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# IMPROVED DESIGN CRITERIA FOR EXTENDING BRIDGE-LIKE INTAKES INTO OPEN CHANNELS

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## ABSTRACT

Extended water intakes are structures established at river sides to divert water for multiple uses and purposes. Previous studies have only focused on extending the intake to a sufficient water depth for ensuring permanent abstraction. They used physical and numerical models to predict the trend of the site riverbed morphological changes for identifying the lowest bed levels and biggest depths to which intakes could be extended. However, they have ignored other parameters that govern the extension. This paper aims to investigate those parameters and introduce a practical and scientific basis that helps estimate the minimum (min) offshore extension distance of a water intake. It is the distance between the point where the annual min water stage meets the channel bank and the point where a critical water depth is sufficient to submerge the suction pipe inlet without producing vortices that affect both the pumping system and channel bed. Based on the definition of the extension distance, the critical water depth under the min water stage at the channel cross section concerned has to be computed. By analyzing the min water stage, it was found that it is equal to the sum of a submergence depth, the diameter of the suction pipe inlet or (the strainer length), and a clearance distance above the channel bed. Doing further analysis, it was found that the submergence depth value depends on the water station discharge requirements, the water suction velocity at the pipe inlet, and the maximum height of a water wave generated by a moving navigation boat near the intake as well as the channel bed morphology. Also, the value of the clearance distance above the bed was found to be a function of the suction pipe diameter or (the strainer length). To compute the min extension distance, a Spreadsheet Model was developed to correlate all the concerned parameters and help study as many scenarios as possible to find the most economical and safest distance. Finally, the research concluded that the computation of the min extension distance is governed by a number of factors such as the min water stage, water station discharge requirements, water suction velocity at the pipe inlet, and maximum water wave height generated by a moving boat near the intake.

**KEYWORDS:** Water Bridge-like Intakes; Offshore Extension Distance; Submergence Distance; Water Stage Recession.

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**Abbreviations:**
BMI = the bell-mouth inlet of a pipe.
$D_1$ = Recession distance.
$D_2$ = minimum extension offshore distance of a water intake.
$D_i$ = the diameter of the BMI of the suction pipe.
H = water wave height in general.
$h_c$= critical water depth.
$H_{max}$ = maximum height of a water wave generated by a moving vessel.
L = strainer length; C = clearance distance above the riverbed.
MSD = minimum submergence distance.
MWS = minimum water stage.
$Q_p$ = plant water requirements.
S = submergence depth; and
$V_i$ = water velocity at the BMI of the suction pipe.

## 1. Introduction

Bridge-like water intakes are structures established at the sides of rivers to carry pipes that divert water for satisfying drinking, irrigation, flushing and cooling purposes. They match rivers that undergo large water surface recession. When the water surface declines, the shoreline gets further away offshore. Such a case entails the extension of pipes for some distance across the river to reach the water and ensure permanent withdrawal round the year. Previous studies have focused on extending the pipes on an intake structure across the river to a spot where water with sufficient depth could be available. This was meant to avoid the potential riverbed morphological changes that might deposit sediment round the pipe inlets. Such changes were feared to obstruct water withdrawal from the water channel. However, these studies have been turned out to be short of deciding on the exact extension length of a water intake as they ignored other essential parameters that influence and govern the pipe extension into water. They ignored, for example, the effect of the navigational movement (boat speed), the consequent wave height generated, the amount of water discharge to be diverted by the intake, the diameter of the pipes to be used, the suction velocity at the pipe inlet. All such parameters should be considered upon designing the intake structure length. For ensuring annual permanent water diversion, intake pipes should be at least extended offshore to cover two main distances: the recession distance ($D_1$) and the offshore distance ($D_2$) as shown in Figure (1). Hekal (2015) [1] defined the recession distance as the horizontal distance between the two points where the maximum and minimum water stages meet the bank of an open channel at any cross section. The offshore distance can also be defined as the horizontal distance between two points; the point where the annual minimum water stage meets the channel side slope and that where a water critical depth ($h_c$) is sufficient to fully submerge the bell mouth inlet (BMI) of the pipe. No air-entraining vortices should be allowed. They cause problems to both the pumping system (such as aeration and cavitation) and the channel bed. This depth could be defined as the sum of a submergence distance (S), a proposed BMI diameter ($D_i$) or a strainer length (L) depending on the vertical or horizontal positions of the suction pipe, and a clearance distance (C) as shown in Figure (2). In fact, the intake diversion/suction pipes should be submerged under water surface at a distance (S) enough to avoid the occurrence of vortices due to both water abstraction and surface waves generated by any moving vessels. Also, the BMI of the pipe should be positioned above the riverbed at a certain clearance distance (C) that ensures the riverbed sediment grains are not affected or agitated.

## 2. Objective

The paper aims to introduce a practical and scientific basis that can help estimate the minimum extension length (offshore distance "$D_2$") of a water intake structure (bridge) into bounded open channel of steady and controlled flow. Based on the above definition of the offshore distance ($D_2$), the main concept is to estimate the critical water depth ($h_c$) under the minimum water stage at the riverbed cross section where the water intake structure is to be extended. Knowing the value of ($h_c$), the offshore distance "$D_2$" can be computed.

