criteria for flood protection works can be estabilished. These are largely determined by the gradient of the wadi bed, discharge characteristics of wadi flow and sediment transport. A typical wadi profile is given in figure 1.

Braiding occurs in the middle/upper reaches of wadis. It is typically related to steeper bed gradients, mostly exceeding 4 percent. Bed materials are a large, coarse fraction of cobbles and gravel and a smaller sand fraction.

Because of the multitude of channels, instability of the wadi bed, high speed of wadi flow and heavy sediment transport during spate events, wadi boundaries are difficult to control. However, there is a higher probability of wadi flow than in the lower reaches, and command over agricultural lands along the wadi for irrigation can be easily obtained.

When the bed gradient gradually drops, a reach can be identified where the process of sedimentation and erosion is more or less in equilibrium and the bed materials will become lighter. The volatile nature of wadi behaviour, however, makes it difficult to establish the boundary between the two and a large transition zone often exists. It is in such lower reaches that another phenomenon can be observed, namely the development of meanders.

The process of meandering is not well understood. It is probably triggered by local obstructions in the wadi course, possibly by bank or bed material with different degrees of erodibility, and/or large fluctuations in discharge and sediment load (typical for wadi flow).

The flow pattern will cause scouring of the wadi bed at the outer curve and sedimentation on the inner side, thus developing the meander further, as shown in figure 2.

It is in these meanders that protection works are most needed. It has been found that the best results in wadi training are obtained when design criteria are based on features of the wadi configuration related to "regime" conditions. However, many factors influence the stability of natural flow channels, and an exact definition of wadi regime is hard to give.

The following description was given by Ingles (1949): "Channels which do not alter appreciably from year to year—though they may vary during the year—are said to be in regime".

It is assumed that a wadi regime is normally related to flows with a return period of one to two years.

Large flood events may, however, dramatically change the course and width of the wadi, and/or straighten out wadi curves. This can be clearly seen on aerial photographs taken from wadi Bana in PDRY after the floods of 1982, which had an estimated return period of approximately 70 years. After such rare events the more common floods will once again reshape the wadi bed and the previous pattern will soon become apparent within the wider flood channel. This extreme flood channel cannot be controlled and training works will be designed to stabilize the smaller "regime" flood channels within the enlarged channel.

The lay-out of protection works will normally be based on the natural ("regime") wadi configuration, and protective measures are only needed at sensitive sites where scour can be expected, i.e. the outer curve of a bend (meander) or at weir sites.

2.2 *Examples of protection works*
2.2.1 *Groynes* Groynes (or spurs) can be constructed in a variety of ways, but have in common that they are more or less perpendicular to the direction of wadi flow (some examples of conventional types of groyne are given in figure 3.)

Protection is provided by the interaction between a number of groynes, which keep the main flow away from the banks and direct it to the desired course. In a well-

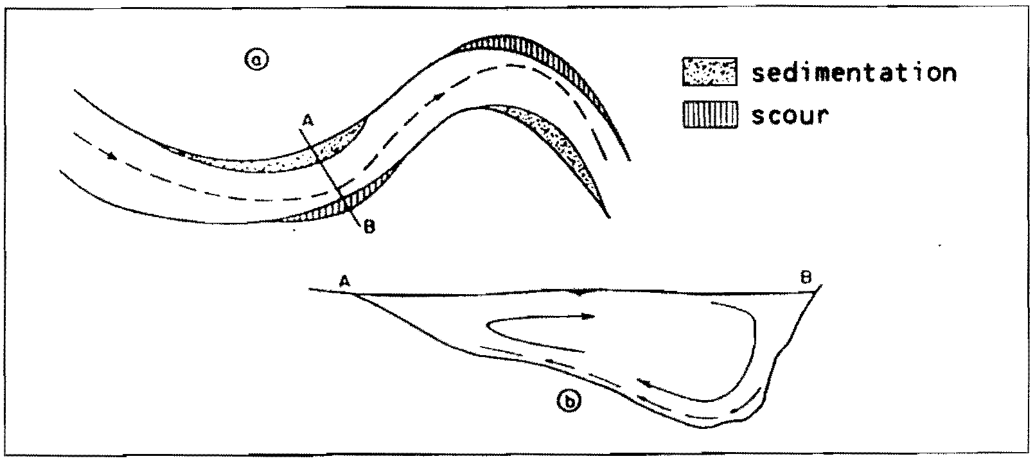
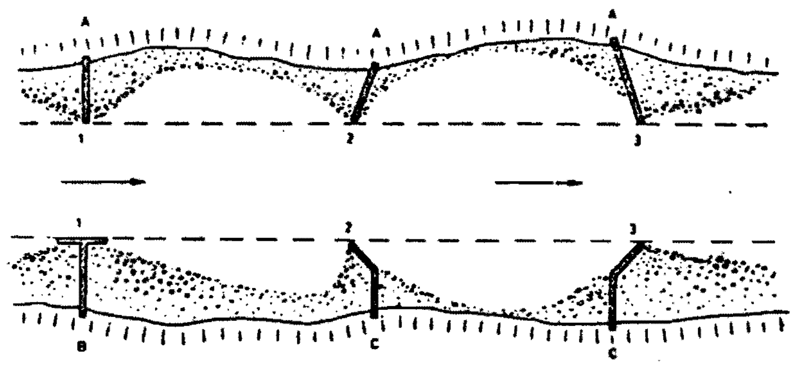


