NATURAL ENGLAND

Geomorphological Briefing notes: Changes in Pagham Spit (West Sussex) Jan-Feb 2014.

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Natural England Request

I. Natural England has an on-going brief: to consider the geomorphological development of Pagham Spit; its spatially associated Pagham Harbour tidal inlet/outlet; and, by association, note the evolving impacts on downdrift shoreline (Pagham Frontage) as Pagham Spit develops.

II. The continuing physical development of Pagham Spit and the changing position of the tidal inlet/outlet have caused considerable concern on the part of Pagham Frontage inhabitants. This has caused Arun Council to undertake remediation works that though defined as Adaptive relative to perceived trigger thresholds of beach change, tend to be reactive to the changing shoreline configuration.

III. Previous reports to Natural England (Orford 2009, 2013) have stressed the importance of allowing Pagham Spit to develop naturally. As such, NE's advice to Arun on the coastal management response to Pagham, has been to maintain the naturally evolving spit.

IV. Following on from the unusual 2014 winter storm activity (Eden 2014) on the south coast, Pagham inlet/outlet has shown further changes that have forced the tidal inlet/outlet (i/o) to move eastwards. This Report is in the form of Briefing Notes to Natural England about this evolving situation.

Glossary

Breach (as in barrier breach): This describes a cross-barrier channel that breaks (or breaches) a barrier. Such breaches are usually generated during extreme storm surge events, whereby high-tide surge water is sufficiently elevated to erode sediment at the barrier crest ('throat' channel) and transport it down the back of the barrier and out across the edge of the back-barrier zone (overwash fan). Extreme flow volumes that persist as the tide falls can enlarge both the width and depth of the channel. Breaches appear when the eroding channel extends through to the barrier's beach-face from the landward side of the barrier. Any overwashing and breaching floodwater volumes that are trapped in the back-barrier zone may exit back through the developing breach as the tide falls (ebb floods) and enlarge and lower the breach. The ephemerality of such breaches depends on how low the breach has fallen relative to the tidal range. Low-lying breaches that may be used by semi-diurnal tidal exchanges, even in fair-weather conditions, could potentially persist. Tidal flow persistence and the size of the breach cross-section is a function of the tidal volume (prism) that ingresses and then egresses each tide. Gravel dominated barriers may see breaches develop by severe storm surge generated overwash, but such channels are usually of an insufficient depth (relative to tidal range) to allow semi-diurnal tidal activity to ensue and are quickly infilled by beach-face longshore sediment transport.

Cannibalisation: The tendency for a beach system where the longshore sediment supply has reduced or failed to use the existing beach sediment as a further source for subsequent longshore sediment transport down-drift. Cannibalisation generally starts at an up-drift position and progressively works alongshore (down-drift) through the beach sequence. Cannibalisation is generally the cause for beach ridge swash-alignment to appear in the up-drift area of a coastal cell.

Flood/ebb delta: The development of tidal deltas relates to the sudden deceleration of the peak tidal flows as they debouch from an estuary inlet/outlet (i/o) channel. It is not unusual to find both flood and ebb deltas associated with a single estuary mouth channel. Increasing asymmetry of tidal flow leads to asymmetry of either the ebb or flood delta, in terms of areal size. The difference in accommodation space either side of the i/o channel indicates that ebb deltas have the potential to be much larger than the flood delta and can hold substantially more sediment. The geometry and seaward extent of an ebb-tide delta is a function of the strength of the ebb currents, the wave climate, and the supply of sediment. A larger tidal prism and stronger ebb currents will tend to push the ebb tidal delta further seaward while a more energetic wave climate will tend to drive the delta back toward the inlet. In this way, over time, the position of the ebb delta will be in some form of balance between tidal prism and wave climate. There are secondary controls that influence inlet behavior, including principally, sediment supply and river freshwater discharge. Distortion of the equilibrium state will result in sediment exchange between the various geomorphic features that make up the i/o system until a new equilibrium is achieved. Disequilibrium can result from natural and human-induced factors, including sea-level rise, wave climate changes, land reclamation of the back-barrier basin, decreased sediment availability, and inlet stabilization, all of which can cause the entire inlet system to shift towards a new equilibrium state. On a local scale, ebb-tidal deltas directly influence the adjacent beaches by altering the incident wave field through wave refraction and can shelter onshore beaches if waves are dissipated on the delta. Ebb-tidal deltas can act as both a source and sink of sediment to/from the adjacent coastline. This exchange can operate on the periodicity of major storms, with spit sediment being brought out to the ebb-delta under storm activity and being reworked on to their flank spit(s) under post-storm constructive wave activity.

