3.5 Movable Weirs

Movable weirs have proven their value for over 80 years in irrigated areas where flow over an off-take structure is variable because of changing crop rotations and water requirements during the growing season (Butcher 1921 and 1922; Romijn, 1932). The layout for a typical offtake is shown in Figure 3.60, with dimensions shown in proportion to the maximum energy head, $H_{\text{max}}$.

3.5.1 Movable weir types

Depending on the water depth in the approach canal to the weir and on the maximum head required over the weir crest, three basic types of movable weirs can be distinguished:

1. **Bottom-gate type**—the weir crest is sealed behind a movable bottom gate or a fixed wall.
2. **Bottom-drop type**—the weir crest is sealed behind the vertical back-wall of a drop in the canal bottom.
3. **Pivoting type**—the weir crest and ramp are part of a parallelogram moving between parallel sidewalls.

**Bottom-gate type**

This movable weir consists of two interconnected gates and a weir crest that are mounted in a steel guide frame (see Figure 3.61). The movable weir is connected to a
horizontal lifting beam by means of two steel strips. It has a vertical travel of $H_{\text{max}}$ and can be padlocked in place at all desired levels. The bottom gate is blocked in place under operational conditions and acts as a bottom terminal for the movable weir. The upper gate is connected to the bottom gate by means of two steel strips that are enclosed by the frame grooves. This gate acts as a stop for the movable weir.

As mentioned, the upper gate (and thus the bottom gate) is locked in place during normal flow conditions. However, to flush sediments that have collected upstream of the structure, both gates can be unlocked and raised by moving the weir crest upwards. After the flushing operation, the gates are pushed in place again by lowering the weir crest. To discourage misuse of the structure, the maximum flow capacity beneath the lifted bottom gate must be less than the flow over the weir in its lowest position. For this to occur, the travel of the upper gate is restricted so that the bottom gate cannot be lifted higher than $0.5H_{\text{max}}$ above the approach canal bottom.

The weir is placed between the vertical walls of a short approach canal, the walls being flush with the groove frame. The upstream head over the weir crest $h_1$ is measured in this approach canal at a distance of between 2 and 3 times $H_{\text{max}}$ upstream from the weir face. The dimensions of the approach canal should comply with the requirements indicated in Figure 3.60. The 2:1 flare of the right-hand abutment must also be used on the left-hand side if the centerline of the weir structure is parallel to or coincides with the centerline of the undivided supply canal (in-line structure) or if the water is drawn directly from a reservoir or storage basin.

If several movable weirs are combined in a single structure, intermediate piers must be provided so that one-dimensional flow is preserved over each weir unit, allowing
the head \( h_1 \) to be measured independently for each unit (see Figure 3.62). The parallel section of the pier should therefore commence at a distance of \( H_{inax} \) upstream from the head measurement station and extend to the downstream edge of the weir crest. Piers must have streamlined noses, for example, semi-circular. To avoid large velocity differences over short distances, the thickness of the pier should be equal to or more than 0.65 \( H_{inax} \), with a minimum of 0.30 m (1 ft).

**Bottom-drop type**

With this movable weir, the crest is sealed behind the vertical backwall of a drop in the canal bottom. The weir, illustrated in Figure 3.63, can be raised and lowered by a self-sustaining hand gear. It can be raised high enough to cut off the flow at full supply level in the supply canal. When the weir is raised, leakage is negligible. Under normal operating conditions, the travel of the weir must be limited so that its crest cannot be lower than \( p_t = \frac{1}{3} H_{inax} \) above the approach canal bottom. In its highest position, the bottom seal must not be disconnected (see Figure 3.63).