Figure 2 Scour and sedimentation in meander curve



(A) *Straight type* - (1) *At right angles to stream* (2) *Slanted upstream* (3) *Slanted downstream.*

(B) *Hammer type.*

(C) *Bayonet type* (2) *slanted upstream* (3) *slanted downstream.*

Figure 3 Conventional types of groynes

designed designed system rapid deposition of sediment will take place between successive groynes and often the spontaneous growth of natural vegetation will help to reinforce embankments.

A solitary groyne protruding in the flow channel does little to control wadi flow, but is more likely to cause unfavourable disturbances in the natural flow path and cause damage at some point further downstream. The distance between successive groynes will depend on their length and on the curvature followed, and should prevent small meanders developing between them and attacking the bank.

Groynes may be built from reinforced concrete, masonry, precast concrete elements, rock boulders, stones, gabions, timber, sheetpiles, or wadibed material and in any combination, and can be classified into rigid, semi-rigid and flexible types.

Rigid structures, made of concrete or masonry, are relatively costly and mostly only considered when there is a solid rock foundation near the surface of the wadi bed.

Semi-rigid structures are a relatively recent development, aiming to combine the advantages of rigid and flexible structures, using interconnected concrete elements, but so far the results have not been encouraging.

Flexible gabion structures are often preferred. They can adjust by deformation without disintergration, and can be made using stones and boulders from the wadi bed. Also the assembly and construction techniques of gabion works are relatively simple, expedient to execute, and do not require sophisticated equipment. A groyne has to be protected against deep scour. The strongest attack will occur at the river end of the structure where strong turbulent flow and eddies develop around the nose end during spates. Protection against undermining at these places is essential.

Deep foundations are usually selected in the upper sections of the wadi, where heavy bedload could easily damage the meshwiring. Rip-rap can be used in these conditions, but the stones and rockfill should be large enough to resist the tractive forces.

A common misconception is that a groyne should not be overtopped, but for most types there is no reason to avoid this. On the contrary, overtopping will have the

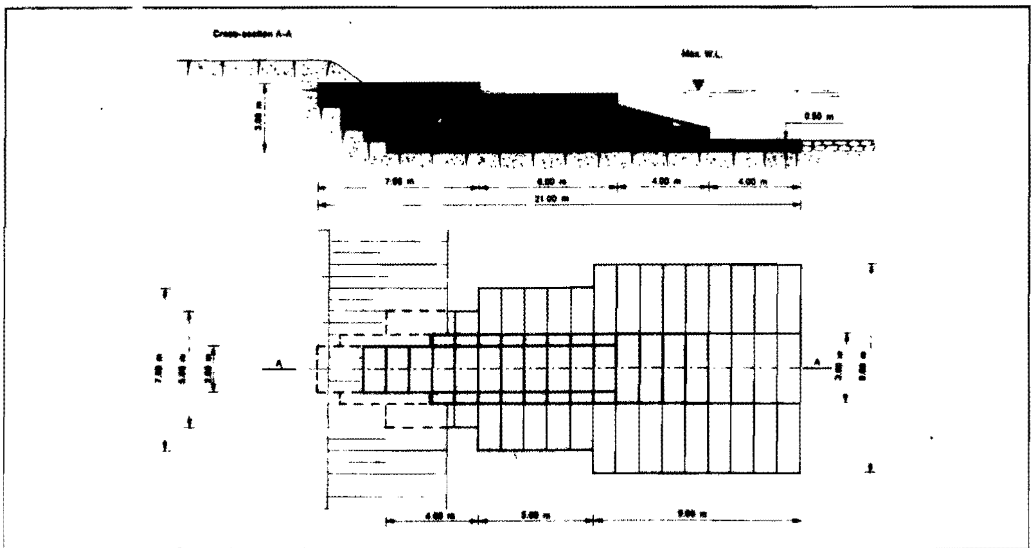


Figure 4 Straight groyne in gabions (courtesy Maccaferri, s.r.l. Bologna)

advantage of reducing scour around the nose-end of the groyne, promotion of sedimentation between groynes and less obstruction to spate flows. It is important, however, not to allow overtopping of the groyne near the embankment, since this would eventually cause outflanking.

