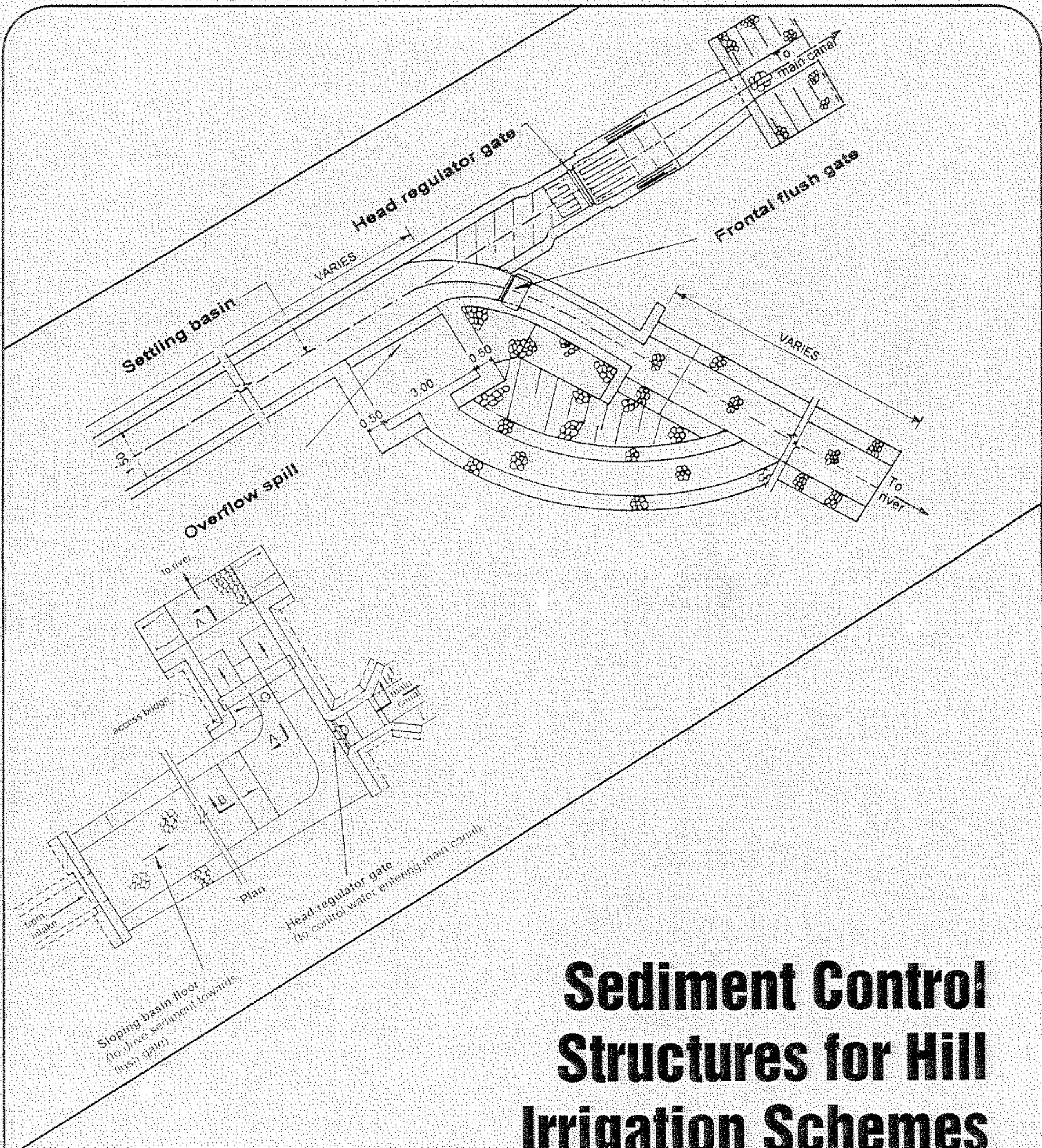
Poverty Alleviation Through Employment Generation in Irrigation Works Programmes

APPROPRIATE DESIGN OF SMALL-SCALE HILL IRRIGATION STRUCTURES



Sediment Control Structures for Hill Irrigation Schemes

NEPAL SPECIAL PUBLIC WORKS PROGRAMME
MANUAL NO. 2

Module No 2

SEDIMENT CONTROL STRUCTURES FOR HILL IRRIGATION SCHEMES

List of Figures

List of Photographs

List of Tables

Sediment in Mountain Rivers and its Effect on Hill Irrigation Canals

Most rivers in the hill districts of Nepal carry large quantities of sediment, especially during flood periods.

The following factors contribute to the sediment load of mountain rivers:

- deforestation,
- soil erosion,
- landslides,
- other natural geological processes.

Typically, these rivers carry particles ranging from:

- large boulders to fine clay during floods,
- gravel to fine clay during normal flow, and
- silt to clay during low flow.

(see Table 2.1 for standard material size terminology)

How Does River-Borne Sediment Affect Irrigation Canals

Larger Particles:

- block canals - reduce canal capacity,
- block canals - assist in accumulation of more sediment behind them.

Smaller Particles:

- are more mobile - move deeper into the canal system.

Finer Particles:

- are even more mobile - may even reach the fields and affect crop yields.

Table 2.1
Material Size Terminology

Class Name	Size Range		
	m	mm	Microns
Very large boulders	4 - 2		(1 micron = 1/1000 mm)
Large boulders	2 - 1		
Medium boulders	0.5 - 0.25	512 - 256	
Large cobbles	0.25 - 0.13	256 - 13	256 - 128
Small cobbles	0.13 - 0.6	128 - 64	
Very coarse gravel		64 - 32	
Coarse gravel		32 - 16	
Medium gravel		16 - 8	
Fine gravel		8 - 4	
Very fine gravel		4 - 2	
Very coarse sand		2.000 - 1.000	2 000 - 1 000
Coarse sand		1.000 - 0.500	1 000 - 5 000
Medium sand		5000 - 0.250	500 - 250
Fine sand		0.250 - 0.125	250 - 125
Very fine sand		0.125 - 0.062	125 - 62
Coarse silt			62 - 31
Medium silt			31 - 16
Fine silt			16 - 8
Very fine silt			8 - 4
Coarse clay			4 - 2
Medium clay			2 - 1
Fine clay			1 - 0.5
Very fine clay			0.5 - 0.24

Source: American Geophysical Union

Sediment entry into irrigation canals can be minimised by taking precautionary measures.

