Bed Form Types and Dimensions at El Ekhsas Gauge Station From Field Measurements

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Abstract

The study of bed form formation in river beds is a complex process. The formation process results from the interaction between the sediment and flow characteristics. The bed forms are responsible for increasing bed roughness. In sediment transport, depending on the condition of the bed form, the fraction of the total shear stress that is responsible for bed load transport changes. Therefore, knowledge of bed form characteristics and geometries are very essential in alluvial system integrated management. In natural rivers, the bed form types and dimensions differ along the river cross section as the depth variation results in different hydraulic characteristics. This research represents the analysis of detailed field measurements at El Ekhsas gauge station in two different dates. Bed form types and dimensions were extracted, analyzed, and compared with the dimensions calculated from the most common bed form predictors. Also, the measured bed form dimensions were compared with the corresponding dimensions resulted from formulas developed for Nile River. It was concluded that some bed form predictors are valid and reliable for Nile River. Also the current research developed new relationships which help in predicting bed form dimensions in the Nile. The study recommends that the other gauge stations should be applied for such research to validate the developed relations.

Key words: Bed form, River Nile, Field Measurements, Formulas, and El Ekhsas.

1 INTRODUCTION

This research will include a field investigation of bed form at El Ekhsas gauge station which is one of the oldest gauges for measuring the discharge of Nile River. This research will include analysis of bed form using three longitudinal profiles passes through the gauge location. Two field reconnaissances were conducted in August, 2008 and November, 2009. Three longitudinal profiles were measured in each trip (west, east and middle of the channel). In addition, the flowing discharge at the time of survey was also measured. Bed form dimensions were extracted from bed profiles using many software programs, AutoCAD, EzySurf, Hypack. Bed form types were identified using ASCE Task Force (1966) definition. Resulted bed form dimensions were compared with formulas proposed by Allen (1968), Van Rijn (1993), Saad et al. (1991), and Kassem (2003).

2 OBJECTIVES

Study of bed form in sand bed rivers has been investigated extensively over many decades several efforts have been made to relate the geometry of the bed form to the hydraulic characteristics of the river (Attia 2003). Testing the applicability of exiting formulae and predictors to the Nile River is one of the main objectives discussed here. The other objective is to develop predictor formula suitable for the Nile River in Egypt.

3 FIELD WORK

Two survey trips were conducted at the location of El Ekhsas station, one at rising stage of the river and the other was in the falling stage. In August 2008 (rising stage), a survey was conducted to calibrate and validate the station. Two control points of known coordinates are established to identify the cross section bench marks. A hydrographic survey system consists of echo sounder and differential GPS connected to a computer was used to survey the cross section, Figure 1. Also, three longitudinal profiles, to represent east, middle and west sides of the cross section were measured. These profiles are passing through the gauge location, Figure 2, from km 887.91 to 889.23 downstream Old Aswan Dam (OAD).

Each profile covers a distance of about 1.320 km, 210 m upstream the gauge location and 1.11 km downstream. Figure 3 shows the three longitudinal profiles. EK-E, EK-M, EK-W are the east, middle, and west profiles respectively. In November 2009 (falling stage), similar survey was conducted to cover a distance of about 1.350 km, see Figure 4.

