Sensitivity Analysis of Head Loss Equations on the Design of Improved Irrigation On-Farm System In Egypt.

Hany G. Radwan

Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, Egypt.
Email: hradwan77@gmail.com

ABSTRACT

Improved Irrigation Project (IIP) in old lands of Delta Egypt has a great benefit of increasing the irrigation efficiency in on-farm system. Improved irrigation Project (IIP) in on-farm system contains designing low pressure pipeline network. This paper has two objectives; first objective is to study the effect of using Darcy-Weisbach equation for head loss calculation in IIP instead of using Hazen-William equation on the design results. Exact Friction coefficient required for Dary-Weisbach equation was developed in this paper using Newton-Raphson method. The second objective is to study the effect of hydrant discharge (20 l/s, or 30 l/s) on the design results. It is concluded from this paper that, using Darcy-Weisbach equation with hydrant discharge of 20 l/s is better than using Hazen-William equation with hydrant discharge 20 l/s or 30 l/s for the following reasons; getting less water level inside the stand tank, getting less civil work’s cost, getting less filling and pipeline costs, and getting less total system cost without including pumps cost into consideration, so it is recommended to use darcy-Weisbach equation with hydrant discharge of 20 l/s in the design of improved irrigation system in old lands of Delta Egypt.

Keywords: Improved Irrigation System; IIP; Darcy-Weisbach equation

1 INTRODUCTION

The major issue facing Egyptian agriculture is the shortage of water. The Nile River is the main and almost exclusive source of surface water for Egypt. The Nile Water Agreement of 1959 with Sudan defines the allocation of Nile water between Egypt and Sudan. Under this agreement, 55.5 billion m$^3$ per year is allocated to Egypt; this supply of water has been constant since then [1]. Agriculture consumes about 80% of Egypt’s share of Nile water annually. Although the country lost part of its fertile land to urbanization, this has been balanced by expansion of agricultural areas [2]. Due to limited available water resources in Egypt, the available fresh water per capita in Egypt dropped from 1893 cubic meters per person in 1959 to 900-950 cubic meters (chronic water scarcity) in 2000 and tends to decline further to the values of 670 cubic meter (chronic water scarcity) by 2017 and 536 (absolute water scarcity) by 2025 [3].

Beside the existing water scarcity in Egypt due to the rapid increase in population, Egypt will face new challenges in the near future like climate change [4],[5],[6], and existing attempts from Nile Countries to change the Nile Water Agreement of 1959 and decrease Egypt’s water share from Nile River through Antebi agreement [7]. Due to the previous bad situation, there is an urgent need to improve the current irrigation management strategies to obtain more sustainable and optimal use of water. The national water strategy of Ministry of Water Resources and Irrigation (MWRI) calls for improving the efficiency of the present water use and protecting environment and health by preventing pollution and by treatment and control of polluted water in an integrated manner and in cooperation with all stakeholders through applying various water policies [1].

One of these policies is applying improved irrigation system either for on-farm or for off-farm system. The irrigation system in Egypt can be divided according to size, operation, and control into two categories; the main system (off-farm system) which consists of main and branch canals, and on-farm system which consists of Mesqa, and smaller order ditches called marwas [8] as shown in Fig. 1.

Improved on-farm irrigation system was passed through two phases. First phase is Irrigation Improvement Project (IIP), and second phase is Integrated Improved Irrigation Management Project (IIIMP). The IIP project concerns with replacing the existing earth cross section of mesqa (see Fig. 2) into buried low pressure pipeline to improve the efficiency of the water use [9].

IIP started at 1989 and was divided into two stages, first stage is IIP-1 which was responsible for the improvement of...
about 237,000 feddan, and second stage IIP-2 was responsible for the improvements of the rest of 250,000 feddan in Beheira and Kafr el Sheikh Governorate in addition to some external areas [10]. The Egyptian Government is planning to continue the improvement works to reach a target of more than 3 million feddan by the year 2017 [11],[12],[13]. Improved Irrigation Project (IIP) had several positive results as compared to the traditional irrigation system such as land saving [14], increase in crop yield [15], and increase of conveyance efficiency, for more details about the impact assessment of IIP see [16],[17],[18],[19].

