Chapter 5

Channel Design and Control Structures

Muhammad Jehanzeb Masud, Muhammad Jamal Khan and Abid Sarwar*

Abstract

Apart from many other factors, the design of Irrigation channels and control structures plays very important role in the successful performance of an irrigation system. Irrigation projects are launched for equitable distribution of water among the shareholders and its efficient use at the farms, for which design of diversions and control structures provide basic framework. Both the service providers and users of water desire that the system should be free of problems and minimum loss of efficiencies. Therefore, all the stake holders need to update their knowledge about the design parameters, principles of design, construction and the properly measured deliveries by the system to the users. This chapter has thus, been designed to include basic concepts, design terminology and principles of design based on various regime theories including Kennedy's Theory, Lindley's Theory and Lacy's Theory proposed for the lined and unlined canals. The chapter further presents the design specifications of control structures, farm outlets and types of intake structures for small canals. It also provides opportunity to the readers for learning from relevant practical examples and multiple choice questions relevant to the subject.

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*Muhammad Jehanzeb Masud[1] and Abid Sarwar
Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan.
[1]Corresponding author's e-mail: mjm.cheema@uaf.edu.pk

Muhammad Jamal Khan
Department of Water Management, University of Agriculture, Peshawar, Pakistan.

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Learning Objectives

- The purpose of this chapter is to:
- Update the knowledge of a reader about various terminologies and design procedures used in the channel design.
- Enhance the knowledge of the reader about various types of irrigation channels being operated in the irrigation system, which may include main canal, branch canal, distributary and watercourse etc.
- Familiarize the readers about the design parameters and models developed for designing irrigation channels.

5.1 Introduction

The performance of an irrigation system is dependent on the design of the network of canals and control structures. The canals might be excavated in different kinds of soils such as alluvial soil, non-alluvial soil etc., the plan consideration in nature differ according to the kind of soil. In addition, the velocity of flow in the canal must be less than critical. That means, the velocity must be non-silting and non-scouring. If the velocity gets less than critical silting may take place and the capability of the canal to carry the design flow will be reduced. If the velocity of flow exceeds the critical velocity, scouring may take place and the waterway will be distorted. Consequently, determination of critical velocity is extremely vital in canal design. Dependent on the water necessities of the plants on the area to be irrigated, the whole structure of major canal, secondary canal, tertiary canal and field distributaries must be planned appropriately for a definite practical value of climax discharge that should pass through them, thus supply sufficient irrigation to the commands. Once more, the design of unlined plus lined canals requires special realistic and economical reflection.

5.2 Terminology Related to the Channel Design

5.2.1 Alluvial Soil

The fine grained fertile soil deposited, developed and shaped by the flowing water is recognized as alluvial soil. The river carries weighty charge of silt, clay and fine sand during raining season. When the river overflows its banks, through the flood these fine soil particles get deposited on the adjacent places. This deposition process continues year past year. This kind of soil is initiated in deltaic area of a river. This soil is permeable and soft plus extremely productive.

5.2.2 Non-alluvial Soil

The soils that form and develop through the breakdown of rock formation because of weather, are recognized as non-alluvial soil. It comes into being in the mountains regions of a river. The soil is rigid and impervious in nature and low in fertility.

5.2.3 Silt Factor (f)

In design and operation of a canal in alluvial soils, the suspended sediment plus the deposited silt inside the canal bed must be taken into consideration. Through the inspection work within various canals in alluvial soil, Lacey recognized the consequence of silt on the determination of discharge plus the canal section. Consequently, he presented a factor which is accepted as 'silt factor'. It is dependent on the key particle size of silt. It is denoted by 'f', which may be determined by the expression

$$f = 1.76\sqrt{m_f} \qquad (5.1)$$

Where m_f = Mean particle size of silt in mm. Table 5.1 summarizes the Particle Size and Silt Factor for Various Soil Textures.

Table 5.1 Particle Size and Silt Factor for Various Soil Textures

S. No	Soil Texture	Particle Size (mm)	Silt Factor (f)
1	very fine silt	0.05	0.40
2	fine silt	0.12	0.60
3	medium silt	0.23	0.85
4	coarse silt	0.32	1.00

Source: Van Reeuwijk, 2002

5.2.4 Coefficient of Roughness (N)

The irregularity of the channel bed influences the velocity of flow. The roughness coefficient (N) represents the integrated consequence of the waterway cross sectional resistance. Table 5.2 gives the values of 'N' for various Bed Materials.

Table 5.2 Values of 'N' for Various Bed Materials (Hazan, 1911)

Materials	Value of N
earth	0.0225
masonry	0.02
concrete	0.013 to 0.018

5.2.5 Mean Velocity

Velocity distribution in a channel section mostly varies from bottom (Least value) to free water surface (Maximum value), this is owing to shear stress at the base and at the sides. Field inspection indicates that mean velocity for open channel flow to be the average velocity calculated at 0.2 plus 0.8 of depth (y) from the free water surface. If the depth of the channel exceeds 0.5 m and if the depth of water in the channel is less than 0.5 m then there is one point method that is, the velocity should be determined at 0.6 d, where d

$$V_{av} = \frac{V_{0.2y} + V_{0.8y}}{2} \qquad (5.2)$$

If the depth of the channel exceeds 0.5 m and if the depth of water in the channel is less than 0.5 m then one point method is that, the velocity should be determined at 0.6 d, where d is the flow depth.

5.2.6. Critical Velocity (V_o)

If the flow velocity of the stream is not silting or scouring, then that velocity is recognized as critical velocity. Usually the critical velocity depends on the kind of the soil formation in which the water flows. Table shows the critical velocities for different soil formations.

Table 5.3 Critical Velocities for different Soil Formations

S. No	Nature of soil	Critical Velocity m/s
1	Sandy soil	0.3 to 0.6
2	Black cotton soil	0.6 to 0.9
3	Firm clay and loom	0.9 to 1.15
4	Gravel	1.20
5	Hard rock	More than 3.00
6	Concrete	6.00
7	Steel lining	10.00

Source: Boadu, 2000

5.2.7 Critical Velocity Ratio (CVR)

Ratio of the mean velocity ‘V’ to the critical velocity ‘Vo’ is known as critical velocity ratio. It is denoted by m.

$$CVR = \frac{V}{V_o} = m \qquad (5.3)$$

When m=1 there is neither silting nor scouring, when m > 1, scouring will occur and when m < 1 Silting will occur. So, by finding the value of m, the condition of the canal can be predicted whether it will have silting or scouring.

