CONTROLLING AND MONITORING FLOW IN TREATMENT WETLANDS USING WEIRS

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Abstract. Adjustable weirs can be used to control ponding depths and measure flows at constructed wetlands. This paper describes how to design, construct and operate weirs at wetlands.

Background

Constructed wetlands have been used successfully to treat acid mine drainage. Most constructed wetlands do not have a way to easily adjust flow into cells of a multiple cell wetland or to easily modify ponding depth in a wetland cell. In addition, accurate flow measurement to and from wetland cells is often difficult if not impossible. This paper presents practical guidance for using adjustable height V-notch (triangular) sharp crested weirs for flow control and flow measurement at wetland sites.

The paper will focus on practical tips on designing and constructing weirs including:

1. description of weirs,
2. flow equations,
3. using weirs for flow control,
4. using weirs for flow measurement,
5. sizing of weirs,
6. location of weirs,
7. materials,
8. range of adjustment,
9. preventing seepage around and under weir structure,
10. structural integrity,
11. operation of weirs.

In general, adjustable weirs are placed on the upstream end of wetlands to distribute flow between parallel cells, aerate water and measure inflow. Weirs are placed on the outlets of wetland cells to control water levels and measure outflows.

Description of Weirs

Weirs are defined as, "a notch of regular form through which water flows." (French, 1985) Outlet weirs can be thought of as the low spot in the dike around the wetland. Inlet weirs can be thought of as the end of the channel conveying water to the wetland. The top of the weir is called the "crest" and are classified according to the front view shape of the weir

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as rectangular, circular, V-notch (triangular) among others. They are also classified as to the thickness of the weir as broad, short or sharp crested.

For the combined purpose of measuring and controlling flow in constructed wetlands sharp crested, V-notch weirs are the easiest to work with and most accurate. Other types of weirs can be used and the rectangular sharp crested weir is also a suitable choice. For a weir to be considered sharp-crested, the thickness of the plate material from which the weir is made should be significantly less than the depth of water flowing over the weir.

Weir Flow Equation

Equations are available relating the flow rate over a weir to the head upstream of the weir from standard hydraulics references (French, 1985; Grant, 1989; SCS, 1956; Streeter, 1971). The equation for a triangular sharp crested weir can be given by

$$Q=\frac{8}{15}C_e\sqrt{2g}(\tan\frac{\theta}{2})h^{2.5} \tag{1}$$

where
Q = flow, cfs (m^3/s)
C_e= discharge coefficient
g = acceleration due to gravity, ft/s^2 (m/s^2)
theta = angle of weir opening
h = effective head, ft (m)

Figure 1 defines some of the terms in equation (1). The discharge coefficient depends on the type of weir and the opening angle but is usually around 0.58 (Bos, 1976). A good angle is between 40 and 90 degrees.

The effective head is the height of the water surface above the tip of the V-notch. It should not be measured at the weir but at least several h's upstream of the weir (at least three). Do not measure h at the weir crest because the surface of the water has curved at that point and the potential energy upstream of the weir has already been converted into kinetic energy to some extent, thus violating the assumption under which equation 1 was derived.

Some other considerations regarding use of equation 1 are (see Fig 1 for definition)s:

1. P should be at least 0.3 ft (0.09 m),
2. h should be at least 0.16 ft (0.049 m),
3. T should be at least 2 ft (0.61 m),
4. h/P should be at least 1.2,
5. the depth of water downstream of the weir (tailwater elevation) should be below the vertex of the V-notch.

As one deviates from the above conditions, equation 1 becomes less accurate.

Using english units (g = 32 ft/s^2), equation (1) can be simplified to

$$Q=14.0\tan(\frac{\theta}{2})h^{2.5} \tag{2}$$

For a 60 degree weir with a head of 4.2 in. (0.35 ft), the flow can be calculated as

$$Q=14\tan\left(\frac{60}{2}\right)0.35^{2.5}=0.58cfs$$

Using Weirs for Flow Control

If the wetland does not consist of more than one cell in parallel, then weirs cannot be used to control flow between or among cells because all of the water flowing into the wetland must go into the single cell. Raising the weir level for the influent to a single cell wetland, only can temporarily store water upstream as the upstream channel fills.

For wetlands with several parallel cells, the relative height of the weirs determines the relative flow through each cell. Lowering the level of an inlet weir relative to others will increase the fraction of the flow entering a given cell.

Weirs can be adjusted by trial-and-error to obtain the best flow distribution. Alternatively, the notch elevations for each weir can be determined mathematically by replacing the head (h) in equation 1 with

$$h_i = H_u - H_i \tag{3}$$

where
H_u = upstream water level, ft
H_i = elevation of i-th weir notch, ft

for each of the n weirs. It is possible to set up a separate weir equation for each weir and solve the set of equations for the notch elevations that will give the desired flow distribution.

