

# Improved Engineering in Spate Irrigation Systems

# 2



Practical Notes Spate Irrigation

## 1. Introduction

Engineering in spate irrigation is entirely different from that in perennial systems. Some of the spectacular failures in improving spate irrigation in the recent past resulted from a lack of appreciation of the special characteristics of spate irrigation systems. An evaluation of 47 relatively minor spate systems built in Balochistan between 1960 and 1990 for instance established that only 16 were still operational in 1990 (Groundwater Consult 1991). The main reasons were that the diversion structures has either been severely damaged by the floods or had been by passed after construction. In some cases disputes between water users had made the system inoperational. Another well-known failure is the Mithawan Dam in DG Khan that filled up with sediment within one year of completion.

Fortunately in recent years the understanding on what works engineering-wise and what does not work in spate irrigation has improved. For spate irrigation in most situations there is an appropriate improvement - be it in improving traditional diversions or in constructing new diversions or in engaging earth moving equipment on (reinforced) soil bunds. Special engineering challenges in spate irrigation are:

- the challenge of capturing as much as possible of the usable floods - in terms of volume, duration and timing
- the need to deal with high floods - these may play havoc with the command area and are usually kept out
- the need to deal with high sediment loads - in spate flows these can run up to 10% of volume. The sediment loads can help built up soils and bring fertility but they can also carry coarse material, clog canals and cause command areas to rise and go out of command
- the need to operate in widely shifting river beds or in very soft alluvial material with the low flow channel moving in different directions and being hard to capture
- the need to be economical - with very costly investment usually not justified in the low or medium value agriculture, that is supported by spate irrigation systems
- the need to respect existing water rights and rules - these are often different in spate irrigation systems. Rules often accommodate a large number of situations - the sequence of water turns between separate command areas, the division of floods between both

river banks, the designation of areas that are entitled to spate irrigation and areas that are not, the practices with changes in the river bed. In many spate irrigation systems there are a series of separate intakes along the ephemeral river rather than one single diversion and water rights systems are based on these.

There is no single approach to the design of improved spate systems. The local situation and conditions - the social setting, hydrology, agronomy (in particular whether the crop is planted pre or post irrigation) and river morphology will determine what is possible and what is most useful. This may be improved earthworks, permanent structures or a combination of both. This note is an overview of best civil engineering practices. It describes experiences with improving diversion structures (section 2) and canal networks (section 3)<sup>1)</sup>. It should be read with Practical Note 3 on working on soil bunds and the experience with making earthmoving equipment available - which complements the work on engineering interventions.

## 2. Improving diversion

In Pakistan traditional diversion structures are in place in many of the ephemeral rivers. In some areas however there is no diversion as yet, but there is scope to do so - particularly if one aims to bring new areas under command (see also Practical Note 1).

Traditional spate irrigation makes use of earthen structures (soil bunds), brushwood or stone deflectors. The intakes can take one of the two forms: spur type deflection or bund type diversion. While traditional intakes appear crude at first sight, they have usually enabled irrigation to be sustained for many years using local materials and indigenous skills and have often performed relatively well. Advantages of traditional intakes typically include:

- **Flexibility:** Location and layout of traditional intakes can be easily adjusted to suit the changing river bed condition; Deflecting spurs can be extended and diversion bunds can be moved upstream when sedimentation on the fields or in the canals starts to take fields out of command, or where head-cutting or stream bank erosion occurs.
- **Appropriate and low cost:** traditional intakes are constructed from local materials and can

1) This note introduces the main engineering concepts. For detailed guidance the different resources at [www.spate-irrigation.org](http://www.spate-irrigation.org) should be consulted.

### Box 1: The importance of siting: the Shebo Headworks

The Shebo Headworks in Balochistan are one of the earliest improved spate systems and they are still operational. They suffer considerably less from sedimentation as they are situated on a side branch of the river.

be maintained without outside support.