The height of this section, which should be solidly keyed into the embankment, is normally set to the maximum energy level of the design flood. When water overflows the lower section of the groyne, this part will act as a submerged weir. Some protection against scour, eg. deeper foundations, rip-rap or aprons, will be required at the downstream flank of the groyne, but need not be extensive. An example of classic groyne design is given in figure 4.

The first in a series of groynes will normally be located slightly upstream of the section to be protected. This groyne will be subjected to strong attack by wadi flow and therefore should be heavily reinforced. It is often constructed as a deflector, strongly slanting downstream, and/ or in combination with a training wall.

The layout for the other groynes will depend on the specific site conditions. It is generally recommended to construct groynes slightly slanted upstream, approximately under a 5 degree angle, to promote sedimentation.

2.2.2 *Training Walls* Contrary to groynes, training walls are aligned in the direction of flow. They are a continuous structure producing a less turbulent flow along the face of the wall. They are, therefore, superior to groynes, and better suited at weir sites where a controlled approach to the weir section and headworks is essential.

However, training walls are significantly more expensive than groynes, and will normally be limited to the most sensitive sites, or where the construction of groynes is less feasible, e.g. at weir sites, narrow and/or steep wadi sections. The same materials can be used and design principles applied as for groynes, except for the condition that training walls should not be overtopped, which would cause erosion of backfill. In some instances articulated concrete slab revetment has been used as in wadi training works near Batais, Abyan Delta.

Most commonly gabions are used in combination with aprons or rip-rap and wadi bed materials. These are most cost effective and have been successfully used for wadi training in a number of countries. They are, however, more vulnerable than groynes because of the much larger area exposed to the abrasive action of the bedload. Therefore it is important to incorporate boxes with internal diaphragms of 1m intervals in this section, and a larger diameter meshwire (3mm).

Reducing the volume of gabions per unit length of training wall could significantly reduce cost of training works, particularly at sites where gabion fill is not readily available. Some examples of training walls are given in figure 5.

2.3 Special considerations

Traditional land reclamation practices, within the natural wadi bed boundaries, often interfere in the planning and construction of flood protection works. Farmers possess a strong incentive to reclaim lands with easy access to spate-

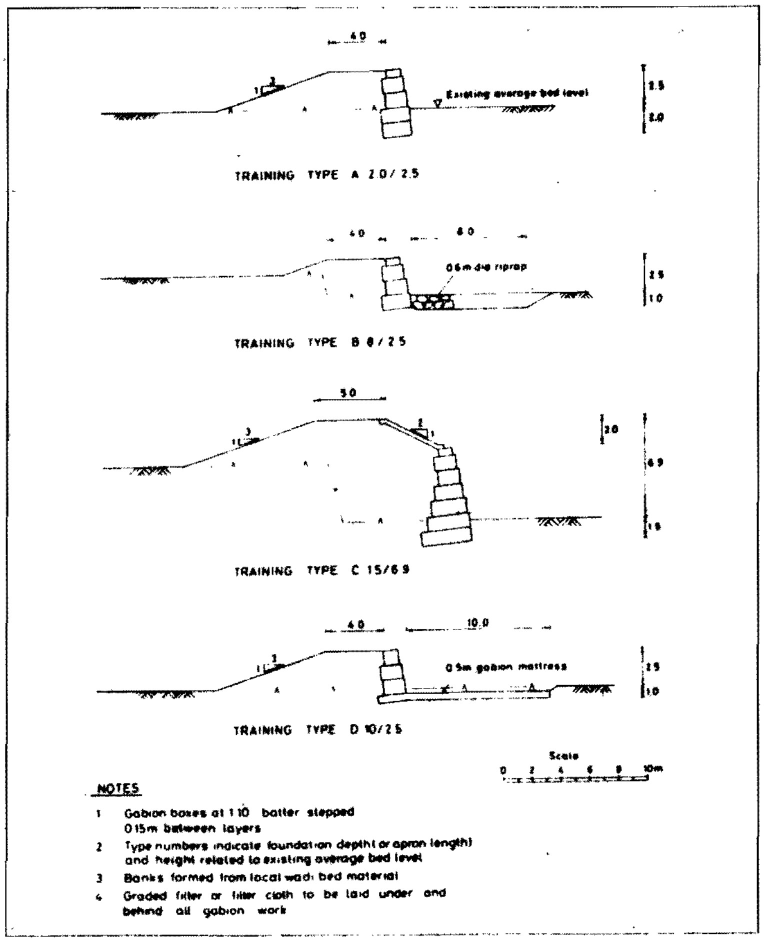


Figure 5 Typical wadi training walls

waters, based on experience that accretion of prime land is a rapid process by repeatedly ponding the silt-loaden spate-waters in basins.

