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Improved Field Water Management in Spate Irrigation

Practical Note

Guideline on Restoring Bundats Under The EFAP Programme

1. Introduction

Spate Irrigation is a form of water management that uses short term floods from dry riverbeds for productive use. it goes under different names in Pakistan: rod-kohi, hill-torrent irrigation, sailaba or nai. The total area that has been prepared under these systems in Pakistan amounts to 1,300,000[2] ha , though not all of this is used. This makes it the second largest source of water used in Pakistan. The spate irrigation areas are an important source for coarse grain (sorghum), wheat, oilseeds (arugula, mustard, sesame, castor) and leguminous crops (like chickpeas, guar, mung). In highland areas they may also be used to support the cultivation of almonds, pistachio or olives. This is particularly promising in areas where groundwater is becoming unavailable due to prolonger overuse.

Production in spate irrigated areas is usually totally organic, because the crops need no fertilizer as the flood water brings fertile sediment. Besides the uncertain nature and the large field dimension do not support fertilizer application. . It is also the system that has a large scope for expansion. Estimates vary but in the 2022 flood event many areas were inundated that sustained a crop. Also, there are many areas where small flood water harvesting systems have been developed in recent years. Clearly this type of water management with the right crop choices, management and marketing has a huge future. At the same it is also the system that has unique challenges: flood water may come with a large force, that should not be allowed to be destructive. Water needs to be spread carefully over the command areas and not be allowed to escape to lower lying areas. Large amounts of silt are carried with the flood water that can rejuvenate the land but also cause channels to be blocked and command area land to go out of command.

Successful spate irrigation depends not only on the diversion of the flood water to the land but in equal measure on the management of water on the land. The aim is to store water in the soil and make it available for cultivation throughout the growth season. The soil in spate irrigation systems comes from the sediment deposits and have often excellent moisture holding capacities, that can be further enhanced by proper land management, in particular planking and deep ploughing. In many areas moisture is mobilized from deeper layers by capillary rise towards the end of the crop season. What is important is for a field to have enough soil moisture to increase water availability above the wilting point of the crop. Though the crops grown in the spate irrigation systems are by nature adopted to the harsh arid conditions, having secure moisture availability can increase crop yields manifold in spate irrigated areas.

The retention of flood water on the land is hence of highest importance in spate irrigation. This guideline – prepared for use in the EFAP program discusses the use of field earthen bunds (bundats) and related structures to optimize water

Box 1: Spate irrigation in Pakistan: diverse systems

Spate irrigation can be different from place to place. The area and topography differs – from small highland spate irrigation systems to larger lowland systems. In the former there is an abundance of stones that can be used for hard structures but a shortage of soil to build up land and field bunds. In lowland areas soils are deep and sediment is all around, yet rocks and boulders may be more difficult to come by.

Every area has its own tradition and time-tested practices. These are the result of local intelligence and the use of available resources. Spate irrigation system can be categorized in many ways depending on the size of the area, the slope of the land, the flooding pattern, the source of the water (in some exceptional areas the flood water is salty) and the weather conditions. In Pakistan spate irrigation is practiced in all provinces but at various scales. The three main categories of systems are (I) flood water diversion from major dry or semi-perennial rivers, such as Nari, Porali and some Zams along the Koh-I-Suleiman (ii) flood water diversion from medium-sized wadis and rods (iii) smaller spate irrigation in the upper catchment areas or along the dry rivers, by building earthen diversion or overflow structures in the khullas. In all the above water resources access to labor is important, to build and rebuild diversion structures and earthen bunds. In the larger system the use of earth moving equipment is essential.

[1] This guideline is prepared by Frank van Steenbergen, Rehmatullah Khan, Karim Nawaz, Allah Baksh, Saleem Buzdar, Abdul Ghani Soomro, Aneelah Hameen Memon and reviewed by Noman Latif Sadozai and Faheem Iqbal. This guidance note is made in loving memory of Dr Shahid Ahmed.

[2] The area actually used varies from year to year, depending on the availability and nature of the short-term floods.

management at the field. In the 2022 floods many of the bundats were washed away and hence it is of utmost importance not only to restore these, but also to build them back better: allowing better field water control and, hence facilitating higher productivity. This is the in essence one of EFAP components.