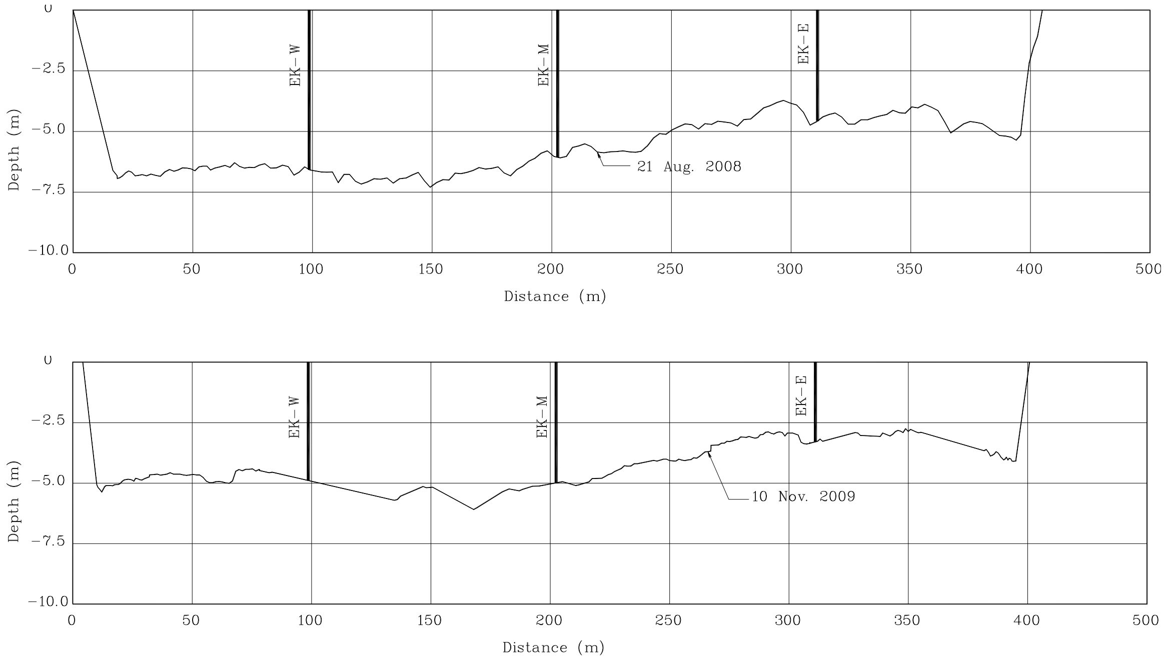

Figure 1: Measured cross sections at El Ekhsas gauge station

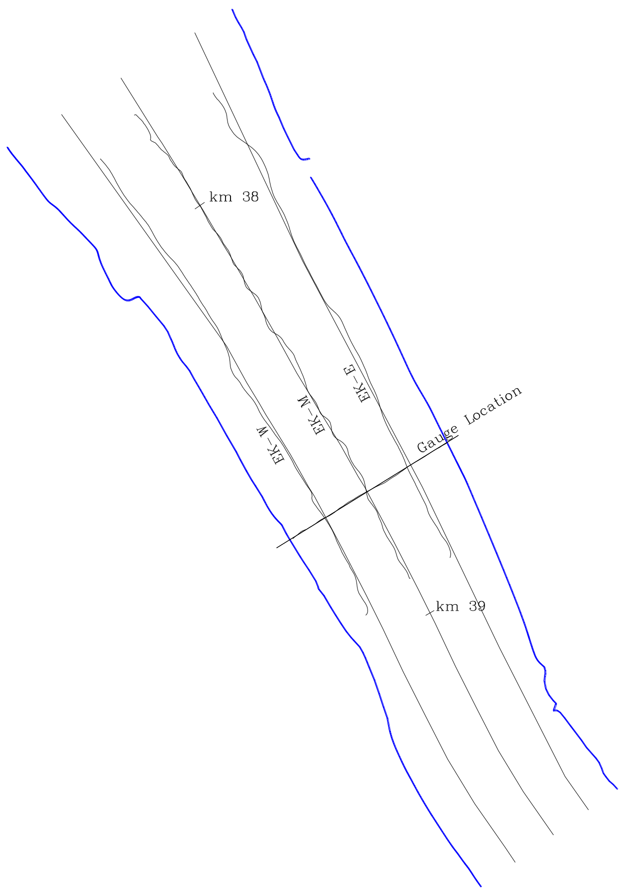

Figure 2: Layout of longitudinal profiles

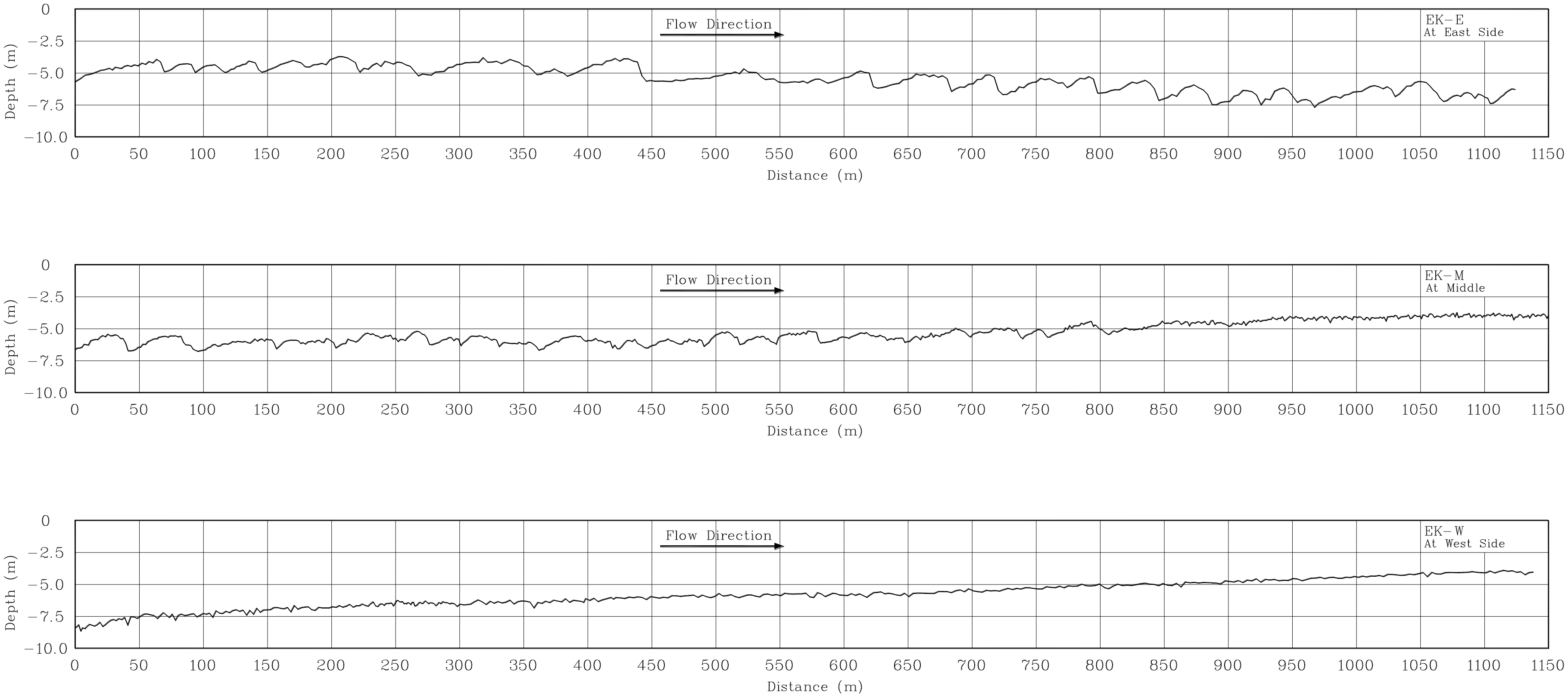

Figure 3: Three longitudinal profiles in 21 Aug. 2008