In the shallow approach canal, flow velocities will be rather high, usually preventing the accumulation of sediments in this section. If, however, the alternative canal bottom shown in Figure 3.63 is used, sediments may accumulate. If so, these should be removed periodically. The paragraphs discussing the approach canal and intermediate piers for the bottom-gate type weir also apply to the bottom-drop-type weir.
Pivoting box-frame type

The pivoting weir consists of a rectangular box-frame containing the weir sill and the sides of the control section. The sidewalls of the control section extend a distance $2H_{\text{max}}$ upstream from the leading edge of the sill to allow the mounting of a staff gage. The box-frame moves up and down within a rectangular canal section. The method by which the box-frame is moved depends on the size of the structure. A portable version is discussed in Section 3.3.3. Large size permanent versions (see Figure 3.50) of the movable weir have been designed and installed in the Northwest United States, based on modification of an overshot gate. These have the bottom as well as the top of the ramp hinged. The adjustable box-frame is part of a hinged parallelogram in which the sill top remains horizontal at all sill heights and the ramp slope varies from nearly zero to about 1:1 (horizontal to vertical) as the parallelogram is adjusted to accommodate an existing flow depth in the canal. The ramp is sealed at the bottom, along the sides, and at the hinge with the leading edge of the sill. The latter seal rounds the ramp-to-sill transition so that the steep (1:1) ramp slope does not cause flow separation. The box-frame moves within a rectangular canal section. The hoist cables run in between the box-frame and this rectangular (approach) canal section.

Figure 3.63 Longitudinal section through a bottom-drop type movable weir.
3.5.2 Groove arrangements

The groove arrangement for weirs with a width between 0.30 and 1.50 m (1 and 5 ft) can be rather simple; the gates and related hoist strips and profiles move in narrow grooves with metal-to-metal water sealing. Water leakage through the horizontal terminals is prevented by using rubber seals.

The groove arrangement and terminal seals for the movable weir with bottom gate shown in Figure 3.61 are given in Figure 3.64. As shown, the groove profiles are flush with the sidewalls of the approach canal. Also, the 8 x 50 mm hoist strips fit entirely in the 10-mm-wide grooves. As a result, the width of the weir equals the width of the approach canal. The crest moves in between these concrete or brickwork sidewalls with a clearance of about 5 mm (0.2 inch). These clearances have no detectable influence on the accuracy of the flow measurement.

As stated in Section 3.5.1, movement of the upper and bottom gates is restricted to minimize the accidental loss or unauthorized passage of water. For this purpose, an 8 x 60 mm strip is welded to the top corner of the upper gate. This strip fits in a related groove and terminates 0.20 m (8 in.) below the top corner construction of the frame (bottom gate is closed). A padlocked blocking wedge fits into a hole (10 x 40 mm) through the frame directly above this strip. If the wedge is removed, the bottom gate can be opened 0.20 m (8 in.), which allows less flow through this opening than over the weir, to discourage misuse.

For weirs with a bottom gate, the vertical weir gate is usually placed so that about half the weir crest is upstream from the gate plane to minimize the torque in this gate near the grooves. Weirs that move behind a bottom drop, however, often have the vertical weir gate at the upstream end of the rounded weir nose (see Figure 3.63) so that somewhat more stiffness is needed along the groove edge of the gate. This stiffness can be obtained by welding the gate to an angle iron, whose angle then moves in a groove, as illustrated in Figure 3.65. The angle iron also serves to raise and lower the weir. Figure 3.65 also shows an example of a bottom terminal and seal for a weir with a bottom drop. The rounded lower edge of the bottom gate is important; it allows the gate to be lowered again after it is raised above the approach canal bottom (for maintenance).

If movable weirs need to be wider than 1.50 m (5 ft), the profiles used in the grooves must become heavier to carry the greater hydraulic forces and the forces needed to move the weir. An example of a suitable groove arrangement is shown in Figure 3.66. The bottom seal for weirs between 1.5 and 4.0 m can be as illustrated in Figure 3.64 and 3.65.

Although Section 3.5.3 gives construction details for a 1.50-m (5-ft) wide weir, we recommend consulting a mechanical engineer if any alterations must be made to the given drawings.
Figure 3.64 Sections showing groove arrangements, terminals and seals for movable weir with bottom gate (dimensions in mm).
Figure 3.65 Sections showing groove arrangement and bottom seal for weir with bottom drop (dimensions in mm).