2. Principles for water management in spate irrigation systems

In spate irrigation water is diverted from ephemeral streams and then guided to the farmland. The ephemeral rivers may be dry rivers or small local streams. The floods typically last a number of hours up to a few days. The flood waters come typically a number of times a year, generated from rain in the upper catchments. In a few cases the dry river flows for a number of weeks or months. The water is typically turbulent and with high loads of silt: five percent by weight is quite common, but in areas with fine soils this can go up to 15%.

In the management of water in the spate irrigation systems, there are three elements:

1. Diversion of flood water from the river or stream bed
2. Distribution of flood water over the command area, in larger systems using wide channels and guide bunds
3. Storage of water and moisture in the fields

The latter is the main topic of this guideline, but we will also discuss the first two elements.

2.1 Diversion of flood water from the river or stream bed

To divert the water from the dry river temporary structures are built traditionally, made from soils, stones, or brushwood. In some areas these have been replaced by permanent diversion structures. Some of these permanent structures have been successful, but not all of them are. Some permanent structures were ill-designed, causing the flood water to wash them away or to have them circumvented with the rivers that were changing course.

There have also been attempts to build storage dams on the ephemeral rivers. The experiences have often been negative, with many storage reservoirs filled with the sediment that are characteristic of the flood water flows.

In diverting flood water from the riverbed, a number of principles apply:

1. Avoid diverting the very large floods, as these would be out of control and do much damage to the earthen structure. The diversion structures should have mechanisms to deal with high floods, either:
   - In case of soil diversion bunds, they should break in case of high floods in order to protect the command areas structures. Alternatively, they may have a permeable spillway, made of gabion and rockfill, that allow high flood water to spill over without damaging the main soil bunds.
   - In case of permanent structures, they should have gates to allow the passage of high water and a possible spillway. A good example is the mini barrages that have been introduced on the Nari System in Balochistan and Zam system in south KP. The gates on these mini barrages can be opened in case of too high a flood, or in case of low floods, some gates can be opened to allow part of the flood water to pass on downstream to fill drinking water reservoirs.
2. Seek to stabilize the riverbed, at the point from where the water is diverted.
   - A hybrid solution combining permanent and temporary structures is the use of bed-stabilizers. These can also be drift/ irish bridges across the riverbed. They will stabilize the riverbed, avoid that it gets rutted and distorted. This makes it easier to construct a soil diversion bund as the riverbed is smooth and even.
3. Avoid ponding up water too long and extensively in front of the diversion structure, as it may either cause sedimentation in the riverbed and/or breaking of the riverbanks, resulting in the river changing course, in particular in slopy areas.
4. In gravel rivers – as common in upland spate system – the diversion weir may be made in such a

way that it ponds up the subsurface flow in the gravel river, effectively combining the function of a small diversion weir and a subsurface dams. This causes higher groundwater tables and secure moisture which can support the cultivation of high value tree crops, such as grapes or almonds.

2.2 Distribution of flood water over the command area

In the distribution of the flood water across the command area the main considerations are to:

- Spread water gently over the area, avoiding the water is become erosive, destroying land, and become difficult to control farmers in this regard traditionally talk about the necessity to 'kill the flood'.
- Manage the flood water over the entire area by having a proper network of flood channels. In general, the flood channel network is key to diverting larger floods.
- Avoid that water escapes to lower lying areas before irrigating the higher land that is entitled to the flood water, as per defined water right.
- Observe the rights to flood water – irrigating land that is entitled to the flood water, and observe the agreed proportion of the flow, where water distributions are in place.