5.2.8 Hydraulic Radius (R)

The Hydraulic Radius (R) is defined as the ratio of the cross-sectional area (A) to the wetted perimeter (P) of the channel

$$R = A/P \qquad (5.4)$$

5.2.9 Hydraulic Depth (D)

The Hydraulic Depth (D) is the ratio of the flow area (A) to the top width (T) of channel or

$$D = A/T$$

5.2.10 Full Supply Level (FSL)

The water level in the canal at the design discharge of the canal is known as full supply level.

5.2.11 Best Hydraulic Section

In general, it has been found that the conveyance capacity of channel increases as the hydraulic radius increases or the wetted perimeter decreases. Among all the possible cross-sections, the best hydraulic section is a semicircle one, which has minimum wetted perimeter for a given area. However, it should be noted that the best hydraulic section is not always the most economical section. Most of the lined sections of the irrigation channels should be constructed considering the best hydraulic section; however, sometime the full supply level in the canal or irrigation channel and the relevant command areas may not allow the construction of best hydraulic section. In practice the following factors must be considered:

- The best hydraulic section minimizes the area required to convey a specified flow; however, the area which must be excavated to achieve the flow area required by the best hydraulic section may be significantly larger if the overburden is considered.
- It may not be possible to construct a stable best hydraulic section in the available natural material. If the channel is lined up, the cost of the lining must be comparable with the cost of excavation.
- The cost of the excavation depends not only on the amount of material which is removed but also on the ease of access to the site and the cost of disposing of the material removed.
- The slope of the channel in many cases must also be considered a variable since it is not necessarily completely defined by topographic consideration.

Table 5.4 Geometric Elements of Best Hydraulic Sections

Cross sections	Area (A)	Wetted perimeters (P)	Hydraulic Radius (R)	Top Width (T)
Trapezoidal: half of hexagon	1.73 Y^2	3.46 Y	0.500 Y	2.31 Y
Rectangular: half of a square	2.00 Y^2	4.00 Y	0.500 Y	2.00 Y
Triangular	2.00 Y^2	2.83 Y	0.354 Y	2.00 Y
Semicircle	0.50 ϑY^2	ϑ Y	0.500 Y	2.00 Y
Parabola T = 2 + 2 Y	1.89 Y^2	3.77 Y		2.83 Y

Source: Stern, 1979

5.2.10 Efficient Section

In open channel, water flows under the force of gravity, on the way to irrigate the command areas on its left and or right sides. The FSL of the channel is usually kept above the natural surface level (NSL). In nature, to hold the water within the canal, it is partially excavated underneath the NSL plus partially on top of the NSL. To be economical, the deepness of excavation is set that the amount of the soil excavated from the canal segment is simply enough to build the banks. The deepness of dig is called balancing depth. In addition to that the transportation of the channel will be proficient when the channel segment has least perimeter for a specified area, slope and roughness coefficient are permanent

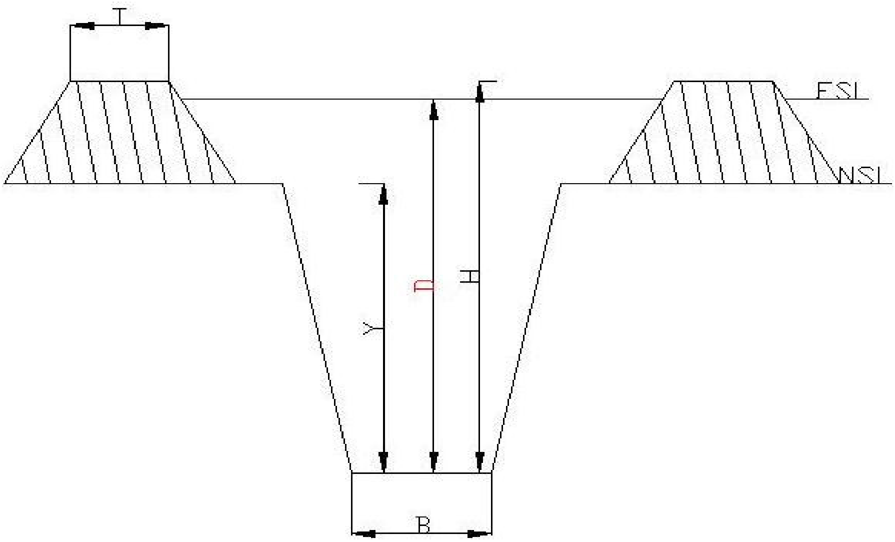

Fig. 5.1 Channel Water Levels

Where:

Y is balancing depth

D is full supply depth

H is height of the top of bank above the bed of bank

T is top width of the bank

B is bed width of the cannel

m: 1 is side slope in cutting

n:1 is side slope in filling

For economical section Cutting = filling in banks

$Y (B + my) = 2 (H - y) (T + n (H - y))$ (5.5)

Generally side slope in cutting is kept 1:1 and filling kept as 1.5:1.

5.2.13 Design Approach

In general, two design approaches are commonly used, i.e. for Silt free water (Manning's equation) and for Silt laden water (Empirical Approach and tractive force approach).

5.2.14 Regime Channel

As the features of the bed substance of the channel are like that of the transported matter plus at the time the silt charges and silt grades are steady, then the channel is supposed to be in its regime and is called a regime channel. A channel in which, neither silting nor scouring takes place and this is known as regime channel or stable channel.

5.3 Design of Non-Alluvial Channels

5.3.1 Design Equations:

The non-alluvial soils are stable and almost impermeable. For the design of channel, in this type of soil, the coefficient of resistance plays a significant role, however, the other factor similar to silt factor has no role. Here, the velocity of the flow is measured very close to critical velocity. Consequently, the mean velocity known by Chezy's expression or Manning's expression is measured for the design of channel in this soil. After along inspection in a variety of canals, Chezy and Manning have recognized the following expressions intended for finding the mean velocity flow.