Due to the positive impacts of IIP, the improved irrigation project was extended to the second phase which is Integrated Irrigation Improvement and Management Project (IIIMP). (IIIMP) is expected to improve 500,000 feddans as a first stage, with the national plan to improve 3.4 million feddans till the year 2017. The improved management (IIIMP) is expected to achieve increased efficiency and more sustainable use of land and water, by replacing earth marwa cross section with buried pipeline and thus have a positive impact on water distribution, quantity, quality, equity, timeliness, and hence, poverty alleviation [17], [18],[19],[20].

In this study, a sensitivity analysis will be developed to discuss the effect of changing in two objects on the existing design of improved irrigation Project (IIP) in old lands in Egypt. First object that will be studied is the effect of using Darcy-Weisbach equation by getting the exact values of friction factor in Colebrook-White equation using Newton Raphson method instead of using Hazen William equation for computing the frictional head loss in pipeline network in IIP. Second object that will be studied is the effect of exchanging the nominal water duty (l/s/feddan) as a new design concept on the existing design elements.

2 LITERATURE REVIEW

The main components of Improved Irrigation Project (IIP) in On-Farm System consists of three components; mesqa and branch mesqa low pressure pipeline, stand (feeder) tank, and pump station takes its water from the branch canal through intake structure and pump sump as shown in Fig. 3.

The design of improved irrigation system is concerning in detecting the suitable diameters for low pressure pipeline network either for mesqa or branch mesqa pipelines, detecting the required water level inside the stand tank for detecting its concrete height, then specify the required pump specifications as shown in Figs.4, and 5.
Mesqa and Marwa Hydraulic Design program “MMHD” is in house open source program for the design of the improved irrigation network. Improved irrigation sector in Egypt uses this computer program with its limited capabilities for mesqa design [10]. The design procedures used in MMHD program were checked and reprogrammed using new Matlab code and after a good calibration was done, some modifications were considered for the new Matlab code to avoid some problems existing in MMHD program [21], [22], [23].

3 Existing design concept for IIP

The design criteria begins with calculating the original head losses at outlet (hydrant) through using the various friction coefficients for minor losses calculations required at hydrant connection, as shown in Fig. 6 [10]. The following sessions will present brief description for the main design procedures that are programmed in the new Matlab program and were used in MMHD program.

### 3.1 Calculation of Mesqa Capacity.

Basic design for Mesqa capacity is to be allowed for 100% rice cropping in the area served with peak daily consumptive use for rice of 13.3 mm. Assuming percolation losses of 1.0 mm/day. Then increase the previous total water requirement by 10% for surface runoff, and that led to a designed peak water duty (W.D.) requirement equals 15.7 mm/day. Mesqa capacity (l/sec.) can be calculated as in (1). The design criteria have passed through several changes to decrease the nominal water duty as follows:

\[ Q = \frac{A \times 4200 \times W.D.}{T} \]  

Where;
- \( Q \): Mesqa capacity (l/sec.);
- \( A \): Total served area (feddan); and
- \( W.D. \): Water duty requirement (mm/ d); and
- \( T \): Working time per day (seconds).

**A- Design Criteria (1)**
- Assuming hydrant discharge =30 l/s.
- Working hours/ day= 16 hr/ day.
- Area served per one hydrant will equals 26 feddan using (1). This means each 26 feddan needs one outlet with discharge 30 l/s working for 16 hr/ day.
- Nominal water duty = 30 (l/s) 26 (fed) = 1.15 l/s/ fed.

### 3.2 Design Criteria (2)

- Assuming hydrant discharge =30 l/s.
- Working hours/ day= 20 hr/ day.
- Area served per one hydrant will equals 32 feddan using (1). This means each 32 feddan needs one outlet with discharge 30 l/s working for 20 hr/ day.
- Nominal water duty = 30 (l/s) 32 (fed) = 0.94 l/s/ fed.

### 3.2 Calculation of the Suitable Pipe Diameter.

Selection of the suitable pipeline diameter depends on the available commercial pipe diameters (200, 250, 315, 355, 400, and 450 mm) and the maximum design velocity which was changed from 1.0 m/s for design criteria (1) to 1.5 m/s for design criteria (2).