In distributing water across the command area, important structures are:

- Flood channels carrying the flood water – these are typically wide and shallow, preferably with a slope of 0.5%, steeper than slopes in conventional perennial irrigation systems.
- Use earthen guide bunds (sometimes alongside shallow flood channels) to guide water over the command areas. A special version of this are periphery bunds, meant to avoid water escaping to lower area not entitled to the flood water. These earthen bunds may be reinforced with gabions at critical sections – for instance where they intersect with local streams – to avoid them breaking.
- Adjust the dimension of the flood channels and bunds over the command area. This can be done by widening the channels and keeping the height of the bunds lower at upstream. Traditionally, farmers build bunds upstream with a maximum height of 8-12 feet, slightly higher in the middle, and between 20-30 feet downstream. The channels upstream are also deeper compared to those downstream. Maintaining the proper ratio between the height of the bunds and the depth of the channels is crucial for a sustainable spate irrigation system. Ideally, there is always a drainage system, locally called a "khad," which is used to divert excess floodwaters. The "khad" cuts through specially designed bunds alongside the channels, known as a "pal."
- Reinforced/ permanent control structures at critical points, for instance gated distribution structures that prevent water going to lower areas too early, opening the gate only when the higher area is served.

Box 2: Example of improving water distribution in the command area (Sindh)

In restoring the spate irrigation area at Motiyo Khan Palari the following was done. The main channel was cleaned, the bed was leveled to meet the channel slope requirements, the channel guide bund was rehabilitated, and all breaches and rate holes have been filled. The channel was created by using a tractor and enlisting manpower. A main control and distribution structure was designed and built as a head of channel that controls two sub-main channels of the Motiyo Khan Palari channel. The strategy was that one sub-main channel of the Motiyo Khan Palari Farm was more developed up to the farm as a model farm, but the second sub-main channel of Muhammad Sidique Baplani channel was also cleaned and rehabilitated up to the head of farm. As with the main channel, the aforementioned the two sub-canals were cleaned, bunds were built, and breaches and rat holes were filled using a tractor. Bushes, shrubs, and vegetation were also removed from the channel bed, and the slope was maintained. Each sub-canal was rehabilitated for 1.5 kilometers in length.

- Flow dividers that split the flow between different areas. The preference is for the flow dividers to have a concave upstream wall, to distribute the water gently. The concave wall maybe extended with soil bunds to calibrate the flow division into agreed proportions. The flow dividers may also have a bed stabilizer, so as to avoid the risk that most water escapes to the land that is more low-lying.

2.3 Storage of water and moisture in the fields

The idea is to store flood water, once diverted during the rainy season, in the soil profile and use this moisture later for cultivation, when the flood season is over and the temperatures in many areas are less demanding. During the flood season water is moved around the command area and the different bunded fields are filled to store the water. The storage depends on the timing of flood water availability. Whereas early floods in May and June were more common in the past, due to climate change late floods (July and August) are now becoming more common[2].

The fields in spate irrigation may be very large, from 0.5 to 2.0 hectares, even up to 5.0 hectares. They are surrounded by the bundats, that are key to the successful ponding and infiltration of the flood water. The higher the field bund, in principle the more water can be stored in the field.

There are two methods of routing water. The first is that each field has its own intake and water from the flood channels serves one large plot at a time. The second method is field-to-field, with water flowing from one plot to another, in a cascade fashion. The advantage of the second method that as the flood water breaches the field bundat sediment is transported out of the area. The risk of the first methods is that silt accumulated. This is usually resolved by pushing up the embankments of the bundats with the accumulated sediment. It is important that the bundats are strong, because if they would break water would escape from the entire area.

3. Techniques at field level

This section discusses the structures at field level to be considered for financial support under the EFAP program. They concern (1) the structures that control the inflow of the water (inlet structures), (2) the structures that control the stor-age and infiltration of water in the fields (the bundats) and (3) the structures that allow the controlled outflow of water from the fields.

3.1 Controlled intake structures

When flood water enters a large bunded field in spate irrigation system, the challenge is not so much to fill the field with water. The larger challenge is to prevent water flowing back out again, once the field is filled. For this controlled intake structures are effective. They make it possible to control the intake once the field is filled. They consist of reinforced intakes that can be closed either with soil/ plastic sheets/ poles or gunny bags, but preferable with a gate or with stoplogs, even with plain soil once the field plot is filled with water. A cutoff wall in front and back of inlet structure beneath the soil is a must to avoid over turning or collapse of such structure.