5.3.1.1 Chezy formula

$$V = C\sqrt{RS_o} \qquad (5.6)$$

Where C is a coefficient which depends on the nature of the surface and the flow and known as chezy coefficient, S_o is bed slope of the channel. C can be calculated from the following formula:

5.3.1.2 Pavlovski formula

$$C = \frac{1}{n} R^{x} \qquad (5.7)$$

In which x= 2.5 $\sqrt{n}$- 0.13 - 0.75 $\sqrt{R}$ ($\sqrt{n}$- 0.1) and n is Manning's coefficient

As a standard, for each equation or formula, we will use the word "Equation" and for explanation of its variables, we will use "Where:"

5.3.1.3 Ganguiller and Kutter formula

$$C = \frac{23 + \frac{1}{n} + \frac{0.00155}{S_o}}{1 + \left[23 + \frac{0.00155}{S_o}\right]\frac{n}{\sqrt{R}}} \qquad (5.8)$$

5.3.1.4 Bazin's formula

$$C = \frac{87.0}{1 + \frac{M}{\sqrt{R}}} \qquad (5.9)$$

Channel M for unlined channel M = 1.30 to 1.75, for lined channel M = 0.45 to 0.85

5.3.1.5 Manning's formula

$$V = \frac{1}{n} R^{2/3} S_o^{1/2} \qquad (5.10)$$

Where:

Manning's n is roughness coefficient known as.

$$Q = AV \qquad (5.11)$$

Where Q is design discharge, m^3/s

A is cross sectional area of the channel m^2

V is the mean velocity of flow

5.3.2 Design Procedures of Non-Alluvial Channels

1. Start through means of a design discharge and select an appropriate permissible velocity (V)
2. Find out the area of the canal from the continuity equation (Q = AV) and A = Q/V
3. Calculate for the hydraulics radius through using Chezy or Mannings equation
4. Write down the hydraulics radius in expressions of B and Y plus, equate it with result of step three
5. Write down the area in expressions of B and Y plus replace with B of step 4 in this equation, and after that you will contain quadratic equation to work out for the value of Y.
6. Add desired free board

Table 5.5 Non-erosive Velocities (Permissible Velocity) in m/s

Channel bed material	Water with sediment (m/s)	Clean water (m/s)
1. Very fine sand	0.75	0.45
2. Sandy loam	0.75	0.55
3. Silty loam	0.90	0.60
4. Alluvial silt	1.00	0.60
5. Dense clay	1.00	0.75

Source: Kinort, 1970

Table 5.6 Minimum Freeboard requirements for Irrigation Channels

1. Earthen Channels	1/3 of the design flow depth or 15 cm whichever is greater
2. Rectangular lined channels	10 cm
3. Trapezoidal lined channels	7.5 cm

Source: Federal Water Management Cell, 1986

Table 5.7 Permissible side Slope (Z) in Earthen Channels

Bed Material	Excavated Side Slope (Z)		Fill Section, Side Slope (Z)	
	Permissible	Recommended	Permissible	Recommended
1. silt loams, silty clays and clays	1:1	1:1	1:1	1.5:1
2. Sandy loams	1.1	1:1	1.5:1	2:1
3. Loamy sands and sand	1.5:1	2:1	2:1	3:1

Source: Federal Water Management Cell, 1986

In may unlined earthen canals side slopes of 1.5:1 have been used, however, side slopes as steep as 1:1 can be used when the channels run through cohesive materials. In lined canals the side slopes are generally steeper than an unlined canal.

Table 5.8 Permissible side Slope (Z) in Earthen Canals (Chow, 1959)

Material	Permissible Z
1. Rock	Near vertical
2. Muck and peat soils	¼:1
3. Stiff clay or earth with concrete lining	½:1 to 1:1
4. Earth with stone lining or earth for large channels	1:1
5. Firm clay or earth for small ditches	1 ½:1
6. Loose sandy, earth	2:1

5.4 Design of Alluvial Channels

If the process adopted for the plan of channels at non-alluvial soil is applied over alluvial channels, after that the silt weight carried by the irrigation water is not measured. The rule of design of a channel on alluvial soil is completely unique from that of channel on non-alluvial soils. Channels on alluvial soil take appreciable silt plus sand load. While the channel water has surplus silt load silting takes place in the channel. On the other hand, when the water is silt free, it picks up the silt from the channel bed plus sides, it comes out in erosion of waterway section. Manning's and Chezy's equation do not consider this feature. When silting takes place, the channel section is minimized plus thus capability of the channel is abridged. When scouring happens initially, the water level is lowered which in turn reduces the command. Secondly, the eroded material is deposited at some other place to upset the equilibrium situation there. Taking the trouble of silt moving in to account, it was essential to evolve certain basis for the design of a steady segment by critical velocity. There are two vital and most usually used theories. They are Kennedy's silt theory plus Lacey's theory.

After extended investigation in different canals plus different environment R.G Kennedy, Punjab and Gerald Lacey have recognized several theories for the design of canals which are identified as 'Kennedy's theory' and 'Lacey theory'. Those two theories are dependent on the features of deposit load (i.e. silt) in canal water. The behavior of the silt load is explained by the theory which is known as ‘silt theory’.

5.4.1 Kennedy’s Regime Theory

Kennedy recognized a relation among non-scouring, non-silting velocity, termed as "critical velocity" of flow plus the stage of flow on the base of experimental work composed from 22 channels on the upper Bari-Doab canal system in Punjab. For any known canal having a specific soil circumstance, the critical velocity ratio which is a role of silt charge in addition to grade as well as rugosity coefficient is uniquely permanent. Kennedy had recommended a common form of equation for critical velocity $V_o= CD^n$. The value of m is dependent upon the silt charge in addition to silt grade. The coefficient "C" plus the power index n are not steady and alteration from site to site. The mainly prevalent values of C as well as n as labored out by Kennedy are 0.546 plus 0.64 correspondingly. Kennedy plotted a variety of graphs among V_o and depth of flow and finally gave a formula to calculate V_o. the formula is

$$V_o = 0.546D^{0.64} \qquad (5.12)$$

Kennedy as well documented that sediment magnitude plays a significant role in shaping the association between velocity and depth. Hence, he projected that for the sediment dimensions other than the one originate in the upper Bari Doab canal system the above equation should be customized to:

$$V_o = 0.546\ m\ D^{0.64} \qquad (5.13)$$

Where V_o critical velocity / no silting velocity [m/s] as well as Y full supply depth [m] plus C is a constant. It is dependent on nature of silt. Coarser the material, greater is the value of the constant plus n is some index. It too depends on the kind of silt. Where m is included to show the function of sediment size $m=V/V_o=CVR$, for course sand value of m might be taken as 1.1 to 1.2. While for finer substance, it might be reserved 0.8 plus 0.9. In adding to approximation, the actual velocity he planned the employ of Chezy's equation in addition to Kutter's coefficient N equal to 0.0225 for Punjab canals. V is the real velocity by Chezy

Table 5.9 Typical "n" Values for Kennedy Regime (Government of India, 1982)

Type of silt load	Value of n
Fine silt	0.53
Sandy silt	0.64

5.4.1.1 Limitations of Kennedy's theory

1. In the lack of B/Y ratio the Kennedy's assumption do not give a straight answer to deal with the channel dimension however by trial and error.
2. Ideal description of silt grade plus silt charge is not given.
3. Complicated phenomena of silt transport is not fully accounted and merely critical velocity ratio idea is measured adequately.
4. There is no provision on the way to decide longitudinal slope beneath the scope of the theory.