Figure 3.66 Sections showing groove arrangement for weirs between 1.5 m and 4.0 m wide (dimensions in mm).
3.5.3 Lifting devices

Force needed to lift movable weir

Lifting devices for movable weirs vary from the simple gear and chain lift to an elaborate electrically operated unit with remote level control. The type selected depends on the gate size, the maximum hydraulic head under which the gate will operate, the type of canal in which it is installed (farm or project), the speed of gate travel, and the method of operation.

A variety of devices are available commercially to meet the needs of many applications. Some devices that can be used on weirs narrower than 1.50 m (5 ft) are described in Section 3.5.3.

In order to operate any movable weir, the lifting device must overcome several forces. These include the weight of the weir and gate(s), weight of the hoist beam and stem, the frictional resistance caused by the hydraulic pressure against the gate(s), and the weight of the water above the weir crest. To determine the lifting force required to move a weir, the following equation is used:

\[ F = fTb_e + W + \rho gh_1 b_c L \]

where

- \( F \) = lifting force required (N),
- \( f \) = friction coefficient (dimensionless),
- \( b_e \) = weir width (m),
- \( W \) = weight of movable weir (and gates) plus hoist strips, beam and stem (N),
- \( g \) = acceleration due to gravity (9.81 m/s²),
- \( \rho \) = mass density of water (kg/m³),
- \( h_1 \) = head over weir crest (m), and
- \( T \) = the area of the shaded triangle or trapezoid in Figure 3.67 (kg/s²).

Figure 3.67 shows the hydraulic pressure on the gates and weirs in four extreme weir positions. Figure 3.67A illustrates the position for which \( F \) becomes maximum with a bottom-gate-type weir. This is because \( T = 0.5 \rho g y_1^2 \) and because all gates and the weir must be lifted for sediment flushing. In Figure 3.67D, the force \( F \) becomes maximum for the bottom-drop-type weir because (with \( y_1 = 0.33 H_{1\text{max}} \)) the value of \( T = 0.4 \rho g h_1^2 \) and because both other terms of Equation 3.2 have a maximum value. Two different friction coefficients are used in Equation 3.2. The first is for unseating the gates from their locked position. An approximate value of \( f = 0.6 \) has been determined to be conservative. After the gate has been moved upward a small distance, this high initial friction is no longer present and the coefficient drops to approximately \( f = 0.3 \). These values are approximate and will vary depending on how long it has been since the gate has been moved, whether the gate is partially covered with silt or sand, and whether the contact faces are lubricated or dry.
Figure 3.67 Examples of hydraulic pressure on movable weirs.

Types of lifting devices

After determining the force $F$, the next step is to select a combination of lifting device and related stem. For the smaller lifting forces, the gear lift and jack lift are very suitable. The advantage of these low-cost devices is that they can be welded together in most machine workshops.

**Gear lift**

The gear lift was developed by Fullerford (1977) to provide a low-cost device for the precise adjustment of small gates. Constructed of heavy-gage steel to the dimensions shown in Figure 3.68, it will provide trouble-free service on the 0.30 m (1-ft) wide weir. If the handle has a length of 6 times the radius of the available gear wheel, and a one-hand pull of 120 N (about 25 lb) is exerted, this device can produce a lifting force, $F$, of about 700 N (150 lb).

**Jack lift**

The jack lift (Figure 3.69), if constructed using the dimensions shown in Figure 3.70, will also provide a reliable method for the accurate adjustment of small weirs. Usually, the jack handle is 6 to 7 times the distance between its hinge point and the lift stem. Because of this leverage, the lifting force is about 750 N (160 lb) if a pull of 120 N (25 lb) is applied to the handle. With this device, however, it is entirely possible to use two hands and increase the pull by using body weight. As a result, lifting forces of up to $F = 3000$ N (650 lb) are feasible if a weir has to be moved only occasionally.

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1 Trade and company names are shown for the benefit of the reader and do not imply endorsement or preferential treatment of the company or product listed.
Figure 3.68 Construction drawing for gear lift (dimensions in mm).
Handwheel lift

For weirs that are raised or lowered regularly and require a lifting force greater than 750 N (160 lb), a handwheel lift is recommended. In practice, this means that weirs with the commonly used crest length of $L = 0.50$ m and a width greater than the minimum width of $b_c = 0.30$ m should be equipped with a handwheel.