Precautionary Measures for Minimising Sediment Entry into Irrigation Canals Include:

- proper locations for intakes
    - outer bend.
- appropriate design
    - raised sill high enough to exclude bed load,
    - vertical trash racks.
- appropriate operation
    - closing of intake during flood flow,
    - extracting only a minor portion of the total river flow during normal operation.

Despite precautionary measures, however, a sizeable quantity of sediment may still enter the canal through the intake.

Other Sources of Sediment

The primary source of sediment in irrigation canals in the hill areas of Nepal is river-borne sediment. However, there are several secondary sources of sediment entering irrigation canals.

These secondary sources include:

- rainsplash erosion and overland flow,
- drainage flows entering the canal,
- minor landslips in the canal,
- excessive erosion of canal banks.

The Solution to the Sediment Problem

The sediment problem is best tackled at source:

- if the river itself brings in a sizeable portion of sediment then the problem must be tackled at the intake;
- any secondary sources which also bring sizeable amounts of sediment into the canal must be tackled at their respective sources.

This module deals only with the problem of river-borne sediment. Other secondary sources of sediment are dealt with in other modules.

Traditional Sediment Removal Methods versus Improved Methods

Particles ranging in size from large cobbles to fine clay can enter the canal through the intake during various times of the year. These particles need to be removed using traditional farmer methods (manual cleaning) or improved methods (hydraulic flushing). Often, a combination of hydraulic and manual methods is the most effective.

Traditionally, farmers remove canal sediments manually. Improved methods, appropriate in the hill system, are:

- gravel traps, and
- settling basins.

In irrigation systems where river-borne sediment is a :

MAJOR PROBLEM - improved methods are favoured.

MINOR PROBLEM - traditional methods are favoured.

Gravel Traps versus Settling Basins

The choice will depend on several factors:

- the availability of a suitable location:
  - gravel traps are small in size and therefore require less space,
  - settling basins are large in size and therefore require more space.
- the amount of available funds:
  - gravel traps are relatively less expensive,
  - settling basins are more expensive.
- the remoteness of the location:
  - both gravel traps and settling basins need frequent manual desilting, especially during times of flood flow in the river.
- the ability of the farmers to operate and maintain these structures:
  - the farmers need to learn correct operation procedures and rules,
  - incorrect operation can cause problems that lead to abandonment of the structure.

Gravel Traps

A gravel trap basically consists of a deep well built in masonry, immediately after the intake, see Figure 2.1.

They are designed to trap sediment consisting of particles greater than the size of gravel, say 2 mm.

The design principle is to reduce the flow velocity in the well to allow the sediment to settle on the floor. Flow velocities inside the well may need to be lowered to 0.3 mps to trap 2 mm size particles.

Table 2.2 indicates the necessary velocities in the gravel trap which will permit trapping of particles varying in size from 100 mm to 2 mm.

The well must have a minimum width of one metre to allow for manual removal of the sediment which collects there.

The overall size of a gravel trap will depend on several factors including:

- rate of accumulation of gravel sediment,
  - large sediment storage capacities, or more frequent cleaning, will be required when sedimentation rate is high,
- the interval between manual cleaning,
- available space,
- cost of the structure.

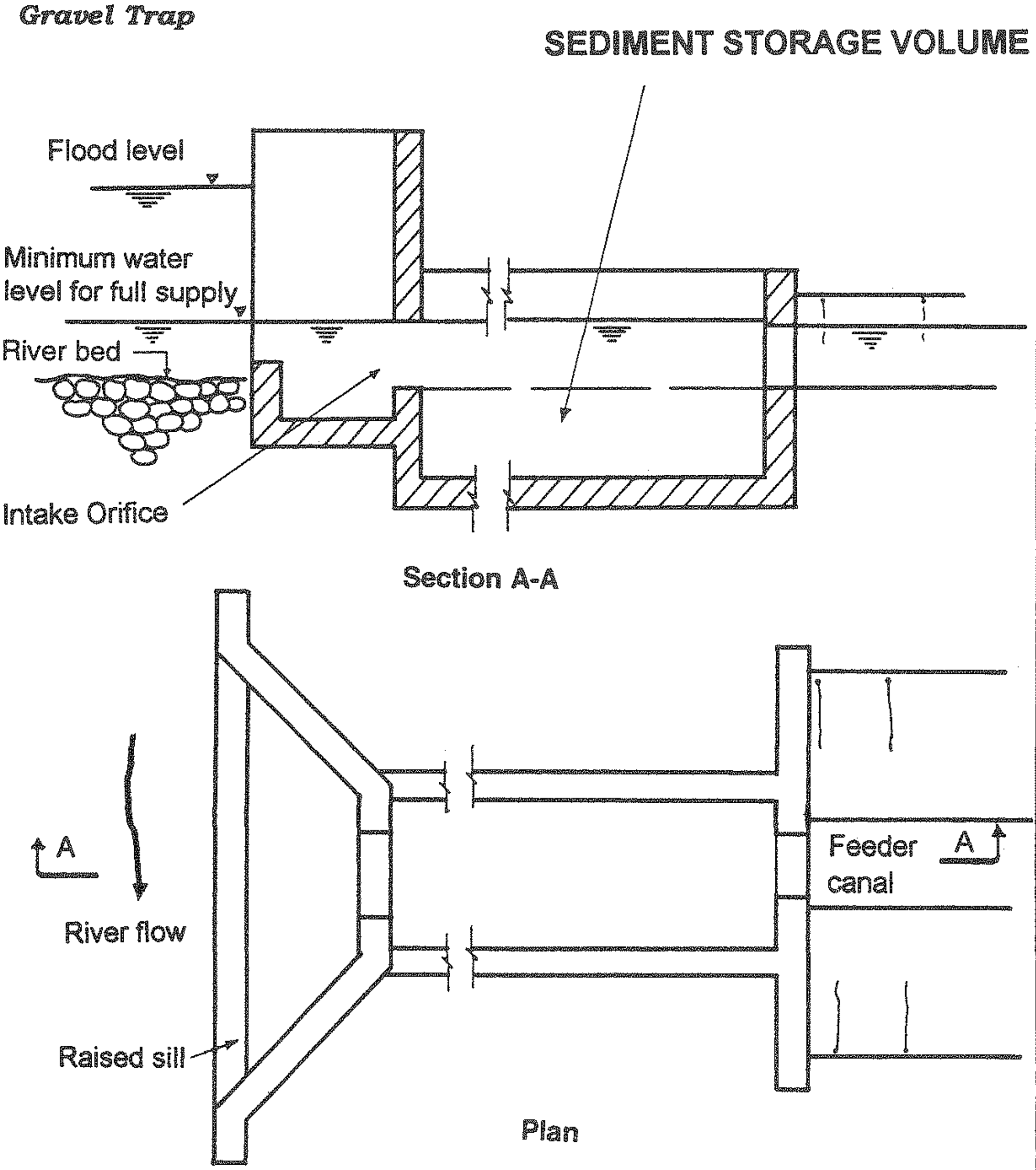
The required volume for sediment storage in gravel traps can be calculated using the formula shown on page 9.