After storing the optimal amount of water, the intake is closed, and the runoff can be released to feed the next area of the land. With this system of improved water control the area under cultivation. Experience where these control structures have been introduced is that the area under cultivation can increase with 35% to 50%. The design preferred for ESAP it is given in Annex 1.

3.2 Controlled storage: bundats

In spate irrigation fields vary in size but they may be very large – more than 3-4 hectares per field is not unusual. The fields are surrounded by field embankments (bundats). The height of the bundats /embankments varies from place to place, based on the locally agreed practice of field water distribution, but may go up to 2 meters.

[3] Over the past five years, climate change has significantly altered flood patterns. Floods that previously occurred in February and March have shifted to late April, while the rains typically seen in June and July have moved to late August. This shift is impacting farmers' crop choices, leading them to adopt new varieties. In the past, farmers would store large amounts of water during early rains to maintain soil moisture for the sowing season, which began in late November for crops like gram and wheat. However, with the rains now arriving later, farmers are more selective, storing only the amount of water they believe will be sufficient for maintaining moisture after a month. Excess water is drained or stored in field slopes for livestock drinking. The shift in rainfall patterns has also deprived farmers of the opportunity to grow seasonal crops, such as watermelons, sorghum, and millet, which are traditionally planted in April and May, as the floods now occur during that time.

Constructing controlled intake: construction, back filling with soil and in operation (preferred design in EFAP)

Controlled intake structure with stop log

Controlled intake structure with gated intake

Over a number of days, the water is allowed to infiltrate and add to the soil moisture. As mentioned, cultivation usually starts later in the year, using this residual soil moisture. To make sure adequate moisture is available farmers practice two techniques once the water has infiltrated: deep ploughing, to move the soil moisture to deeper layers and planking, closing the soil pores and hence reduce evaporation.

The height of the field bunds determines how much water can be ponded up in the field to infiltrate. The field bund will have a height between 0.5 to 2 meters, depending on local practice, which should be discussed and verified. The slope of the bundats is typically as follows: height: width = 1:2. The length and position of the bundat is determined by existing practice. What is important is that the field bunds are well compacted and free of ratholes.

1. Water retention: Bundat are designed to capture, store, and retain spate flow, or in some cases rainwater, in order to prevent it from quick evaporation or lost through surface runoff. Retention of water, under spate irrigation system, in the field is the best practice to conserve moisture effectively to cope with water stress for crops.

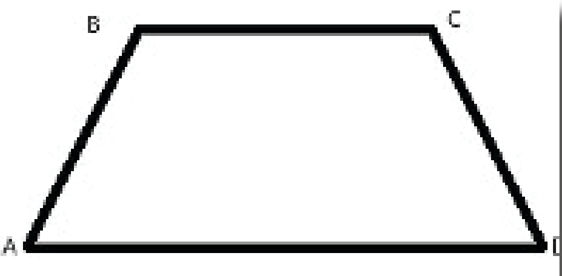
2. Slope design: The field is made with gentle slope from inlet to down part of the field so that water collection and holding is secured. Care is taken to minimize erosion and maximizing water storage/retention.

3. Embankments design: The embankments are usually one to one and half meter high. The bases are about 2.5 to 3 meters and top are one meter. Ideal slope of embankment is 1:2. The storage/retention capacity is to accommodate water in such a way that downstream fields/ farmers are not deprived. The breadth of the earthen bund breadth should be two times of depth or height of bund.

4. Flood depression. In addition to field bunds a good common practice is to create a depression in front of the bundats, this slows down the flood water entering the field, rushing towards the bundat, helping to avoid damage,

5. Vegetation: Embankments are strengthened for stability and water conservation by vegetation of local species such as tamarix. It helps the structure, reduce soil erosion, and promote the infiltration of water into the ground.

6. Simple methods of construction: Embankments are made of local available materials at the site in particular soil, but sometimes also rocks, and stones. The work is done by local tractors. The sediments came with spate flow are used to erect and strengthen the embankments. In this way double benefits are achieved - Compaction of embankments is very important for sustainability.



7. Sustainability: Bundat are prevailing in arid region since centuries and contribute to sustainable agriculture and livelihood in arid regions. Bundat help in recharging ground water and improve soil fertility, support vegetation growth and control desertification.