There are several alternative designs for adjustable outlet controls including telescoping valves and gates. These devices are quite expensive and are only justifiable where water level is changed frequently. For a constructed wetland, water level only needs to be changed occasionally. Therefore the authors have developed an adjustable weir as shown in Figure 2 which consists of three fixed plates (A, B and C) and one movable plate held in place by screws.

Using Weirs for Flow Measurement

Weirs are a very easy device to use for measuring flows over a wide range. The only field measurement is the head. The problem is that the head must be measured relative to the weir notch. For fixed (non-adjustable) weirs this can be done by placing a marked staff in the upstream water. For an adjustable weir the water surface elevation and the V-notch elevation (or the difference in elevation) must be known.

With acid mine drainage a staff placed in the water becomes stained and unreadable over time.

An alternative is a portable device that is attached to the weir and is placed in the water only when the flow is being measured. One such device, designed by the authors, is shown in Figure 3. This device is attached to the weir such that the zero line on the ruler is at exactly the same elevation as the notch (bottom of V) of the weir. This can be done by installing anything that sticks out of the weir plate at the elevation of the notch.

Another device for measuring flow can be constructed from two carpenter's squares and a carpenter's level as shown in Figure 4. (US DOD, 1982)

In all measurements, the weir plate and the measuring staff must be vertical.

Sizing of Weirs

The two design parameters in weir design are the notch angle and the maximum height of the notch.

The notch angle determines the sensitivity of the weir. The more narrow the angle the greater the change in head for each change in flow. If the angle is too narrow, the head may vary more than desired in the wetland.

The maximum height is determined using the maximum flow rate expected over the weir. The height can be determined by solving equations 1 or 2 solved for h. Once the maximum height is determined the height at the minimum and average flow rates should be checked to make sure the values are not so small that h is insensitive to changes in Q.

For example, consider a weir where the maximum flow rate is 0.5 cfs, the average is 0.2 cfs and the minimum is 0.08 cfs. Equation 2 can be rearranged to give

$$h=\left(\frac{0.714Q}{\tan(\frac{\theta}{2})}\right)^{0.4} \qquad (4)$$

which yields maximum, average and minimum heads of 0.66, 0.46 and 0.32 respectively. If the heads were too small to measure accurately or below the minimum range for the weir equation, then the notch angle would need to be decreased.

The weir must not be placed in a shallow channel but in front of a pool area to insure that the distance from the bottom of the channel to the notch (P in Figure 1) is great enough to insure that the conditions described earlier with regard to P are satisfied.

The maximum range of adjustment is another design consideration for adjustable weirs. The maximum water level can be given by the value of H_A in Figure 2. The minimum level can be given as

$$H_A - h_D + h_v$$

in Figure 2. In addition

$$h_B > h_D - h_v$$

so that plate D can be slid behind plate B.

Location of Weirs

From the standpoint of measurement accuracy weirs can be placed virtually anywhere in a wetland. However, from a water treatment standpoint, the wetland designer wants to maximize the average detention time of water molecules travelling through the wetland. This can be done by placing the inlets and outlets (weirs) at the opposite end of the wetland to achieve what process design engineers refer to as "plug flow." (Levenspiel, 1972; Viessman and Hammer, 1993) In some cases it may even be desirable to use several weirs. (Walski and Schroeder, 1978)

Ideal plug flow cannot be achieved in real wetlands due to turbulence and mixing but it can be approached by constructing wetland with a large length to width ratio. If the basin has a good length to width ratio as shown in Figure 5a, one need only insure that the inlet and outlet are on opposite sides. If on the other hand the location of inlet and outlet are constrained Figure 5b, the spur dikes (or baffles) can be introduced into the wetland as in Figure 5c to improve the length to width ratio and hence approach plug flow.

Constructed wetlands for AMD treatment have a great deal in common with dredged material containment areas and some of those references can be helpful for the hydraulics of constructed wetlands. (Shields, Thackston and Shroeder, 1987; Walski and Schroeder, 1978; US Army Corps of Engineers, 1987)

The next consideration is whether the weir should be constructed as a "drop inlet" with a pipe under the dike (embankment) or as part of the dike as shown in Figure 6. Drop inlets have the advantage of not interfering with the design and construction of the dike. However, because they are some distance away from the dike, it is more difficult to reach them to read water levels or make adjustments. On the other hand, weirs in the dike can lead to structural problems in the dike due to differential settlement. (Hammer and Blackburn, 1977)

Materials

Sharp-crested weirs should be constructed of material that is easy to work with, strong even if it is thin, durable and inexpensive. Galvanized sheet metal was selected by the authors. Wood could also be used but it would need to be fairly strong to resist the forces on it. For example plywood would need to be so thick, it might no longer be considered a sharp crested weir at low flow rates.