### 3.3 Calculation of Water Level inside the Stand Tank.

Detecting water level inside the stand tank is required to overcome the all friction losses through the critical operating case. These friction losses are divided into minor and main losses, for more details about minor losses see [23]. Main friction losses through Mesqa’s pipelines (h_f) are calculated using Hazen-William equation:

\[ h_f = \left( \frac{3.59}{CH} \right)^{1.852} \left( \frac{L}{D^{4.87}} \right) \]  

Where;
- \( h_f \): Friction losses in pipeline (m); and
- \( CH \): Coefficient taken 150 for P.V.C pipe; and
- \( Q \): Discharge flow in pipeline reach (m³/sec.); and
- \( D \): Diameter of pipeline reach (m); and
- \( L \): Length of pipeline reach (m).

### 3.4 Detecting the Suitable Pump

One of the main components of the improved irrigation system is to detect the suitable pump according to the final required system curve based of the critical operating case. There was concern about the high cost of the IIP improvements (civil works and associated equipment), which has increased from about 2,300 LE/fed at the time of mid-term review in May 2000 to about 5,600 LE/ fed in 2004 [24]. To repay the costs of improvements, farmers would have to make annual payments per feddan per year over several years ranges from 10 to 20 year, so any reduction in the total improved system can relieve something from the farmer’s problem [25]. Mesqa improvement works comprise four main cost components [10]:-
- Cost (1): Mesqa pumping station civil work’s cost (in- take box concrete section with screen, intake pipe, suction sump, and pump house as in Fig. 5 and stand tank as shown in Fig.4).
- Cost (2): Cost of filling old mesqa cross section.
- Cost (3): Pipelines cost.
- Cost (4) :Pumps cost.
Radwan et al. [26] studied the effect of some design constraints on the cost of each item and on the total system cost of the improved irrigation system through detecting the optimal design velocity for minimum total system cost either in case of using stand tanks as a system feeder or using direct pumps (without tanks).

4 SENSITIVITY ANALYSIS

4.1 Sensitivity Analysis of New Design Criteria.

According to the existing previous two design criteria mentioned before, the outlet design discharge was 30 l/s and the nominal water duty (NWD) was decreased from 1.15 l/s/fed to be 0.94 l/s/fed. As a result of the previous two design criteria, it has been observed a sharp decline in the water level in the branch canals at mesqa intake and that cause sharp decline in the water level at next mesqa’s intake. This is clearly shown in the water deficit in the mesqa at the ends of the branch canals. This is resulted in the inclusion of the new design criteria (Design criteria 3) which aims to reduce the nominal water duty (NWD) to be 0.84 l/s/fed by reducing hydrant discharge to 20 l/s instead of 30 l/s working for 20 hr/day. Impact of this change on the design outputs and cost outcomes for each element of the design and its impact on the total cost will be clearly shown through its application to the next case study.

4.2 Sensitivity analysis of using Darcy-Weisbach Equation in the Design.

Estimation of head losses due to friction in pipelines is an important task in the hydraulic analysis of pipelines and water distribution systems. In all the previous criteria, Hazen-William equation as in (2) was used to calculate the friction head loss through mesqa pipelines. The best equation for computing the frictional head loss in a given pipe for a given discharge is the Darcy-Weisbach equation [27]:

\[ h_f = \frac{fLV^2}{2gD} \]  

(3)

Where:
- \( h_f \): Head loss (m);
- \( L \): Pipeline length (m);
- \( V \): Average pipeline velocity (m/s);
- \( g \): Acceleration due to gravity (m/s²);
- \( D \): Pipeline diameter (m);
- \( f \): Friction factor.

For turbulent flow, the friction factor \((f)\) is a function of Reynolds number \((Re)\) as in (4), and the relative roughness \(\left(\frac{e}{D}\right)\),

\[ R_e = \frac{VD}{\nu} \]  

(4)

Where \( Re \) is the Reynolds number, \( \nu \) is the kinematic viscosity (m²/s) which is a function of temperature, and \( D \) is the pipeline diameter. One of the earliest and most popular formulas exists relate the friction factor to the Reynolds number and relative roughness is the Colebrook-White equation [27]:

\[ \frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right) \]  

(5)

