

# TEMPORAL AND SPACIAL CHANGES IN BED-FORM DUE TO CHANGE IN FLOW IN A FLUME ENVIRONMENT

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## ABSTRACT

Although rates of bed-form growth for steady flows (Nikora and Hicks 1997), have been clarified, practical implications and models accessible to the engineer remain to be elaborated. For example, how and at what rates bed forms change for increasing and decreasing flows remains to be quantified. There has not been much progress since Julien and Klaassen 1995 in defining a relationship between flow and bed-form characteristics. Sediment transport engineers in the current era have a very good idea of the size and shape of a particular dune at various discharges and sediment types. But very little is known about the time it takes to change the dune when the flow was to experience an increase or decrease. Previous research in this specific area was done by (J.R.L. Allen, 1976) who did an earlier model for dune time-lag in periodically varying unidirectional flows.

The research undertook measurements of a river and data over discharge and dune wavelength over the year. This data was then computed on a monthly basis. Model showed that hydrograph shape could substantially influence dune behaviour in unsteady flows. For the same flow period and extreme discharge values, a reduction in the relative duration of the high-water stages causes an increase in the phase differences between dune dimensions and flow, and an increase in the dimensions averaged over the flow cycle as compared with the similarly averaged dimensions given no lag.

The relative range of dimensions over the flow cycle is little affected. This research is mainly about how the bed form reacts to the change in flow and specifically the time it requires for a specific bed form to adopt its new bed form in regards to increase/decrease in flow. This research takes an experimental form to develop a stochastic modal for the time required for the change in bed-form morphology in relation to the change in flow. This includes the dune shape and height. The experimental analysis is in a flume with controlled sediment type/density/size, water depth and also the flow rate. The analysis is for the flow in a uni-direction. The depth of the dunes, shape and the velocity of the flow is measured by an ADV, and analyzed later using matlab to include a 3D representation and analysis. Through which the temporal and special changes in bed form due to change in flow is made clear and presented herein.

## 1. INTRODUCTION

Dunes migrating along bars in a river are moving through a spatially changing sediment transport field that is associated with the larger-scale bed topography. Dunes respond to this change in their environment in three basic ways :( 1) by adjusting their shape,( 2) by adjusting in size, and (3) by adjusting their rate of downstream migration. The accommodation path the dunes take on any particular section of bar surface seems to be strongly dependent on the character of the bar topography forcing the change. Conversely the dynamics of the bar cannot be understood without taking into account the effects of dunes. For example, change in their shape as dunes move along point bars strongly affects the transport paths of sediment grains of different sizes, thereby affecting the sorting of bed material throughout meander bends and the equilibrium shape of point bars.

This stream wise change in dune shape is the consequence of a systematic cross-stream variation in dune migration rate. In another example, down current decrease in the average size of dunes has been linked directly to the deposition of sediment and growth of languid bars. In this case the average rate of migration remains constant as dunes become smaller by transferring sediment into underlying bar forms. Clearly, the ability to predict the migration rate of dunes is important to forecasting dune-bar interactions. Because dunes are themselves composed of transported sand, their rate of migration must be related to the local sediment transport rate. If all sediment moving over dune crests is captured on

adjacent lee faces, then by conserving sediment as it is straight forward to relate the rate of dune advance to the volume flux of sediment and vice versa. Many trains of dunes are, however, imperfect sediment traps, and the behaviors of these dunes cannot be predicted from the sediment transport in a channel until the fraction of sediment that is bypassing dunes and therefore not contributing to their mass is known.

Accurate prediction of stage and flow developments for a flood must recognize the transient nature of erodible-boundary roughness, implying knowledge of bed-form generation and development processes as flows increase and decrease in intensity. From an experimental / measurement perspective and probably from a theoretical modeling perspective, the transient problem in which dune characteristics change over time poses *additional* severe difficulties beyond those of the equilibrium case. For sediment transport engineering, a minimum contribution desired of a theory ~model, understanding! for bed-form development would be a reliable means of determining which equilibrium would be established, i.e., delineating stability boundaries. Attempts have been made to base such boundaries on theoretical stability models, a` la Kennedy ~1969!, but engineering approaches ~e.g., van Rijn 1984a, b, c! have been primarily based on dimensional analysis and empiricism.