Where flow measurement is not a consideration and water depth need not be controlled exactly, weirs can be constructed of boards placed vertically inside a metal frame. (US Army Corps of Engineers, 1987)

Preventing Seepage

Seepage under and around weirs can be a serious problem in accurately measuring flow. By using very few parts, seepage through the weir can be minimized.

Seepage under and around the weir can be reduced by grouting any joints between the weir and the dike or floor or the weir. Clay can be packed along the bottom of the weir to prevent seepage under the weir.

Structural Integrity

Weirs act as part of the dike and can be the weakest portion of the dike around the wetland. (Hammer and Blackburn, 1977) When the foundation material under the dike is a weak soil, the dike can settle faster than the weir structure. This can open up seepage paths between the weir and the rest of the dike. In addition, the material adjacent to the weir needs to be compacted well when it is placed so as not to allow seepage between the weir and the dike to start.

In the authors' weir, the weir plate was extended beyond the side wall into the dike to make it virtually impossible for water to seep around the weir as shown in Figure 7.

The weir acts as a dam and is therefore subject to significant forces due to the hydrostatic pressure of water upstream of the dam. The maximum force on a weir acts at the centroid and can be determined based on the maximum height of water behind the weir and the submerged area of the weir plate according to

$$F=\gamma h_c A \qquad (5)$$

where

F = force on weir, lbs
h_c= depth at centroid of weir, ft
A = cross sectional area, sq ft
gamma = specific weight of water, 62.4 lb/cu ft

The centroid is usually two thirds of the way down the weir. For a two foot wide three foot high weir, the force is

$$F=62.4(2)(2x3)=750\,lb$$

From the above it is clear that even a small weir has significant forces acting on it and must be well supported from the downstream side or else it can fail. The support can come from earth, masonry block or poured-in-place concrete.

Water flowing over the weir must not be allowed to erode or scour the channel leaving the weir and hence weaken the weir structure.

In cold climates where frost can penetrate to a significant depth, the weir structure should be placed on a deep footer to reduce the possible damage due to frost heaving.

Operation

Water level in constructed wetlands should not need to be adjusted frequently. Once the water level is set and flow distribution between cells is fixed they should stay roughly the same over time. However, adjustable weirs provide the opportunity to experiment with relative ease with alternative flow distributions and ponding depths while knowing the flow and loadings in the wetland.

Adjustable weirs also provide the ability to shut off flow to a cell for a period to perform maintenance and study the cell in some detail. The ability to raise the weir level also provides the opportunity to raise the ponding elevation in the wetland to maintain the same depth even though the wetland begins to fill with sediment.

Summary

Properly designed and constructed adjustable weirs can be an effective way to control and measure flow in constructed wetlands.

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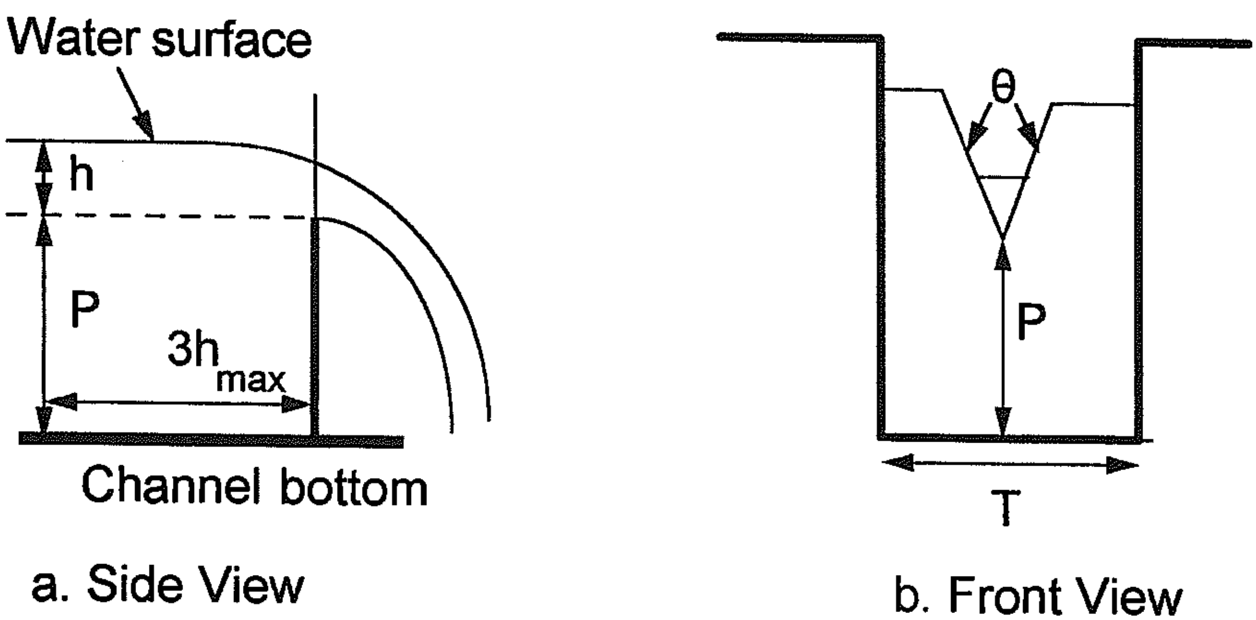