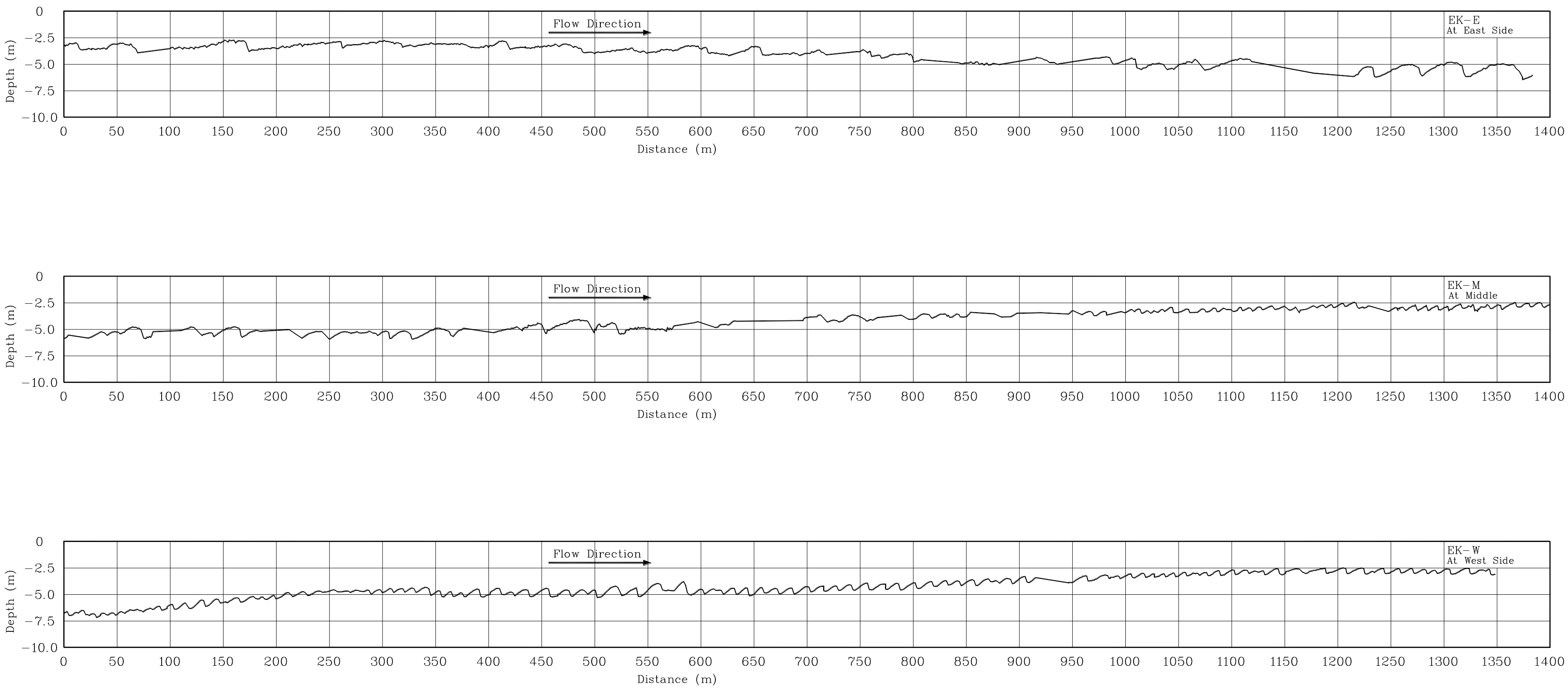

Figure 4: Three longitudinal profiles in 10 Nov. 2009

Three bed material samples were collected at El Ekhsas in 21 August 2008, and in 10 November 2009. Gain size distribution curves are represented respectively in figure 5 and figure 6.