When site conditions and/or cost restrictions do not permit large gravel traps to be built, cleaning intervals need to be adjusted.

Table 2.2
Maximum Permissible Flow Velocity Through Gravel Traps

Particle size mm	Nominal Velocity m/s for Depths of:		Design Velocity m/s for Depths of:	
	3 m	1.5 m	3 m	1.5 m
100	4.0	3.5	2.0	1.7
60	3.4	3.0	1.7	1.5
40	3.0	2.6	1.5	1.3
20	2.3	2.1	1.2	1.1
5	1.8	1.6	0.7	0.8
2	0.8	0.7	0.4	0.3

Figure 2.1
Gravel Trap



Determining Storage Volume in Gravel Traps and Settling Basins

$$V_S = \frac{Q \quad X_{max} \quad Ef \quad FI \quad 3600 \quad 24}{BD \quad 10^6}$$

Where:

V_S	=	storage volume (cu m)
X_{max}	=	nominal sediment concentration (mg per litre)
Ef	=	trap efficiency (0.9)
BD	=	bulk density of sediment (tons per cubic metre)
FI	=	flushing or cleaning interval (days)
Q	=	flow rate (cumecs)

For example, when

X_{max}	=	1000 mg/l,	BD	=	2.0 ton/cubic metre,
Ef	=	0.9,	FI	=	3 days, and
Q	=	0.3 cumecs, then			

the required storage volume of the setting basin = 35 cubic metres

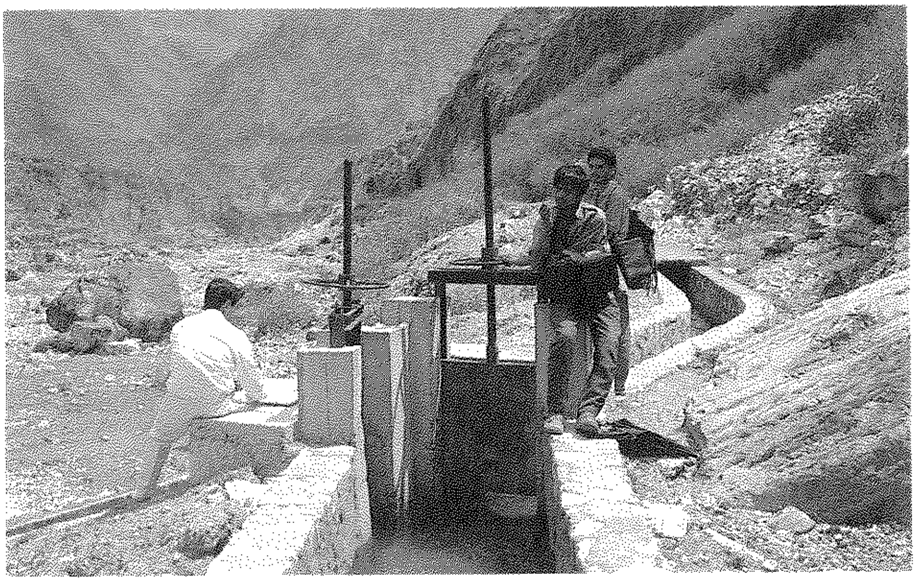
Typical Suspended Silt Concentrations in Hill Tributary Rivers	
During low flow	10 - 100 mg per litre
During normal flow	100 - 1000 mg per litre
During flood flow	500 - 5000 mg per litre

Settling Basins

Photographs 2A, 2B, 2C and 2D, and Figures 2.2 and 2.3 show essential features of a settling basin.

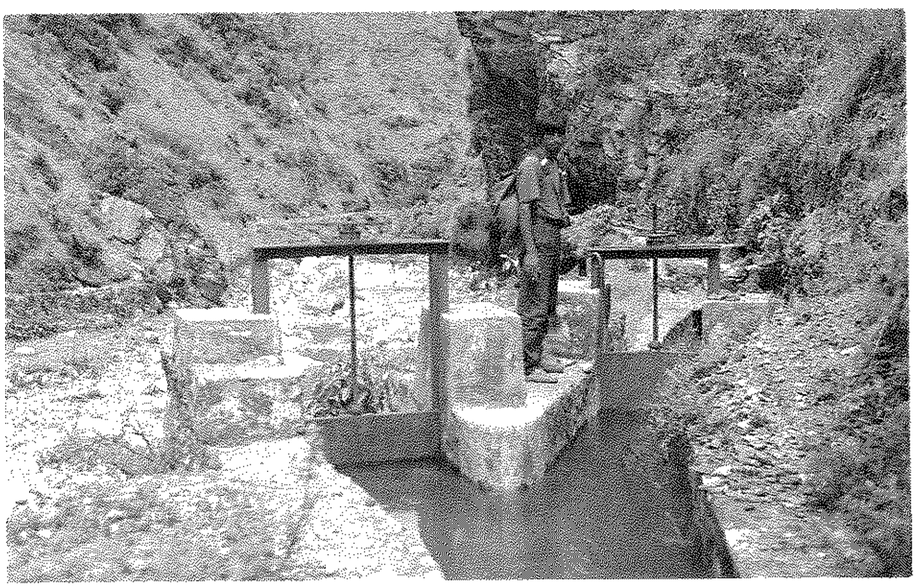
These essential features include:

- a widened basin:
  - to lower the flow velocity and start the sedimentation process.
- a sloping basin floor:
  - to generate scour velocities when the flush gates are opened.
- silt flush gate/s:
  - to flush sediment,
  - to control the water level in the basin during floods in the river by spilling excess water.
- a depressed floor for the flush gate:
  - to provide adequate flow depth through the gated opening to enable free discharge of all the water entering the settling basin.
- a head regulator gate:
  - to control the flow into the main canal,
  - to shut off flow into the main canal during repairs or emergencies.
- a side spill:
  - to automatically spill excess water entering the settling basin during times of river flood.