Figure 1. Definition Sketch for V-notch Weir

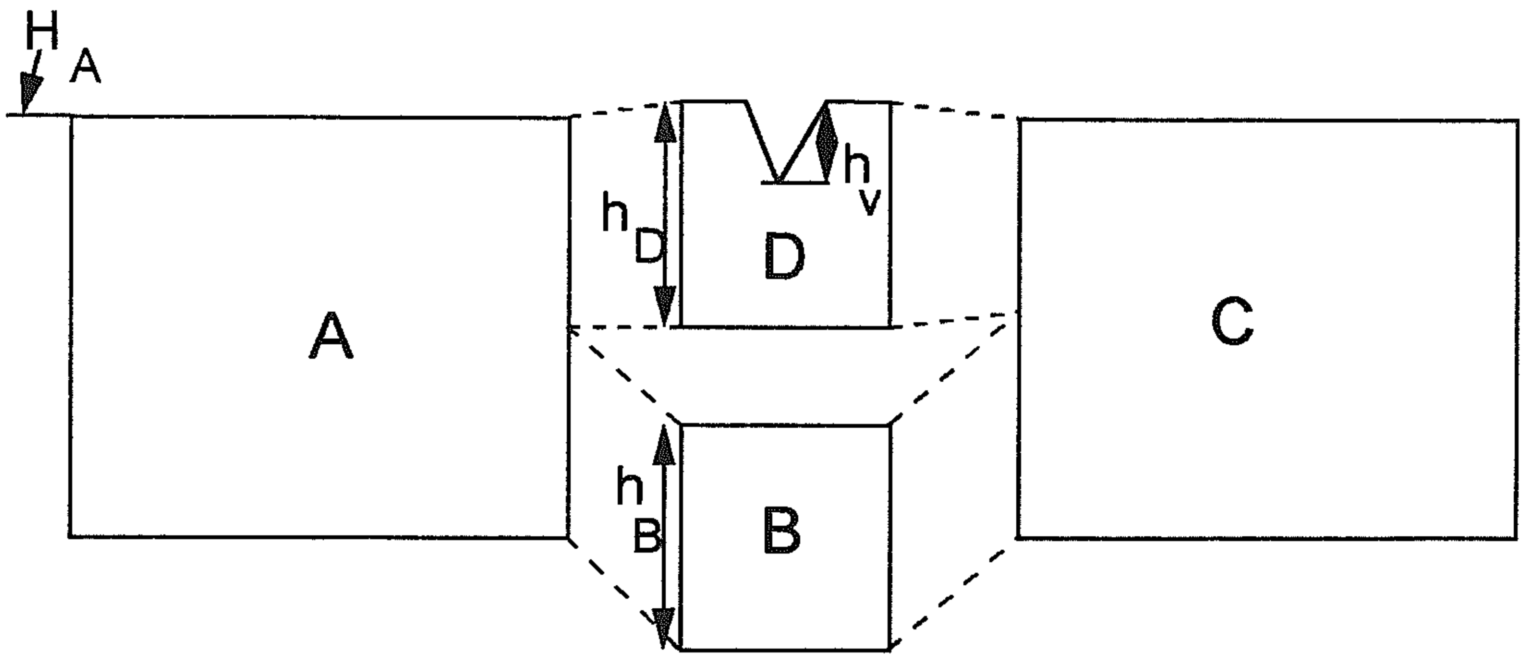

Figure 2. Plates Used in