The problem arises from uncontrolled land reclamation activities, which often affect the natural course of the wadi. Certain sections may become narrower than the regime width and spate flow might be induced to follow an erratic pattern, with subsequent danger of bank erosion. To prevent this, standard design procedures must be adhered to.

The farming communities involved have to be made clear that this is eventually in their own interest. Liaison with local authorities and farmers' leaders is important, and, if possible, a general consensus should be obtained in order to avoid endless disputes. It may also be required to establish a compensation plan for farmers who are adversely affected by the implementation of protection works. Another issue is the effect of permanent diversion works on wadi bed levels due to accretion of sediment, which should be taken into account when establishing the height of protection works and in assessing scour levels for determining the depth of foundations. However, in the low cost approach for weirs with fusebunds, the matter is rather more complicated. The fusebunds are normally set to be breached by floods with return periods lower than the design flood for protection works, and periodically accreted bed materials upstream the diversion will, to some extend, be eroded.

It is difficult to predict accurately how wadi bed levels will behave upstream of a diversion, where this intermittent process of accretion and erosion will occur. Such behaviour will depend on many factors such as the design capacity of the weir, and wadi discharge characteristics but also on operational aspects, e.g. time of reconstruction of the fusebund after breaching.

A decision on height and foundation levels of protection works is very cost sensitive, particularly for lower reaches with lesser gradients where the above described effects may affect a considerable distance. The designer should therefore take the necessary care to analyse these effects, and may have to establish criteria for fusebund repairs.

The actual construction of protection works can be conveniently carried out during the dry seasons, when wadi flow is unlikely to occur. However the proximity of groundwater levels to the wadi bed might create a problem when constructing deep foundations. A pump may be used to lower the watertable in the construction pit, but this is often not sufficient to obtain the required level. The best solution in this case is to modify the design and use a combination of rip-rap with shallower foundations.

Finally, it has to be concluded that wadi protection works are too often carried out on an ad-hoc basis and not as a comprehensive plan, in which survey, planning and design are necessary inputs. Construction materials are often distributed among cooperatives and/or individual farmers, without any further technical assistance or supervision often leading to wasteful use of materials, ineffectiveness and failure.

3. Low cost diversion structures

The annual volume of water carried by wadis in the region is relatively low, and show large seasonal and annual fluctuations. Nevertheless typical flood events have high flow intensities over a short period, which often require diversion works of considerable dimensions and cost for sufficient control over the occasional spate waters.

Another limitation is the decreasing probability that wadi flow will reach a certain diversion the further it is downstream, and to serve subsequent command areas with spatewaters, which makes the construction of high cost works increasingly difficult to justify. In these conditions the planner has to examine the feasibility of lower cost structures such as the traditional ogmas or more sophisticated gabion weirs.

Ogmas are relatively cheap to construct, particularly with earthmoving plant. However, their vulnerability to damage even by smaller spates make them rather inefficient and costly to maintain, but they cannot be completely discarded. Gabion weirs are more costly to construct but will require less maintenance and offer higher diversion efficiency.

3.1 Basic design principles and approach

The design principles for these low cost diversion works are similar to those for the larger, concrete weirs. The idea is to construct a relative short weir in combination with a fusebund which will be washed out or deliberately breached when wadi discharge exceeds a predetermined value.

3.1.1 *Siting of weir and intake.* Selection of the proper location of the weir and intake will have a major impact on the effectiveness of the structure in diverting spate water.

The diversion works should preferably be at a bend with the intake at the outer side of the curve, as sediments are deposited mainly on the inner side of a bend (or meander) and a deeper flood channel is maintained by scour in the outer side of a curve. However, the largest sediment flux will also occur in the outer curve, and water can only be successfully diverted if provisions are made to prevent large amounts of sediment entering the canal.

Another important consideration in selecting sites for diversion works will be the composition of the wadibed. Considerable savings on construction cost can be obtained, if solid foundations like rock outcrops can be found on which to construct a certain diversion. Also important is the width of the high flow channel, which should be equal to or wider than the regime width. A too narrow section would mean unfavorable stage/discharge relationships, unsuitable for weir/fusebund construction.

3.1.2 *Sediment control.* It is difficult but essential to control the large amounts of sediment carried by spate waters. Typically during larger spate flows, sediment transport is high as the concentration increases exponentionally with velocity (or discharge).

In sediment control, a distinction should be made between:

wash load: containing very fine sediment (silt and lutum fraction), which originates from erosion of the basin and remains normally in suspension under the prevailing hydrological and hydraulic conditions of wadi flow; and

bed load: which contains the courser fraction, under certain flow conditions, and also larger pebbles and boulders, originating from and transported over the wadi bed.