- Relatively efficient in water use and sharing between users: Typically, series of traditional intakes are used along larger rivers, each serving their own separate command area. This can achieve high overall diversion efficiency and better water equality. As they pass down a river, large spate floods will destroy intakes located at the heads of each spate command area, with those upstream intakes breaking sooner than those further downstream. Once the flood peak (or rising limb of the flood hydrograph) has destroyed traditional diversion bunds at one location, the flow passes to the next one further downstream and so on, sharing water between many off-takes and not permitting the upstream site to “steal” all of the flow. Although the lower sites experience less severe flood peaks, the way in which the flood hydrograph is gradually modified through its passage downstream, means that they are exposed for longer periods, thereby compensating for water not received from other smaller floods that only reach the upper intakes.
- Restrict diversion of high flows with high sediment loads: the breaching or destruction of deflecting spurs, diversion bunds and breach sections of main canal at high river discharges abruptly lower the water level at the canal intakes, reducing the discharges that are diverted, limiting the damage to the downstream canals and field systems and preventing the incursion of high concentrations of coarse bed material sediments transported in large floods.

There are however some major disadvantages associated with traditional diversion structures. The most important one is the enormous input of labour and materials needed to maintain and reconstruct intakes that are damaged, or washed out by large floods. In many cases, exposure to available floods is reduced and lost and as repair works are not completed in time and suitable floods often occur within a few days of each

other. In locations where river bed widths are large ( $> 200$  m), traditional techniques – using soil bunds or brushwood – are not appropriate as they do not resist large floods at these sections of rivers.

There are many options for improving diversion structures depending on the site conditions, water use rules and the available resources and farmers’ preferences. Table 1 gives a menu of options. The usual objective for improvement is to reduce the labour required to maintain intakes and to facilitate and improve the control of water entering the system while respecting the system of water rights along a river. In general improvements should make it easier for farmers to operate and not require the large inputs of labour or other resources to maintain; prevent large and uncontrolled flood flows from entering the conveyance system and thereby damaging canals and field systems; help maintaining the distribution of water within the system in line with accepted rules and rights, while providing flexibility to accommodate changing hydrological patterns, future changes in water distribution and cropping pattern and equality of water shares between upstream and downstream users; encourage an appropriate balance between the needs of different irrigation water uses and other water users (agriculture, drinking water, forestry, rangeland, downstream users, recharge).

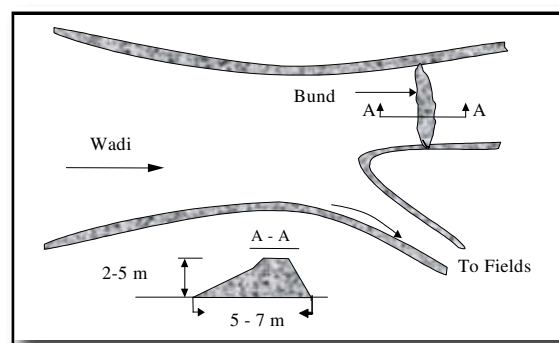


Figure 1. Controlled bund type of intake

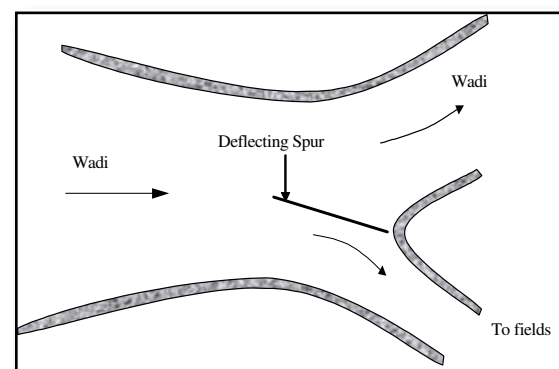


Figure 2. Free spur type of intake



Figure 3. Bed stabilizer with free intake

**Box 2: Single or multiple intakes**

When improvements to diversion arrangements are envisaged, a common pitfall has been to provide a limited number of major diversion structures, often only one, serving a large new main canal that connects into (and often dissects) the existing traditional canal networks that then become sub-main or secondary canals. The major disadvantage of the single new intake approach is that it reinforces the upstream users control over diverted flows with significant proportions of the annual flood flow going to these users and leading to an increase in the inequity between upstream and downstream users' access to water. Also, traditional numerous intakes enable many attempts at abstraction of water from the flood hydrograph with the abstraction envelope giving much greater water volume than the single intake.