8. Community participation: the fields and the embankments are constructed through community efforts involving fellow farmers and local organizations. This approach creates a sense of ownership, cost and time sharing and ensures long term maintenance of these structures.

These characteristics of bundats can vary from area to area and hence the design and implementation has to follow from well-structured local discussion.

3.3 Controlled outflow structure

When the bunded fields fill with flood water, water may need to be drain out by controlled overflow structures or field spillways. They ensure the controlled outflow of water once the field has been filled. They prevent that the bundats break during the flood season, where water pressure builds up on the earthen embankments in an uncontrolled way, causing all water to be lost to the field and uncontrolled gullying and erosion to occur. These controlled overflow structures are set at a height above field level, in accordance with the agreed norms on irrigating a field. Farmers of the concerned field and the adjacent field are to be consulted for deciding on the height above field level

In developing the overflow or spillway structure, a few considerations are essential:

- The location of the spillway needs to be chosen carefully, so that the outlet is either to an adjacent field that is entitled to the overflow water or to an open area/ flood channel.
- The spillway is preferably situated on a side bundat and at an area that is neither the lowest nor the highest point in the field embankment to avoid the force of the released water, damaging the spillways. Sites with steep slopes and loose soil material should be avoided.
- The spillway needs enforcement and may be made stone masonry, bricks masonry or local material. In mountain areas stone masonry is preferred. In lowland area there may not
- The spillway needs downstream protection – by stone or concrete to avoid that the water that spills out from the overflow is not creating scour holes and gullies, that would undermine the structure and damage the adjacent land. Vegetation around the areas is encouraged to minimize erosion and deepening.

- If the drop is high, the spillway may have a stepped structure on the downstream side, particularly if it is higher to break the force of the water that overflows.
- The spillway should be wide enough. Spillway capacity is based on an estimate of the water to escape from spillway within a reasonable time (1-2 day). Knowing the dimensions of the field and the depth of the water, the design capacity can be calculated. Not all the water will be evacuated – as a rule of the thumb half of the water stored is released towards the downstream fields. Some free board and safety margin may be included, for instance in accommodating the accumulation of sediment in front of the spillways.
- The bottom height of the spill ways is to set in agreement with farmers, observing local practice and agreement with the users of the neighboring plots.

The design used in EFAP is given in Annex 2.

Controlled outflow spillway structure at Motiyo Khan Palari Farm (Sindh) with rocks to dissipate energy at the outlet. Note that a different design is used in EFAP.

Spillway with stepped structure to break the force of water.

4. Managing the process

4.1 Community engagement

Community involvement in planning and management of spate irrigation activities from start to the end is essential as this system usually works without much government institutional support. Planning, designing, implementation, sourcing of material. repair and maintenance all pivot around the local organizations. It is important that community needs and priorities are well considered in the rehabilitation and build back better of the local water management structures.

Community role in decision making and taking responsibilities is essential. This will include resources mobilization, conflict resolution, facilitating dialogues among communities and promoting collaboration among stake holders, negotiations with the project. Community cooperation is also important to make sure that the works are undertaken in line with existing water rights and practices.

Gender equity is another aspect that needs to be considered: the involvement of women, priorities to women headed households, small farmers, lower status socio-economic farmers so that they are empowered ultimately. Women are the source of local knowledge, and their valuable inputs can be considered in spate irrigation management system.

As part of the program, it is important to an agreed plan with the local community organization to build capacity of community regarding different aspects of spate irrigation – technical training, operation and maintenance of system, water user association roles and responsibilities, awareness, and education such as importance and additional values of spate irrigation system such environment friendly system, organic produces and cost effective.

Communities can also play an important role in monitoring, evaluation and getting feedback on the effectiveness of spate irrigation activities and results and this helps to further improve the system.