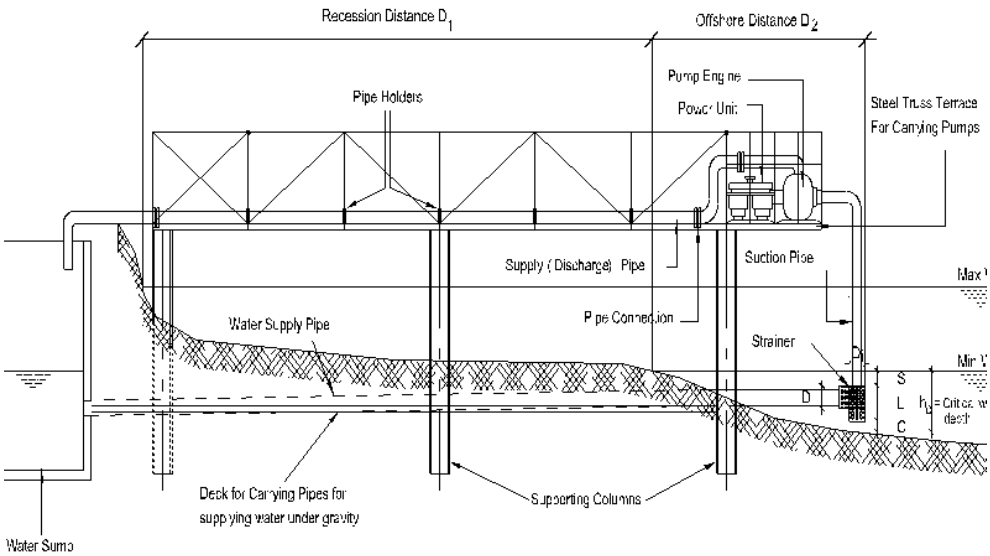


**Fig. 1**: A schematic diagram of a bridge-like water intake structure (after the author).

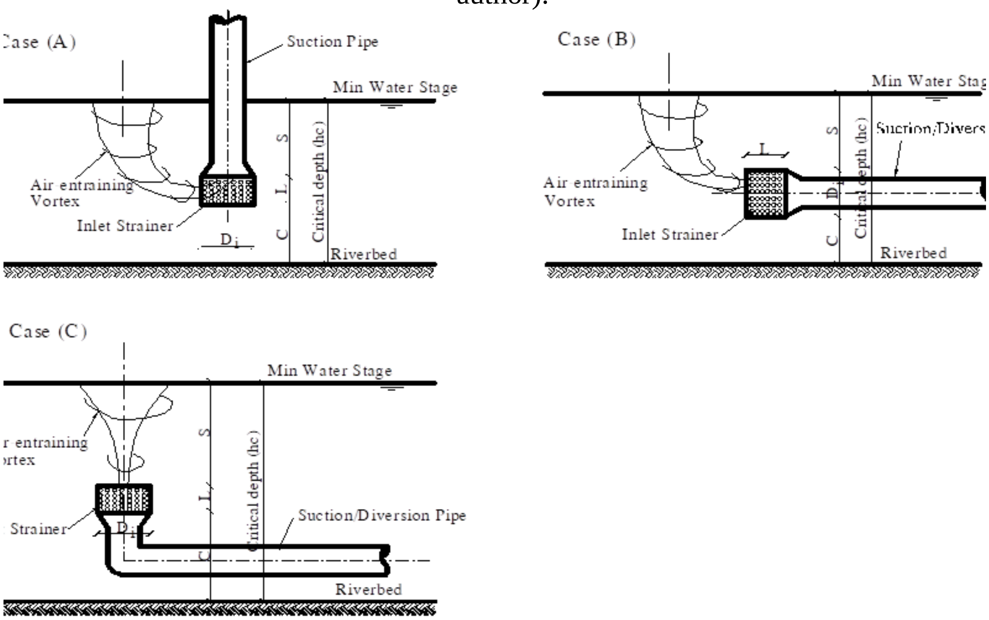


Fig. 2: Common different positions of suction pipes under water surface (re-drawn by the author)

## 3. Materials and Methods

As shown in Figure (2), the critical depth ($h_c$) is found to be equal to the sum of the submergence distance (S), the vertical clearance distance (C), and the strainer length (L) or the BMI diameter ($D_i$) according to the proposed (vertical/horizontal) position of the suction pipe. This means that ($h_c$) can be computed according to the following equation:

$$\mathbf{h_c = S + C + L} \quad \textbf{or} \qquad (1\text{-a})$$
$$\mathbf{h_c = S + C + D_i} \qquad (1\text{-b})$$

Therefore, the research investigates how the values of S, C, L, and Di are estimated. Once they are obtained, the value of hc can be determined and $D_2$ is computed accordingly. Indeed, much empirical, and theoretical work has been done to compute the values of S and C. They were found to be variable values that depend on other parameters. Such parameters will be investigated to estimate them properly. The following shows how these values could be computed in previous research work.

### *3.1 Computation of (S) value*

The value of (S) in an open channel could be defined according to Hekal (2010) [2]. It is the sum of the Minimum Submergence Depth (MSD) of a suction pipe inlet in a sump of a still water surface and the half (wave trough) of a free surface water wave height (H) generated by a moving vessel in the vicinity of the pipe inlet. The value of (S) could be computed using the following formula:

$$\mathbf{S = MSD + H/2} \qquad (2)$$

Now, the computation of (MSD) and (H) are introduced.

#### *3.1.1 Computation of (MSD) value*

Whitesides (2008) [3] developed an empirical formula to compute the MSD that avoids vortex occurrence in a sump well where the water surface is standstill. It is worth mentioning that a vortex could be defined by Whitesides (2012) [4] as a smooth, roughly conical, rotating liquid void that forms in a fluid body because of a low-pressure area. Vortices exist as both free-surface and subsurface manifestations. He, further, added that this liquid void spells trouble for pumps; it allows, and brings with it, air into the pump's suction. He, also, elaborated that the entrained air causes flow reductions, vibrations, structural damage, and loss of efficiency in turbines or pumps and in water conveying structures. The mathematical relation developed depends on the mean water velocity at the inlet of the suction pipe as follows:

$$\boldsymbol{MSD = 0.96\, e^{0.184 V_i}} \qquad (3)$$

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Where: $\mathbf{V_i}$, the mean velocity at the pipe inlet in (ft./sec) & $(3 \leq V_i \leq 10)$
**MSD**, in (ft.), If ($V_i$) is in (m/sec), the formula changes to:

$$\mathbf{MSD = 0.96\, e^{0.0561V_i}} \quad \& \ (\mathbf{0.9144 \leq V_i \leq 3.048}) \tag{4}$$

But from the continuity equation for incompressible fluids, it is known that:

$$\mathbf{V_i = Q_p/A_i} \tag{5}$$

Where: $\mathbf{Q_p}$ is the water flow rate to be withdrawn by the plant through the suction pipe ($m^3$/sec). $\mathbf{A_i}$ is the cross-sectional area of the BMI of the suction pipe ($m^2$). Accordingly, it is found that the MSD essentially depends on the flow rate ($Q_p$) required by the water plant and the cross sectional Area ($A_i$) at the BMI of the pipe that is based on or related to the proposed pipe diameter. A smooth BMI connection with a relevant diameter at the pipe inlet can adjust the required inlet mean velocity ($V_i$).

*3.1.2 Computation of (H) value*

The waves generated by a moving vessel can be shown in Figure (3 – a, b) by two pictures taken by the author during his field work. Picture (a) shows the wave wake generated while picture (b) shows wave troughs at the suction pipe inlets.

In previous research works, the wave height was estimated as follows:

- Balanin and Bykov (1968) [5] derived an equation for estimating the maximum wave height ($H_{max}$) in meters in the vicinity of a moving vessel in a bounded waterway as:

$$\mathbf{H_{max} = 2.5}\ \frac{v_s^2}{2g}\left[1-\left(1-\frac{1}{\sqrt{4.2+n}}\left(\frac{n-1}{n}\right)^2\right)\right] \tag{7}$$

Where:

$\mathbf{v_s}$ is the vessel speed; $\mathbf{n}$ = A/a =1/S; $\mathbf{g}$ is acceleration due to gravity (m/s$^2$).

**A** is the wetted cross-sectional area of the open channel ($m^2$); and

**a** is the wetted cross-sectional area of the vessel ($m^2$) = 0.98 * $D_v$ * $B_v$.

$\mathbf{B_v}$ = Vessel Beam (m); and $\mathbf{D_v}$ = Vessel Draught (m).

**Fig. 3 – a:** A boat moving near a water intake generating a wave wake (taken by the author).

**Fig. 3 – b**: Generated wave troughs reaching the pipe inlets (taken by the author).

- Hochstein (1980) [6] derived an empirical formula for the maximum wave height ($H_{max}$) caused by a moving vessel in a bounded waterway as follows:

$$\mathbf{H_{max} = 0.0448}\ v_s^2 \sqrt{D_v/\lambda}\,(1-S)^{-2.5} \qquad (8)$$

Where:
**S** = a/A; and $\lambda$ = Wavelength (m). It is computed by trial and error as follows:

$$\lambda * \left(\tanh\left(\frac{2\pi h}{\lambda}\right)\right) = \frac{2\pi v_s^2 \sin^2(\varphi)}{g}$$

Where: $\varphi$ is the angle of the feather-let waves = 55°.