5.4.1.2 Sketch of Irrigation Canal by Kennedy Theory

When an irrigation canal is to be planned by Kennedy theory, it is necessary to recognize FSD Q, coefficient of regosity N, CVR m plus longitudinal slope of the channel. Then by means of equations 5.13, 5.11 and 5.6 the canal section can be planned.

The process of scheming might be outlined in the subsequent steps:

a. Suppose practical trial full supply depth Y
b. By equation (5.13) find out the value of V_o
c. By this value of V, using equation (5.11) plus design discharge find out A
d. Suppose side slope in addition from the information of A and Y find out the bed width B
e. Work out the hydraulic radius (R)
f. Using equation 5.6 locate the value of the real velocity V
g. While the assumed value of Y is accurate, the value of V in step f will be similar as Vocalculated in step b, if not, suppose another appropriate value of Y plus replicate the process till both values of velocity are the identical.

5.4.2 Lindley's Regime Theory

Information from steady channels of Punjab were analyzed in addition to provide the subsequent similar equations like Kennedy for non-silting as well as non-scouring velocity taking Manning's n=0.025 along with side slope 0.5:1.

$$V_o = 0.57Y^{0.57} \quad (5.14)$$

$$V_o = 0.27B^{0.35} \quad (5.15)$$

Equating the above two will give as:

$$B = 7.80Y^{1.61} \quad (5.16)$$

Among the few alterations by Lindley one is that he articulated an equation for merely B/y ratio. He also formulated equation of V_o taking depth y along with B as a function.

5.4.3 Lacey's Regime Theory

Improved and customized technique was developed by Lacey. His regime theory postulates that dimension of bed width; depth as well as slope of canal attains a condition of equilibrium with time which is called regime state. Lacey distinct a regime canal as a steady channel transporting a smallest amount bed load coherent with fully active bed. In accordance to him, a waterway will be in regime if it carries a steady discharge as well as it flows uniformly in unlined incoherent alluvium of similar character. Lacey also stated regime between the initial along with the final regime conditions of channel. The initial regime condition is attained soon after it is put into process after building and the channel begins to regulate its bed slope either by silting or scouring even though bed width is not changed. The cannel subsequently appears to have attained stability, except it is not actually the last condition of stability and hence it still represents the initial regime state. Ultimately continuous action of water overcomes the opposition the resistance of the banks and sets up a state such that the channel adjusts its whole section, after that final or true regime condition is attained.

In accordance to Lacey, there is only single longitudinal slope at which the canal will carry a specific discharge with a specific silt grade. Usual silt transporting channels have an affinity to assume semi-elliptical section. The coarser is the silt, larger the water way of such channel with narrower depth. The finer the deposit, larger is the deepness with small waterway as revealed below:

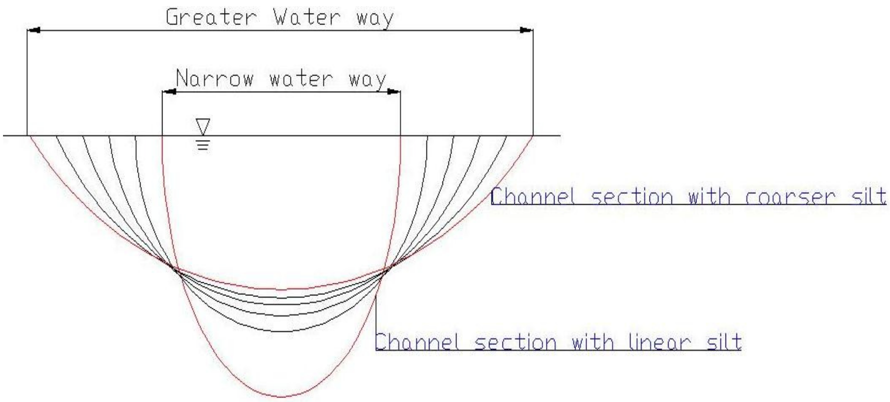

Fig. 5.2 Channel Section According to Lacey's Theory

5.4.3.1 Lacey's Regime Equations

Lacey collected a large number of data of stable channels in Indo-Gangetic plains. Analyzing the data, he gave the following equation of regime channel relating regime velocity V_o, silting factor f, hydraulic radius R, area A, sediment size in mm and bed slope So. Lacey plotted a graph between regime mean velocity and hydraulic mean radius and gave the relationship:

$$V_o = KR^{1/2} \qquad (5.17)$$

Where K is a constant

Lacey recognized the importance of silt grade in the problem and introduced a concept of function 'f' known as silt factor. Above equation is modified as:

$$V_o = K\sqrt{Rf} \qquad (5.18)$$

After studying and plotting of large data to justify his theory, Lacey gave four fundamental equations for design of irrigation channels.

$$V_o = 0.639\sqrt{Rf} \qquad (5.19)$$

$$Af^2 = 141.2V_o^5 \qquad (5.20)$$

$$V_o = 10.8R^{2/3}S^{1/3} \qquad (5.21)$$

$$f = 1.76\sqrt{d} \qquad (5.22)$$

5.4.3.2 Relationship between Wetted Perimeter (P) and river Discharge (Q)

The relationship between wetted perimeter and discharge can be given be the equation as follows:

$$P = 2.667\ Q^{1/2} \qquad (5.23)$$

From the relationship the approximate width of stable waterways (Ww) can be determined as:

$$Ww = 2.667\ Q^{1/2} \qquad (5.24)$$

5.4.3.3 Scour Depth (R)

The river channel is continuously in state of change for attainment of regime condition and adjusts its slope by meandering, scouring or silting. The scour depth for river work, weir or barrage can be determined from Lacey's formula given below:

$$R = 0.9\ (q^2/f)^{1/3} \qquad (5.25)$$

q = flow discharge per unit width, cfs

f = silt factor

5.5 Control structures

For regulated discharges and water levels in the main canal, distributaries, minor and outlets of various types of control structures are required at different locations along and across the canal. These consist of canal regulation structures, cross drainage structures and outlets. Engineering planning, design and construction of dams, barrages, diversion weirs, main intake works, pumping stations and main canals are usually carried out at a high degree of efficiency. Generally, the operation of such headworks is also efficient and well organized and thus the amount of water lost from the total supply is usually small. The Canal regulation structures generally consist of head, regulator, cross regulator, fall regulator, escapes, silt ejectors and farm outlets.