4.2 Selection criteria

The following criteria are proposed to prioritize the work on the bundats and the inflow and outflow structures:

Exclusion criteria;

- Areas outside flood effects of 2022
- There is no source of water diversion and harvesting,

- Areas not entitled to flood water or having no water rights
- Areas with High-Security Risk,
- Areas of community dispute over land and water resource and rights,
- Local communities not willing to contribute in kind of the project cost (10-25%),

Programmatic criteria

- Selection of Community: Within boundaries of the designated area affected by flood of 2022.
- Community willingness for active participation in planning, decision-making, implementation, and maintenance,
- Preferably communal or joint bundat,
- Community contribution, equivalent to 10-25% of the total cost in kind (labor, land, transport, local material such as filling soil, etc.),
- Community commitment to post-construction operation and maintenance (O&M),
- In case of more application for bundat then schemes can be equally distributed to areas/ union councils across the district, and or ballot system will be used to select the schemes.

Technical Criteria

- Bundat are damaged fully/partially and causing further desertification and erosion,
- There is high potential that bundat will get spate flow in coming season,
- Water losses (evaporation and infiltration) through existing damages bundat are high,
- The spate flow reached recently (after the flood of 2022) but due to non-existence/damaged embankments, inlet/outlet the farmer is not in position to construct and repair it.
- The construction, repair of bundat and inlet/ outlet has no negative environmental effects.

Vulnerability criteria

Following segments of farming community get priority:

- Poorest households,
- Women-headed households,
- Households of disabled members,
- Households with orphans,
- Households with jobless members

5. EFAP

The spate irrigation field water management structures in EFAP follow the principles discussed above. The design are made in such a way that they can be replicated by farmers.

It is suggested to combine the introduction of the emergency bundats and inlet and outlet structures with basic information on cropping practice. Much can be found on: https://floodbased.org/documents/practical-notes/

Basic principles of field water management are:

- Moisture conservation by deep ploughing and planking after flood water has infiltrated
- Using internal mini-bunds to guide water over the entire bunded field
- Land levelling, pushing up excess soil to the field bundat.

Annex 1: Formulas for Controlled Bundat Inlet and Outlet Structures

This serves as a guidance, the exact amounts can be precisely assessed.

a. Flow Rate (Q):

The flow rate through an inlet or outlet structure can be calculated using the Manning's Equation:

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

Q=1/n×A×R^2/3×S1/2

Where:

- Q = Flow rate (m^3/s)
- n = Manning's roughness coefficient (dimensionless)
- A = Cross-sectional area of flow (m^2)
- R = Hydraulic radius (m)
- S = Slope of the channel (m/m)

b. Continuity Equation:

For steady flow through the structure:

$$Q = A \times V$$

Where:

- V = Velocity of the flow (m/s)

c. Weir Flow (Rectangular Weir):

If the inlet or outlet acts as a weir, the flow rate over the weir can be calculated using the

Weir Formula:

$$Q = C_w \times L \times H^{3/2}$$

Q=Cw×L×H^3/2

Where:

- Cw = Weir coefficient (depends on the weir geometry)
- L = Length of the weir (m)
- H = Head over the weir (m)

2. Formulas for Developing Embankments

a. Slope Stability (Factor of Safety, FS):

The stability of embankment slopes can be analyzed using the Factor of Safety (FS) against sliding:

$$FS = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

FS=Resisting Forces / Driving Forces

For a simple planar slip surface:

$$FS = \frac{c' \times L + W \times \cos(\theta) \times \tan(\phi')}{W \times \sin(\theta)}$$

Where:

- c' = Effective cohesion (kPa)
- L = Length of the slip surface (m)
- W = Weight of the soil mass (kN)
- θ = Slope angle (degrees)
- φ \phi= Effective angle of internal friction (degrees)

b. Seepage Analysis (Darcy's Law):

To estimate seepage through the embankment:

$$Q = k \times i \times A$$

Where:

- k = Coefficient of permeability (m/s)
- i = Hydraulic gradient (m/m)
- A = Cross-sectional area of flow (m^2)

c. Compaction Requirements:

To achieve the desired compaction level:

$$\rho_d = \frac{W_d}{V}$$

Where:

- ρd = Dry density (kg/m^3)
- Wd= Weight of the dry soil (kg)
- V= Volume of the soil sample (m^3)

3. Hydrological Considerations

a. Runoff Estimation (Rational Method):

$$Q_p = C \times I \times A$$

Where:

- Qp= Peak runoff rate (m^3/s)
- C = Runoff coefficient (dimensionless)
- I = Rainfall intensity (mm/hr)
- A = Drainage area (km^2)

b. Time of Concentration (Kirpich Equation):

$$t_c = 0.0195 \times L^{0.77} \times S^{-0.385}$$

t_c= 0.0195×L^0.77×S^−0.