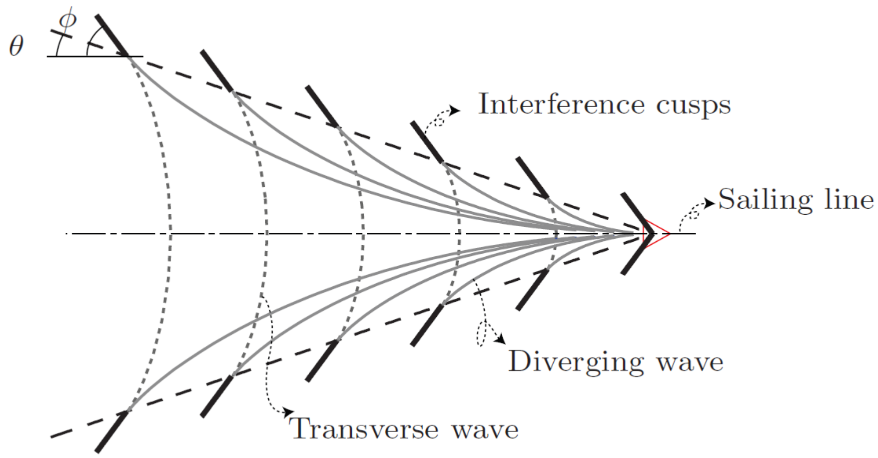


**Fig. 4:** The angle of the feather-let waves φ is 55◦ (after [5])

- Stoker (1957) [7] stated that the exact description of secondary wave pattern in deep water has been derived first by Lord Kelvin and is the subject of many publications. In deep water (roughly when "the Froude depth number (ship speed relative to the bank) "$F_r = \frac{V_s}{\sqrt{gh}} \le 0.6$), it has the same shape regardless of the speed or shape of the vessel. The V-pattern consists of diverging and transverse waves. These waves interfere on a line about 19° (θ) with the sailing line. The resulting interference cusps (called feather let waves) lie on this interference line. The feather let waves have an angle φ of about 55◦ with the sailing line.
- De Schipper (2007) [8] illustrated the full pattern with angles as shown in Figure (4).

- Havelock (1980) [9] derived mathematically the following equation to compute the wave height at a location "y" from the vessel:

$$\mathbf{H_{max} = h}\ \alpha_1 \left(y/h\right)^{\frac{-1}{3}} \left(F_r\right)^{\alpha_2} \tag{9}$$

Where:
**h** is the water depth [m]. Note that (h) is normally decreasing as you go towards the banks of the river. Accordingly, ($H_{max}$) is relatively decreasing. Therefore, and for simplicity purposes, (h) is taken equal to the hydraulic depth at the concerned cross section.
**y** is the distance to the bow perpendicular to the sailing line (y > 0) [m]. "y" is taken in calculations as half of the vessel width at the middle.
$\mathbf{F_r}$, the Froude depth number ($v_s/\sqrt{gh}$) [-] (should be < 1 to keep the flow sub-critical); $\boldsymbol{\alpha_1}$ is the shape coefficient, and $\boldsymbol{\alpha_2}$ is dimensionless wave height versus Froude depth number coefficient (speed dependency coefficient).

The coefficient $\alpha_1$ is associated with the geometry of the vessel. Uniform parts amid vessels therefore barely contribute to the pattern and the overall length of the hull, $L_s$, has a small influence. The changes in the cross section can be characterized by $D_v/L_e$ (with $L_e$, the entry length, the length from the bow to the parallel cross section). It can be computed for a specific hull shape, but the coefficient varies from 0.35 for (unloaded) slender vessels to 1.0 for blunter hull shapes. The relation between the wave height and Froude depth number is given by the exponent $\alpha_2$, and an $\alpha_2$ = 4 showed the best agreement with experimental data.

- Bhowmick et al. (1982) [10] developed the following equation for computing the maximum wave height (Hmax) based on field measurements in the Illinois and Mississippi Rivers:

$$\mathbf{H_{max} = 0.113 * (} D_v v_s / \sqrt{gh} \mathbf{)} \tag{10}$$

From the above equations (7 to 10), the maximum wave height generated by a moving vessel ($H_{max}$) and adjacent to its hull could be computed. The resulting values of ($H_{max}$) are close. However, equation (7) will only be considered in computations since it does not rely on the water depth (h) which is a variable value depending on the position of the vessel in the river. As the worst case is sought to be avoided, it will be assumed that the vessel may pass very close to the pipe inlet. Accordingly, the wave trough (H/2) generated will be equal to ($H_{max}/2$). Adding equation (4) and the result of dividing equation (7) by 2, and substituting the mean velocity ($V_i$) at the BMI with ($Q_p/A_i$), equation (2) turns to the following form:

$$S = \mathbf{0.96}\ \mathbf{e}^{\mathbf{0.0561(Q_p/A_i)}} + \mathbf{1.25}\ \frac{v_s^2}{2g}\left[1-\left(1-\frac{1}{\sqrt{4.2+n}}\left(\frac{n-1}{n}\right)^2\right)\right] \qquad (11)$$

### *3.2 Computation of (C) value*

The BMI of the suction pipe should be positioned at a certain vertical clearance distance (C) from the riverbed or sump well floor. According to previous experimental works, Machina (1987) [11] stated that the clearance of the BMI from the floor of a sump, C, should be in the range of 0.50 to 0.75 times $D_i$, the BMI diameter. If C is less than $0.25D_i$, the flow area under the lip of the bell is less than the flow area into the bell and the resulting deceleration causes unsteady flow in the BMI. If C is greater than $D_i$, there is a tendency for the upward component of flow into the BMI to become unstable and promote swirling flow. He added that the proximity of the end and side walls to the bell-mouth inhibits the production of swirling flow and vortex formation.
Whitesides (2012) [4] also, recommended that the minimum vertical clearance (C) between the suction pipe end and the sump floor should range between $0.3D_i$ and $0.5D_i$.
Samsudin et al. (2014) [12] found that the bed load sediments would have several influences on the flow field within the pump intake. Course sediments would settle to the bottom, accumulate, and solidify under hydrostatic pressure over time to permanently change the floor profile. Excessively low floor clearance and converging floor profile can increase the mass flow rate towards the BMI of the suction pipe, thereby inducing vortex formation. On the other hand, fine sediment would flow with the water intake and carried along, influencing the density and energy of the moving fluid.
From the abovementioned literature, it could be concluded that (C) should be ($0.25D_i < C < D_i$). But in computation of the critical water depth ($h_c$) that is necessary to compute the suction pipe extension into the river, C will be taken as an average value to avoid sub-surface vortexing as follows:

$$C = 0.75 * D \qquad (12)$$

Now, substituting the values of S and C from equations (11 & 12) into equation (1), the critical water depth ($h_c$) turns to be as follows:

When the suction pipe position is <u>vertical</u> (Cases A & C) as shown in Fig. 2.

$$h_c = \mathbf{0.96}\ \mathbf{e^{0.0561(Q_p/A_i)}} + \mathbf{1.25}\ \frac{v_s^2}{2g}\left[1-\left(1-\frac{1}{\sqrt{4.2+n}}\left(\frac{n-1}{n}\right)^2\right)\right] + 0.75\ D + L \quad (13)$$

When the suction pipe position is horizontal (Case B) as shown in Fig. 2,

$$h_c = \mathbf{0.96}\ \mathbf{e^{0.0561(Q_p/A_i)}} + \mathbf{1.25}\ \frac{v_s^2}{2g}\left[1-\left(1-\frac{1}{\sqrt{4.2+n}}\left(\frac{n-1}{n}\right)^2\right)\right] + 1.75\ D \quad (14)$$

### *3.3 Development of a Spreadsheet Model*

Having a formula that enables the computation of the critical water depth ($h_c$), it is indispensable to develop a Spreadsheet Model that helps correlate all the parameters concerned and speed up the computational process. The Model has been designed to compute ($h_c$) and the corresponding offshore distance ($D_2$) at any proposed cross section along the river. In this way, you can compare the values of ($D_2$) at different cross sections within a specific study area (a river segment) and decide properly on the most economical and least problematic location for the proposed water intake structure. Further, the Model can compute ($D_2$) at both sides of the open channel simultaneously.