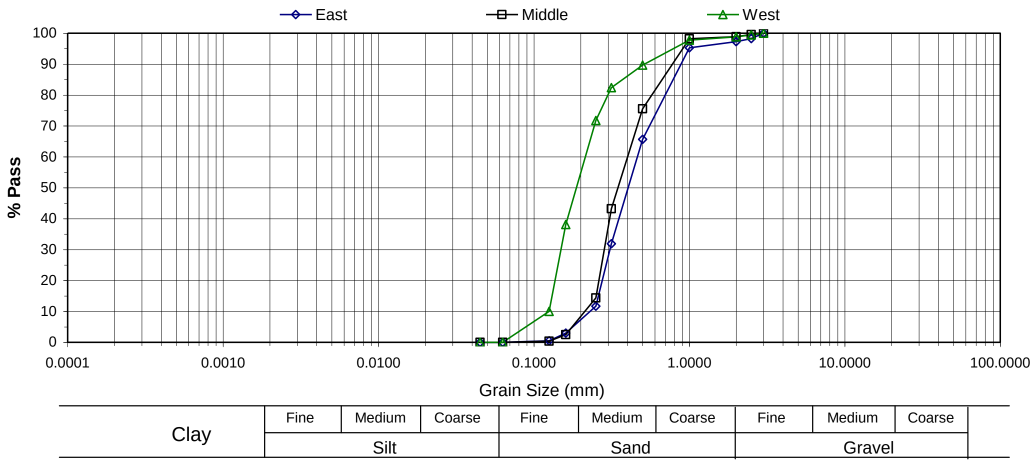

Figure 5: Grain size distribution at El Ekhsas in 21 Aug. 2008.

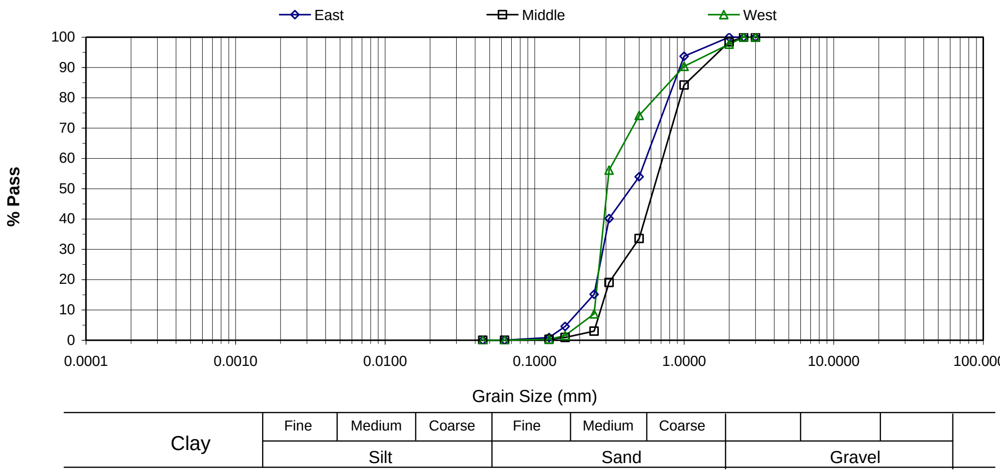

Figure 6: Grain size distribution at El Ekhsas in 10 Nov. 2009.

4 BED FORM PREDICTORS

Empirical investigations nearly always start from dimensional analysis to determine the important dimensionless parameters affecting bed form geometry, and proceed to using graphical and multiple regression techniques to determine relations between the bed form geometry and the dimensionless variables. Bed form predictors discussed here are divided into two categories; first predictors defined by Allen (1968) and Van Rijn (1993) which were derived using data from many rivers around the world and the second predictor used here are that derived using data from the Nile River only such as Saad et al. (1991) and Kassem (2003). Allen (1968) related the height (Δ_d) and length (λ_d) of ripples with the flow depth (D) as follows:

$$\Delta_d = 0.086 \ D^{1.19} \quad (1)$$

$$\lambda_d = D^{1.6} \quad (2)$$

Van Rijn (1993) derived some relationships for dune height and dune length by analyzing a large number of flume data and field data. Van Rijn classified bed forms on the basis of particle size, represented by the dimensionless particle parameter (D_*), and transport regime which is measured by a transport stage which is the dimensionless parameter of the shear stress (T).

$$D_* = \left[\frac{\left((\rho/\rho_s) - 1 \right) \; g}{\nu^2} \right]^{1/3} d_{50} \tag{3}$$

$$T = \frac{\tau'_b - \tau'_{b,cr}}{\tau'_{b,cr}} \tag{4}$$

Van Rijn (1993) distinguished ripples into mini ripples and mega ripples. The bed form classification is summarized in *Table (1)*.