There is a difficulty with using Colebrook-White equation due to it is an implicit function of the friction factor \((f)\). Many approximate formulas were developed to solve Colebrook-White equation. Srbislav et al. [28] made a comparison between using many approximated friction factor equations and using the Colebrook’s equation in terms of different types of error. Colebrook – White equation is typically solved by iteration scheme or by using Newton Raphson method [29]. The Newton-Raphson method is based on the principle that if the initial guess of the root of \( f(x) = 0 \) is at \( x_i \), then if one draws the tangent to the curve at \( f(x_i) \), the point \( x_{i+1} \) where the tangent crosses the x-axis is an improved estimate of the root as shown in Fig. 7, for more details about Newton Raphson method see [30]. According to the procedures of Newton Raphson method and using equation (5) and Fig.7, the following equations can be obtained:

\[ x = \frac{1}{\sqrt{f}}, \quad a = \frac{e}{3.7D}, \quad and \quad b = \frac{2.51v}{VD} \]  

(6)

\[ f(x) = a + bx - 10^{-0.5x} = 0.0 \]  

(7)

\[ f'(x) = b + 0.5(ln10)10^{-0.5x} \]  

(8)

\[ x_{i+1} = x_i - \frac{f(x_i)}{f'(x_i)} \]  

(9)

Fig.7 Geometrical illustration of the Newton-Raphson method.

Using Darcy-Weisbach equation in the design concept instead of using Hazen-William equation will affect on the design outputs (required water level inside stand tank, and re-
quired pump specifications) also it will affect on the individual element cost and the total system cost as it will be clearly appeared in the following case study.

4.3 Sensitivity Analysis of Maximum Design Velocity.

According to Darcy-Weisbrook equation, the design velocity will affect the total friction loss used in the design which will be reflected on the design outputs and costs as it will be cleared in the following session.

5 Case STUDY

The general planning for mesqas of Eastern Awqaf canal which branching from Mahmudia Canal- West Delta is shown in Fig.8. Eastern Awqaf canal Serves about 260 feddan divided into three mesqas capacities; two mesqas each serves 72 feddan; one large mesqa serves 78 feddan, and finally two small mesqas serve a total area about 39 feddan.

The studied mesqa contains seven outlets with seven reach lengths starting form the connection with Eastern Awqaf Canal to the end of mesqa as follows 10,10, 160.21, 198.21, 121.02, 104.40, and 103.00 m. The calculated mesqa capacity using (1) will equal 71.4 l/ s using a constant peak water duty requirement equals 15.7 mm/d, and working hours of 20 hour/day. The corresponding working outlets equals 3.0 opened outlets using design criteria 2 (hydrant discharge Q=30 l/s) with a revised mesqa capacity equals 90 l/s. The corresponding working outlets equals 4.0 opened outlets using design criteria 3 (hydrant discharge Q=20 l/s) with a revised mesqa capacity equals 80 l/s.

5.1.1 Effect of hydrant discharge on the design results such as the required water level in the stand tank, and the total system cost.

The critical operational case for the design is to let the number of working outlets at the end of each mesqa. In the next session, the new Matlab program developed by Radwan et al. [10] will be used to design the studied mesqa and discuss the effect of hydrant discharge, maximum design velocity, and using Darcy-Weisbach equation on the design results such as the required water level in the stand tank, and the total system cost.

6 RESULTS

For using Darcy-Weisbach equation, the following values will be used in the calculation [27]:
- The kinematic viscosity for water for 20° C is 10-6 m2/s.
- For PVC pipeline, the internal pipeline roughness (κ) is taken to be 0.0015 mm.

The design was based on the following data:
- Land level overall the total area is fixed to be (+3.0).
- Height of hydrant above the natural land is 0.5 m
- All improved mesqa pipelines are impeded into trench

Water is extracted from the hydrant under a pressure head (outlet pressure) equals 0.2 m [10]

The new Matlab program [10] has been used twice to design the studied mesqa; first design was based on an actual hydrant discharge equals 30 liter/sec (Design criteria 2), and the second design was based on an actual hydrant discharge equals 20 liter/sec (Design criteria 3). In each design either using design criteria 2 or 3, the required water level inside the stand tank is calculated twice; the first time using Hazen-William equation and again using Darcy-Weisbach equation. The results of the required water levels inside the stand tank are shown in Fig. 10. These water levels inside the tanks will be in turn reflects on the desired characteristics of the required system pumps.