Overtopping: Process in which a small percentage of swash flows reach the top of the beach (=crest). They have the potential to move particles to the ridge top and help to build up the crest. The crest is usually only included in such swash flows during storms.

Overwashing: Process in which swash flows reach the beach crest and pass over it to flow down the back of the sediment accumulation. Generally only observed when the beach is part of a freestanding barrier. Such flows have the potential to move sediment from the beach face, and beach crest, down the back barrier slope, and are central to the barrier rollover process.

Briefing Notes

1. The following notes are based on both a site inspection (11.4.14) and comments from the Arun Council Technical Director (Mr Roger Spencer) also on site. The Environment Agency has supplied maps of the contour changes during; i) 2013 (Fig 1 in Orford, 2013); ii) from September 2013 to February 2014 (Fig.1 in this briefing); and from February 2014 to May 2014 (Fig.5 in this briefing). These figures have been the basis for spit change statistics.

2. During Jan and Feb 2014, the unusual incidence of deep cyclonic storms from off the Atlantic, generated significantly higher wave heights and periods from the southwest through the English Channel. The Isle of Wight acted as a major baffle to this increased southwest wave climate, thus shadowing the Pagham shoreline from the full force of the storms, however a stronger than usual southerly wave component had been evident for much of February alongshore at Pagham. Likewise some extra storm surge component had been experienced in early Jan 2014 and early Feb 2014 coincident with extreme spring tides, thus generating high water volume excursions (visually assessed only) through the Pagham inlet/outlet.

3. In the last Advice (Orford, 2013) Pagham Spit terminus appeared to be moving onshore under wave refraction (and southeast storm waves of the winter/spring of 2013). The then lack of any sub-tide delta to support easterly spit extension, was thought to account for the more rapid onshore movement of the spit terminus to the northeast, towards the shoreline. That Advice suggested that the 1st major rock-armoured groyne would then be a shore side control point for the tidal outlet channel, such that it would stabilise the position of the tidal i/o by preventing further easterly migration. The deceleration of the spit terminus longshore growth, identified in late spring 2013, was indicative of the stabilisation of the i/o and the resistance to further eastward spit extension. At that stage Advice (Orford 2013 para 25) indicated that if the spit did extend it would be likely to hold its present

offshore position, due to the tidal i/o moving seaward of the 1st rock armoured groyne. It was still uncertain as to the rate of future spit growth, as the question of sediment supply to the spit was still unknown.

4. The dynamics of the spit had in 2013 been morphologically identified as showing cannibalisation phases (Orford 2013), such that source supply of sediment was intermittent. Future dynamics of the spit would be heavily dependent on the supply rate and its inherent fluctuations. It was noted that the unknown sourcing of this sediment supply would be a major element of uncertainty in any future analysis of the spit.

5. Figure 1 shows the changes in the 3m (upper beach) and 0m (lower beach) contours for four time positions between Sept 2013 and early February 2014. Contours are supplied by the Environment Agency superimposed on 2013 photo base. Contour coverage has been provided for: 10.9.13; 3.1.14; 7.1.14; and 6.2.14. The last three dates are especially relevant given the coincidence of the high spring tides and extreme storms in Jan and Feb 2014. Unfortunately there is no data currently available to show the Sept 2013-February 2014 changes relative to pre-Sept 2013, so overall annual rates of change are not yet available.