Where:

- t_c= Time of concentration (minutes)
- L = Length of the watershed (m)
- S = Slope of the watershed (m/m)

c. Storage Requirement (Hydrograph Analysis):

Using the Snyder's Unit Hydrograph Method:

$$Q_u = \frac{C_u \times A}{t_r}$$

Where:

- Qu = Unit hydrograph peak discharge (m^3/s)
- Cu = Regional coefficient
- A = Watershed area (km^2)
- tr = Time to peak (hours)

Detailed Steps for Hydrological Considerations:

1. Rainfall Analysis:

- Determine the design rainfall event based on historical rainfall data using statistical methods like frequency analysis. It is to be noted that this is not always practical in spate/ rod kohi systems. Spate /rod kohi is never dependent on predictable rainfall and often flood appears in broad day light with no sign of rain in vicinity. The volume of flood can't be predicted with statistical analysis.

2 Watershed Delineation:

- Delineate the watershed boundary using topographic maps or GIS tools to identify the contributing area for runoff, where possible. This is practically not always possible on ground, as the water shed spreads miles and often trans boundary issues appear in the ephemeral river flows.

3. Runoff Coefficient (C):

- Estimate the runoff coefficient based on land use, soil type, and surface conditions.

4. Time of Concentration (tc):

- Calculate the time it takes for runoff to travel from the farthest point in the watershed to the outlet using Kirpich or other relevant equations.

5. Peak Discharge (Qp):

- Use the Rational Method or other hydrologic models to estimate the peak discharge for the design storm event.

6. Hydrograph Development:

- Develop a unit hydrograph to simulate the runoff response of the watershed and estimate the flow rates over time.

7. Storage and Routing:

- Design storage facilities or routing structures like reservoirs or detention basins to manage peak flows and reduce downstream flooding.

Example: To calculate the discharge flow (runoff) generated from a catchment area due to rainfall, you can use the Rational Method. This method is widely used for small to medium-sized watersheds. Here's how you can do it:

1. Rational Method Formula

The Rational Method formula is:

$$Q = C \times I \times A$$

Where:

- Q = Peak runoff rate (m^3/s)
- C = Runoff coefficient (dimensionless)

- I = Rainfall intensity (mm/hr)
- A = Drainage area (km^2)

2. Step-by-Step Calculation

Step 1: Determine the Runoff Coefficient (C)

- The runoff coefficient C represents the portion of rainfall that will turn into runoff. It depends on the land use, soil type, and slope of the catchment area. Typical values range from 0.1 (for permeable areas like forests) to 0.9 (for impervious surfaces like paved areas).

Step 2: Estimate the Rainfall Intensity (I)

- Rainfall intensity I is the average rate of rainfall over the duration of the storm. This is typically obtained from Intensity-Duration-Frequency (IDF) curves for the region. The units should be consistent with the formula (e.g., mm/hr).

Step 3: Measure the Drainage Area (A)

- The drainage area A is the size of the watershed contributing to the runoff. It's usually measured in square kilometers (km^2).

Step 4: Calculate the Peak Runoff (Q)

- Use the formula $Q=C \times I \times A$ to calculate the peak runoff rate.

Note: If I is in mm/hr and A is in km^2, you should convert the units appropriately to ensure Q is in cubic meters per second (m^3/s).

3. Example Calculation

Let's say you have a watershed with the following characteristics:

- Runoff Coefficient (C): 0.5 (mixed land use)
- Rainfall Intensity (I): 50 mm/hr
- Drainage Area (A): 2 km^2

Calculation:

1. Convert rainfall intensity to consistent units if necessary. Here, let's keep it in mm/hr.
2. Apply the Rational Method formula:

$$Q = 0.5 \times 50 \times 2$$

$$Q = 50 \text{ m}^3/\text{s}$$

Interpreting the Result:

- The peak runoff rate Q from the catchment area is 50 cubic meters per second (m^3/s). This is the maximum flow rate generated during the rainfall event.