Weir Construction

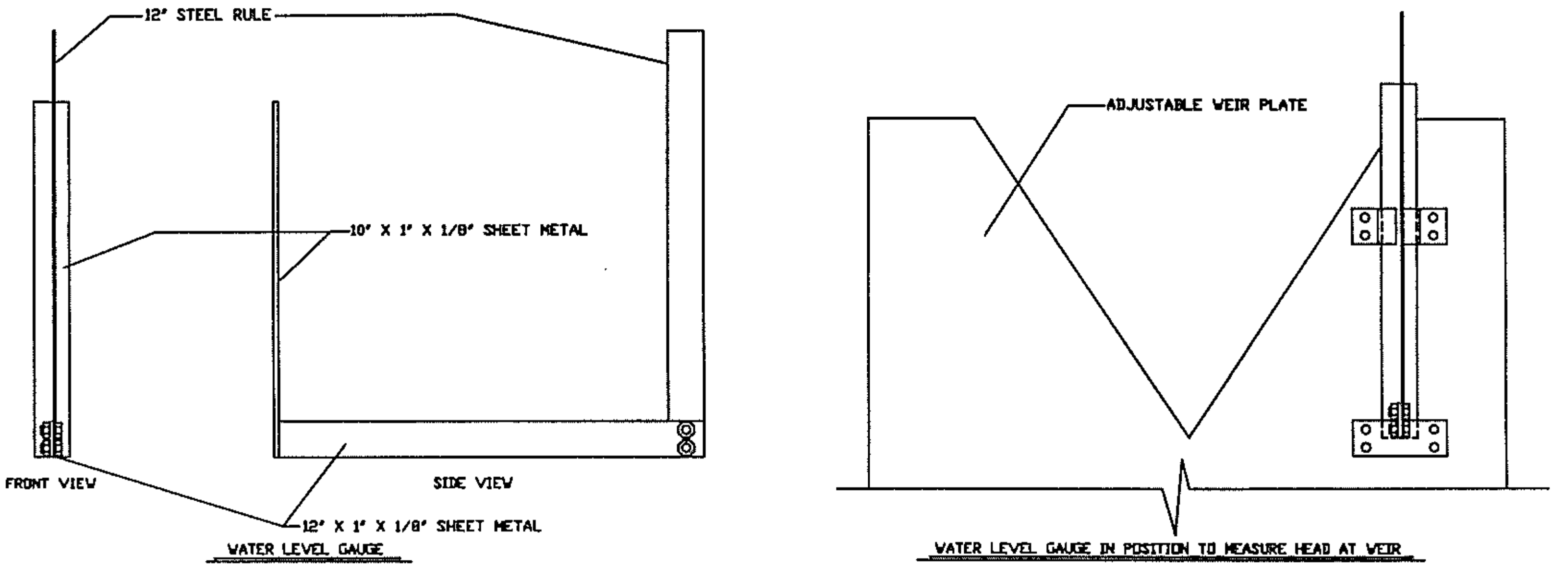

Figure 3. Depth Measuring Device