Many kinds of handwheels with either cast iron or bronze lift nuts are commercially available. Because of their higher corrosion resistance, greater durability, and higher efficiency, we strongly recommend the use of bronze lift nuts rather than cast iron lift nuts. To select a suitable handwheel and lift stem combination, consult the manufacturers for detailed information. The data provided in Figure 3.71 may be used for preliminary design.

To avoid unauthorized changes in the weir crest or division board position, a length of chain should be welded to the wheel support for use in padlocking the wheel. If the handwheel is removed upon operating the weir or board, this chain must make one turn around the wheel seat of the lift nut so that no other tool can be used to adjust the structure.

Weirs having a width of $b_c = 1.50$ m (5 ft) or less can be moved with a single lifting device placed above the center of the weir on the top beam(s) of the frame (Figure 3.72). An example of the top beam arrangement is given in Figure 3.73. The top corner is bolted to enable removal of the entire weir for maintenance.
Figure 3.70 Construction drawing for jack lift (dimensions in mm).
Figure 3.71 Handwheel dimensions (adapted from ARMCO Steel Corporation 1977).

Figure 3.72 Handwheel.
3.5.4 Sample construction drawing

As discussed in Chapter 1, the bottom and sidewalls of the structure may be constructed from brickwork, reinforced concrete, or a combination of these materials. As illustrated in Figure 3.62, masonry with natural stone gives good results. The choice of the construction material should be based on factors such as the availability of materials and the skill of laborers, both of which influence the construction cost of the structure. From a hydraulic viewpoint, there is no preference for a particular construction material.

The movable weir is well suited to regulating and measuring the flow that is taken from a main or lateral irrigation canal. In the example shown in Figure 3.74, we use reinforced concrete since this is the most common construction material. The structure accommodates a standard size weir with bottom drop \((L = 0.50 \, \text{m})\). If the approach canal bottom is lowered, however, a weir with a bottom gate can be installed in the concrete structure.

3.6 Flow Divisors

Many of the world’s older irrigation systems are cooperative stock companies in which the individual water users have rights to proportional parts of the water supply furnished by the canal system, the division being in proportion to the stock owned in the canal company. Under this system it was often considered unnecessary to measure
the flow very accurately; it was only important for each user to get their proportionate share. This led to the use of a variety of divisors and division boxes (Cone 1917; Neyrpc 1955; Cipolletti 1886). Our attention will be confined to divisors that can be used for accurate flow measurement and for making the intended division of the water.

A flow divisor consists of a broad-crested weir with rectangular control section and a partition board. The partition board has a sharp (less than 10 mm thick) upstream edge. If the intended division of flow remains near constant, the partition board can be a fixed steel plate, otherwise the board is movable.

- In the upstream reaches of an irrigation system, where water needs to be divided over canals serving areas with about the same cropping pattern, divisors with a fixed board are common. Depending on the number of canals, one or more boards can be used (Figure 3.75). The board starts at the downstream edge of the weir crest and continues downstream for a distance of $H_{max}$. The board divides the overfalling nappe without interfering with the shape of the nappe.

- In the middle and downstream reaches of an irrigation system, the division of water into lateral canals needs to be adjusted to match changing downstream requirements. The flow divisor with movable partition board is the only structure that can accomplish this task by adjusting only one “gate”. For proportional flow the board is adjusted so that

\[ \frac{b_{c,o}}{b_c} = \text{intended part of } Q \]

where $b_{c,o}$ is the distance (width) from the center of the sharp edged board to the side of the control section, and $b_c$ is the width of the weir (Figure 3.76). The board can be kept in this position until the intended division of water changes. If flow into the lateral off-take needs to equal $Q_o$, while the incoming flow, $Q$, changes, the width $b_{c,o}$ should be adjusted so that

\[ b_{c,o} = b_c \frac{Q_o}{Q} \]

For a given upstream head, the incoming flow, $Q$, can be read from a rating table or calculated with the head-discharge equation (see Chapter 8). If board movement is automated, a local control device can activate an electric motor to adjust the board to the intended value of $b_{c,o}$ and thus maintain constant flow into the off-take.