Due to the complicated previous graph of Fig. 10, a new graph was introduced in Fig.11 which represents the percentage of decrease in water level inside the stand tank taking the water level inside the tank for the case of using Hazen-William equation and hydrant discharge of 20 l/s as a reference (because this is the actual design status) as follows:
Where:

\[ W.L_{L,20} : \text{Water level inside the tank in case of using Hazen-William equation and Hydrant discharge of 20 l/s.} \]

\[ W.L : \text{Water level inside the tank for other cases.} \]

Positive percentage in Fig. 11 means the water level inside the tank in this case is smaller than the case of using Hazen-William equation with hydrant discharge of 20 l/s, and vice versa for negative percentage. It is clear from Fig. 11 that for example at design velocity of 1.5 m/s, using Darcy-Weisbach equation with hydrant discharge of 20 l/s gives water level with about 2.0% less than using Hazen-William equation with hydrant discharge 20 l/s, and using either Darcy or Hazen equations with hydrant 30 l/s \((Q_t=90 \text{ liter/s})\) gives water level inside the tank with about 20% less than using Hazen-William equation with hydrant discharge 20 l/s.

After finishing the design steps and detecting the required water level inside the stand tank, now it is the time to discuss the impacts of using Hazen-William or Darcy-Weisbach equations with various hydrant discharges on the cost of each system element. Here we will study the first three components of the total system cost which are civil works \((\text{cost 1})\), filling cost \((\text{cost 2})\), and pipelines cost \((\text{cost 3})\) without taking the pumps cost into consideration because there are various pumps types with various ranges of specifications and costs that can achieve the required characteristics. So, the total system includes the summation of the first three costs without pumps cost. Fig. 12 represents civil work’s cost \((\text{cost 1})\) due to using the various design concepts.

\[ \% \text{ Decrease in Cost } = \left( \frac{\text{Cost}(\text{L,20}) - \text{Cost}(\text{L})}{\text{Cost}(\text{L,20})} \right) \times 100 \]  

Where \( \text{Cost}(\text{L,20}) \) represents civil work’s cost in case of using Hazen-William equation with hydrant discharge of 20 l/s, and \( \text{Cost}(\text{L}) \) is the value of civil work’s cost for other cases. All positive percentage in Fig. 13 means that civil work’s cost for all other cases is less than civil work’s cost in case of using Hazen-William equation with hydrant discharge of 20 l/s. For example at design velocity of 1.5 m/s, using Darcy-Weisbach equation with hydrant discharge 20 l/s will decrease cost \((\text{1})\) with about 0.4% than using Hazen-William equation with hydrant discharge 20 l/s, and also using either Darcy or Hazen-William equations with hydrant discharge of 30 l/s will decrease cost \((\text{1})\) with about 12% than using Hazen-William equation with hydrant discharge 20 l/s.

Results of filling cost \((\text{cost 2})\) for the various design concepts are shown in Fig. 14. It is obviously cleared from Fig. 14 that using Hazen-William or Darcy-Weisbach equation will not affect on the filling cost because it is only affected with the designed pipeline diameters and the initial mesqa cross section and that has nothing to do with friction loss equations. Using hydrant discharge of 20 l/s gives less filling cost than using hydrant discharge 30 l/s because as the designed discharge decreases, as the required designed diameter decreases for the same design velocity, and the filling area for trench section will decrease because it is a function of the designed diameter [10]. Fig. 15 represents the percentage of decrease in filling cost due to using hydrant discharge 20 l/s instead of using 30 l/s. For example at design velocity of 1.5 m/s, there will be a decrease in filling cost equals 8% due to using hydrant discharge of 20 l/s instead of 30 l/s.
The third cost in the total system cost is the pipeline cost (Cost 3). Pipeline cost is independent on the friction loss equation, but dependent on the designed hydrant discharge as shown in Fig.16. Using designed hydrant discharge of 20 l/s leads to small diameters than using hydrant discharge of 30 l/s which is reflected in the pipeline cost. Fig. 17 shows the percentage of decrease in pipeline cost due to using designed hydrant discharge of 20 l/s instead of 30 l/s with a maximum decrease of 28% in the pipeline cost at design velocity 1.5 m/s.