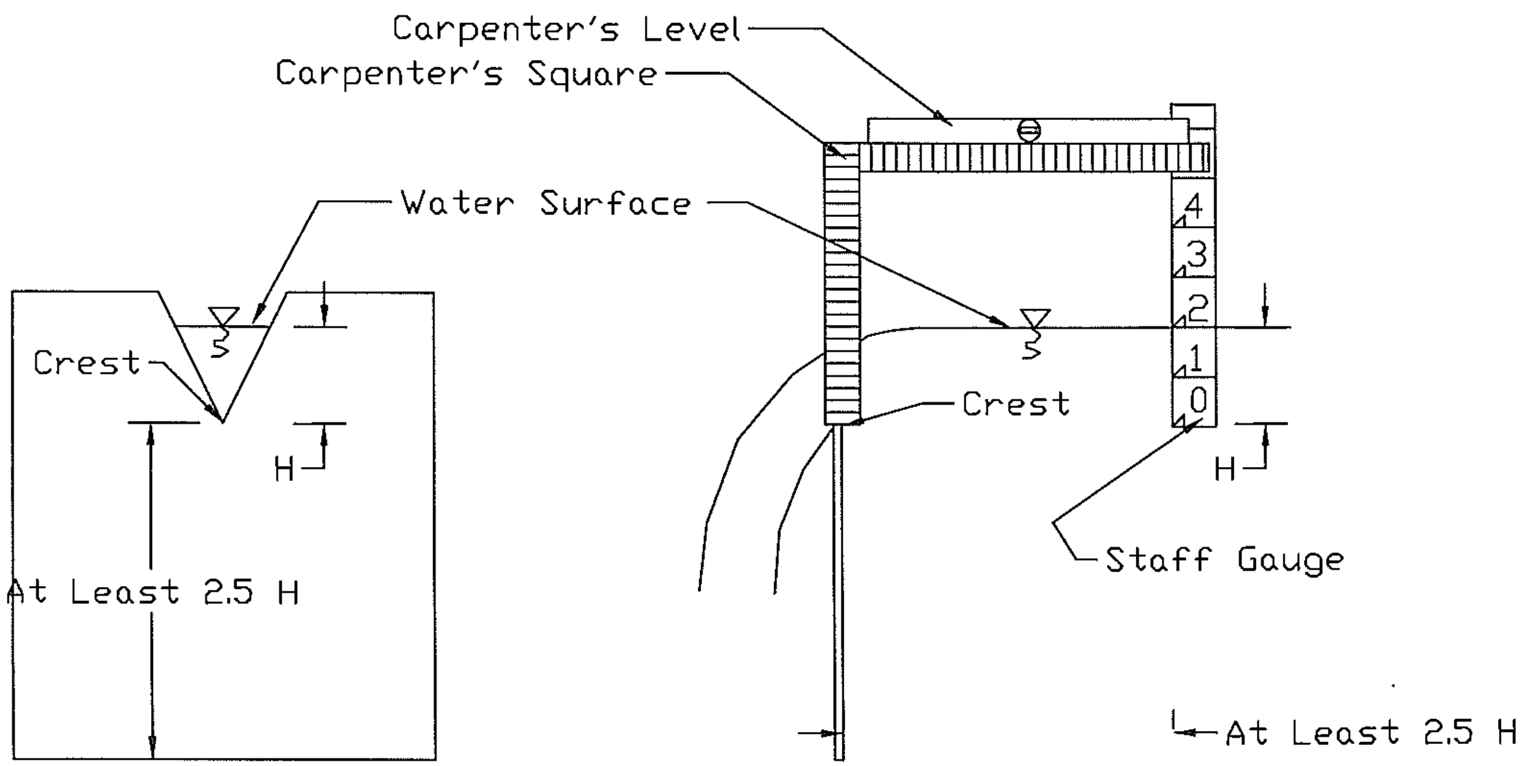

Figure 4. Alternative Method to Measusre Depth

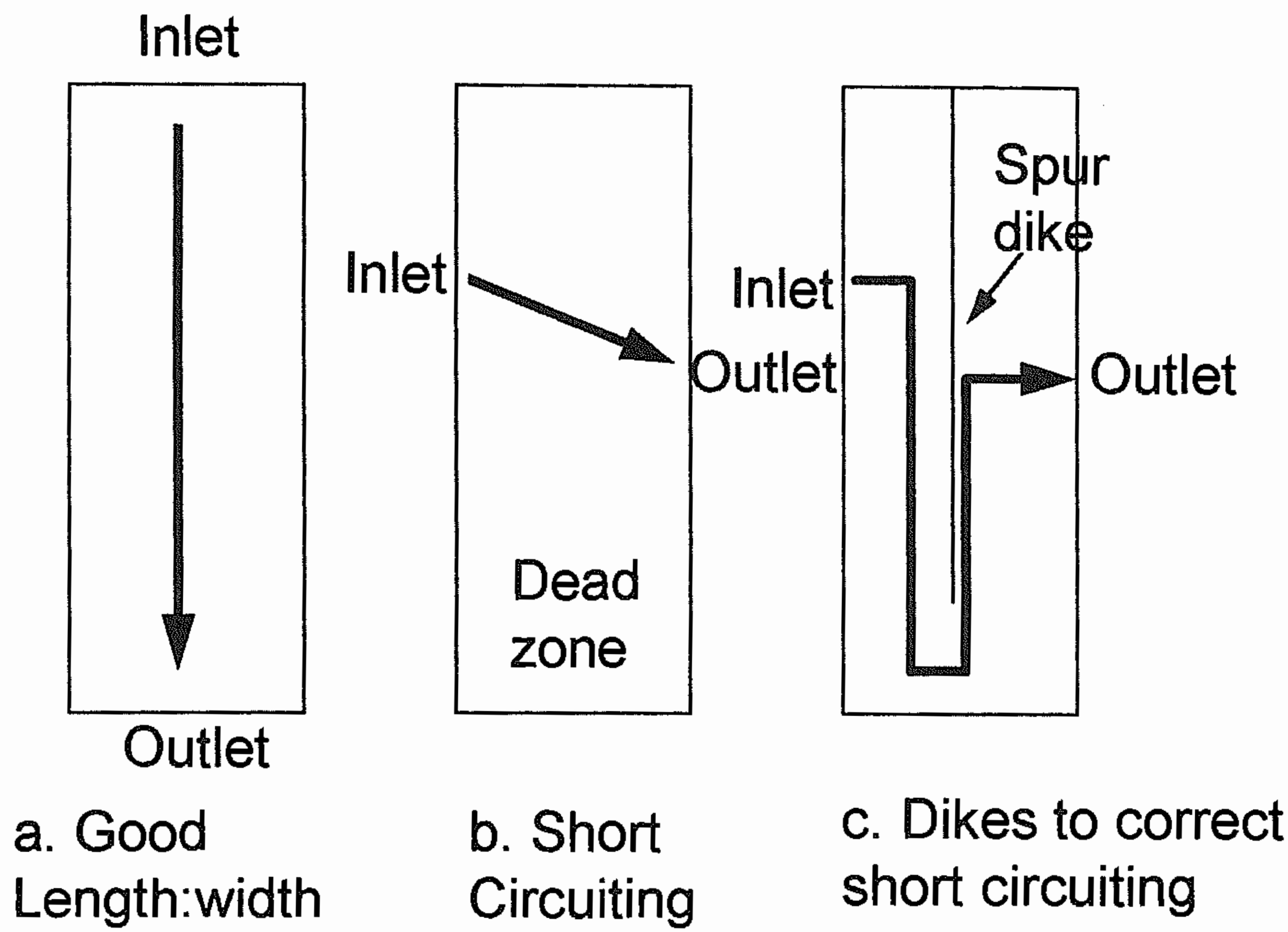