Recent experimental and theoretical works ~e.g., Coleman and Melville 1996; Coleman and Fenton 2000! have focused on the bed-form initiation process. Are there any implications of initiation and instability mechanisms for the finite-amplitude dune bed that is of most practical interest? Although turbulence may not be an essential feature of the initial instability of a sediment bed ~Coleman and Eling 2000!, does it play a more prominent role at later stages of bed evolution? While the mechanics of bed-form development ~Coleman and Melville 1994, and rates of bed-form growth for steady flows ~Nikora and Hicks 1997, have been clarified, practical implications and models accessible to the engineer remain to be elaborated. For example, how and at what rates bed forms change for increasing and decreasing flows remains to be quantified. The problem of transitions to a dune bed from a rippled or plane bed and from a dune bed to an upper-regime plane bed or antidune bed is also of much practical interest. Has recent work shed any light on this important aspect of non-equilibrium beds? Does turbulence modulation drive the dune upper regime plane bed transition?

## 2. PROCEDURE

The aim of this flume experiments is to see how the bed form reacts to the change in flow and specifically the time it requires for a specific bed form to adopt its new bed form in regards to increase/decrease in flow. This research takes an experimental form to develop a stochastic modal for the time required for the change in bed-form morphology in relation to the change in flow. This includes the dune shape and height. The experimental analysis is in a flume with controlled sediment type/density/size, water depth and also the flow rate. The analysis is for the flow in a uni-direction. The depth of the dunes, shape and the velocity of the flow is measured by an ADV, and analyzed later using matlab to include a 3D representation and analysis. Through which the temporal and special changes in bed form due to change in flow is made clear and presented herein.

In defining dunes and ripples, the following figure is used. Bed form classification is performed accordingly. Additional Phase diagram formed by eliminating time explicitly between the variation with respect to time of the independent quantity discharge and the variation with respect to time of the chosen dune dimension, the dependent variable. Comparison with theoretical models, show that the dune dimensions vary on the same period as the discharge but on a different phase.