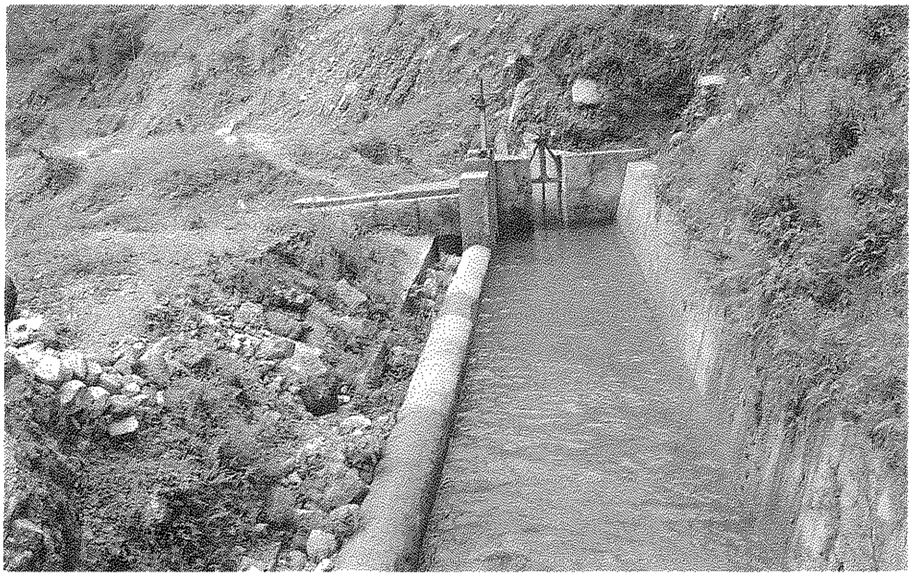


Photograph 2A
Settling Basin with a Side Flush Gate and a Head Regulator

The head regulator gate allows greater control over flood water entry into the main canal.



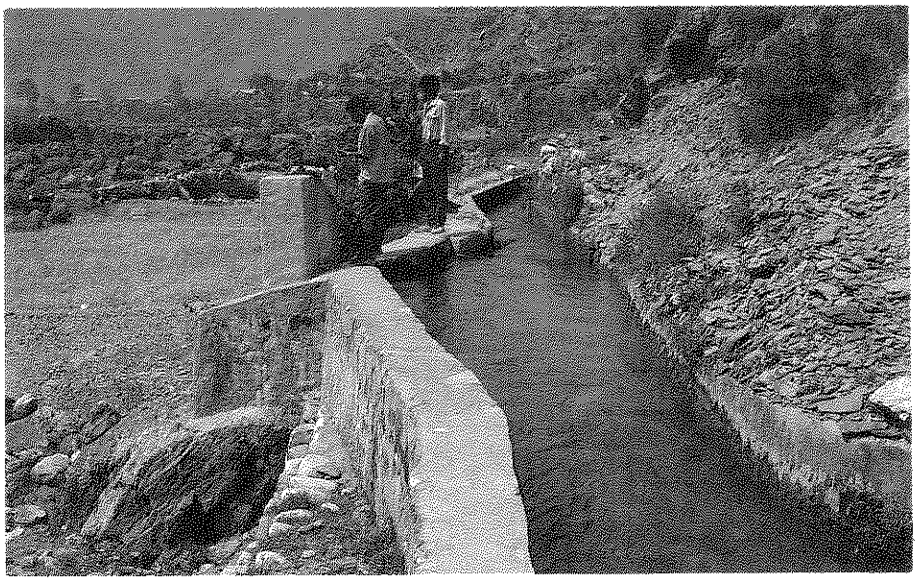
Photograph 2B
Settling Basin with a Frontal Flush Gate and a Head Regulator



Photograph 2C
Settling Basin with a Long Fixed Crest Side Spill

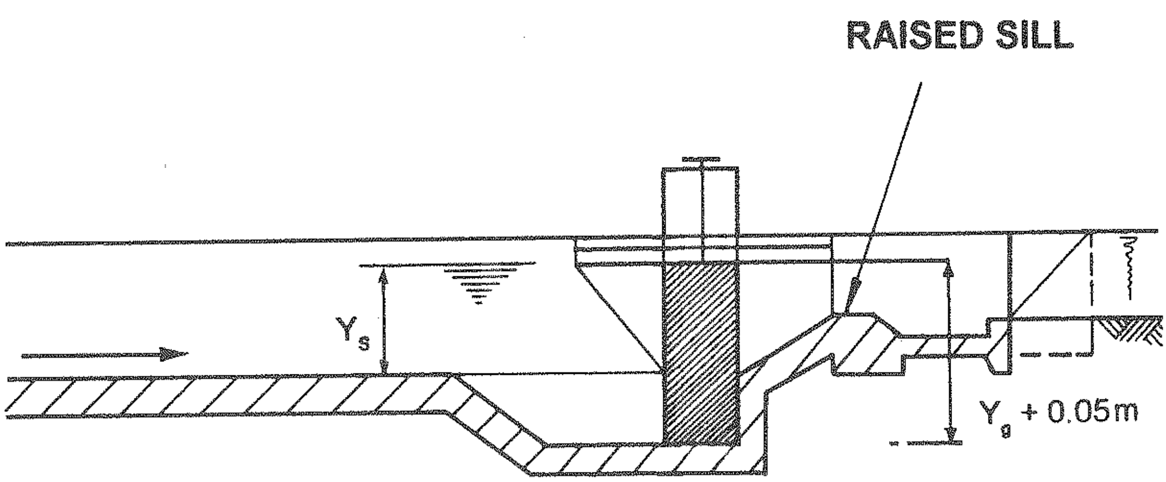
The farmers preferred the use of the flush gate as an escape spillway.