In principle one can argue that water user associations have a role to play here and that agreements should be made on the distribution of water from a single off-take. While this is very much true in practice it is not always so easy as after the construction of a single new off-take a new power equation emerges. This was the lesson of the construction of the Rehanzai Bund in the Jal Magsi area in Balochistan. Prior to the construction of this large and technically very successful new soil bund, agreements were made between upstream and downstream users on breaking of diversion bunds in the common flood channel - endorsed by the local government. However once the Rehanzai Bund was in operation - very successfully technically - a large number of people moved back to the upstream area, adding to the political clout of this area and the agreements that were made earlier were not honoured.

Improved diversion structures ideally consist of:

- A bed-stabilizer or a moderately raised weir, to stabilise and fix the water levels at the division point. In many cases high weirs - and sometimes even low weirs - are not needed to provide command, as both the land and river bed slopes are steep. With the sediment loads in spate rivers the areas in front of weirs often silt up. The idea of bed stabilizers or low weirs is for farmers to build simple earthen or brushwood diversion structures on top of them. It provides for stable location for offtake and the possibility to rebuild the traditional weir at same location once the floods have passed whereas the erosion that occurs with the washing away of traditional weirs can make it difficult to rebuild a traditional weir at the same location again
- Where high weirs have to be used (for instance to make up for the head difference) stilling basins are required as well as scour sluices to remove sediments. A so-called breaching bund or fuse plug may be part of the design too. This is an earthen section in the headworks that breaks at high flood levels, thus protecting the structures and the command area from excessive damage
- A canal head regulator or an orifice, to hydraulically regulate the flood flows entering the canal network. These structures should



prevent very large and destructive floods entering the command area. Particular in alluvial plains such large floods can do substantial damage to the command area and effectively take it out of production for many years to come. Improved embankments. Bank protection serves to stabilize the off-take points and to avoid changes in river course. Bank protection can make use of a range of material - gabions and stone pitching void gates

- Flow splitters. When there are off-takes on both side of the river, flow divisions will be able to divide the water and make sure that floods do not end up at one side of the river only. They can be very useful in consolidating the river bed. In constructing flow splitters - or for that matter other permanent structures in the river bed - the use of conical abutments - akin to the traditional 'algama' of Yemen - may be considered. These provide permanent anchor points for earthen or stone intake or flow dividers and are relatively easy to construct and maintain. As splitters face the full force of flow, they need to be well designed to prevent scour damage - depths of scour of 2.5 -3.5 metres at these nodes is not uncommon.

If the lay of the land does not make river bed stabilizers or low weirs practical and more command is required, it will be necessary to look for a suitable site further upstream or to perhaps adopt a higher weir. such structures must be properly designed, will be more complicated to design (needing more experienced engineers with appropriate hydraulic design and skills and experience and will also be costly to construct and complex to operate.

- In wide rivers a fuse plug or breaching bund may be used with the weir spanning only part of the river width. The fuse plug is an earthen section in the diversion structures that is designed to fail if a high flood occurs and will cover part of the river bed width? The fuse plug serves two purposes. The first is that it reduces cost as part of the diversion structure can be built from soil. The second is that it acts as a safety valve at times of extremely high floods. In designing fuse plugs there are a number of considerations:
  - It is important to design the body and the height of the scour sluice is such a way that it does not break too early or too late. In this respect one has to take into account the inevitable compaction over time of earthen structures as well;
  - The location of the weir-cum-fuse plug is important. If it is too close to the river



Figure 4. Embankment with stone pitching



Figure 5. Flow division structure Barkhan

- quickly accumulate behind a structure, unleashing a massive volume of water once the breaching bund breaks.
- A second element in a relatively high spate diversion weir is a gated scour or under sluice, to exclude from the canal some of the very coarse sediments moving along or close the river bed during periods of high flow. Sluices can usually only be operated for the short periods when the river flows exceed the canal discharge. Farmers in many instance have blocked the scour sluice as they are keen not to loose any water. This can be partly avoided by making sure that the water that escapes through the scour sluice is picked up elsewhere and used further downstream.
- Sedimentation ponds. To avoid that (too much) coarse sediment enters the flood channels or that the command area rises rapidly because of the sediment deposition sedimentation ponds are sometimes considered. There are few examples of sedimentation ponds operating easily. The main issue is the cleaning quickly accumulate behind a structure, unleashing a massive volume of water once the breaching bund breaks.