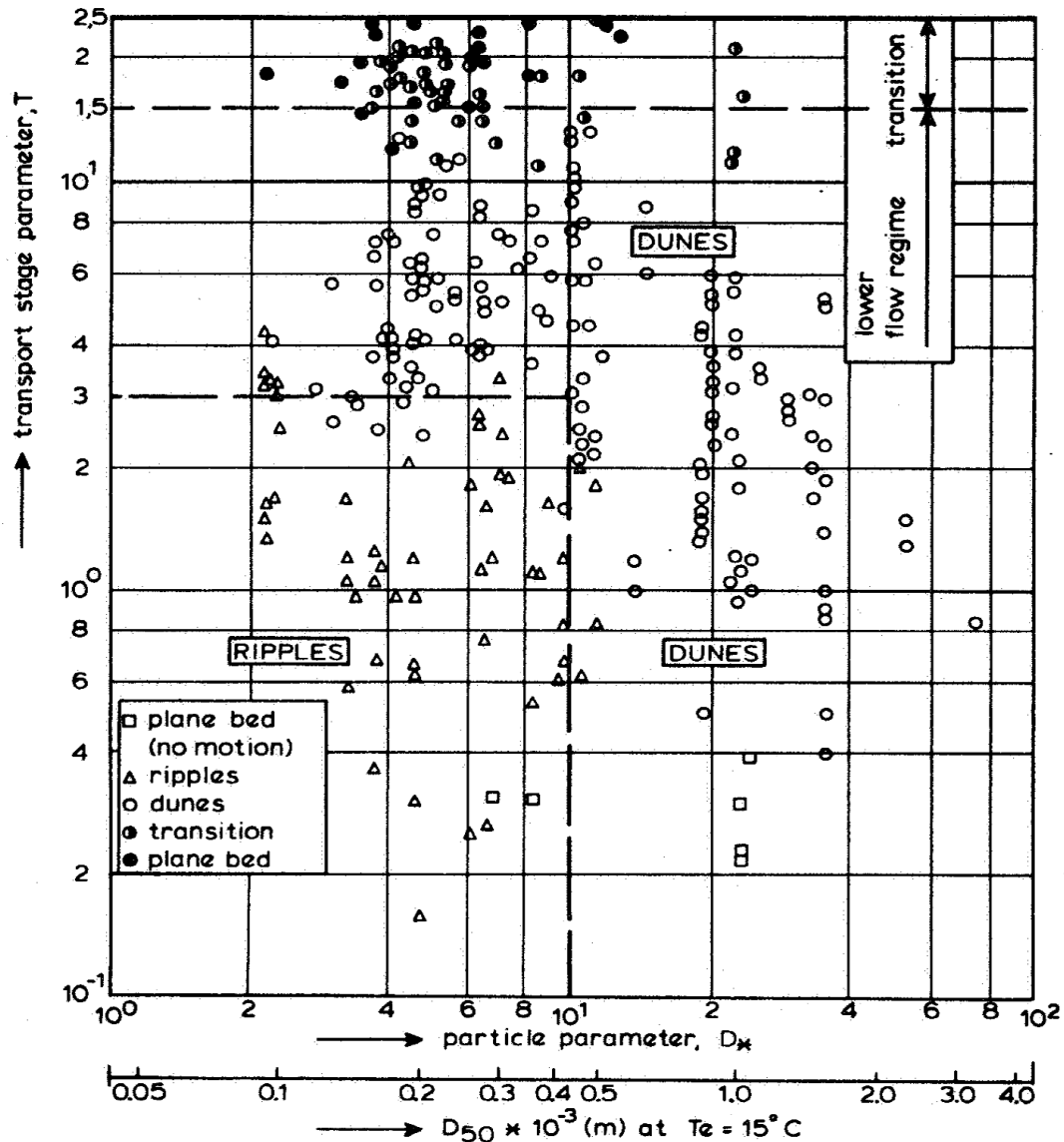
Although time is eliminated explicitly, each has only one correct trajectory, namely, anticlockwise in all the examples. The loops differ sharply from the theoretical relationships between dune wavelength, height and discharge in the absence of lag, that is, had the dunes always responded perfectly to flow changes. The effect of increasing dune excursion is to make the dune assemblages of both series depart increasingly from this simple theoretical picture. At the smallest excursion, the range of mean

actual wavelength is nearly identical with the theoretical range. At the largest excursion, however, the wavelength is virtually constant, although the discharge varies nearly six-fold. Mean actual dune height responds similarly to changing dune excursion, though the trend is weaker, because the dunes individually have some ability to respond in terms of height to the changes of flow, but no ability to vary in wavelength.

The two series differ most in terms of the shapes of the phase diagrams. Loops from Series tend to a smoothly oval form, closely resembling yielded by the earlier model for comparable excursions and the same simple-harmonic discharge variation (i.e.  $k=1$ ). In contrast, graphs from Series B tend to be either pointed or flattened on the side representing low discharges. In these experiments, distinguished by a long low-water season, there are large reductions in dune dimensions over this extended period of almost constant flows.

### ***Equivalent phase differences***

A quantitative estimate of the phase difference between the variation of discharge and the variation of some dune dimension is obtainable using an earlier procedure. Briefly, the area of each loop is measured graphically, together with the area of the smallest escribed rectangle that has sides parallel with the ordinate and abscissa of the graph. The phase difference is estimated as an "equivalent" value by introducing the ratio of the two areas into the graphed function relating area ratio to phase difference in a doubly simple-harmonic theoretical model. It was earlier found that the equivalent phase difference generally increased with increasing excursion and time ratio, the latter a measure of the ratio of the long-term mean theoretical dune life-span to the flow period.