The fixed crest and the side channel are now redundant.



Photograph 2D
Photograph and Sectional Elevation of a Settling Basin with a Side Flushing Gate and a Raised Sill for Regulation of Flow into the Canal

The raised sill does not allow fine control over the flood water entering the main canal.



Sectional View

Figure 2.2
Typical Features of a Settling Basin

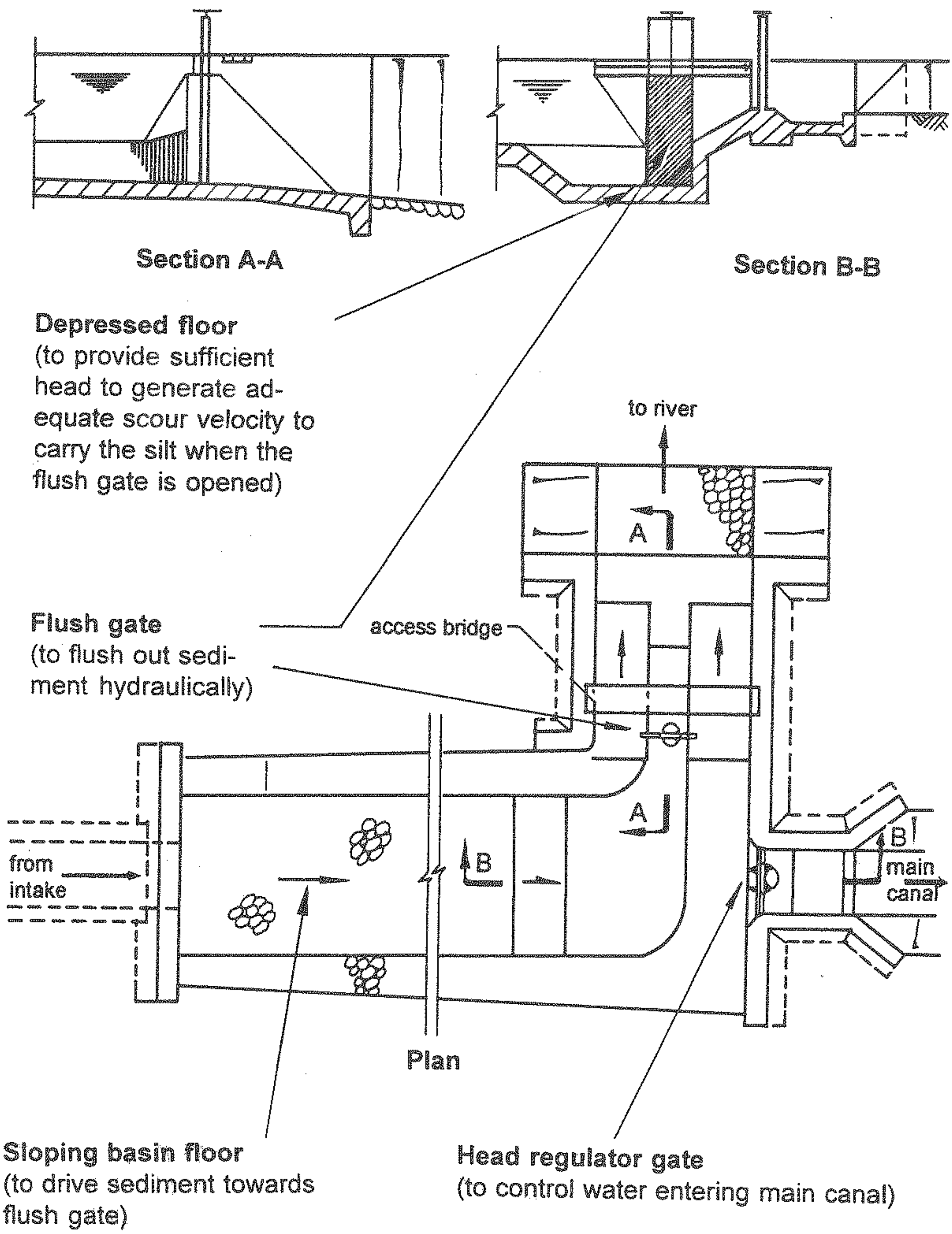
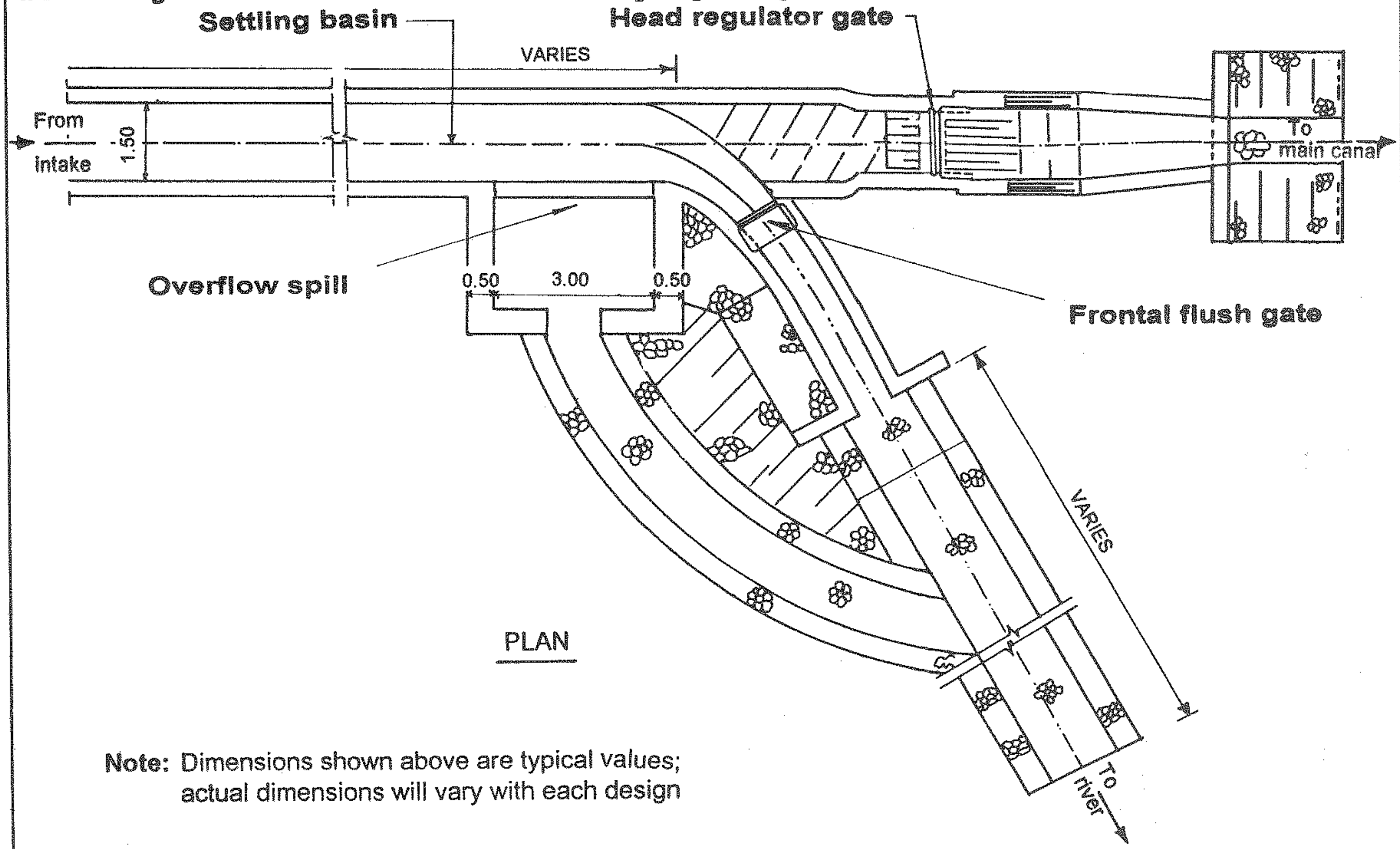