5.5.1 Head Regulator

A structure constructed across a canal to regulate supply level, allow full supply discharge and control entry of silt into canal is called Head Regulator. In general, the capacity of the canal is kept 10% more than the required discharge for silt build up, weeds or to tackle other emergency situation.

Head Regulator for an off-taking channel (branch canal, distributory or minor) allow designed supplies to the off-taking canal, manage supplies in the canal network and distribute silt load as well as allow desired supplies to the off-taking canal as per rotation schedule in case of low supply in the canal system.

5.5.2 Cross Regulator

Structures constructed across the main canal are at regular intervals, at locations of off-takes of branch canals, distributaries or minor canals to maintain the desired level and supplies into off-taking canals (branch canal, distributary or minor canal).

5.5.3 Fall Regulator

Fall regulator structures are provided on the canal to break the long steep slope and to maintain the water surface level close to the natural ground surface to reduce the flow velocity to permissible limit and to minimize the cost of cutting and filling. The depth of falls may be different and depends on the topography of the land, however, very deep fall should be avoided and should be replaced with several small falls.

5.5.4 Tail Regulator

A regulator is provided at the tail of the canal to control water level and for proportional distribution of water among different watercourses is called tail regulator.

Escapes: Escapes on the canal are provided for quick removal of water from the canal under emergency situation. The emergency situations may arise from sudden breach in the canal, unexpected rise in the water level or due to rainfall events, runoff water into the canal. Under these scenarios, the canal has to be emptied quickly, therefore, escapes on the canal are provided and the water is generally drained into natural waterways through escapes to avoid damage to life, property and agriculture land.

Sometimes secondary and tertiary canals and control structures are less carefully made, while smaller canals and those at the farm level and their structures are more often badly made or omitted entirely from engineering plans. It must not be overlooked that besides headwork's and larger canals, irrigation works involve in the building of many small structures and small earthworks of unsophisticated design spread over extensive areas of land. Engineers have often neglected these "minor" works, particularly those required at the farm level; to contractors these do not mean much profit and these are dispersed and difficult to supervise; and last but not least, authorities have sometimes appeared less willing to invest in tens of thousands of such small scattered works than in large works having greater prestige value. This results in many omissions of essential small structures, and failures or unnecessary deficiencies in some irrigation systems.

The great impact of small structures on satisfactory operation and overall performance of gravity irrigation systems is, however, apparent from their large number. In gravity flow systems, 90 out of 100 structures usually have capacities of less than 1,000 liters per second. The total number per unit area depends largely on the size of holdings and fields, on the delivery pattern and on the topography, but ranges from a few hundred to several thousand per thousand ha. The total irrigated area of the world at present exceeds 200 million ha and potentials exist for doubling this area. The number of small hydraulic structures already in existence exceeds 100 million, and the number that will need to be modified, replaced or newly built every year is s likely to run into millions.

In view of their great impact on the saving, equitable delivery and reliable supply of water, small hydraulic structures must be designed, built and operated with much the same completeness, efficiency and accuracy as large ones.

The factors governing the design and subsequent construction and operation of irrigation works are the water resources available, the methods of water delivery to farmers, and the methods of water application practiced by them. Successful operation requires adequate facilities for the control and measurement of flow at all strategic points along the whole network, including the farm and field levels. Each small hydraulic structure must be efficient, simple in design, construction and operation, and must be durable. The largest structures discussed in this publication are the intakes from tertiary canals or intakes from small rivers into complete irrigation systems, the head discharges of which do not exceed one cubic meter per second. Intakes are required to control flow into a subsequent canal or canal system; often they are combined with silt- excluding devices, Intakes should be designed to control and regulate water with minimum entrance losses and as little disturbance as possible.

1. *Intake Structures*
2. *Intakes of Small Canals*
3. *Silt Selective Head intake.*
4. *Venturi head intake.*
5. *Square head intake.*

5.5.5 Canal Outlets

The Canal Outlet is a turnout structure at the head of a watercourse through which irrigation water is diverted from the main canal, distributary or a minor into the watercourse. The supply (or distribution) canal is usually under the control of an irrigation authority. The authority may be a Government department, a public, or semi-public organization such as a district or an irrigation association. Thus, the farm outlet is the connecting link between the canal operator representing the authority and the farmer or user. Types of Intakes can be classified into the following categories depending on their sensitivity to water level in the parent canal and watercourse.

1. Modular farm outlets
2. Semi-modular
3. Non-modular farm outlets

The intakes for minor as well as sub-minor canals urbanized in Punjab are planned for proportional sharing of supplies. In general, the "Open Flumes (OF)" and the "Adjustable Proportional Flumes (APF) are used as Intakes. Whichever of the two types are adopted, the following conditions should be satisfied.

(a) For open flumes the setting of the crest must be at 0.9 of the full supply depth of the mother canal (Y1); the crest should be on top of the level of the downstream canal bed; the width of the crest across the flow should be at least 6 cm.
(b) If the above situation does not exist, an adjustable proportional flume must be used wherever the crest will be at 0.75 of the full supply deepness of the off-take canal (Y2), along with so that the-depth of the base of the roof block underneath the full supply level in the parent canal (Hsof) ranges between 0.35 y1 to 0.48 y1. The setting of the crest should also be on top of the level of the downstream canal bed.