6. The main change since September 2013 has been in the rapid extension of the spit terminus and its unchanging directional vector of deposition since Sept 2013. Table 1 indicates the rate of change (m/day) of the spit terminus at the 3m and 0m contour positions. Overall between Sept 2013 and Feb 2014, the spit at 3m and 0m has been extending at 0.5m/day and 0.68m/day. This acts as some calibration to the slower pre-storm rates posted up to 3.1.14 (0.3 and 0.5m/d), then the rapid increases during the Jan 6 storm (3.9 and 2.9m/day) and then a slow down during Jan 2014 (0.6 and 0.8m/day) at both the 3m and 0m contours respectively. It is likely that the post-Jan storm changes (up to Feb 6th) have been inhibited by the increasing squeezed control of the i/o as it was pushed against the 1st rock groyne position. From the contour orientation (Fig 1.) the spit's depositional vector has been forced towards the 1st groyne's flank. This is probably related to the persistent southerly wave approach during the winter storms.

7. Given the absence of water levels and tidal flow velocities, one can only surmise on the effect and control of the i/o channel as the spit encroached. It is likely that spring tides plus surge volumes would have enhanced the power of channel flows. Due to continuing spit squeezing on its southern flank, the channel power to excavate the groyne flank and push i/o flows across the root of the 1st rock groyne during the February storm, can be understood. Once the rock groyne was breached the i/o channel would have been able to excavate the shoreline down-drift of the 1st rock groyne and produce the situation evident in early March (Fig.2) and again by early April (Fig.3).

8. Since the Feb 2014 breach, it appears that the ebb-delta has been prograding. There are now two low water channels observed (11.4.14) across this platform (Fig.4), which suggests relatively lower rates of platform aggradation. As of late May 2014, EA map analysis (Fig.5) shows slight retreat of the spit terminus at the 3m contour, without any change at the 0m contour position between 20.2.14 and

16.5.14. Despite a relatively reduced resistance to the shifting i/o channel, (now that it has breached the 1st rock groyne) continuing spit aggradation is only noted around the 0m contour on the spit flank and centre ebb-delta. The tendency for two low water channels (as seem in early April) has been retained. It is possible that these two channels retain influence on ebb delta deposition with two deposition centres defined as residuals between the two channels. One depositional centre is attached immediately to the spit flank south of the terminus; the other centre lies between the shoreline-parallel outlet channel (to the north) and the other channel flowing due south across the delta. There is map change evidence (Fig.5) that this deposition is moving onshore. A caveat has to be mentioned. Evidence of monthly change is now becoming available, but forecasting future changes on sub-seasonal data carries increased uncertainty over annual change data. This does not mean we should discount short-term data, but it needs to be set in context with annual trends, rather than used to forecast behaviour trends *per se*.

9. Spit width changes are considered for two positions: i) west of the dominant recurves (Fig.1: white profile line) shows no net loss of width at both the 3m and 0m contour positions during the Sept 2013 to February 2014 period. However, ii) east of the recurves (Fig.1: yellow profile line) into the post-2013 growth area, there have been pulsed longshore changes in the 0m contour, indicative of lower beach reworking (post 3.1.14) followed by some growth by 6.2.14. Generally there has been retreat of the 0m contour between Sept 2013 to February 2014 east of the recurves. Such sediment loss might account for spit terminus growth. Data for 7.1.14, though missing for the flank position, shows growth at spit terminus following the Jan 2014 extreme event (Table 1). Overall the distal spit extension shows a steepening flank beach face, indicated by the retreat of both contours on the spit's distal seaward flank.