Figure 2.3

Typical Arrangement of a Settling Basin with a Frontal Flush Gate, a Head Regulator Gate and a Fixed Crest Escape Spillway



Note: Dimensions shown above are typical values; actual dimensions will vary with each design

A settling basin is essentially a modification of gravel trap in that it allows large particles and a limited range of small particles to be trapped.

The design principle of a settling basin is as follows:

- lower the flow velocity in the basin to assist small particles to settle to the floor rapidly,
- create hydraulic conditions in the basin to prevent rescouring of particles during normal operation,
- create hydraulic conditions for automatic scouring of certain sizes of small particles when the flush gate is opened,
- provide adequate sediment storage volume, taking all factors into account,
- provide an automatic spillway to allow flood waters to spill over the structure,
- provide a head regulator gate to control the flow of water into the main canal during normal and flood flow times.

Design of Settling Basins

The PDSP Design Manuals recommend sediment load and particle gradation analysis as prerequisites for the design of settling basins.

Both sediment load and particle gradation analysis are difficult for small hill irrigation systems.

Alternatively, the design method can be slightly modified as below:

1. Fix the size of the smallest particle that will be trapped inside the stilling basin (recommended size = 0.5 mm).
2. Fix the size of the smallest particle that will be flushed automatically when flush gate/s are fully opened (recommended size = 0.8 mm).
3. Use nomogram in Figure 2.4 to determine the minimum size of the settling basin required (recommended width = 1 to 1.5 m).
4. Use nomogram in Figure 2.5 to determine the minimum flow depth required in the stilling basin to prevent rescour of the smallest particles. (During normal canal operation, with the silt flushing gate closed, the velocity in any part of the settling basin should not exceed the value obtained from Figure 2.5.)
5. Use nomogram in Figure 2.6 to determine the scour velocity necessary to flush solid particles of size fixed in 2 above.
6. Use Manning's Formula to determine the required scour slope necessary to generate the velocity calculated in step 5.
7. Assuming standard gate width, determine the level of the sand sluice floor below the level of the settling basin floor, see Figure 2.7.
8. Compute available sediment storage volume and adjust dimensions of settling basin. (Ensure that hydraulic requirements for settling and scouring are still maintained.)
9. Determine the necessary sill level at the head regulator to control the flow into the main canal during normal operation.
10. Determine the length and crest level of the automatic sidespill, assuming the flush gate/s are fully closed.
11. Determine expected flow into the main canal during flood. If flow is very much in excess of design flow, provide a head regulator gate for control. (A gate is always desirable to shut off the main canal for repairs or during emergencies.)
12. See Figure 2.7 for more explanation of design steps.