Here are some commonly used outlets in Pakistan

(i) Open Flume Farm Outlet
(ii) Adjustable Orifice Semi- Module
(iii) Jamrao Type Orifice Semi-Module
(iv) Pipe Semi-Module
(v) Scratchley Outlet
(vi) Pipe Outlet

Intake structures or head regulators are hydraulic devices constructed at the start of an irrigation canal. The reason of these devices is to acknowledge and control water from a parent canal or else original source of supply, such as a dam or a stream. These set ups may also serve up measuring the amount of water flowing through them

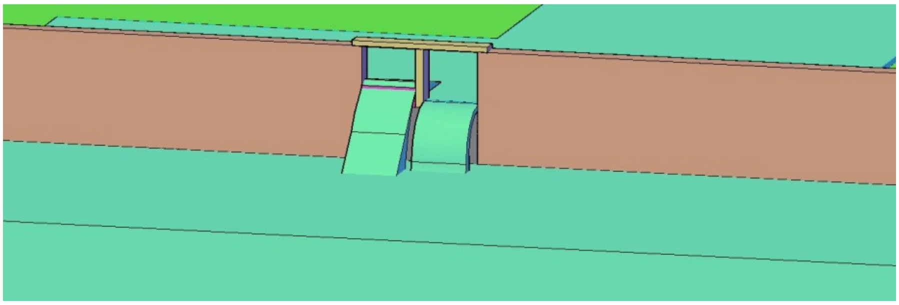

Fig. 5.3 Intake Structure on Secondary Canals, Spillway and Wooden Gate

5.5.5.1 Open Flume

$$Q = CB_tH_{crt}^{\frac{3}{2}} \quad (5.26)$$

Where:

Q is the discharge rate

H_{crt} is the head over the crest

B (t) is the width of throat.

C is the Coefficient

Values of 'C' for various flow rates are given in Table …

Table 5.10 Value of C for Various Flow Rates

Q	value of C	
	Intake angle 60°	Intake angle 45°
up to 0.56 m3/s	1.60	1.61
0.57 to 1.4 m3/s	1.61	1.63

5.5.5.2 Adjustable Proportional Flume (APF)

$$Q = 0.0403B_tH_{orf}\sqrt{H_{sof}} \quad (5.27)$$

Where,

H_{orf} = the height of the opening or orifice above the crest,

H_{sof} = the depth of the underside of the roof block below the full supply level in the parent canal,

B_t= width of throat.

The value of H_{sof} should fall within the range of 0.375 y to 0.48 y_1

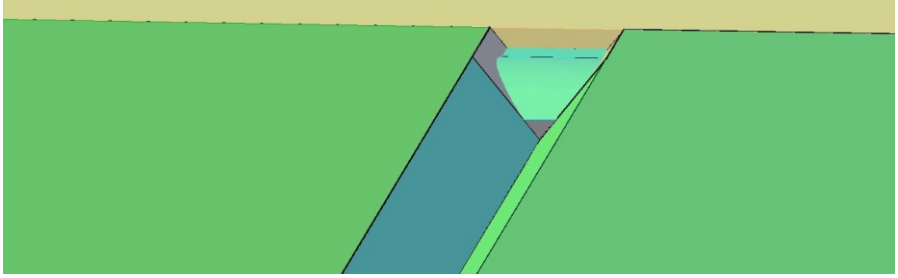

Fig. 5.4 Intake Structure on Secondary Canals

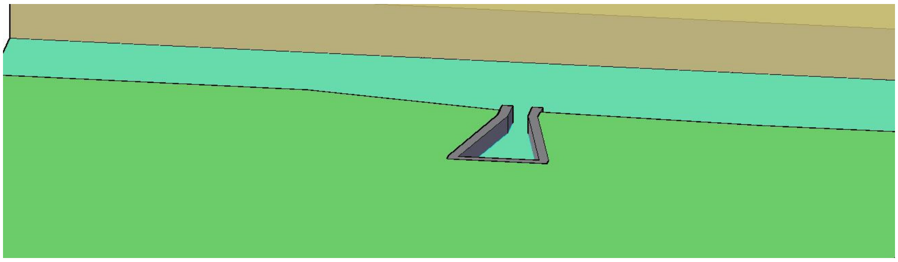

Fig. 5.5 Open Flume Farm Outlet

5.5.5.3 Modular Farm Outlets

In a modular outlet, the discharge is within reasonable working limits, independent of the water level in the supply canal and the watercourse or field lateral. This class of outlets may be regarded as the best type of farm outlets from the farmer's viewpoint. However, modules cannot absorb fluctuations of water supplies in the parent canal and, therefore, the parent canal could either flood or become dry in the tail reach. Thus, modules should be limited to:

- Branch canals or distributaries and minors in which the supply varies only within predetermined limits;
- Outlets located above control points where water levels can be maintained;
- Canals in which additional water is delivered to certain selected outlets for leaching or for other purposes.

5.5.5.4 Semi-modular

The discharge of a semi-module outlet is independent of the water levels in the watercourse or field lateral, but dependent on the water levels in the supply canal, so long as a minimum working head is available for the device. These types of modules are not useful for supplying water to farmers on a volumetric basis unless they are accompanied by an auxiliary device, such as a notch or a weir, a venturi flume, a Parshall flume or an open flow-meter attachment on the downstream side. The usual use of semi-modules is to distribute, equitably, upstream variations in the supply canal within their range of operation. When the water supply to the farm outlets is charged with silt, it is essential to use semi-modules which can draw a proportional share of the silt. In this case, proportional distribution of the water is neither necessary nor feasible and the following types of outlets may be used.

When the-water supply to the outlets is free of silt and a shut-off gate is not necessary, the following types of outlets are open to choose.

(i) **Open flume outlets** – Preferred at tail clusters, and in tail reaches with setting of the crest at 0.9 y for proportional discharge.

(ii) **Adjustable orifice semi-module** – Installed in head reaches with setting of the crest at 0.6 y for proportional discharge.

(iii) **Jamrao type orifice semi-module** – Preferred in head reaches with setting of the crest at 0.96 y for proportional discharge.

(iv)**Scratchley outlet** – It can be a choice if it is not desirable to install any other type of semi-module, which may be probably due to cost.

(v) **Pipe semi-module**– when the banks of the supply canal are very wide; the setting of the module will be as indicated in Open flume outlets and Adjustable orifice semi-module.

(vi) **Fayoum standard weir outlet**– Its setting has been standardized, and it may be used successfully on all distributing canals.