Notes:

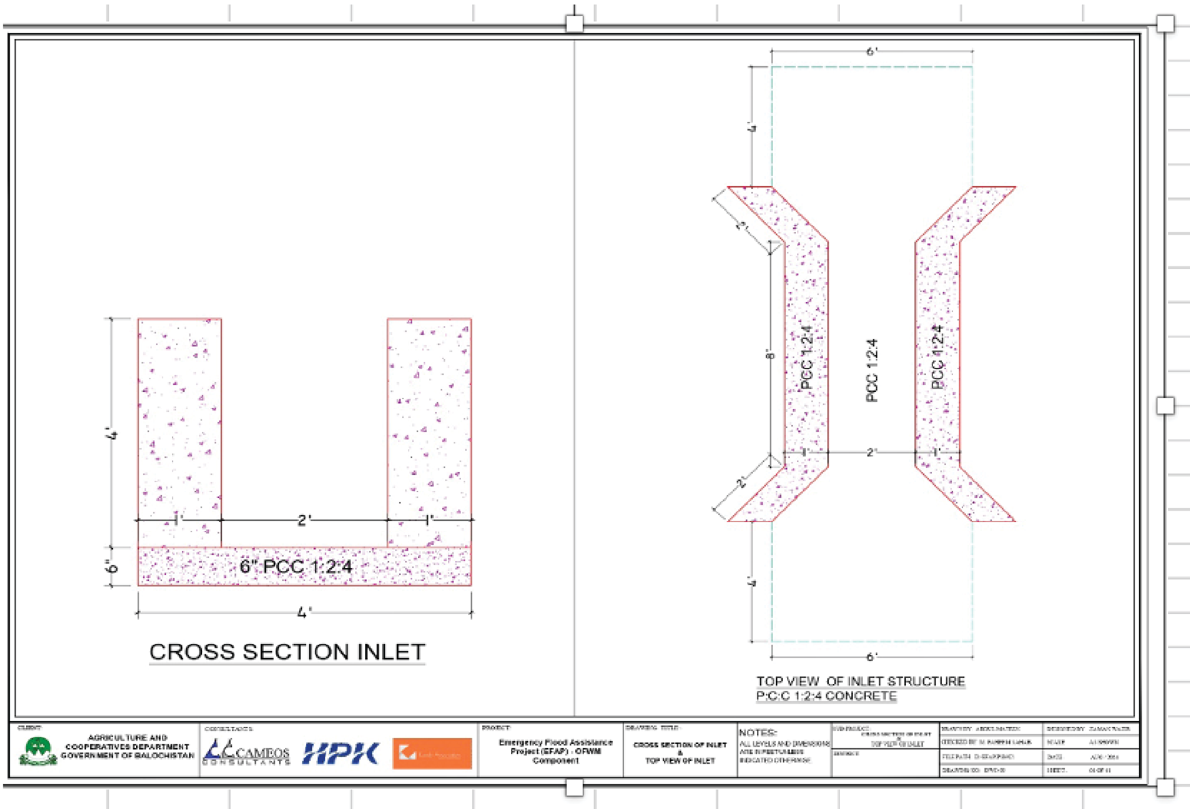
- The Rational Method is most accurate for small to medium-sized watersheds (up to 200 hectares or about 2 km^2). For larger watersheds, more complex hydrological models are typically used.
- If the watershed area is given in hectares, use the conversion 1 km2=100 hectares

This calculation provides an estimate of the peak runoff flow that would need to be managed by any flood control structures or drainage systems in the area.

Annex 2: Sample design controlled intake

Note slot for stoplog to be provided

Cut off wall in front and back of the structure to be added.



Colophon

This guideline is prepared by Frank van Steenbergen, Rehmatullah Khan, Karim Nawaz, Allah Baksh, Saleem Buzdar, Abdul Ghani Soomro, Aneelah Hameen Memon and reviewed by Noman Latif Sadozai and Faheem Iqbal. This guidance note is made in loving memory of Dr Shahid Ahmed.

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