#### *3.3.1 Input Data Required*

To get ($D_2$), there are data that have to be given as an input to the designed Model. They should include the following:

**1- River data:**

- A bathymetric cross section that shows the riverbed morphology.
- The minimum water stage at such a cross section (Min. WL) (above mean sea level) in (m); and
- The wetted cross-sectional area of the river (A) at the cross section in ($m^2$).

**2- Intake Data:**

- Water requirements of the plant ($Q_p$) in ($m^3/s$).
- The BMI diameter ($D_i$) of the diversion/suction pipe in (m). It depends on the mean suction velocity at the pipe inlet that has to be within the ranges mentioned at equation (4). It should be noted that the more the velocity, the less the $D_i$ and vice versa; and
- The length (L) of the strainer that is fitted on the BMI to inhibit the coarse sediment particles, in (m).

**3- Vessel Data:**

- **$v_s$**, maximum allowable vessel speed (m/s) through the study reach of the river.
- Vessel wetted cross sectional area (a) = 0.98 $B_v$ * $D_v$ ($m^2$).
- **$B_v$** = Vessel Beam (m); and
- **$D_v$** = Vessel Draught (m).

*3.3.2 Contents of the Model*

The developed Model is a Spreadsheet File (workbook) that consists of four basic worksheets as shown in Figure (5). They are as follows:

A. An "Input-Data" sheet containing all the data mentioned above except the river cross section data.

B. An "Allsecs" sheet that contains the cross section bathymetric data as an input. Each cross section is represented in points of two coordinates: distance and elevation above mean sea level. Column (B) contains the Distance Data arranged such that the farther from the starting point of the section, the bigger the distance. Column (C) contains the corresponding riverbed elevations. As for column (A), it has the name of each section beside the first row of its data. The data of each section is separated from the next section by, at least, a blank row so that the data can be easily imported and selected.

C. A "Sec-Properties" sheet that contains an arrangement of columns having some mathematical formulas that compute the distances where the water level intersects the cross section. It also computes the wetted cross-sectional area under the given water level. This sheet is used to receive each cross section apart and its corresponding water level after importing from the "Allsecs" sheet, process them together, and return the wetted area and the intersection distances.

D. The “Calculation” sheet is designed to run the computations based on some embedded mathematical relationships to finally return both ($h_c$) and ($D_2$).

It is worth mentioning that the Model has been written by the Visual Basic Language for Applications. Table (1) shows the Coding with which the Model Sub-routines are written. This coding together with Figure (5) below illustrates the computation process of ($h_c$).