Table 1: Summary of bed form classification after Van Rijn (1993)

Transport regime		Particle size	
		$1 \le D_* \le 10$	$D_* > 10$
Lower	$0 \le T \le 3$	Mini ripples	Dunes
	$3 < T \le 10$	Mega ripples and dunes	Dunes
	$10 < T \le 15$	Dunes	Dunes
Transition	$15 < T < 25$	Washed-out dunes, sand waves	
	$T \ge 25$, $Fr < 0.8$	(symmetrical) sand waves	
Upper	$T \ge 25$, $Fr \ge 0.8$	Plane bed and/or anti-dunes	

Van Rijn (1993) derived some relationships for dune height and dune length by analyzing a large number of flume data and field data for each bed form type as follows:

Mini ripples

$$\Delta_{mir} = 50 \text{ to } 200\ d_{50} \tag{5}$$

$$\lambda_{mir} = 500 \text{ to } 1000\ d_{50} \tag{6}$$

Mega ripples

$$\Delta_{mer} = 0.02\ D\ (1 - e^{-0.1T})\ (10 - T) \tag{7}$$

$$\lambda_{mer} = 0.5\ D \tag{8}$$

Dunes

$$\frac{\Delta_d}{D} = 0.11 \left[\frac{d_{50}}{D} \right]^{0.3} \left(1 - e^{-0.5T}\right) \left(25 - T\right) \tag{9}$$

$$\frac{\Delta_d}{\lambda} = 0.015 \left[\frac{d_{50}}{D} \right]^{0.3} \left(1 - e^{-0.5T}\right) \left(25 - T\right) \tag{10}$$

Saad et al. (1991) studied bed forms for six different reaches at the River Nile in Egypt. Saad et al. suggested the following formula for the relation between dune height and water depth for different reaches:

$$\Delta = 0.1\ D \tag{11}$$

Kassem (2003) performed an extensive field survey along the entire length of Dammitta Nile branch. Based on the analytical regression of non-linear relationship, Kassem used three approaches to derive formulas for Dammitta Nile branch for both bed form length and bed form height. The third approach was selected because it was derived based on flow depth (D) as follows:

$$\Delta = 0.427\ D^{0.57} \tag{12}$$

$$\lambda = 99\ \Delta^{1.45} \tag{13}$$

5 BED FORM EXTRACTION

ASCE Task Force (1966) defined ripples as the features having wavelength less than 0.30 m (1 ft) and its height less than 0.03 m (0.1 ft) and defined dunes as having wavelength and height greater than ripples but less than bars which have lengths comparable to the channel width and height comparable to mean flow depth. Based on previous descriptions, all observed bed form types were dunes. Figure (7a) shows sample of measured bed form dimension extracted from measured bed profiles.

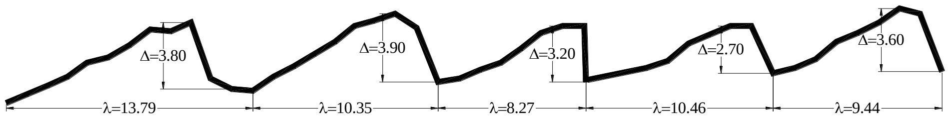

Figure 7a: Bed form dimensions

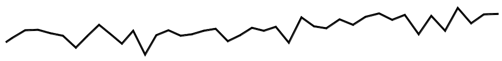

Figure 7b: Unrecognized bed form types

The extraction of bed form dimensions is done according to the following steps:

1- The three bed profiles were surveyed, as mentioned before, using hydrographic survey system; the final product of hydrographic survey was XYZ coordinates of each profile.
2- The profiles were drawn in AutoCAD program.
3- The bed form types are identified according to Van Rijn (1993)
4- There are some bed form feature are recognized and classified, see Figure 7a. Other features are not recognized, the later features are shown in Figure 7b.

6 ANALYSIS OF BED FORM GEOMETRY AND TYPES

Different bed form types were defined according to the definition of ASCE Task Force (1966). The relation between measured length and height of each individual bed form is represented in Figure 8; the measured bed form lengths ranged from 3.09 m to 69.56 m, and bed form height ranges were from 0.07 m to 1.58 m. The dominant bed form type observed at El Ekhsas in Aug. 2008 survey was dune type and some features were mega ripples superimposed on dunes. The dominant bed form type in Nov. 2009 was dune type. This concedes with that predicted by Van Rijn method using the average hydraulic characteristics of the cross section measured at El Ekhsas in the same day of survey as can be seen in Figure 9 and Figure 10. In these figures Van Rijn procedure results in a single bed form length and bed form height for each survey, which is attributed to the use of the average hydraulic characteristics of the cross section. In the same figures the extracted bed form dimensions (length and height) in Aug. 2008 and Nov. 2009 respectively are shown.