Although the washload may be troublesome for maintenance of the spate water conveyance system, it has no major consequences for the performance of diversion structures. Moreover the fine sediment fraction is highly valued by farmers. It provides them the means to reclaim land, improve soil characteristics and maintain acceptable levels of soil fertility under traditional agricultural practices.

Transport and deposition of bedload materials, however, poses a major obstacle in operation and performance, resulting in large maintenance cost on spate systems. Provisions should, therefore, be made to flush out bed materials from in front of the intake, and prevent, as far as possible, the bedload entering the canal.

Large concrete weirs have gated sand excluders which can be manipulated so that optimum sediment sluicing is achieved. The capacity of the excluders are normally designed to pass a flow of at least 30 percent of the intake capacity. Very low flows may be completely diverted by closing the sluice gates.

Low cost structures rarely have gated sluices, but only open sluiceways and intakes, which cannot be operated in this manner. However, baseflows, minor, spates and a portion of the larger spate events, particularly during the recession period, cannot be diverted but would pass the sluiceway. A considerably higher diversion efficiency can be obtained by constructing a fuseplug in the sluiceway, or a deflecting bund towards the intake in front of the sluiceway, which would be breached when wadi discharge exceeds a certain portion of the intake capacity.

With larger sluiceways the opening can be divided into two sections. One has a small capacity with a fuseplug to be washed out at a relatively low wadi discharge, and the other with a larger capacity and would become operational at higher flows. Model studies have also found that for successful sediment control the approach of the flow towards the intake and sluices is a factor of great importance. Improved performance can be accomplished by an arrangement whereby the intake and sluiceway are set back in relation to the weir, combined with smoothly curved guiding piers *(see figure 3, Technical Background Paper No 9, Hewitt, von Lany).*

3.1.3 ***Fusebunds*** Fusebunds are built to protect weirs, appurtenant structures, and conveyance structures against damage from larger floods. The bund is designed to breach when wadiflow exceeds the combined design capacity of weir, intake and sluiceways. The top of the bund, or a section thereof, is set at a predetermined level corresponding to the wadi stage at this capacity, and will be automatically washed out.

Breaching can also be executed manually or by earthmoving plant, in which case less attention can be given to the exact setting of the bund level, as long as the minimum level is not underscored. The obvious risk lies in the reliance on manpower or machinery, and therefore the first method should be preferred. Wadi flow can reach peak discharge in only 1 or 2 hours. If the fusebund is not washed out quickly, excessive flow can pass the weir or enter the canal with disastrous results. This can lead to sediment accretion upstream of the fusebund, particularly since its location would normally be at the inner side of the curve. During spate events, with peak discharge lower or equal to the design capacity, wadi flow, which may have a substantial sediment carrying, capacity, is passed over the weir section whilst the fusebund remains intact. Coarse material will be caught against the upstream face of the bund, and might delay breaching. This risk can be reduced by constructing the fusebund at an angle to the normal. The upstream face, however, is more prone to scour, and some form of protection will be required to prevent untimely breaching. It will also be difficult to design top levels of oblique bunds accurately, since it is almost impossible to assess water slope with precision. Because of the uncertainty of timely fusing, it might be desirable to be conservative when establishing design criteria.

3.1.4 *Design criteria.* The type of diversion works selected will depend on the location in the wadi system, the amount of water to be diverted, the required level of diversion efficiency and, last but not least, available funds.

Design criteria will therefore vary from one structure to another. In general the following criteria can be used as a guide:

i. ogmas should breach when wadi flow exceeds the intake capacity of the intake;
ii. fusebunds, in combination with (gabion) weirs, should be breached before wadi flow exceeds combined design capacity of weir, sandsluices and intake;
iii. weir crest should be set at that level at which the full supply discharge can enter the canal before overtopping;
iv. permanent diversion structures should be equiped with sediment excluders with a capacity of approximately 30 percent of the intake capacity;
v. permanent diversion structures should not sustain damage by medium sized to larger floods (e.g. up to the 1 in 10 year value), when the fusebund is washed out; and
vi. permanent diversion structures should be constructed in such way to minimize damage by floods exceeding the value set in (v).

3.2 Types of low cost diversion works

3.2.1 *Ogmas.* Ogmas are bunds constructed in the wadi from local wadi bed materials and are still widely used as a traditional low cost method to divert spatewaters. Their size may range from small, oblique bunds, protruding upstream, to capture only baseflow or very small spates, to large massive earthworks of several hundred metres length completely closing off the wadi and capable of handling much larger flows, until wadi flow exceeds intake capacity. This may, in some cases, be over 60 m^3/s.