Table 1. Options for engineering structures in spate irrigation

Category	Structure	Notes
Diversion	Weirs	<ul style="list-style-type: none"> <li>▪ Create additional head and stabilizes the river bed - but siltation in front of the weir is almost inevitable - and small earthen/ gravel/ brushwood structures are often required in the end</li> <li>▪ Cut off weirs should be provided with weepholes as they may interfere with the subsurface flows</li> </ul>
	Flow dividers	<ul style="list-style-type: none"> <li>▪ Useful to keep flows in manageable proportions - need enough protection (for instance with aslar) to avoid damage</li> </ul>
	Deflection spurs	<ul style="list-style-type: none"> <li>▪ Common higher up the river/ gravel fans</li> <li>▪ Catches parts of the flood - and in case of high flood can be overtopped and exclude the large flood</li> </ul>
	Gravel dykes/bunds	<ul style="list-style-type: none"> <li>▪ Suitable to divert flows towards intakes and can be alternative for permanent weirs (but need rebuilding)</li> <li>▪ Reinforcement with gabions or abutments</li> <li>▪ Often at angle</li> </ul>
	Soil dykes/bunds	<ul style="list-style-type: none"> <li>▪ Suitable in lowland alluvial spate systems: low cost</li> <li>▪ Location and choice of material is important (silty-loamy, non-saline)</li> <li>▪ Reinforcement by gabions, plastic sheets, brushwood or pegs</li> <li>▪ Often build at angle</li> </ul>
	Conical abutments	<ul style="list-style-type: none"> <li>▪ Can protect intakes or heads of spurs and stabilize soil bunds</li> </ul>
	Breaching bunds	<ul style="list-style-type: none"> <li>▪ Will act as 'fuse plugs' and break and allow large floods to pass and save main infrastructure and command area</li> <li>▪ Avoid having breaching bund high up the gravel fan as they may break too fast - proper location is in plain areas</li> </ul>
Intakes	Multiple intakes (and short canals)	<ul style="list-style-type: none"> <li>▪ Preferred so as to minimize conflicts and management problems</li> </ul>
	Open intakes	<ul style="list-style-type: none"> <li>▪ Large dimension - so as to pass large volume of flood water in short time</li> <li>▪ Curved wing-walls preferred</li> </ul>
	Orifice intakes	<ul style="list-style-type: none"> <li>▪ Will make it possible to exclude unwanted large floods</li> </ul>
	Gated intakes	<ul style="list-style-type: none"> <li>▪ Can allow closure of area if it</li> <li>▪ Mechanical operation may be difficult and mechanical operation is expensive</li> </ul>
	Rejection spillways	<ul style="list-style-type: none"> <li>▪ Allows rejection of destructive floods</li> </ul>

Table 1 (continued). Options for engineering structures in spate irrigation

Category	Structure	Notes
Intakes	Scour sluices (preferably with curved skimming weir)	<ul style="list-style-type: none"> <li>Can work but are often closed by farmers as they do not want to lose water</li> </ul>
	Sedimentation ponds	<ul style="list-style-type: none"> <li>In most these do not work - as cleaning and flushing is cumbersome and farmers do not want to 'spend' water on this</li> </ul>
	Trash racks	<ul style="list-style-type: none"> <li>Put at angle so trash is guided to main river</li> <li>Need provision to clean as large trash catches smaller trash</li> </ul>
River bed stabilization	Bed stabilizer	<ul style="list-style-type: none"> <li>Make sure weepholes are provided to allow subsurface flows to pass</li> <li>Masonry: steep river slopes</li> <li>Gabions: flat river slopes</li> </ul>
	Gabion spurs	<ul style="list-style-type: none"> <li>Location and shape is important to avoid loss of area or undercutting over river bank</li> <li>Stepped nose to avoid scour around nose</li> </ul>
	Revetments (several materials)	<ul style="list-style-type: none"> <li>Important to have strong undertoe</li> </ul>
	Vegetative bank protection	<ul style="list-style-type: none"> <li>Can be natural or planted - needs protection against cutting</li> </ul>
Canals and command area structures	Steep channels	<ul style="list-style-type: none"> <li>Preferred in upstream areas with heavy sediment load to carry fine sediment all the way to fields (for slope look at natural drains)</li> </ul>
	Shallow wide channels	<ul style="list-style-type: none"> <li>Preferred in downstream areas with soft alluvial soils to prevent uncontrolled scour</li> </ul>
	Stepped drop structures	<ul style="list-style-type: none"> <li>Effective in dissipating energy</li> <li>In general try to avoid drop structures - can sometimes be avoided by using a different channel route</li> </ul>
	Gabion flow division/diversion structures	<ul style="list-style-type: none"> <li>Ensure that downstream apron of gabion structure is long enough to avoid back cutting</li> <li>Can stabilize the bed of the flood channel</li> </ul>
	Flow spreaders	<ul style="list-style-type: none"> <li>Will spread flow at end of lined channel to avoid scour and ensure water is distributed over large section</li> </ul>
Field structures	Improved field intakes	<ul style="list-style-type: none"> <li>Allows closure of field after it is filled with water</li> </ul>
	Overflow structures	<ul style="list-style-type: none"> <li>Useful if there is level difference between to prevent uncontrolled gulying in downstream field</li> </ul>
Groundwater management	Low recharge weirs	<ul style="list-style-type: none"> <li>Will reduce velocity of flows and induce recharge</li> </ul>