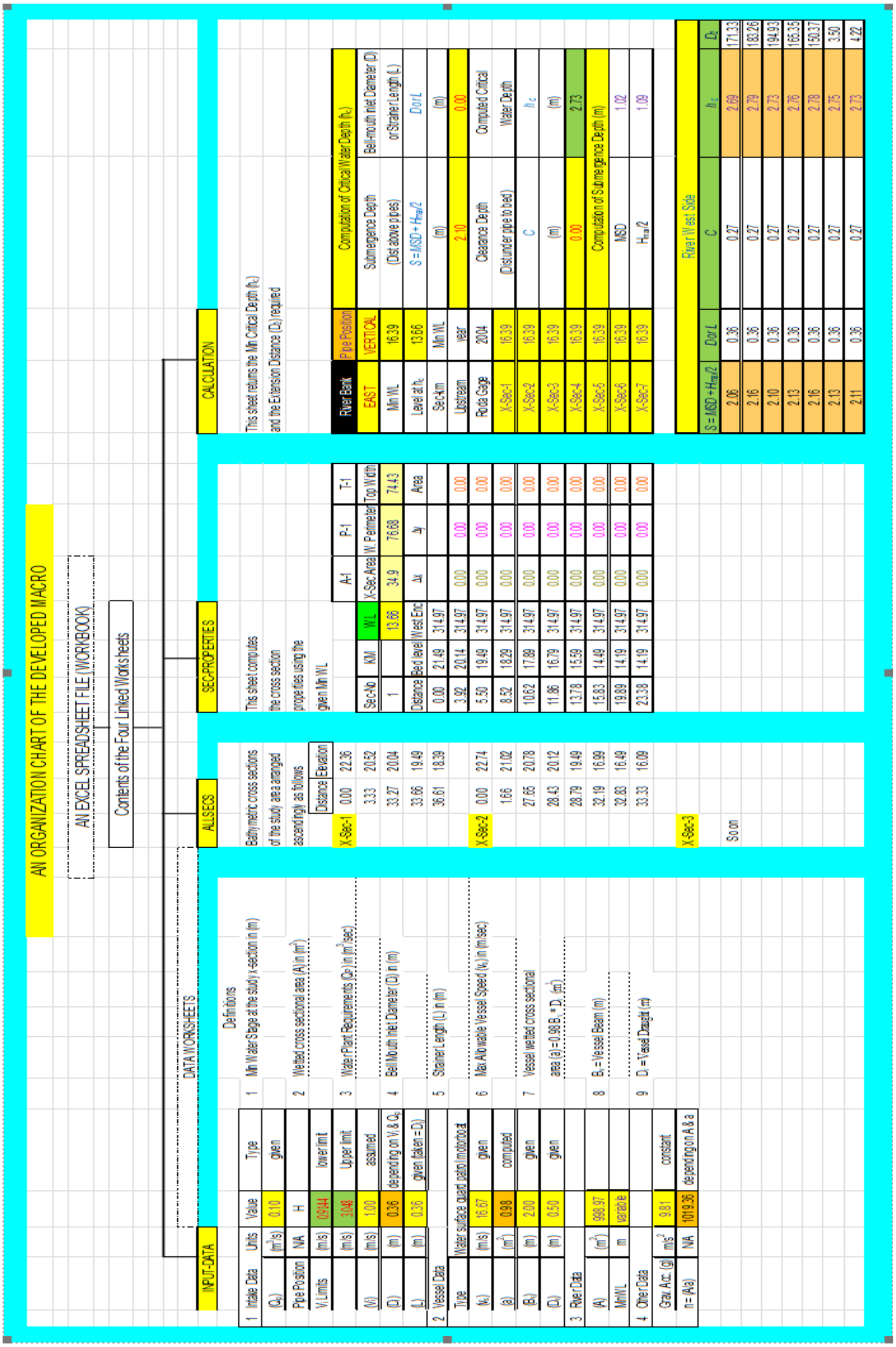


**Fig. 5:** An Organization Chart for the Developed Model

**Table 1:** Coding of the Developed Model Sub-routines

| | | |
|---|---|---|
| Public Sub **PIPE EXTENSION AT WESTSIDE OR EASTSIDE ()**<br>This Model Is Developed by Dr\Nasr Hekal On Jan 4, 2018 To Compute The Minimum Extension Distance of A Water Intake Pipe into Open Channels At the West Side.<br><br>Dim Rw As Integer<br>Dim Rc As Integer<br>Sheets("**calculation**").Select<br>Range("M6:T10000").Select<br>Selection.Clear<br>Range("A3:A5").Select<br>Selection.Copy<br>Range("M3").Select<br>ActiveSheet.Paste<br>Rw = 6<br>Do Until IsEmpty(Range("A" & Rw)) = True<br>Sheets("**calculation**").Select<br>Range("D7:F10000").Select<br>Selection.ClearContents<br>Range("A" & Rw).Select<br>Selection.Copy<br>Range("M" & Rw).Select<br>ActiveSheet.Paste<br>Sheets("**Sec-Properties**").Select<br>Range("A5:B10000").Select<br>Selection.ClearContents<br>Sheets("**Allsecs**").Select<br>Columns("A:A").Select<br><br>Selection.Find(What:=Sheets("**calculation**").Range("A" & Rw), After:=ActiveCell, LookIn:=xlFormulas_ ,<br>LookAt:=xlWhole, SearchOrder:=xlByRows, SearchDirection:=xlNext_ ,<br>MatchCase:=False).Activate<br><br>ActiveCell.Offset(rowOffset:=0 , columnOffset:=1).Select<br>Range(Selection, Selection.End(xlToRight)).Select<br>Range(Selection, Selection.End(xlDown)).Select | Selection.Copy<br>Sheets("**Sec-Properties**").Select<br>Range("A5").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Sheets("**calculation**").Select<br>Range("D7").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br><br>Range("B" & Rw).Select<br>Selection.Copy<br>Range("B1").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Sheets("**Sec-Properties**").Select<br>Range("C3").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Range("G3").Select<br>Selection.Copy<br>Sheets("**calculation**").Select<br>Range("N" & Rw).Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Sheets("**Sec-Properties**").Select<br>Range("L3").Select<br>Selection.Copy<br>Sheets("**Input-Data**").Select<br>Range("D19").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False | Sheets("**calculation**").Select<br>Range("K6") = Range("H6") + Range("I6") + Range("J6("<br>Range("B2") = Range("B1") - Range("K6("<br>Range("B2").Select<br>Selection.Copy<br>Sheets("**Sec-Properties**").Select<br>Range("C3").Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Range("G3").Select<br>Selection.Copy<br>Sheets("**calculation**").Select<br>Range("O" & Rw).Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Range("H6:J6").Select<br>Selection.Copy<br>Range("P" & Rw).Select<br>Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _<br>=: False, Transpose:=False<br>Range("S" & Rw) = Range("K6("<br>Range("T" & Rw) = Range("O" & Rw) - Range("N" & Rw (<br>Sheets("**calculation**").Select<br>Rc = 7<br>Do Until IsEmpty(Range("D" & Rc)) = True<br>Range("F" & Rc) = Range("B1") - Range("E" & Rc(<br>Rc = Rc + 1<br>Loop<br>Rw = Rw + 1<br>Loop<br>Sheets("**calculation**").Select<br>Range("N6").Select |
| Public Sub **PIPE EXTENSION** | Selection.Copy | Selection.Copy |

```
LENGTHAT DIFFERENT DIAMETERS ()
This Model Is Developed By Dr\Nasr Hekal On Jan 4, 2018 To Compute The Minimum Extension Distance Of A Water Intake Pipe Into Open Channels For Different Pipe Diameters.
  Dim Rw As Integer
  Dim Rc As Integer
   Sheets("calculation").Select
   Range("W6").Select
   Range(Selection, Selection.End(xlToRight)).Select
   Range(Selection, Selection.End(xlDown)).Select
   Selection.Clear
   Range("A6").Select
   Range(Selection, Selection.End(xlDown)).Select
   Selection.Copy
   Range("W6").Select
   ActiveSheet.Paste
   Range("W3").Select
   Application.CutCopyMode = False
Range("C2").Select
Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
=:      False, Transpose:=False
  Rw = 4
  Rc = 24
  Do Until IsEmpty(Cells(Rw, Rc)) = True
   Cells(Rw, Rc).Select
   Application.CutCopyMode = False
   Selection.Copy
   Range("I6").Select
   Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
=:      False, Transpose:=False
   Application.Run "Pipeextension"
   If Range("W3") = "WEST" Then
   Range("S6").Select
   Range(Selection, Selection.End(xlDown)).Select
   Cells(Rw + 2, Rc).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   Else
   Range("T6").Select
   Range(Selection, Selection.End(xlDown)).Select
   Selection.Copy
   Cells(Rw + 2, Rc).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   End If
  Rw = Rw
  Rc = Rc + 1
  Loop
  Range("W6").Select
End Sub
```

```
Public Sub PIPE EXTENSION()
This Model Is Developed By Dr\Nasr Hekal On Jan 4, 2018 To Compute The Minimum Extension Distance Of A Water Intake Pipe Into Open Channels At Both Sides.
Sheets("calculation").Select
If Range("C2") = "WEST" Then
Application.Run "PIPEEXTENSIONATWESTSIDE"
Else
Application.Run "PIPEEXTENSIONATEASTSIDE"
End If
Application.CutCopyMode = False
End Sub
```

## 4. Case Study

In order to recognize the importance and necessity of determining how long offshore a water intake structure should be extended into an open channel, a small segment of the River Nile was subject to a hydrographic and hydrologic study in September 2007 by the Nile Research Institute (NRI) where a water intake structure was to be constructed. The centerline of the proposed intake was found to be lying at km (38.590) upstream Roda gage in Cairo, Egypt as shown in Figure (6-A). Seven cross sections with intervals ranging from 50 m to 150 m and covering a distance of about 580 m along the study area including a cross section at the intake centerline were

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hydrographically surveyed to detect and identify the riverbed morphology, Figure (6-B). The lowest water level (Min. WL = 16.39) within the previous ten years at the site was computed from historical hydrologic data of upstream and downstream gauging stations NRI (2018) [13] by interpolation. It is plotted on the measured 7 cross sections as shown in Figure (6- C).
A water surface guard patrol motorboat was selected for simulating the vessel that is likely to move past the suction pipe inlet at a high speed especially during rescuing or chasing operations. A high-water wave is always generated and expected to affect the pipe inlet. The assumed vessel data are shown in Figure (5). The water intake data such as the plant water requirements ($Q_p$), the BMI diameter ($D_i$), the strainer length (L), the position of the suction pipe with respect to the water surface (vertical/horizontal), and the proposed inlet mean velocity ($V_i$) are all mentioned in Figure (5).

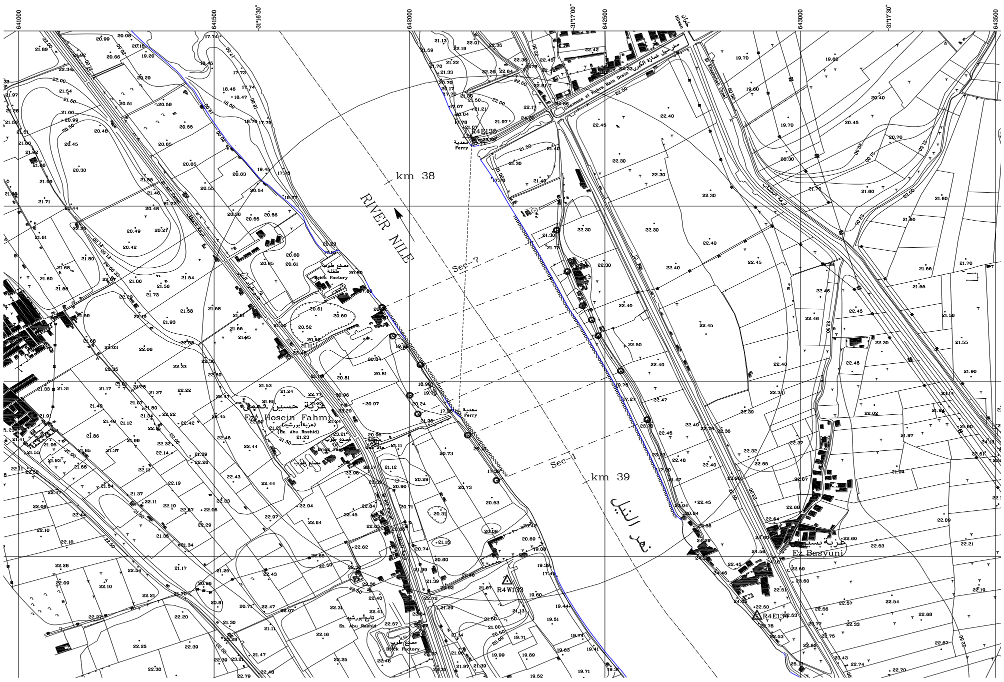


**Fig. 6 –A:** The study site on a topographic map of 2003 showing the distance U/S Roda Gauge (Nile Research Institute (NRI) Maps).