(vii) **Pipe outlet**– in view of its low cost, a pipe outlet may be used on all distributing channels with center of the pipe set at 0. *3* y.

5.5.5.5 Non-Modular Farm Outlets

The discharge of non-modular outlets depends on the difference of water levels in the supply canal and the watercourse. The water level in the watercourse below the outlet varies considerably, depending on: whether high or low areas are being irrigated at any given time; and where silting occurs, the extent of silt clearance in the farm lateral. Where silting is a dominant feature, the canals fitted with non-modular outlets are always liable to flooding at the tail of the canal when farmers in the head reach do not clear silt so that they draw their full share of water during periods of slack demand. On the other hand, water is always in short supply at the tail end during periods of keen demand, when farmers in the upper reaches tend to do the opposite, to clear their watercourses too much. Non-modular outlets should, therefore, be avoided as far as possible. Their use is justified only when the working head available is so small that a semi- modular outlet cannot be used.

5.5.5.6 Design Requirements for a Farm Outlet

As far back as, Kennedy (1906) set forth criteria for the efficient design of a farm outlet in Punjab Irrigation as summarized below.

a. To keep the discharge automatically constant as adjusted and indicated, however much (within working limits) the water levels may vary in the distributary channel, or in the watercourse, or in both at once
b. To allow the slight variations in the discharges as adjusted, so as to avoid the need of constantly removing and replacing the outlet, whenever the discharge must be somewhat altered.
c. Work with high 'heads' as well as low - down to three inches or so to:
d. Be free from derangement by silt or weeds.
e. Be light, portable, easily removed and replaced elsewhere.
f. Be cheap and durable, with no complicated mechanism.
g. Be all closed in and immune from outside interference or derangement in working.
h. Be capable of being opened or closed off entirely by the cultivators from outside.
i. Indicate from outside when the working head is insufficient to give the full discharge, and therefore also the necessity for clearance of the watercourse.
j. Work as a module, only within certain limits of level in the feeder, above and below these limits to give proportionately increased or decreased

discharges if that is desired and adjusted. This is with special reference to farmer's canals, where each man is entitled to a proportion of the whole available supply.

k. Allow floods- in the distributary to be passed off by increased discharges through the outlets, to avoid damage.
l. When the distributary supply is very low and inadequate, it will be proportionally distributed to all outlets, those with very high command not being allowed to draw off all the water there is.
m. Discharges may be provided for anything between half and four cusecs with possible duplication above the latter Fig.

5.5.6 Intake Structures

5.5.6.1 Silt Selective Head Intake.

The sketch of a silt selective intake was developed by the late K.R. Sharma of the Punjab Irrigation Department in 1936 on the supposition so as to the concentration of silt in a stream in the lower layers is larger than that in the upper ones, in addition to if the lower layers had been permitted to run away with no interfering with the silt sharing, the left over water would have fewer silt per unit quantity than the water upstream of the intake.

5.5.6.2 Venturi Head Intake

The design of this venturi head intake was developed in the 1920's through the development of the Sarda Canal in Uttar Pradesh, India, to stimulate economy by providing a flumed throat with appropriate wing wall connections to re-establish the full bed width of the off take canal.

The characteristics of this structure are as following.

a. The head loss is Hcrt /9 or less as well as the discharge is a small over the theoretical value due to the streamlined approach.
b. The venturi head may be planned for any angle of off take from and for any bed width of the off take canal up to 7.5 m.
c. The design is like that the surplus energy of the water is dissolute by the creation of a hydraulic jump.
d. The structure does not gauge discharge properly as well as is not successful in scheming the entry of silt into the off take canal.

5.5.6.3 Square head intake.

The square-head regulator is a straight forward intake arrangement supplied at the heads of secondary and tertiary canals to extract water supplies from a main or branch or secondary canal, the last one is called the parent canal plus the former the off taking canal. The structure is typically positioned at right angles to the parent canal. The arrangement is not a meter plus it is not silt- selective. It is primarily intended to control water supplies into the off taking canal. Regulation is influenced by process of the insertion of stop-logs or a sliding gate within the grooves supplied on the upstream side in the abutments.

5.5.7 Silt Control Devices

1. King's silt vanes,
2. Gibbls Groyne.
3. Curved wing with silt vanes
4. Silt platforms:

a. simple platform;
b. silt platform with a guide wall

5. Reverse vanes.
6. Vortex tube sand trap.
7. Sloping- sill sand screen.

5.5.7.1 King's Silt Vanes

Amongst the silt-excluding devices, King's silt vanes are not appropriate wherever a minor off taking canal is located among two large canal branches plus when its bed is at an elevated level, and/or wherever the water level is possible to rush forward over a substantial range. When the off taking, canal has its bed at a high level, the mechanism Silt platforms is preferable.

5.5.7.2 GibblsGroyne

GibblsGroyne is used while together the off taking plus the supply canals contain the similar sediment transportation capacity. When the consequence of this mechanism is not enough to manage the entrance of silt into the off taking canal, the mechanism King's silt vanes might be used in addition to improve the presentation of GibblsGroyne.

5.5.7.3 Silt Platforms

The silt platforms are appropriate merely wherever the parent canal is deep enough. The mechanism Silt platforms (b) have the benefit that (no relation of the slight heading triggered by the curved wing) a minute head of 3 to. 4.5 cm is shaped at the off take which raises the velocity of the water plus prevents silt being deposited in the head reach of the off taking canal. While a canal divides into two canals, one of which silts up very poorly, as well as there is no sufficient space to accommodate vanes, the device (incomplete)

5.5.7.4 Reverse Vanes

Reverse vanes may be constructed to pass by additional silt into the canal that does not silt.

5.5.7.5 Sand Trap

The mechanism Vortex tube sand trap is appropriate for minor canals whose bed widths are less than 3 meters. It demands that some additional discharge be allowed into the off taking canal for the process of the tube.

5.5.3.6 Sloping- Sill Sand Screen

The device Sloping- sill sand screen has been used in Egypt to accurate local irregularity in the flow outline at the intake of distributary canals.

5.5.8 Flow Dividing Structures

Flow Dividing Structures are used in irrigation networks to separate the flow of a channel into two or more segments. Every division is a defined amount of the whole flow. Therefore, flow separating set ups vary from intakes as well as off takes in that the last are planned to draw off a specific portion of the flow in the parent channel, but the precise quantity of this fraction to the whole flow or to the remainder in the parent channel is usually irrelevant. A flow separating structure demands a control section in both the off take channel plus in the parent channel. Yet, not all flow dividing structures are built to provide precisely proportional separation.