The introduction of modern earthmoving plant has

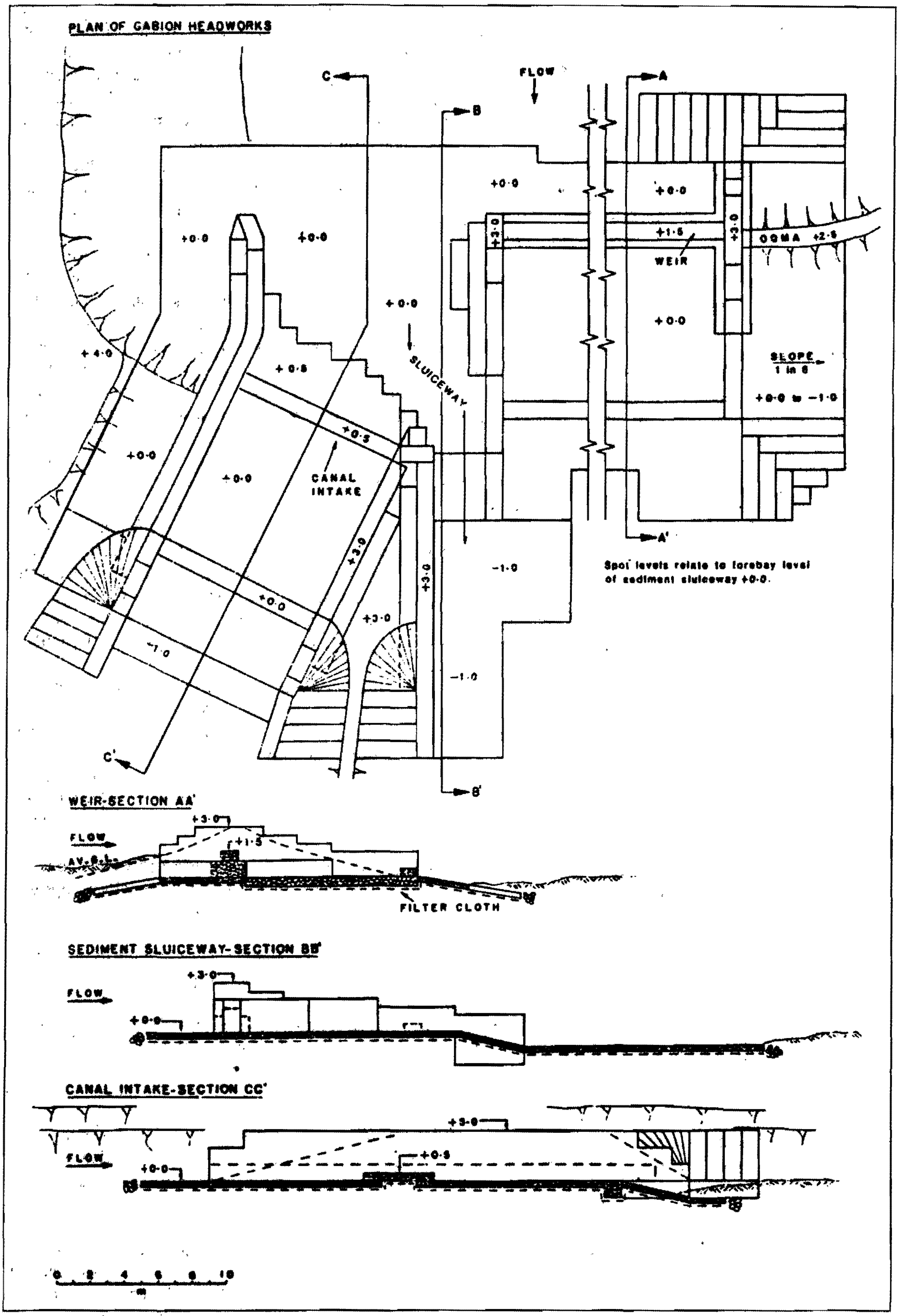


Figure 6 Sketch of proposed improvements to traditional diversion weir by gabions

made it possible to construct ogmas with relative ease and low cost. As a result, these structures have become more massive and reconstruction is less of a problem. They do have some major shortcomings:

- overall low diversion efficiency;
- high maintenance or reconstruction cost; and
- poor discharge and sediment control.

The low diversion efficiency is the result of frequent damage of the ogma by spates exceeding the intake capacity. Quick repair will be more important for larger ogmas serving large command areas, but less relevant for the multitude of smaller ogmas which might only irrigate some acres near the periphery of the wadi. These smaller ogma's are normally considered redundant after sufficient water is diverted to irrigate this area, which is usually after one spate. Traditionally, farmers are accustumed to cultivate a crop on one application of water only and are sometimes even reluctant to reconstruct the ogma to capture more spates during the growing season. This practice may also be stipulated by local water rights, but would probably not apply if the main objective is land reclamation.