**Box 3: Coming to terms with diversion in large spate rivers: Sanghar**

In Sanghar in DG Khan, the challenge is to develop the command area using the diverted floods from a very wide riverbed. A design based on the ideas of a sub-engineer residing in the area for a long time has now been implemented. It consists of very low crest weir spanning the 400 meters width of the river. The foundations of the weir extend 4 metres below the river bed level and the crest is only 60 cm above the riverbed level. In general the depth of foundation is important as even though scour does not seem to have taken place when inspected after the flood, during spate flows, the whole river bed may become mobile. In Gash (Sudan) for example, 2 metres of bed becomes turbulent and forms part of the river flow.

On either side of the weir there is an open intake. In addition the banks of the Sanghar River are reinforced to avoid that the shallow river changes course. The design has a number of strong elements:

- it stabilizes the river bed and makes it easy to catch the low flows;
- the flow over the crest can be regulated by farmers with very small bunds, either just in front of the weir (to divert more to the canals) or in the canal intake (to divert more to the main river), therefore reducing maintenance costs;
- large floods automatically pass over the crest and stay in the river bed - not causing damage to the command area;
- the open intakes set a maximum as the flood volume that can go into the command area.



Figure 6. Low diversion weir between off-takes Sanghar



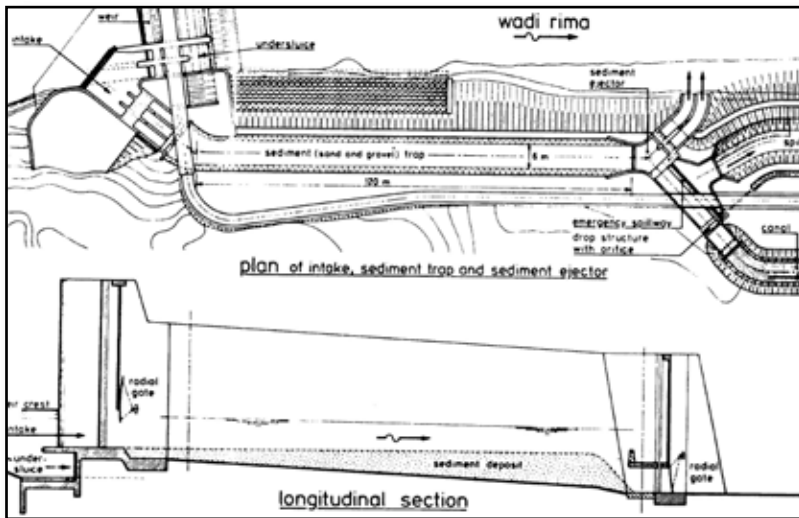


Figure 7. Conventional design with sediment trap

gorge, the time to flood peak may be too short or flood velocities may be either too high for fuse plugs to resist or floods may