5.5.8.1 Fixed Proportional Divisors

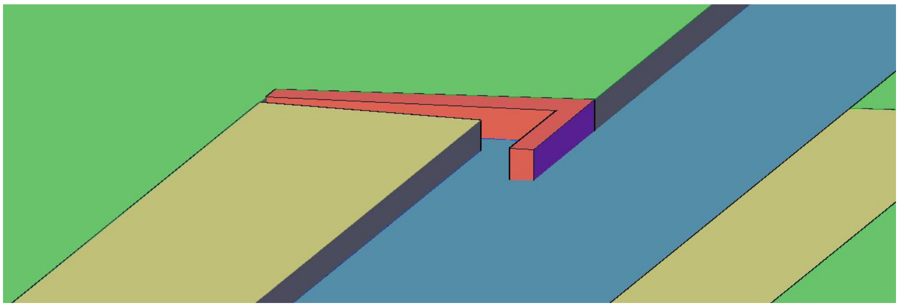

Fig. 5.6 Simple Fixed Proportional Flow Divisor of Low Accuracy

The major characteristic of fixed proportional divisors is that the everlasting splitting of the' flow into two or more than two components required in a control segment wherever a condition of supercritical flow, i. e. Free fall or shooting flow is produced. This calling for certain head loss in the arrangement by allowing the flow pass a ridge or flumed section or by producing a drop, but is not necessary for the splitting of a flow into two precisely equal proportions supplied that: the dimensions are symmetrical; that the flow segment in the arrangement is of consistent roughness; that there is a level canal alignment of 5 to 10 m upstream of the divisor; as well as, finally, that no backwater influence is produced in any of the off take channels. Through setting up a succeeding 1:1 divisor, the flow will be divided into the proportions of 2: (i.e. 1:1). Through rejoining two of the streams, a proportion of 3:1 might be provided.

5.5.8.2 Structures with Adjustable Splitter

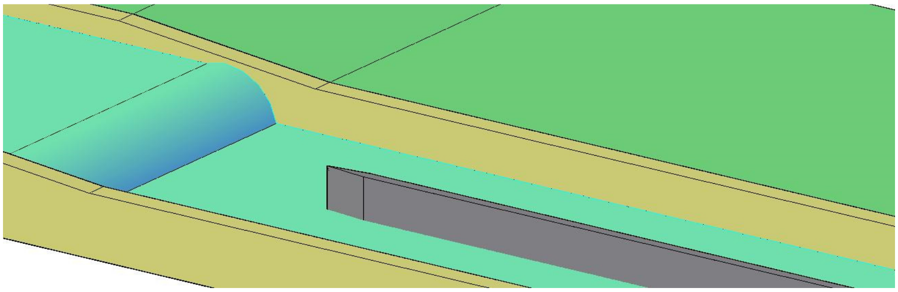

Fig. 5.7 Flow Divisor with Adjustable Splitter, Argentina

Set ups with an adjustable splitter typically consist of a hinged gate made of sheet metal, which can move across the flow segment of the parent channel as well as inflexible in any preferred location through the help of an arch bar or screw bar. The flow must be finished supercritical for precise proportioning through the induction of a control crest or drop in bed level.

5.5.8.3 Proportional Distributors

A typical feature of proportional distributors is that the flow is not divided into fractions by thin plated divisors but is diverted from the parent channel into the off takes by means of individual openings, which however, are grouped to form a single structure. Each opening or off take is constructed as a flume or free over fall weir and is dimensioned to pass a given fraction of the total flow. In other words, the controlling section (flume section, elevated floor, or weir crest) is not in the supply channel, but is in the individual off takes. This arrangement requires accurate calibration by model tests or field rating and great accuracy in construction.

5.5.8.4 Distribution Boxes

Division Boxes normalize the flow as of one channel to another one, or to several others. They mostly consist of a box in addition to vertical walls in which convenient openings are supplied. Metallic, wooden slide gates or stop-logs are usually set up to control the separation of flow at a given point of channel in addition to shut off flow in any branch when preferred. The walls of the box can be of concrete (pre-cast or in situ), masonry or of wood.

5.6 Solved Examples

Example 1: Design an irrigation canal with the following data

(a) Discharge of the canal = 24 cubic meters / second
(b) Permissible mean velocity = 0.8. m/sec
(c) Bed slope = 1:5000
(d) Side slope = 1:1
(e) Chezy's Constant, C = 44

Given data, Q = 24 cumec, V = 0.8. m/sec, S = 1/5000 = 0.0002, Side slope = 1:1

Solution:

Let, B = bed width, D = depth of water.

Cross-sectional area, A = (B + D) D

Using the relationship of Q and V with A, we get A = Q/V = -24/0.8 = 30 m^2

Thus, 30 = (B + D)D

Wetted Perimeter $P_w = B + 2\sqrt{2}\ D = B + 2.828\ D$

Hydraulic Mean Depth, $R = A/P_w = \frac{-30}{B+2.828D}$

From Chezy's formula

$$V = C * \sqrt{RS}$$

$$0.80 = 44\sqrt{R * 0.0002}$$

$$0.64 = 1936 * R * 0.0002$$

or $R = 1.65$

From (2) and (3), $1.65 = \frac{30}{B+2.82\ D}$

or $1.65\ B + 4.67\ D = 30$

$B = 18.18 – 2.83\ D$

Putting the value of B in Eq. A= (B + D) D

$30 = (18.18 – 2.83\ D + D)D$

$= (18.18 – 1.83\ D)D$

$=18.18\ D – 1.83\ D^2$

or $1.83D^2 – 18.18\ D + 30 = 0$

or $D = \frac{18.18 \pm \sqrt{(18.18)^2 - 4*1.83*30}}{2*1.83}$ When, D = 2.09 m

$= \frac{18.18 \pm 10.53}{3.66} = 7.84$ or 2.09 m B = 18.18 – 2.83 * 2.09

When D = 7.84 m = 12.27 m (it is acceptable)

B = 18.18 – 2.83 * 7.84

= - 4.00 (It is absurb)

Check: A = (B + D)D

A = (12.27 + 2.09) * 2.09

= 30.01 (Checked and found correct)

So, finally, bed width = 12.27 m, depth of water = 2.09

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