The results of the total system cost without including pumps cost are obviously clear in Fig.18 for different design concepts. Fig. 19 represents the percentage of decrease in total system cost without pumps cost relative to the total cost without pumps cost in case of using Hazen-William equation with hydrant discharge of 20 l/s as follows:

\[
\% \text{ Decrease in Total Cost} = \frac{T.C._{H,20} - T.C}{T.C._{H,20}} \times 100 \tag{12}
\]

Where, \(T.C._{H,20}\) is the total cost without pumps cost in case of using Hazen-William equation with hydrant discharge 20 l/s, and \(T.C.\) is the total cost without pumps cost for other cases.

Positive percentage in Fig. 19 means less total system cost without pumps cost than the case of using Hazen-William equation with hydrant discharge of 20 l/s. From Fig.19, it is clear that using Darcy-Weisbach equation with hydrant discharge of 20 l/s gives less total system cost without pumps cost with a maximum percentage of decrease equals 0.33 % than using Hazen-William equation with hydrant 20 l/s and it is valid for a wide range of design velocities ranges from 0.8 m/s to 2.0 m/s.

To study the effect of the values of \(\varepsilon\) in Darcy-Weisbach equation to get friction loss close to Hazen-William equation under hydrant discharge of 20 l/s, various values of \(\varepsilon\)
were assumed in the range of PVC pipeline (0.0015, 0.01, 0.02, and 0.03 mm) starting from smooth to rough PVC pipes. The percentage in difference in water level between using Hazen-William equation and using Darcy-Weisbach equation with varied internal pipe roughness is clear in Fig. 20 as follows:

\[
% \text{ Difference in } W.L. = \left( \frac{W.L_{H,20} - W.L_{D,20}}{W.L_{H,20}} \right) \times 100
\]  

(13)

Fig. 20. Percentage of Difference in Water Level for the Studied Mesqa between Hazen and Darcy equations for various values of internal pipe roughness.

Where; \( W.L_{H,20} \) is the water level inside the stand tank using Hazen-William equation with hydrant discharge of 20 l/s, and \( W.L_{D,20} \) is the water level inside the stand tank using Darcy-Weisbach equation with hydrant discharge 20 l/s and varied values of \( \varepsilon \). From Fig. 20, it is clear that for the studied mesqa case head loss using Hazen-William equation can be reached by using Darcy-Weisbach equation with \( \varepsilon \) equals 0.015 mm with percentage error less than 1%.

7 Conclusion

First of all the default design procedure used nowadays is to use Hazen-William equation for head loss calculation with hydrant discharge of 20 l/s and maximum design velocity of 1.5 m/s. So, the main conclusions in this paper can be summarized in the following points.

- Using Darcy-Weisbach equation with hydrant discharge of 20 l/s gives less water level inside the stand tank with about 2.0% (at design velocity 1.5 m/s) than using Hazen-William equation with hydrant discharge 20 l/s (default design procedure). Also using either Darcy-Weisbach or Hazen-William equations with hydrant 30 l/s gives less water level inside the stand tank with about 20% (at design velocity 1.5 m/s) than using Hazen-William equation with hydrant discharge 20 l/s.

- Using Darcy-Weisbach equation with hydrant discharge 20 l/s will decrease civil work’s cost with about 0.4% (at design velocity 1.5 m/s) than using Hazen-William equation with hydrant discharge 20 l/s, and also using either Darcy-Weisbach or Hazen-William equation with hydrant discharge of 30 l/s will decrease civil work’s cost with about 12% (at design velocity 1.5 m/s) than using Hazen-William equation with hydrant discharge 20 l/s.

- Using hydrant discharge of 20 l/s instead of 30 l/s can decrease the filling cost with about 8% (at design velocity 1.5 m/s), and can decrease pipeline cost with about 28% (at design velocity of 1.5 m/s).

- Using Darcy-Weisbach equation with hydrant discharge of 20 l/s gives less total system cost without pumps cost with a maximum percentage of decrease equals 0.33% than using Hazen-William equation with hydrant 20 l/s and that is valid for a wide range of design velocities (0.8 m/s to 2.0 m/s).

- Head loss calculated using Hazen-William equation can be reached using Darcy-Weisbach equation by detecting the suitable internal pipe roughness, for the studied mesqa it equals 0.015 mm with a percentage error less than 1%.

References


[20] Sabour Consultant, “Terms of Reference for the Tendering of Consulting Services for the Integrated Irrigation Improvement and Management Project (IIIMP) and Instruction to Tenderers”, 2004