Figure 5. Alternative Flow Paths through Wetland

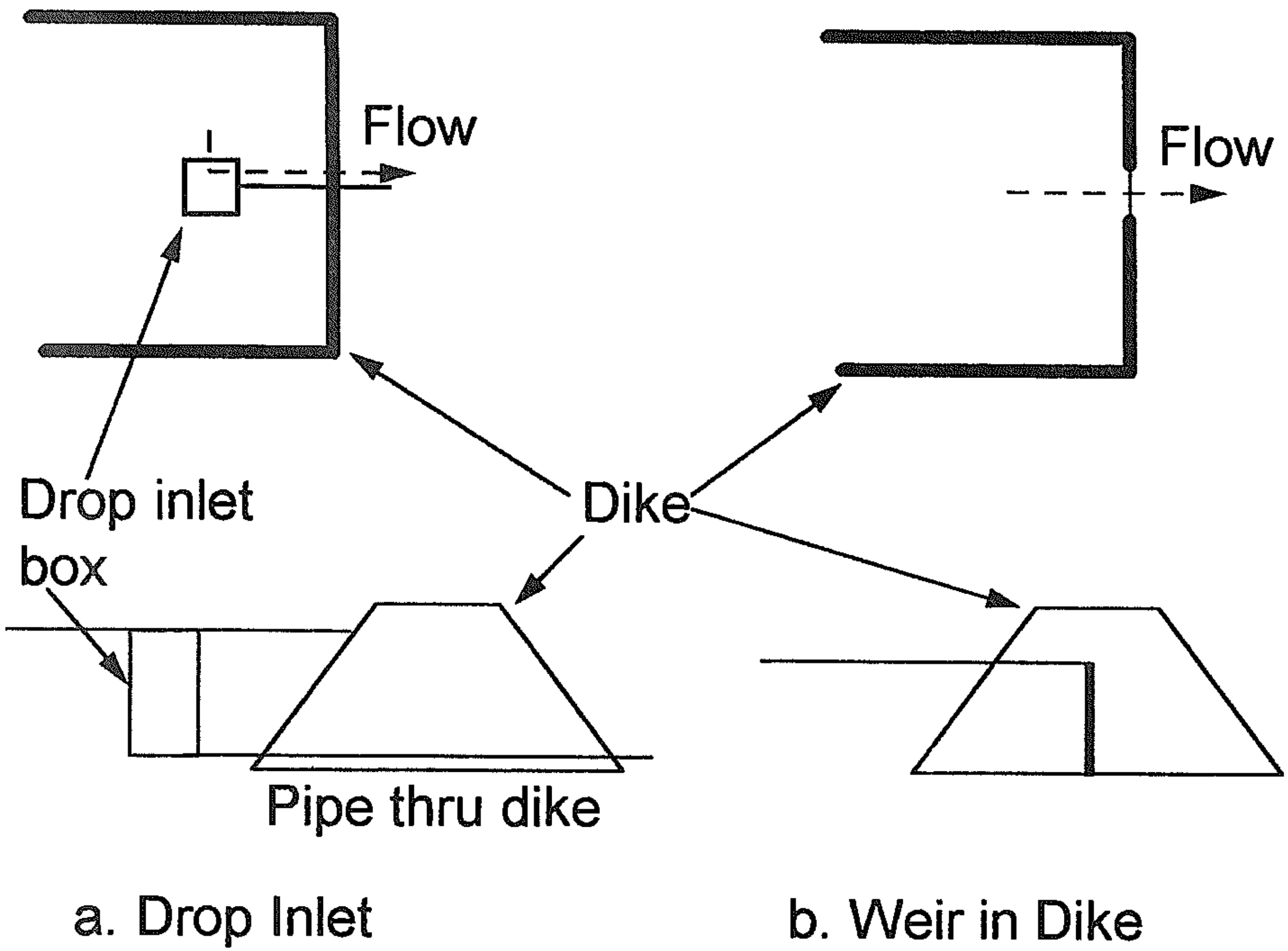