Nevertheless, reconstruction of the smaller ogmas, if not directly after the spate event, should be promoted as this can contribute to better use of spate waters, particularly since base flow or very small spates cannot efficiently be diverted to areas further away, and would otherwise be lost by infiltration in the wadi bed. Reconstruction will not be a major expense and most likely be outweighed by the benefits. Replacement by permanent structures would not be feasible.

The considerable maintenance or reconstruction cost and poor operational features of large ogmas are much more of a burden, and therefore replacement by low cost permanent structures, which in fact can be seen as modified ogmas, is recommended, as proposed in figure 6.

Most ogmas have open "unconfined" intakes. Without timely breaching, a spate canal may become severely eroded and get out of cotrol. It is possible that even after the ogma breaches, the main flow of the wadi would still enter the then enlarged spate canal. Eventually the wadi could establish this as a new course, causing heavy damage to spatelands.

The build-up of large amounts of sediment upstream of an ogma is less likely, since ogmas will be breached frequently at relatively low wadi discharges; whatever is deposited will be not be very coarse and easily washed out. The local wadi bed material, of which the ogma is composed, may, however, be much coarser and resist erosion. Field observations have also learned that in practice little attention is paid at setting the ogmas at the proper level and therefore breaching often has to be induced with earthmoving machinery.

3.2.2. *Low cost gabion weirs.* According to the shape of the downstream face, gabion weirs can be classified in three principal types, namely vertical, stepped and sloped weirs.

The vertical type is best suited under wadi flow conditions carrying heavy bedload and where simplicity of construction is important. Examples of this type are given in figure 7.

Stepped weirs are sometimes constructed in steeply sloping water courses but are not recommended for diversion structures in wadis as they are not designed for large discharges and heavy sediment transport.

Sloped weirs are constructed in such a way that the water nappe adheres to the weir face. From the hydraulic point of view, these are better suited to handle larger unit discharges and will, in soils with poor bearing capacity, result in a higher stability for overturning or sliding.

This latter type of weir is, however, more complicated to construct and prone to damage by the abrasive action of bedload materials passing over the weir during spates. Protection can be achieved by coating the crest and downstream face with concrete or asphalt mastic, but this method is costly in materials as well as technical know-how; the equipment is not always readily available in third world countries. Nevertheless construction could be considered as an alternative to higher cost concrete weirs. Crest design of these structures are similar to those of high-cost concrete weirs.

In order to gain sufficient head to supply the irrigation intake at full capacity and meet sluicing requirements, the weir-crest has to be raised above the existing wadi bed. The hydraulic energy level is thereby also raised in the upstream reach of the wadi. The dissipation of the excess energy downstream of the weir can be achieved safely by a stilling basin. The design of this basin should aim at containing the hydraulic jump, if formed, at the upstream end of the basin floor so that most energy is dissipated in the basin section and turbulance will be reduced to levels which will not damage the unprotected downstream wadi bed. Various types of stilling basins may be considered on the basis of wadi bed composition, unit discharge and drop in water level. Some typical examples are shown in figure 7.

The pool of water in the scour hole will act as a water cushion, dissipating the kinetic energy of the nappe.

Increasing the downstream water depth will reduce the depth of scour. A counter weir downstream, with sufficient height to form sub-critical flow upstream, will create the extra depth. The foundation of the weir section should, in both cases, be deeper than the maximum scour. The type selected will depend on the cost of foundations and/or counterweir.

Training works directly upstream the diversion are required to encourage the approach flow to follow a predetermined course towards the headworks and prevent outflanking of the weir. Training walls may be too costly, and a series of groynes used instead.

To encourage very low flows to move towards the intake, the weir crest should be sloped along its length (approx. 23 percent). Setting the weir section, and/or the fuse bund, obliquely will also help this and the fusebund section can be constructed with a gabion floor to prevent the formation of a deep scour channel when breached.

For larger structures it is sometimes recommended to construct secondary sand sluices which would maintain an approach channel towards the intake during lower flows.