- A second element in a relatively high spate diversion weir is a gated scour or under sluice, to exclude from the canal some of the very coarse sediments moving along or close the river bed during periods of high flow. Sluices can usually only be operated for the short periods when the river flows exceed the canal discharge. Farmers in many instance have blocked the scour sluice as they are keen not to loose any water. This can be partly avoided by making sure that the water that escapes through the scour sluice is picked up elsewhere and used further downstream.
- Sedimentation ponds. To avoid that (too much) coarse sediment enters the flood channels or that the command area rises rapidly because of the sediment deposition sedimentation ponds are sometimes considered. There are few examples of sedimentation ponds operating easily. The main issue is the cleaning of the sedimentation pond. If the pond traps the sediment effectively regular cleaning of the pond throughout the season of floods may be an immense job - particularly if there is much fine sediment, creating quicksand type of conditions. In some spate irrigation systems in Yemen dual sedimentation ponds have been designed - with the idea that excess floods can be used to flush out a filled sedimentation ponds. The problems - as with a scour sluice - is that farmers maybe reluctant to use flood water for flushing out sediments and may rather use in on their land. Engineers want the farmers to use the rising limb of the hydrograph, farmers want to use the falling

limb as by then they know the extent and size of the flood.

### 3. Improving canal networks

In spate irrigation systems, the objective is to divert the maximum possible amount of water to the fields during the very limited spate flood duration period. Intakes and canals thus have a very much larger discharge capacity per unit area served than would be the case in perennial irrigation schemes (10 - 100 times). Discharge capacities have to be selected taking

account of the distribution of flows within the annual hydrograph, the duration of and discharge variations during flood events, as well as crop water requirements.

There are important considerations in designing spate canal systems:

- A canal network will already be in place when existing spate schemes are being improved. Improved canal networks can give better control and overcome some of the other disadvantages of the field-to-field water distribution system, but will probably also require a change in the way that water is distributed. This could have a large impact on existing water rights and rules.
- Any improved system must ensure that irrigation can be carried out quickly, in the short periods that spate flows occur. This is certainly of utmost importance to downstream farmers while it is of less important to upstream farmers who have more control of water. Improvements should obviously be developed with the farmers to ensure that they understand and agree with any implied changes to water distribution.
- In existing schemes, where canals are performing reasonably satisfactorily, the design of new or extended canals should be based on the slopes and cross sections of existing traditional canals, derived from surveys. If the discharge capacity is to be changed, then the survey data can be used to select a canal design method that best predicts the existing canal slopes and dimensions. The selected method can then be applied to design the new canals. New canals should not block flows entering through traditional intakes at the lower ends of the systems.

- Particularly in areas with alluvial soils scour damage should be avoided - through appropriate canal dimensions and slope and controlled intakes;
- Conventional "regime" canal design methods were developed for canals in perennial irrigation systems that are operated within a fairly narrow range of discharges and have a small sediment input. This contrasts with the situation in spate canals where discharge varies rapidly over the full range of flows from zero to the maximum discharge. Sediment inputs are very large and canal designers are not free to set the canal cross section and slope to carry the optimum discharge, without also providing an appropriately high sediment transporting capacity. This rules out the use of most conventional canal design procedures. Maintaining flow velocity within the conveyance system takes over higher importance in spate systems.

systems consist of:

- Check and drop structures - these may serve to reduce velocities and prevent destructive erosion of canals but will still require good designs with downstream erosion protection works
- Flood canal stabilizers - similar in function as river bed stabilizers - fixing important off-take points
- Flow splitting structures - to divide water in manageable portion over the command area and in proportion to agreed/traditional flow proportions
- Controlled field inlets - particularly in the high bunded fields of many spate system in Pakistan these will make it possible that water does not flow out the fields once irrigated; and
- In-field overflow structures - to have controlled overflows from one field to another avoiding the rutting and gullying of downstream fields.