10. The lack of any 2012-2013 contour data does not allow further scale and time analysis of up-drift spit-width changes. The latest spit growth could be partially accounted for by width reduction of the 2013 extension-spit (i.e. cannibalisation). The issue of a reducing width is key to the overall sediment supply issue. It is intriguing that given the persistent southerly wave component in Jan 2014, that (remembering the limited spatial perspective of Fig.1), any new supply to the terminus did not appear to come from any upper beach sediment deposited in the pre-2012 period. The readjustment of spit width to spit extension length in the post Sept 2013 period might indicate a lack of longshore supply (hence the cause of flank cannibalisation). This however does not preclude movement of low-beach and sub-tidal sediment along the foreshore to supply the growing ebb-delta and further pressure the i/o channel position.

11. Of principal contemporary concern is whether the spit will continue to prograde eastwards, and push the locus of Pagham Frontage shoreline erosion laterally alongshore towards the 2nd rock groyne? Until a future breach exit emerges updrift of the spit terminus, the i/o channel is likely to resist the spit terminus welding directly to the Pagham Frontage shoreline (thus activating further erosion concerns). The lack of extension of the spit's terminus during spring 2014 underlines the continuing hydraulic ability of the i/o to maintain its [position relative to Pagham Frontage. It is also worth noting that the extremes of water

levels and wave activity in early Jan and Feb 2014 did not force such a breach on the spit's flank up-drift of the present spit terminus. This indicates that the width/ height ratio of the spit is still above the threshold for storm overtopping sufficient to generate a switch in channel i/o outlet. That stated, the thinning of the flank during future spit extension may be preparing the spit for future successful over washing and by extension future breaching. Given that the extremes of southerly storm wave action during winter 2013-14 did not cause breaching, it is probable that it will require direct onshore storm activity from the south-east, both to direct overwashing on the spit's flank, as well as causing a tidal lock on the i/o at high water to raise the hydraulic pressure to force a new outlet breach in any overwashing channel. On that basis alone, it is worth considering the possible location of a future breach position, but to do that, contouring of the spit at 0.5m intervals above the 3m contour will be required.

12. Would direct remedial action on the spit prove successful? In the short term rock armour from the centre of the 1st groyne has been removed by Arun Council to protect the channel flank shoreline around where the i/o is positioned. These rocks are regarded by Arun as a moveable asset that may have to be mobilised in the future, especially if the point of shoreline erosion shifts down drift (eastwards) due to channel changes. This may be expected as a consequence of any future extension of the spit terminus (Fig.4). This is seen as a reactive policy and as such is unlikely to have any long-term influence on spit position.

13. In the long-term, the case being urged by Frontage inhabitants is to artificially cut a new breach up-drift of the spit terminus. The dimensions of such a channel would have to mimic the hydraulic competency of the existing i/o, while the existing i/o would have to be closed off by artificial fill. The opening of any new breach and infilling of the old i/o would need to be simultaneous to maintain the 'new breach' flow. The logistics of achieving these two outcomes are beyond the remit of these notes. However, if there is still active longshore sediment supply along the spit flank, then the new breach would be under infill closure pressure, which in turn could pressure a reopening of the present i/o channel. To maintain an up-drift breach in the long term will also require considerable onshore movement of the spit terminus sediment across the present i/o position (i.e beach face swash bar welding), so as to resist the potential reopening of the old i/o entrance.

14. Both short and long term remediation choices will be affected by the dynamics of spit extension and the sediment sourcing by which such extension occurs. It is unfortunate that we do not have an understanding of the sourcing of sediment along the spit, other than some possible consequences of spit morphologic changes that may be indicative that the recent (post 2012) spit extension may be related solely to up-drift alterations of the spit body. If this latter situation is the case, then any future spit extension may well be at the expense of spit width, and by association the probability of up-drift spit breaching under southeast storm conditions may be increasing. There is still the need to establish the initial source of spit sediment, now most likely to be the offshore shoals (Kirk Arrows and Inner Owers). At this stage there is no direct evidence of these sources. It is by inference only that these shoals are considered possible sources, on the basis that there is no other viable source. The longer period southerly waves over winter 2013-14 may have effected greater bed shear over the shoals and hence lowered the erosion base offshore, thereby moving extra gravel from these source shoals onto the shoreline.