Figure 2.4
Nomogram for Determining Required Surface Area of Settling Basin

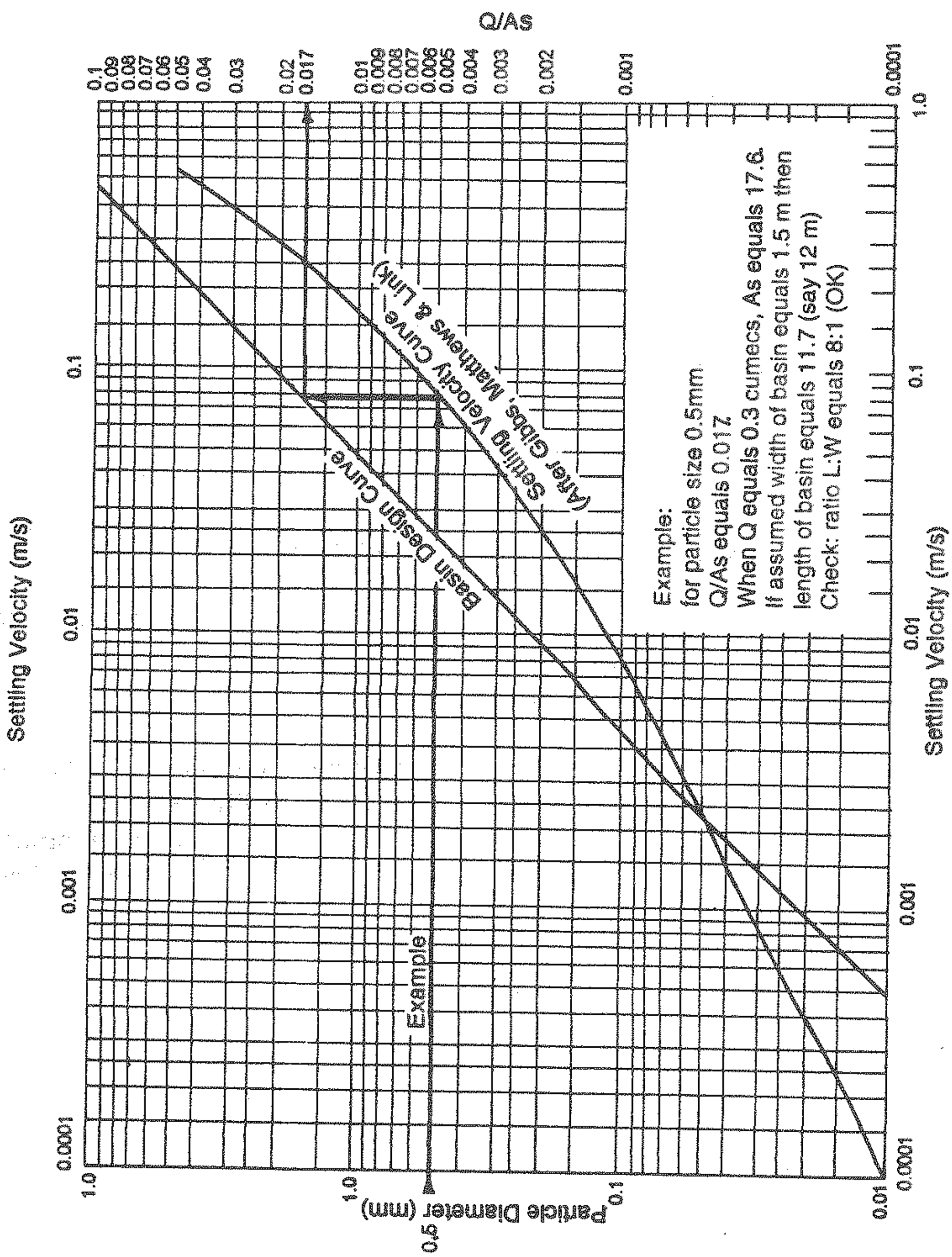
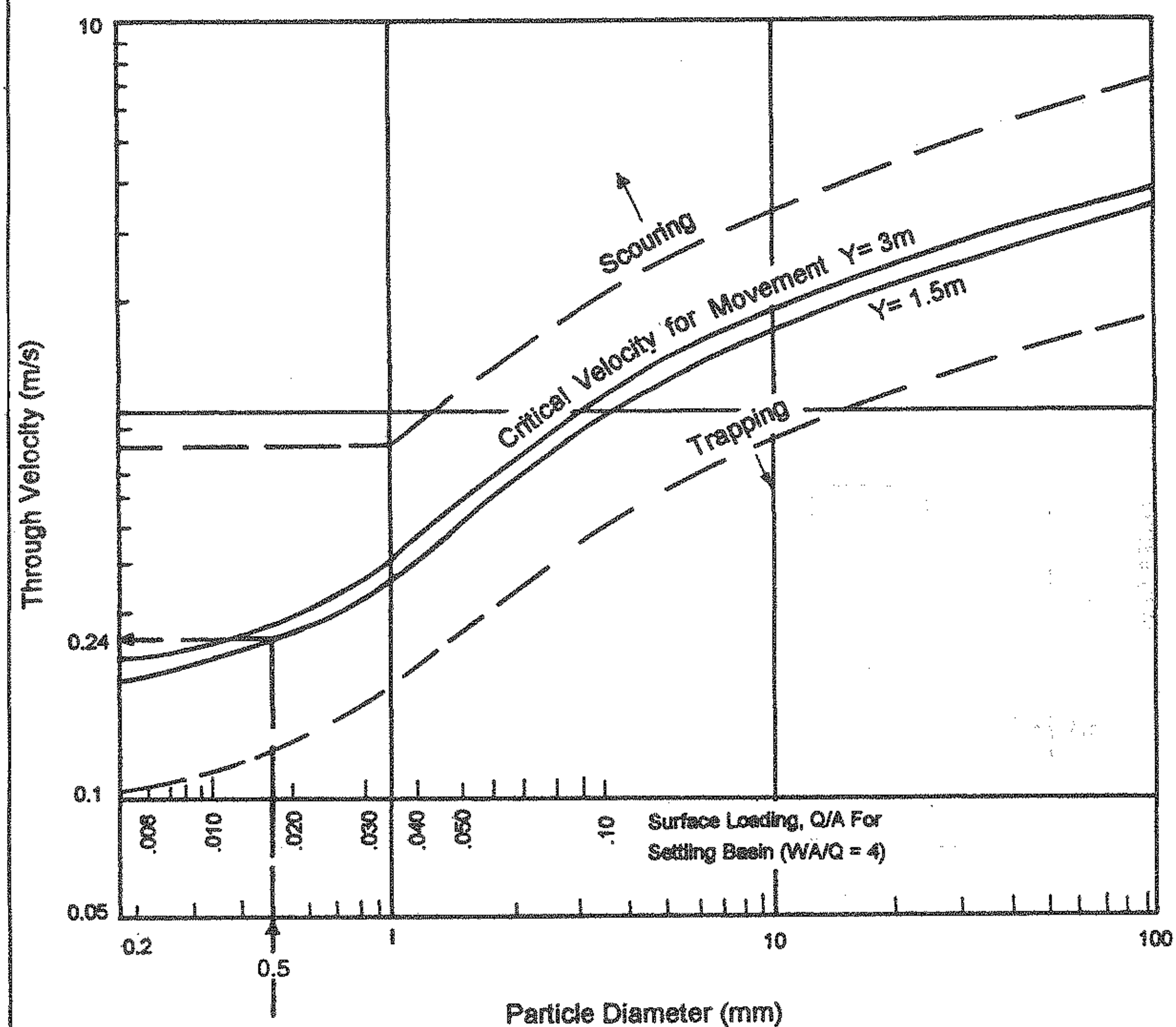


Figure 2.5
Nomogram for Determining Minimum Depth of Settling Basin to Prevent Rescouring of Sediment Particles from the Floor of the Basin During Normal Canal Operation



Example:
for particle size 0.5mm,
critical bottom velocity (from above graph) equal 0.24mps
for Q equals. 0.3 cumecs,
minimum flow depth = Q / (velocity x width)
= 0.83m (say 85 cms)