While traditional canals in spate schemes are usually constructed without drop structures and are far steeper than conventional canals used in perennial irrigation systems, many of the water control structures used in improved spate systems are similar to those used in conventional perennial irrigation practice. Reference is also made to Practical Note 4 that discussed command area improvements. There is the challenge of moving large volume of water quickly and at the same time avoid that the water flows do not become erosive – in the words of farmers in part of Pakistan the challenge is 'to kill the flood'. Improved canal structures in spate irrigation



Figure 8. Tamarix providing vegetative flood protection

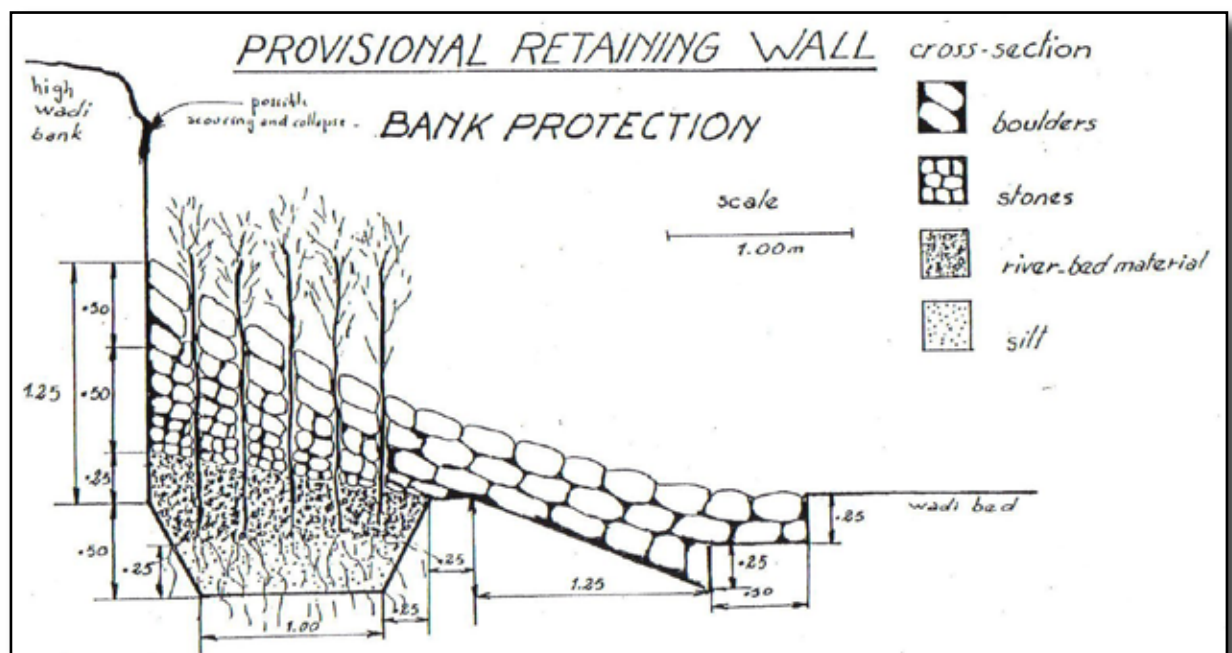


Figure 9. Embankment with vegetative protection

Box 4: Some recommended practices



Figure 10. Typical conventional diversion structure

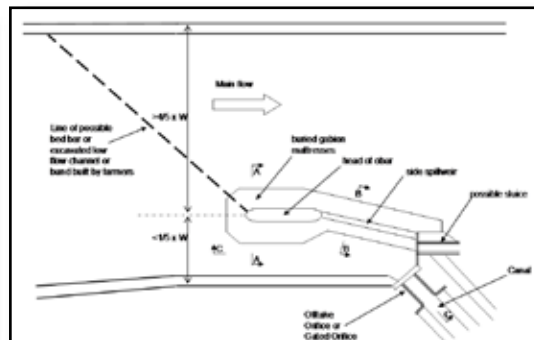


Figure 11. Typical layout of improved intake



Figure 12. Bed bars



Figure 13. Bagr canal intake



Figure 14. Stepped drop structure



Figure 15. Weir with cascaded toe

Colofon

This note was prepared by Frank van Steenberg with inputs of Ian MacAnderson and John Ratsey. The Practical Notes series is prepared as part of the strengthening of the Pakistan Chapter of the Spate Irrigation Network, supported by World Bank and Royal Netherlands Embassy.

The Pakistan Spate Irrigation Network supports and promotes appropriate programmes and policies in spate irrigation, exchanges information on the improvement of livelihoods through a range of interventions, assists in educational development and supports in the implementation and start-up of projects in Spate irrigation. For more information: [www.spate-irrigation.org](http://www.spate-irrigation.org).