### *4.1 Application of the Model*

The available range of BMI velocity ($V_i$) and the possibility of sharing out the required discharge ($Q_p$) among a few pipes are essential factors in governing the extension of a water intake structure into a river. Therefore, to present a wide range of options of ($h_c$) and ($D_2$) for a water intake structure in order to make up a sound judgment and a final decision, the Model will be run for multiple values of ($Q_p$) and ($V_i$) keeping the motorboat velocity ($v_s$) as a constant value and the suction pipe position as "vertical" since it is common. It should be considered that the generated wave height $H_{max}$ is a function of ($v_s$). Throughout all the Model runs, ($v_s$) is taken equal to a value of 60 (km/hr) or 16.67 (m/s).

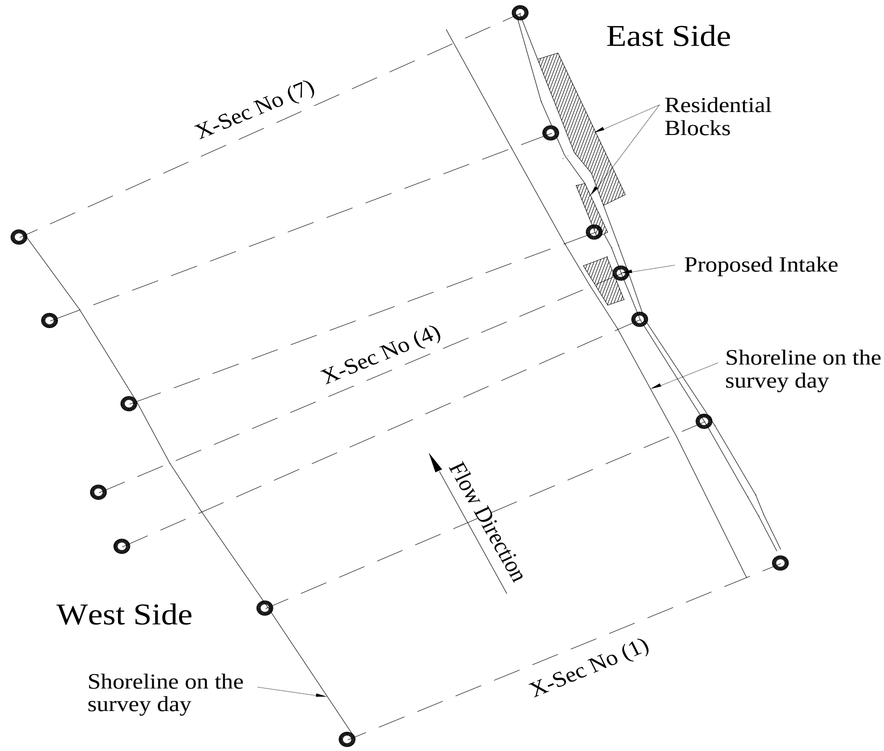


**Fig. 6 –B:** A traverse showing the locations of the surveyed cross sections

### *4.2 Results and Analysis*

The results obtained are displayed in Table (2). By examining them, several observations could be identified as follows:

1. At a certain BMI velocity ($V_i$), it was found that the more the discharge ($Q_p$) required to be withdrawn from the river, the bigger the BMI diameter ($D_i$) and the offshore distance ($D_2$).
2. At a certain ($Q_p$), it was found that the more the BMI velocity, the smaller both BMI diameter and the offshore distance.
3. At any value of ($V_i$), the more the ($Q_p$), the bigger the ($h_c$) and vice versa. This means that ($h_c$) is directly proportional to ($Q_p$) and is not affected by any changes in ($V_i$).

4. The negative values of ($D_2$) in the table mean that the computed critical water depth ($h_c$) required was bigger than the river water depth available.
5. At all scenarios, the least offshore distances were found to be at cross section (7). This means that such a section was the most economic for implementing the required water intake structure; and
6. Although cross section (4) was favored by the water plant engineer to erect the water intake at, the study results showed it was unfavorable at all to construct the intake there as it needed an extension length of more than 200 m at all scenarios. This means that the determination of the extension distance is a must that should never be ignored especially at the preliminary study phase.

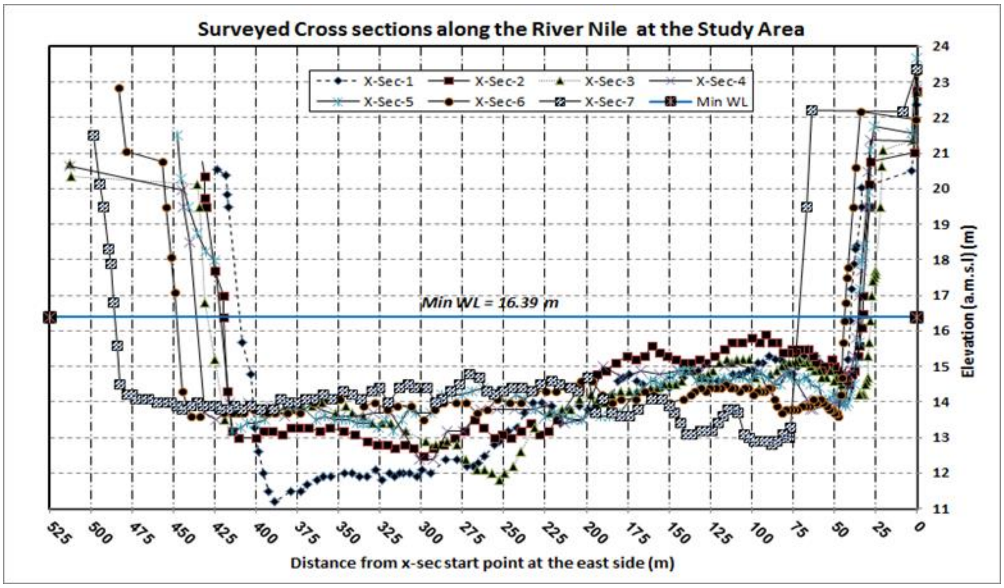


**Fig. 6 –C:** The riverbed morphology at the seven cross sections.

**Table 2:** Model results showing probable BMI diameters ($D_i$) and offshore Distance ($D_2$) for different scenarios of ($Q_p$) and ($V_i$).