Figure 2.6
Nomogram for Determining Scouring Velocities in Sand Traps

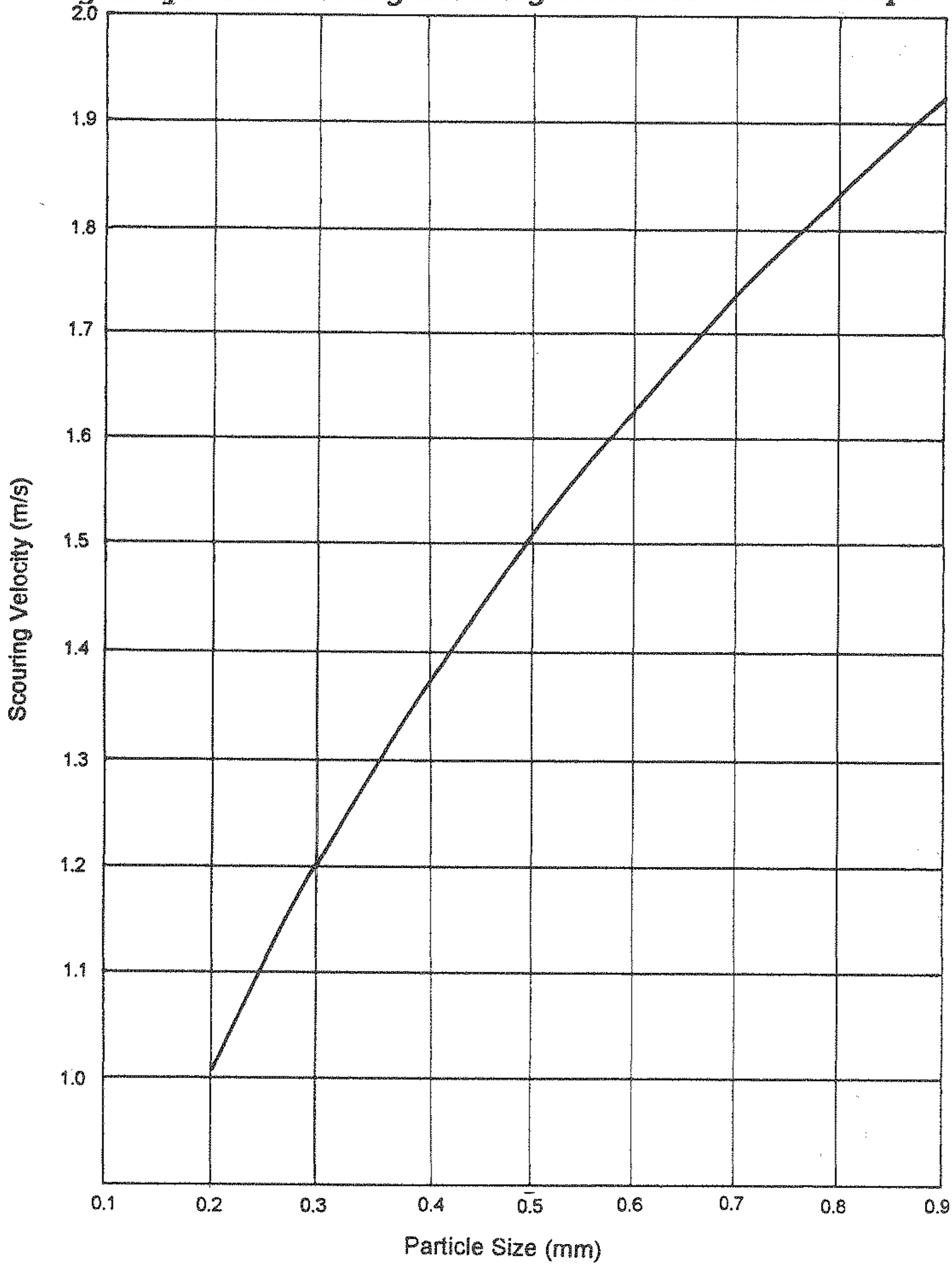
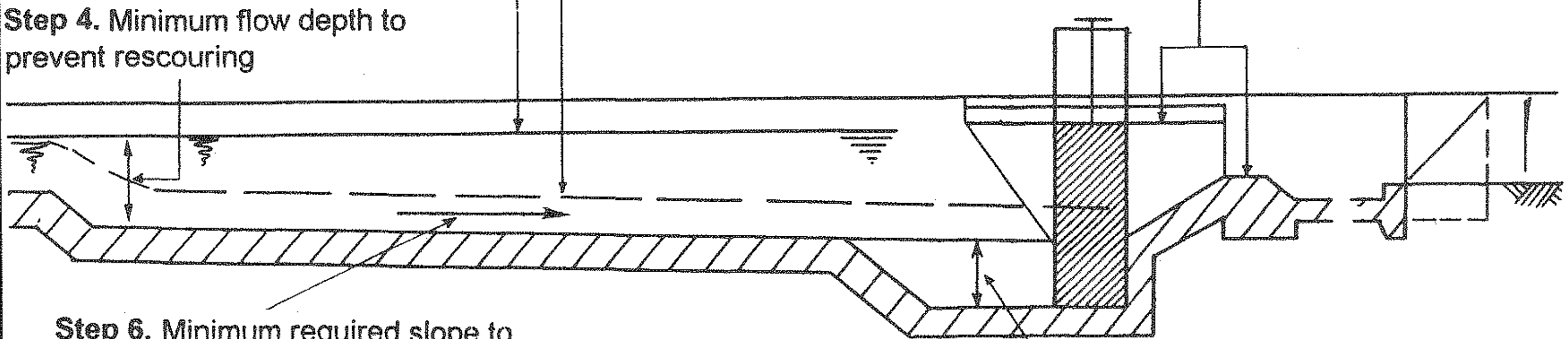


Figure 2.7
Some Important Design Steps in the Design of Settling Basins



Conclusion

- Not all small/medium hill irrigation projects need sediment control structures.
- When the source river carries heavy sediment only during short periods of the year, sediment entry into the canal can be controlled by appropriate operation of the intake gates.
- When river-borne sediment is a major problem, sediment control structures may be considered.
- Less expensive and easy to build gravel traps must be used in preference to more expensive settling basins.
- Farmers must strictly follow desilting schedules to ensure that gravel traps and settling basins are properly utilised.