In each Series the equivalent wavelength phase difference increases steeply with the time ratio for small values of the ratio. At larger ratios, equivalent phase differences comparable with  $7\pi/2$  rad are obtained. Some of the phase diagrams are ambiguous, however, affording a phase difference either somewhat smaller or a little larger than  $7\pi/2$  rad. A similar ambiguity was occasionally found earlier. At the larger time ratios, appear to yield the smaller wavelength phase differences.

The equivalent height phase difference also increases steeply with the time ratio for small values of the ratio. There are no ambiguous loops, however, the larger differences over the full range of experimental conditions. The generally smaller phase differences obtained for height as compared with wavelength may also be attributed to the effect of the non-zero coefficient of change, causing the dune assemblages to lag less in height than in wavelength.

#### *Instantaneous phase differences*

The phase difference as estimated above is merely a "characteristic" value, which could diminish in usefulness as the experimental system becomes more complex in behavior. Following an earlier discussion, when it was suggested that the life-span of a bed form was set partly by the prevailing environmental conditions, it seems likely that this characteristic difference is in truth a time-average,

determined by the changing dune properties over the whole flow cycle. Because the equivalent phase difference increases with the time ratio, the difference must also increase with the long-term actual dune life-span. It follows that, although excursion is constant in each experiment, the life-span of a large dune created at high discharge will be substantially more than that of a small dune fashioned at low stage. Hence when large long-lived dunes typify the bed, we should expect to observe different values of an "instantaneous" phase difference (perhaps generally larger) than when small short lived forms predominate.

The practical estimation of the instantaneous difference may be illustrated by the case for dune wavelength. Dune wavelength in the model theoretically is linearly proportional to flow depth, which itself varies as the discharge to the power  $2/3$ .

### 3. DISCUSSION

Ripples and dunes in many natural environments are subject to flows having high-frequency directional variations and can be expected to follow the same rule of alignment as the experimental wind ripples and subaqueous dunes. The dominant bedform trend parallels the resultant transport direction (upper right to lower left), but as the experimental conditions are near the transition to transverse bedforms, transverse bedforms are present also.

Although the vector resultant is the appropriate parameter for describing the net rate and direction of sediment transport, the problem of bedform genesis is so different that another parameter is needed to characterize flow conditions. When sediment is transported toward opposing directions, the opposing transport cancels out—a physical process that is accurately described when the resultant is calculated.

It can be argued that all transport should be considered to have a positive effect, because all transport may be involved in creating bedforms. For example, consider a wave-generated onshore-offshore flow combined with a small unidirectional alongshore flow. If the onshore and offshore components are equal, then they cancel out, and the resultant of the system is equal to the unidirectional vector. Regardless of the strength of the onshore-offshore flow, it has no effect on the resultant—yet it is typically this stronger wave generated oscillatory flow that is responsible for producing bedforms.

For problems of bedform alignment, a new parameter is needed to characterize a multidirectional flow in such a manner that flow toward opposing directions is represented rather than cancelled.

One such parameter is 'gross bedform-normal transport. Transport over any bedform can be resolved into two components, one normal to the bedform trend and one parallel to the bedform trend. In a purely unidirectional flow, all transport over perfectly transverse bedforms is bedform-normal, and no transport over longitudinal bedforms is bedform-normal.

Where a bedform is subject to two or more transport vectors, bedform-normal transport is defined as the sum of the bedform-normal components. Net bedform-normal transport is the sum of the bedform-normal components, considering forward transport across the bedforms to be positive and reverse transport to be negative. Gross bedform-normal transport is the sum of the bedform-normal components, considering all transport to be positive. By treating all transport as positive, no transport is lost to the cancellation of opposing vectors.

A complexity arises when determining bedform normal transport of a flow because the quantity cannot be determined independently of bedform orientation; a single multidirectional flow has different amounts of bedform-normal transport for different arbitrary bedform orientations.

Results of the present experiments with subaqueous dunes and the previous experiments with wind ripples indicate that the bedforms take the orientation that for the given pair of flow vectors has the 'maximum gross bedform-normal transport'

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