The division board is constructed as a V-shaped box, being closed at all sides and hinged to the division wall. The transition between the board and the wall is streamlined in such a way that no shock waves are created. The board moves with a narrow (about 1-cm) spacing behind the weir crest, with the position adjusted by a cable and pulley system (Figure 3.77 and 3.78). No seals are required under the board and near the hinges. Because there is usually little head difference across the board,
Figure 3.75 Flow divisor with fixed boards in an irrigation canal (Argentina).

Figure 3.76 General layout of a flow divisor.
Figure 3.77 Movable flow divisor behind broad-crested weir showing division door. The door position is adjustable with a cable. (Argentina).

Figure 3.78 Flow divisor for 65 m³/s (same structure as Figure 3.77) (Argentina).
flow through the spacing is negligible. For smaller structures, an adjusting rod and hand crank can replace the cable and pulley system (Figure 3.79). The length of the board depends on the required travel distance of the board. The angle of the board with the centerline of the weir should always be less than 1:6.

The flow divisor cannot be used to cut off flow into the lateral canal. For emergency canal closures a gate should be placed downstream from the divisor. Under normal operational conditions the gate must be lifted entirely out of the water. The gate should not be used for flow control because this would take flow control away from the weir, submerge a portion of the crest, and invalidate the flow measurement.

If the divisor board is parallel to the direction of flow over the broad-crested weir and the water level in both downstream canals is equal, the only force to overcome to move the board is the friction on the hinges. Maximum force is needed to move the board away from its maximum deflection (being \( \frac{1}{6} L_{\text{board}} \)). This maximum force is approximately:

\[
F = \frac{1}{6} L_{\text{board}} \Delta H H_c \rho g
\]

This force is considerably less than the force needed for vertical weir movement.
3.7 Drain Pipe through Weir

Since weirs contract the channel from the bottom, a pool will be maintained upstream, even with no flow. A drain pipe should be installed through the base of the weir for convenient winter drainage and control of mosquitoes in summer, particularly if the canal is for intermittent use, as is usually the case for canals in a tertiary unit or a large farm system. As a rule of thumb, a pipe diameter of approximately $D_p = L_p/50$ is recommended, where $L_p$ is the length of the drain pipe. This yields pipe diameters of 25 to 75 mm (1 to 3 in.) for typical small to medium size weirs. The discharge through the drain pipe for a head loss across the weir of $\Delta h$ is (Bos 1989)

$$Q = \frac{\pi}{4} D_p^2 \sqrt{\frac{2g \Delta h}{\xi}}$$ \hspace{1cm} 3.6

For such “small diameter pipes” friction losses in the pipe are more significant than the entrance and exit losses, and the coefficient $\xi$ is approximately

$$\xi = 1.9 + f \frac{L_p}{D_p}$$ \hspace{1cm} 3.7

where $f$ is the Darcy-Weisbach friction coefficient. For smooth, small diameter pipes a value of $f = 0.020$ is appropriate (Bos 1978). Hence, for the ratio $L_p/D_p = 50$ the coefficient $\xi = 2.9$. Equation 3.6 yields Figure 3.80 from which the pipe discharge can be read as a function of $D_p$ and $\Delta h$.

![Figure 3.80 Discharge through drain pipe with $L_p/D_p = 50$, as a function of diameter and head loss over the structure.](image)
For example, Figure 3.80 shows that flow through a 25 mm (1 in.) drain pipe (appropriate for typical small irrigation weirs) with $\Delta h = 0.6 \text{ m (2 ft)}$ is 1.0 liters/s (0.035 ft³/s). Such a flow is negligible with respect to $Q_{max}$ of the weirs for which such a drain would be appropriate. If the drain diameter is larger than $L_p/50$, or if the weir operates near its minimum capacity during long periods, the drain pipe should be at least partially blocked. This can be done with any available materials such as valves, brick covers, styrofoam cups, or rags. The latter can be quickly pushed out of the tube with a stick or rod when drain-down of the canal is desired. Complete blockage is not required. Sediments, which tend to accumulate at the base of the ramp, may plug the drain pipe and should be cleaned out periodically.