| $V_{inlet}$ = 1.00 (m/s) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q (m³/s) | 0.10 | | | | | 0.20 | | | | | 0.30 | | | | | 0.40 | | | | | 0.50 | | | | |
| Sec No | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ |
| Sec-1 | 2.06 | 0.36 | 0.27 | 2.69 | 171.33 | 2.06 | 0.50 | 0.38 | 2.95 | 174.54 | 2.06 | 0.62 | 0.46 | 3.15 | 204.47 | 2.06 | 0.71 | 0.54 | 3.31 | 209.28 | 2.06 | 0.80 | 0.60 | 3.46 | 211.75 |
| Sec-2 | 2.16 | 0.36 | 0.27 | 2.79 | 183.26 | 2.16 | 0.50 | 0.38 | 3.05 | 187.35 | 2.16 | 0.62 | 0.46 | 3.25 | 192.14 | 2.16 | 0.71 | 0.54 | 3.41 | 246.89 | 2.16 | 0.80 | 0.60 | 3.56 | 251.99 |
| Sec-3 | 2.10 | 0.36 | 0.27 | 2.73 | 194.93 | 2.10 | 0.50 | 0.38 | 2.99 | 200.69 | 2.10 | 0.62 | 0.46 | 3.19 | 204.30 | 2.10 | 0.71 | 0.54 | 3.35 | 206.39 | 2.10 | 0.80 | 0.60 | 3.50 | 208.23 |
| Sec-4 | 2.13 | 0.36 | 0.27 | 2.76 | 165.35 | 2.13 | 0.50 | 0.38 | 3.02 | 235.84 | 2.13 | 0.62 | 0.46 | 3.22 | 249.00 | 2.13 | 0.71 | 0.54 | 3.38 | 250.82 | 2.13 | 0.80 | 0.60 | 3.53 | 252.42 |
| Sec-5 | 2.16 | 0.36 | 0.27 | 2.78 | 150.37 | 2.16 | 0.50 | 0.38 | 3.04 | 279.59 | 2.16 | 0.62 | 0.46 | 3.24 | -34.33 | 2.16 | 0.71 | 0.54 | 3.40 | -34.33 | 2.16 | 0.80 | 0.60 | 3.55 | -34.33 |
| Sec-6 | 2.13 | 0.36 | 0.27 | 2.75 | 3.50 | 2.13 | 0.50 | 0.38 | 3.01 | -43.73 | 2.13 | 0.62 | 0.46 | 3.21 | -43.73 | 2.13 | 0.71 | 0.54 | 3.38 | -43.73 | 2.13 | 0.80 | 0.60 | 3.52 | -43.73 |
| Sec-7 | 2.11 | 0.36 | 0.27 | 2.73 | 4.22 | 2.11 | 0.50 | 0.38 | 2.99 | 4.62 | 2.11 | 0.62 | 0.46 | 3.19 | 4.97 | 2.11 | 0.71 | 0.54 | 3.35 | 5.32 | 2.11 | 0.80 | 0.60 | 3.50 | 12.99 |

| $V_{inlet}$ = 1.50 (m/s) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q (m³/s) | 0.10 | | | | | 0.20 | | | | | 0.30 | | | | | 0.40 | | | | | 0.50 | | | | |
| Sec No | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ |
| Sec-1 | 2.09 | 0.29 | 0.22 | 2.60 | 158.92 | 2.09 | 0.41 | 0.31 | 2.81 | 172.89 | 2.09 | 0.50 | 0.38 | 2.98 | 174.90 | 2.09 | 0.58 | 0.44 | 3.11 | 202.76 | 2.09 | 0.65 | 0.49 | 3.23 | 207.94 |
| Sec-2 | 2.19 | 0.29 | 0.22 | 2.70 | 181.95 | 2.19 | 0.41 | 0.31 | 2.91 | 185.19 | 2.19 | 0.50 | 0.38 | 3.08 | 187.81 | 2.19 | 0.58 | 0.44 | 3.21 | 190.34 | 2.19 | 0.65 | 0.49 | 3.33 | 210.36 |
| Sec-3 | 2.13 | 0.29 | 0.22 | 2.64 | 189.88 | 2.13 | 0.41 | 0.31 | 2.85 | 197.72 | 2.13 | 0.50 | 0.38 | 3.02 | 201.33 | 2.13 | 0.58 | 0.44 | 3.15 | 203.89 | 2.13 | 0.65 | 0.49 | 3.27 | 205.39 |
| Sec-4 | 2.16 | 0.29 | 0.22 | 2.67 | 164.65 | 2.16 | 0.41 | 0.31 | 2.88 | 166.37 | 2.16 | 0.50 | 0.38 | 3.05 | 236.35 | 2.16 | 0.58 | 0.44 | 3.18 | 238.75 | 2.16 | 0.65 | 0.49 | 3.30 | 249.95 |
| Sec-5 | 2.19 | 0.29 | 0.22 | 2.69 | 145.76 | 2.19 | 0.41 | 0.31 | 2.91 | 277.36 | 2.19 | 0.50 | 0.38 | 3.07 | 280.07 | 2.19 | 0.58 | 0.44 | 3.20 | -34.33 | 2.19 | 0.65 | 0.49 | 3.32 | -34.33 |
| Sec-6 | 2.16 | 0.29 | 0.22 | 2.67 | 3.33 | 2.16 | 0.41 | 0.31 | 2.88 | 254.47 | 2.16 | 0.50 | 0.38 | 3.04 | -43.73 | 2.16 | 0.58 | 0.44 | 3.18 | -43.73 | 2.16 | 0.65 | 0.49 | 3.30 | -43.73 |
| Sec-7 | 2.13 | 0.29 | 0.22 | 2.64 | 4.09 | 2.13 | 0.41 | 0.31 | 2.86 | 4.41 | 2.13 | 0.50 | 0.38 | 3.02 | 4.66 | 2.13 | 0.58 | 0.44 | 3.15 | 4.90 | 2.13 | 0.65 | 0.49 | 3.27 | 5.15 |

| $V_{inlet}$ = 2.00 (m/s) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q (m³/s) | 0.10 | | | | | 0.20 | | | | | 0.30 | | | | | 0.40 | | | | | 0.50 | | | | |
| Sec No | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ | S | D or L | C | $h_c$ | $D_2$ |
| Sec-1 | 2.12 | 0.25 | 0.19 | 2.57 | 157.07 | 2.12 | 0.36 | 0.27 | 2.75 | 172.05 | 2.12 | 0.44 | 0.33 | 2.89 | 173.80 | 2.12 | 0.50 | 0.38 | 3.01 | 201.10 | 2.12 | 0.56 | 0.42 | 3.11 | 202.63 |
| Sec-2 | 2.22 | 0.25 | 0.19 | 2.66 | 181.36 | 2.22 | 0.36 | 0.27 | 2.85 | 184.16 | 2.22 | 0.44 | 0.33 | 2.99 | 186.38 | 2.22 | 0.50 | 0.38 | 3.11 | 188.29 | 2.22 | 0.56 | 0.42 | 3.21 | 190.20 |
| Sec-3 | 2.16 | 0.25 | 0.19 | 2.60 | 187.03 | 2.16 | 0.36 | 0.27 | 2.79 | 196.23 | 2.16 | 0.44 | 0.33 | 2.93 | 199.36 | 2.16 | 0.50 | 0.38 | 3.05 | 201.99 | 2.16 | 0.56 | 0.42 | 3.15 | 203.86 |
| Sec-4 | 2.19 | 0.25 | 0.19 | 2.63 | 164.33 | 2.19 | 0.36 | 0.27 | 2.82 | 165.82 | 2.19 | 0.44 | 0.33 | 2.96 | 172.70 | 2.19 | 0.50 | 0.38 | 3.08 | 236.87 | 2.19 | 0.56 | 0.42 | 3.18 | 238.71 |
| Sec-5 | 2.21 | 0.25 | 0.19 | 2.66 | 145.04 | 2.21 | 0.36 | 0.27 | 2.84 | 166.76 | 2.21 | 0.44 | 0.33 | 2.98 | 278.59 | 2.21 | 0.50 | 0.38 | 3.10 | 280.57 | 2.21 | 0.56 | 0.42 | 3.20 | 282.31 |
| Sec-6 | 2.19 | 0.25 | 0.19 | 2.63 | 3.26 | 2.19 | 0.36 | 0.27 | 2.81 | 252.96 | 2.19 | 0.44 | 0.33 | 2.95 | -43.73 | 2.19 | 0.50 | 0.38 | 3.07 | -43.73 | 2.19 | 0.56 | 0.42 | 3.17 | -43.73 |
| Sec-7 | 2.16 | 0.25 | 0.19 | 2.61 | 4.03 | 2.16 | 0.36 | 0.27 | 2.79 | 4.31 | 2.16 | 0.44 | 0.33 | 2.93 | 4.52 | 2.16 | 0.50 | 0.38 | 3.05 | 4.71 | 2.16 | 0.56 | 0.42 | 3.15 | 4.89 |