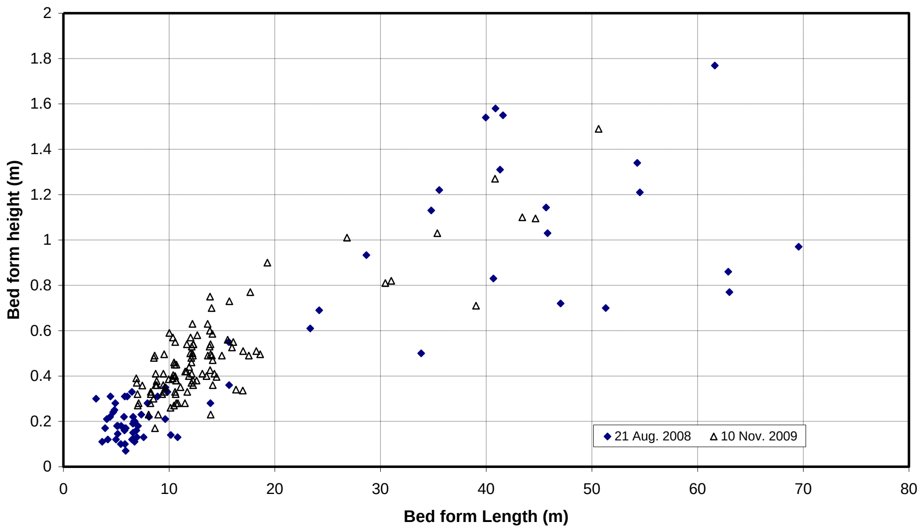

Figure 8: Measured bed form dimensions

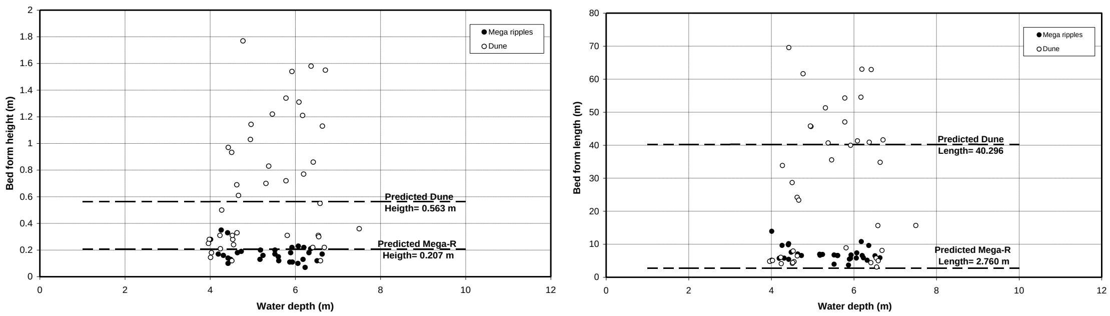

Figure 9: Geometry of dunes and mega ripples observed in Aug. 2008

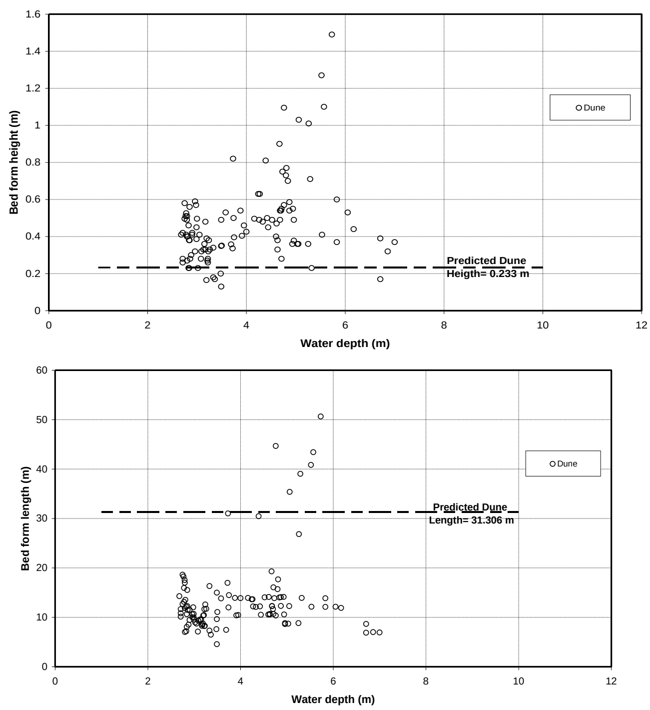

Figure 10: Geometry of dunes and mega ripples observed in Nov. 2009

Comparing the observed dune dimensions, obtained from Aug. 2008 survey, with predicted ones shows that most of measured dune height is greater than the predicted one for average hydraulic characteristics, and measured dune length have value smaller than the predicted dune length value. Also for Nov. 2009 survey, the measured dune height is greater than the predicted one, but most of observed dunes having length smaller than predicted. The predicted length of mega ripples was smaller than the observed one and vice versa for the mega ripples height.