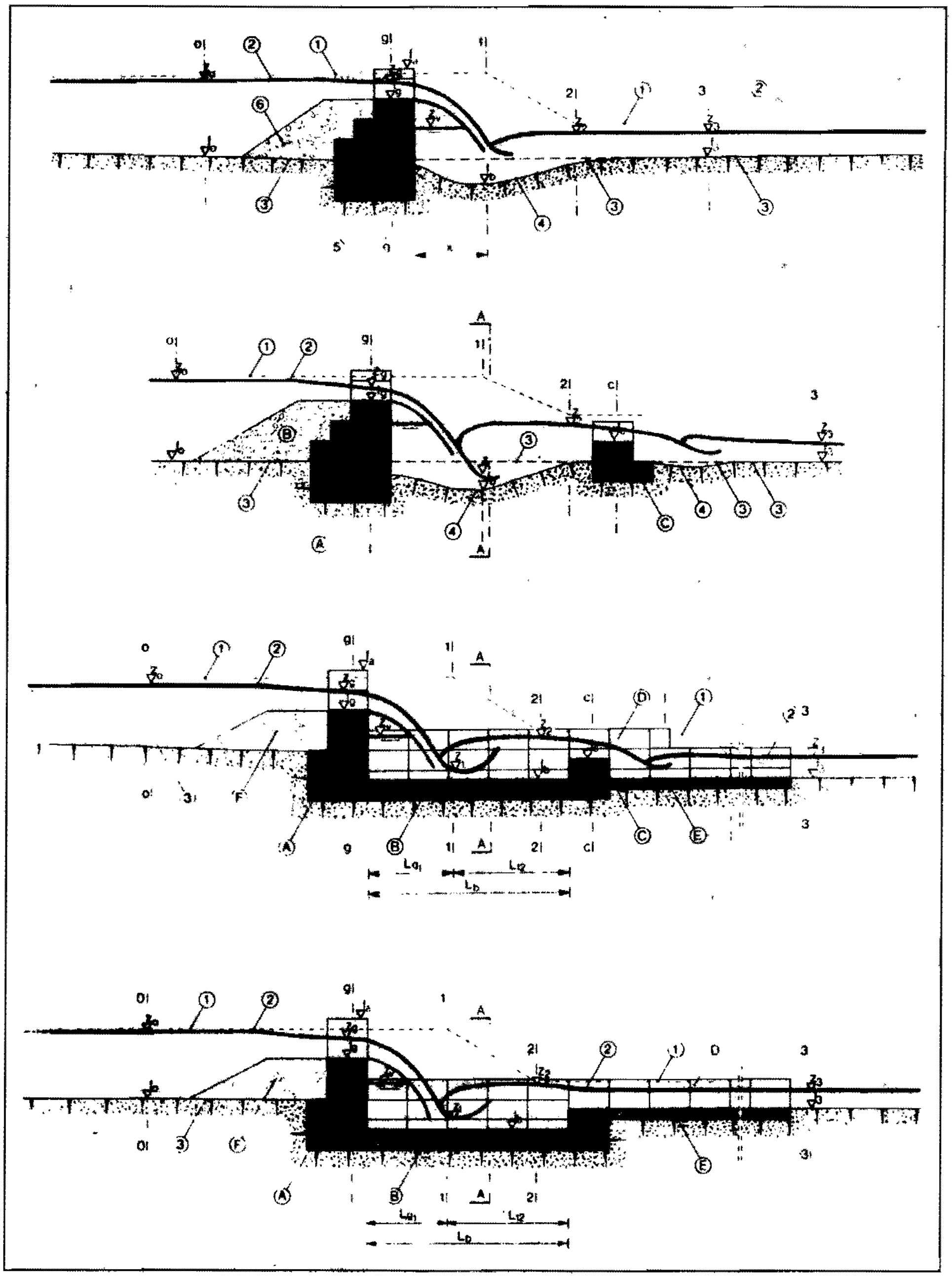


Figure 7 Types of stilling pools

Details of proposed improvements to traditional spate diversion works using gabions are given in figure 6.

In some instances a second intake is constructed on the opposite side of the weir, but this is generally not recommended as its performance is bound to be poor and would be difficult to fit in with the overall arrangements of weir and fuse bund.

3.3 Special considerations

Other design parameters for weirs and stilling basins will have to be derived from analysis of forces acting on the structure, such as gravity, hydrostatic pressure, soil pressure and hydraulic uplift. The ultimate design should ensure stability against overturning, sliding and uplift forces and take account of seepage control. The required calculations are beyond the scope of this paper and the reader is referred to relevant technical reports (see also references).

Some characteristics and consequences of using gabion material in constructing weirs should, however, be mentioned. The very high permeability of gabions might cause removal of fine particles of the backfill and foundation materials by water flowing through or around the gabion structure. If no preventive actions are taken, piping can develop resulting in the eventual failure of the structure. This danger is often brought forward by some designers against the use of gabions.

To minimize this danger, adequate filters should be installed at the interface of soil and gabions, for which a synthetic material, and also gravel, can be used, although the latter will be more complicated to construct. Installation of such a filter is a must in the presence of sandy or silty soils, but is usually recommended as standard procedure for all gabion works. The additional cost would only be a fraction of the total construction cost.

Field observations of gabion structures in several wadis have indicated that proper filters are often not installed. Apart from shortcomings in design, this is probably the main cause of failure in gabion structures.

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