Recommendations:

15. Natural England should seek continuation of Environment Agency's contoured overlays of Pagham Spit from Selsey Bill to the eastern end of Pagham Frontage. Also to ensure that for each year, both the 3m and 0m contours are plotted throughout the spit length. Likewise a detailed 0.5m contour (or less) is undertaken for the upper spit to check for possible potential breach positions.

16. Probably somewhat late in the day, but there is a continuing need for a water level recorder in Pagham Harbour to monitor tidal prism changes plus any surge components.

17. There is also a need to establish likely offshore source areas for Pagham spit. It would be of value if Multibeam coverage of the offshore shoals (Kirk Arrows and the Inner Owers) and possible connecting onshore sediment pathways from these shoals, could be obtained.

References

Eden,P 2014. February 2014 Weather Log: Exceptionally cyclonic and very wet. Weather -London, 69; Part 4, pp. i-iv.

Orford,J.D., 2009. Geomorphological Advice in respect of Pagham spit, West Sussex. Report for Natural England, pp13.

Orford, J.D., 2013. Geomorphological Advice in respect of Pagham spit (West Sussex). Report for Natural England, pp21.

Fig.1: Pagham coastal-gravel spit system showing 3m and_0m contour changes between 10.9.13 (purple); 3.1.14(red); 7.1.14 (blue) and 6.2.14 (green). This analysis covers the period of the extreme springs in Jan and Feb 2014. White/ yellow lines indicate where measured rates of change of spit width calculated. (@Environment Agency 2014)