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## 5. Conclusion

The research has introduced a scientific and practical basis for estimating the length with which any proposed water intake structure can be extended into an open channel. It has discussed the parameters affecting the diversion/suction pipe inlet positioning that may cause problems to the pumping system. It also presented a practical formula that can be used to compute the critical water depth ($h_c$), at which such problems could be avoided. This water depth has been found to be essential in computing the offshore extension distance ($D_2$), which is the main objective of the paper.
The research has also developed a Spreadsheet Model that computes the required offshore distance. It can correlate and process all the parameters and data required for achieving the job in a very short time. In this way, it can help examine any number of scenarios to identify the specific trends of the parameters affecting the offshore distance. Based on the results of such scenarios, it becomes much easier to decide on selecting the most economical and appropriate location for a proposed water intake structure. This was clear as shown in the given example (case study).

## References

[1] Hekal, N., 2015. Effect of Water Surface Recession on Bridge-Type Intakes Proposed along The River Nile. International Water Technology J. 5. 4, pp. 272- 283.

[2] Hekal, N., 2010. Effect of Water Surface Fluctuations on Water Intake Performance. The 14th International Water Technology Conference Proceedings. Cairo, Egypt. pp. 1017-1033.

[3] Randall W. Whitesides. 2008. Practical Considerations in Pump Suction Arrangements. PDH Course M134, www. PDHonline.org, 2003 – 2008.

[4] Randall W. Whitesides. 2012. Practical Considerations in Pump Suction Arrangements. PDH Course M134 (3PDH), www. PDHonline.org, 2003 – 2008.

[5] Balanin, V.V., and Bykov, L.S., 1968. Selection of leading dimensions of navigation channel selections and modern methods of bank protection. Proc 21 Int Nav Cong sec S 1-4, PIANC, Stockholm.

[6] Hochstein, 1980. Gallipolis locks and dam's replacement, Ohio River, Phase I, advanced engineering and design study, General Design Memorandum. Appen J, Vol. I, Environmental and Social Impact Analysis, U.S. Army Corps of Engineers, Huntingtion District.

[7] Stoker, J.J., 1957. Water waves; the mathematical theory with applications. Interscience Publishers; New York.

[8] M.A. De Schipper, 2007. On the generation of surfable ship waves in a circular pool: Part I. MSc. Thesis, Delft University of Technology; Delft. Faculty of

Civil Engineering and Geosciences, Section of Hydraulic Engineering and Environmental Fluid Mechanics.

[9] Havelock, T.H., 1980. The Propagation of Groups of Waves in Dispersive Media with Application to Waves on Water Produced by a Traveling Disturbance. Proceedings of the Royal Society, London. Series A, Vol LXXXI, pp. 398-430.

[10] Bhowmick, N.G., Demissis, M., and Guo, C-Y, 1982. Waves Generated by River, WRC Res Rep No. 167, Un of Illinois Water Resources Center, Urbana, Ill.

[11] Machina D. W., 1987. Physical and Numerical Modeling of an Aerated Sump. Ph.D. Thesis, Irrigation and Hydraulics department, Faculty of Graduate Studies, Windsor Univ., Ontario, Canada.

[12] Samsudin, M. L., Munisamy, K.M., Thangaraju, S. K., 2014. Application of Multiphase Modeling for Vortex Occurrence in Vertical Pump Intake – A review. The 7th International Conference on Cooling & Heating Technologies (ICCHT 2014). IOP Publishing. IOP Conf. Series: Materials Science and Engineering 88 (2015) 012024 doi:10.1088/1757-899X/88/1/012024.

[13] NRI, 2018. Records of Discharges & Water Levels along the River Nile. Department of Water levels & Discharges, El-Qanater, Cairo, Egypt.

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# معايير تصميم محسنة لمد مآخذ المياه الشبيهة بالكباري داخل القنوات المكشوفة

## الملخص العربي

تعتبر مآخذ محطات المياه الممتدة هي منشآت تقام على ضفاف النهر لتحويل وسحب المياه لاستخدامات وأغراض متعددة. وقد ركزت الدراسات السابقة فقط على مد مأخذ المياه إلى عمق كافٍ من المياه لضمان السحب الدائم. وتم استخدام نماذج فيزيائية ورقمية للتنبؤ بشكل التغيرات المورفولوجية في قاع النهر أو المجرى المائي لإيجاد أعمق نقطة لمد المأخذ إليها. ومع ذلك، فقد أغفلت هذه الدراسات العوامل الأخرى التي تحكم هذا المد. ويهدف هذا البحث إلى مناقشة وتقديم تلك العوامل، وإدخال أساس عملي وعلمي يساعد في حساب أقل مسافة لمد المأخذ داخل النهر من أجل سحب المياه. هذه المسافة هي المسافة بين النقطة التي يلتقي فيها أقل منسوب سنوي للمياه مع ضفة القناة المكشوفة والنقطة التي يكون فيها عمق المياه الحرج كافياً لغمر فوهة ماسورة السحب دون احداث دوامات قد تؤثر على كل من نظام الضخ وقاع المجرى المائي. واستنادًا إلى تعريف مسافة الامتداد، يجب أن يُحسب عمق المياه الحرج تحت أقل منسوب لسطح المياه عند المقطع العرضي للقناة المكشوفة المراد مد المأخذ عنده. وبتحليل أقل منسوب مطلوب للمياه، وُجد أنه يجب أن يساوي مجموع عمق الغمر، وقطر فوهة ماسورة السحب أو طول المصفاة (فانوس الفلتر)، وعمق خلوص فوق قاع مجرى القناة. وبإجراء مزيد من التحليل، وُجد أن قيمة عمق الغمر المطلوب تعتمد على الاحتياجات المائية لمحطة المياه، وسرعة شفط أو سحب المياه عند فوهة الماسورة، وأقصى ارتفاع لموجة مائية ناتجة عن مركب ملاحي متحرك بالقرب من المأخذ، وكذلك شكل سطح قاع المجرى المائي. أيضا، وُجد أن قيمة عمق الخلوص بين قاع المجرى وفوهة الماسورة هو عبارة عن دالة في (يتناسب مع) قطر ماسورة السحب أو طول المصفاة (فانوس الفلتر). ولحساب مسافة أقل امتداد للمأخذ، تم تطوير نموذج رياضي (جدول بيانات) لربط جميع العوامل المذكورة أعلاه، والمساعدة في دراسة أكبر عدد ممكن من السيناريوهات المختلفة لإيجاد المسافة الآمنة والأكثر اقتصادية. وأخيرًا، خلص البحث إلى أن حساب أقل مسافة لمد المأخذ داخل المجرى المائي يتحكم فيه تحديد ومعرفة عدة عوامل مثل أقل منسوب لسطح المياه، والاحتياجات المائية لمحطة المياه وسرعة شفط (سحب) الماء عند فوهة ماسورة السحب وأقصى ارتفاع لموجة المياه المتولدة عن قارب ملاحي متحرك بالقرب من فوهة ماسورة المأخذ.