There are many factors affecting the resulted bed form type and dimension such as velocity and water depth, Figure 1 shows the variability of water depth in the cross section. Velocity ranged from 0.62 m/s to 0.80 m/s for Aug. 2008 and from 0.31 m/s to 0.61 m/s for Nov. 2009. Change in parameters will result in different bed form. So that to specify which predictors will be the most applicable here, the observed bed form was divided into three groups according to its dimensions as follows:

- First group was accompanied by mega ripples superimposed; this group is having length and height greater than that predicted using Van Rijn formula.

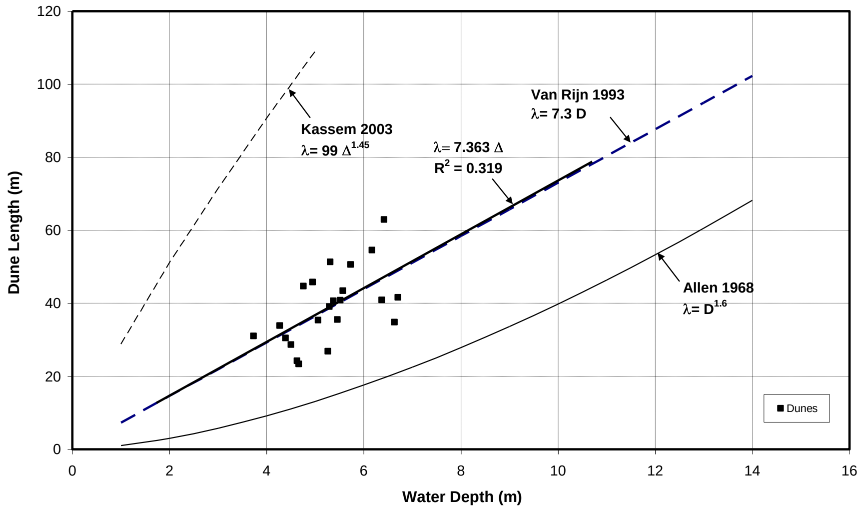

Figure 11: Water depth – dune length relationship (second group)

- Second group resembles trend of that predicted by Van Rijn (λ=7.3 D). Figure 11 shows the relation between water depth and dune height in both Aug. 2008 and Nov. 2009, the best fit relation is (λ=7.363 D) which agrees quite well with Van Rijn Relation. The predicted dune length using Allen's formula gives smaller values compared to that measured for second group of dunes. Predicted dune length using Kassem (2003) approach was greater than the corresponding values occurred at El Ekhsas. This can be attributed to the fact that the dune bed form lengths measured by Kassem are greater than those measured at El Ekhsas.

Figure 12 shows relation between water depth and dune height for second group, superimposed on it the formula proposed by Saad et al. (1991) which resulted in smaller values of dune height than measured at El Ekhsas gauge station and Kassem's formula which gives acceptable values compared to that measured at El Ekhsas for the same range of water depths. The best fit relationship between water depth and dune height for second group is Δ=0.19 D.

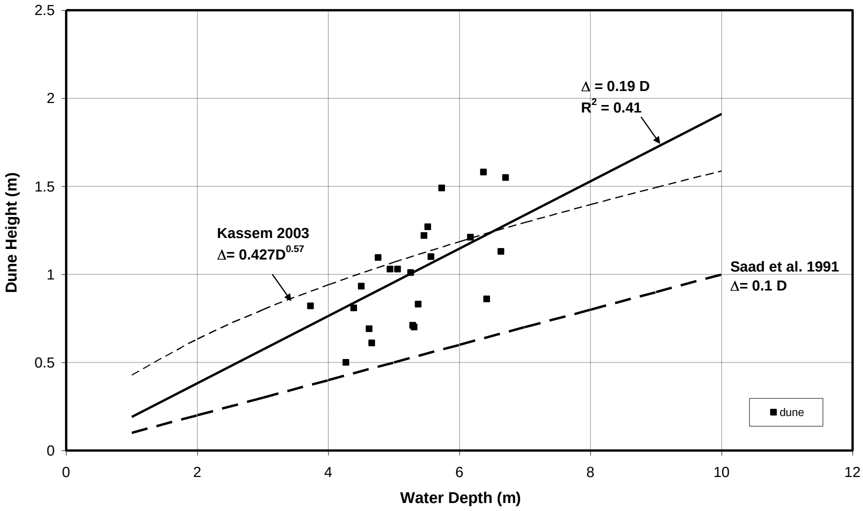

Figure 12: Water depth dune height relationship (second group)

- Third group of observed dune bed form at El Ekhsas gauge station was characterized by having length equals 0.5 to 6 time the measured water depth. The relation between water depth and dune length is represented in Figure 13, the figure shows the large discrepancy between the measured and predicted lengths given by Van Rijn formula. Predicted dune lengths using Allen (1968) formula gives acceptable values compared to the measured dunes length. Relation between flow depth and measured dune length can be represented by λ=2.40 D.