Figure 6. Alternative Location of Weir Structure

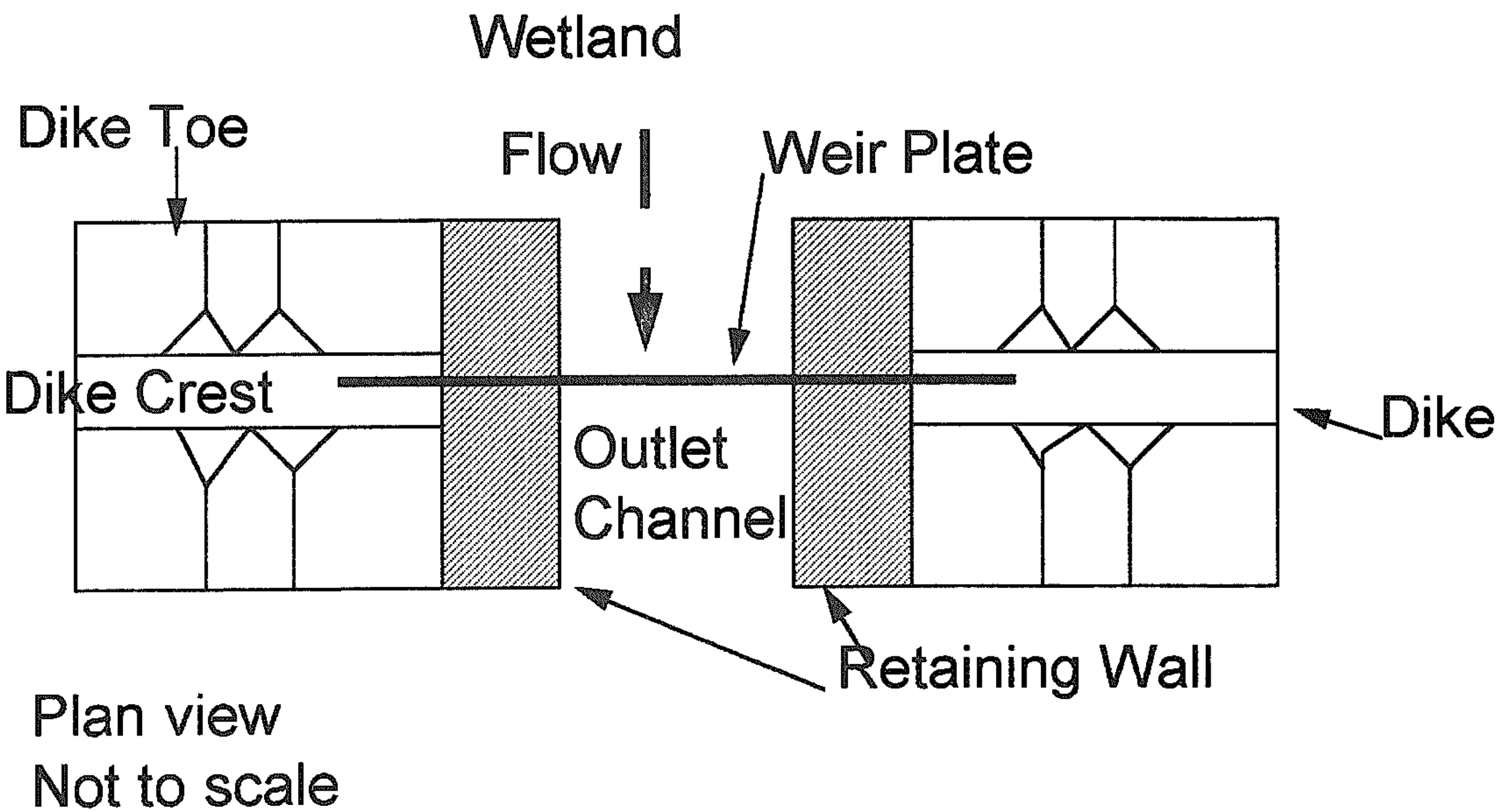

Figure 7. Plan View of Weir Structure