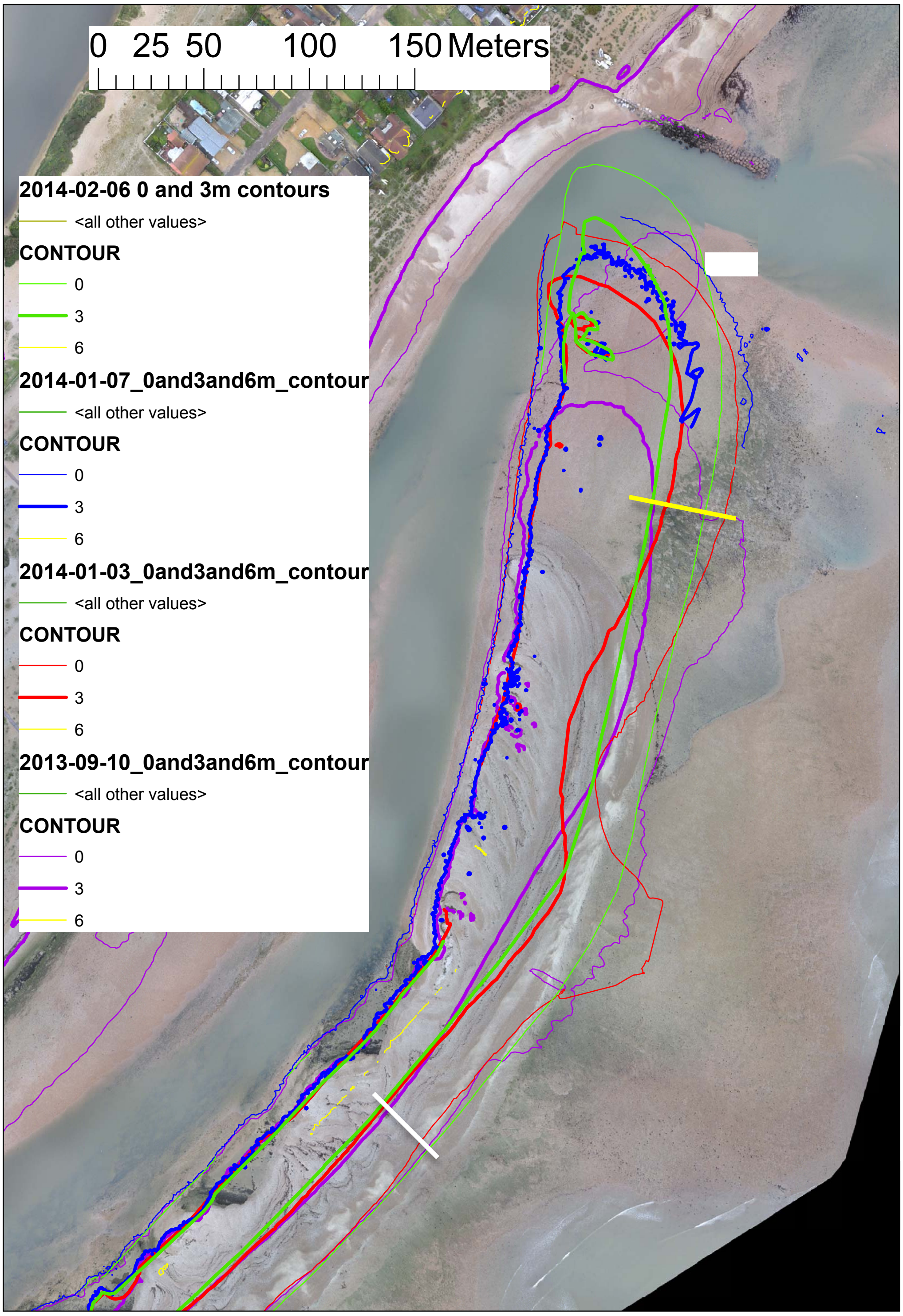

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Table 1; Overall and serial distal spit extension distances (m) and deposition rates (m/day) at the 0m and 3m contour positions. Measured between 10.9.13 and 6.2.14. Data sourced from contour changes shown in Fig.1.

		0m contour		3m contour	
Date	Diff (days)	Distance (m)	Rate m/day	Distance (m)	Rate m/day
10.9.13					
3.1.14	115	63	**0.5**	39	**0.3**
7.1.14	4	12	**2.9**	16	**3.9**
6.2.14	30	24	**0.8**	18	**0.6**
Overall	143		**0.68**		**0.5**

Fig.2: Aerial view of the i/o position and the breach of the 1st rock groyne on 9.3.14. (@ Brian James). The 'missing' middle zone of rock armour from the 1st rock groyne has been used to bolster the eroding Pagham Frontage

Fig.3: Shoreline condition at the 1st rock groyne near HW (11.4.14). Looking south towards the extending spit terminus. The remnant of the 1st rock groyne appears at the RHS of the image. The extension of the rock groyne, from which Arun Council removed rock armour, can be seen projecting into the i/o channel. Image taken from where focus of future expected erosion of Pagham shoreline could occur with future extension of the spit (@J.Orford)

Fig.4: Pagham i/o at LW. This is a stitched 180^o panorama so spatial distortion of the site is inherent in the image. The LHS shows the down drift Pagham shoreline (to the 2nd rock groyne). The centre far-ground shows the developing ebb delta with two sub-tidal channels and the encroaching spit terminus. The RHS shows the post-Jan 2014 remediation to protect the then eroding Pagham Frontage. The centre foreground shows the eroding shoreline (erosive scarp) downdrift of the 1st rock groyne. This is the zone where future rock armouring may be installed if the spit further extends in spring 2014. (@Chris McMullon: April 2014)

Fig.5: Recent morphological changes around the i/o exit, spit terminus and ebb delta between 20.2.14, 30.3.14 and 15.5.14. Map analysis supplied by Environment Agency.