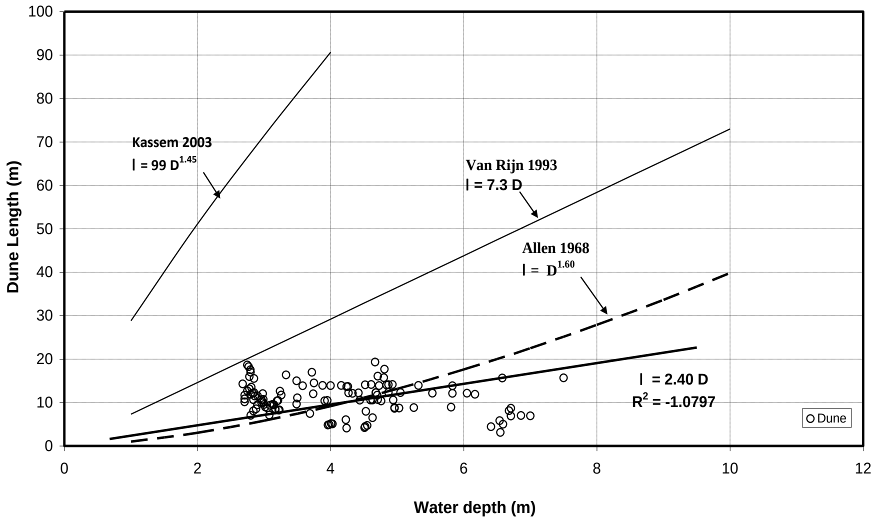

Figure 13: Water depth dune length relationship (Third group)

Figure 14 shows relationship between flow depth and measured height for third group, formulae of both Allen (1968) and Kassem (2003) are superimposed. Kassem (2003) formula gives value greater than that measured at El Ekhsas. Allen (1968) formula gives value smaller than that measured at El Ekhsas. Relation between flow depth and measured dune length can be represented by λ=0.09 D, which approaches formula given by Saad et al. (1991) (Equation (11)).

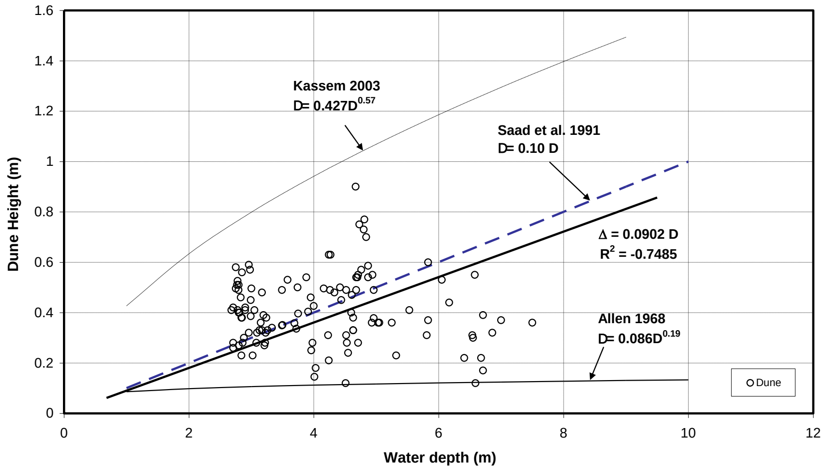

Figure 14: Water depth dune height relationship (Third group)

7 CONCLUSION

The drawn conclusion can be summarized as follows:

A- Predominate bed form type was dune with the appearance of dunes with mega ripples especially in August, 2008.

B- The observed bed form can be classified into three groups:

- **First group**

  This group was dunes with mega ripples, it was characterized by having length and height greater than that predicted using Van Rijn formula.

- **Second group**
  - The measured dune length has a trend like that predicted using Van Rijn procedure.
  - Saad et al. (1991) formula resulted in smaller values of dune height than measured at El Ekhsas gauge station.
  - Kassem (2003) formula gives acceptable values of dune heights compared to that measured at El Ekhsas for the same range of water depths.
  - The best fit relationship between water depth and dune height for second group is $\Delta=0.19$ D.

- **Third group**
  - Allen, 1968 formula gives acceptable values compared to the measured dunes length for the same range of water depths.
  - Relation between flow depth and measured dune length can be represented by $\lambda=2.40$ D.
  - Relation between flow depth and measured dune height can be represented by $\Delta=0.09$ D, which approaches formula given by Saad et al. (1991)($\Delta=0.10$ D).
  - Kassem, 2003 formula for dune length gives values greater than measured at El Ekhsas for the three groups of dune.

8 LIST OF SYMBOLS

D:	Water depth	m
D_*:	Particle parameter	
d_{50}:	Mean diameter of the particles	mm
g:	Gravitational acceleration	m/s^2
T:	Transport stage parameter	
Δ_d:	bed form height	m
λ_d:	Bed form length	m
ν:	Kinematic viscosity	m^2/s
ρ:	Water density	kg/m^3
ρ_s:	Sediment density	kg/m^3
$\tau'_{b,cr}$:	Critical bed shear stress	kg/m^2
τ'_b:	Bed shear stress due to the grains	kg/m^2

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