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Gravel beach erosion and nourishment in Nice, French Riviera

Érosion et rechargement artificiel des plages de galets de Nice, Côte d'Azur

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Abstract - Since 1976, beach width measures have been carried out on 50 transects over the 4.5 km long gravel beach in Nice (French Riviera). Statistical analyses of beach width highlight very little significant change over the last 30 years in spite of massive gravel nourishment amounting to 558,000 cubic meters. The results suggest that this nourishment may be necessary to stabilise beach width that would otherwise diminish due to chronic gravel loss to the very steep nearshore zone, within a context of cessation of gravel supply by the nearby Var river. The practise of artificial beach widening through flattening of the profile in summer in order to enhance the beach-goer 'carrying' capacity of this strongly frequented beach may favour sediment loss by bringing close to the very steep nearshore zone several cubic meters of gravel for each meter of beach that can be permanently lost downslope during autumn and winter storms.

Résumé - Des mesures de largeur de plage sont effectuées depuis 30 ans sur 50 transects, le long des 4,5 km de la plage de galets de Nice (Côte d'Azur). Des analyses statistiques de ces données montrent peu de changements significatifs durant cette période, malgré des rechargements massifs en galets d'environ 558 000 m³. Les résultats suggèrent que ces rechargements sont vraisemblablement nécessaires pour stabiliser la largeur de la plage qui, sans eux, diminuerait par perte de galets vers l'avant-côte très pentue, dans un contexte d'arrêt des apports de galets par le fleuve Var. L'élargissement de la plage et l'aplatissement de son profil en été, afin d'augmenter sa capacité d'accueil lors des très fortes fréquentations touristiques estivales, pourraient favoriser la perte définitive de sédiments en les poussant vers le large, sur une avant-plage très pentue, et ainsi faciliter leur évacuation vers le fond par les tempêtes d'automne et d'hiver.

I - Introduction

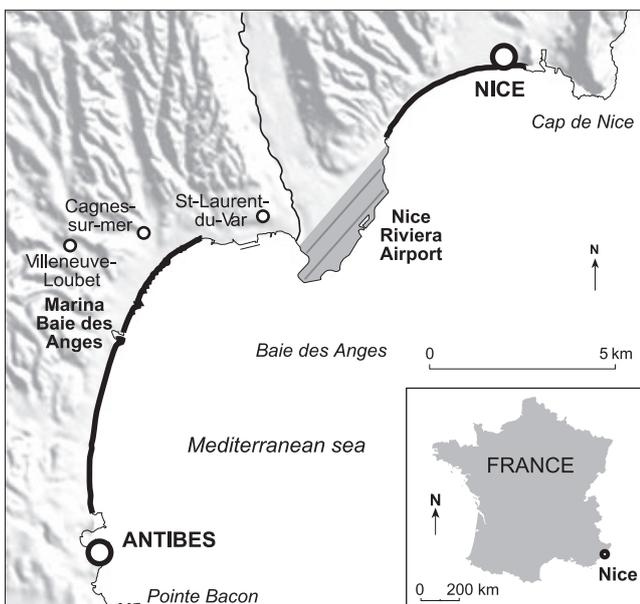


Fig. 1 - Nice beach on the steep continental margin of the French Riviera.
Fig. 1 - La plage de Nice, en bordure de la marge continentale raide de la Côte d'Azur.

Beaches act not only as buffer zones against coastal flooding and erosion, but can also be a vital socio-economic asset, providing recreational outlets for residents but also for tourists. Beach erosion has become a problem of increasing concern for many coastal communities (BIRD, 1996; ANTHONY,

2005), resulting in extensive recourse to beach nourishment. Although nourishment is now widely practised, there is still debate as to whether it is the best solution to the problem of beach erosion (FINKL and WALKER, 2005). Strongly practised in America since the 1960s (Finkl, 1996), beach nourishment has gained considerable ground in Europe, guided by various strategies and objectives (HANSON *et al.*, 2002; HAMM *et al.*, 2002). Rapid socio-economic development in the Nice area, the most important urban zone (permanent population: 500,000) on the French Riviera (Fig. 1) has brought considerable pressure to bear on the 4.5 km-long beach bounding Nice bay, generating chronic beach erosion and beach narrowing. This situation embodies an important paradox, since beach erosion and narrowing are not compatible with a large 'carrying' capacity of beach goers, while beach recreation has emerged over the last three decades as a powerful attractor of tourist revenue in this area (ANTHONY, 1997). The problem is compounded by both the gravel composition and the micro-tidal regime (mean spring tide range = 0.65 m) of Nice beach, which is generally characterised, following autumn and winter storms, by a narrow multi-bermed profile (Fig. 2). The gravel composition also makes for less 'comfortable' beaches compared to sandy beaches. The solution to the problem of beach sediment depletion and the consequent narrowing of the beach in Nice bay has resided in artificial beach nourishment and flattening of the beach profile in order to restore the sediment budget and to lessen beach face steepness and reflection. Due to armoring of the shores of the reclaimed Var delta, the only current source of gravel for the 4.5 km-long beach in Nice is through artificial



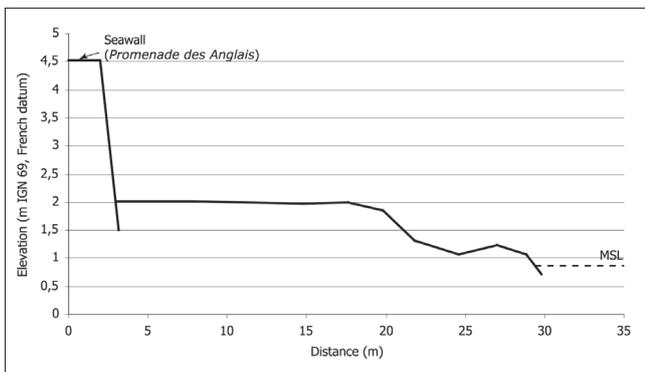


Fig. 2 - Example of a narrow multi-bermed early spring beach profile (on Regency beach, transect 7).
Fig. 2 - Exemple d'un profil étroit à berms multiples de début du printemps (plage de Regency, transect 7).

nourishment. The beach has been recharged over the last 30 years to the tune of 558,000 cubic meters, making this little known long-term operation one of the most important in France, and certainly one of the most significant for gravel beaches in the world. This paper analyses the nourishment practice in Nice beach and its efficiency.

2 - General setting of Nice beach

The gravel beach in Nice forms the shoreline rim of a steep continental margin (Fig. 1), where the southern French Alps abruptly meet the Mediterranean Sea. Several canyons practically impinge on the beach, especially in the Nice

embayment east of the Var delta, and appear to be the seaward prolongations of the steep coastal streams. Shoreface slopes are extremely steep, ranging from 4 to 6° between the 0 and -10m contours. The gravel beaches in the two embayments (collectively called the Baie des Anges) on either side of the Var delta represent former discrete interlinked barriers of dominantly limestone clasts reworked from coastal outcrops of Pliocene deltaic puddingstones supplied by the lower Var and Paillon catchments and the other smaller rivers (ANTHONY, 1993; ANTHONY et al, 1998). The French Riviera beaches are exposed to fetch-limited, low-energy wind waves with mean and significant heights of 0.6 m and 0.96 m (COHEN, 1996). This low wave-energy regime is punctuated by storm conditions during which breaking wave heights may exceed 2 m a few days in the year (maximum offshore annual height = 3.1 m). Beach clast sizes are dominated by medium-sized gravel (5-10 cm in diameter).

In spite of the possible existence in the past of longshore variations in barrier dynamics related to sediment source proximity, drift cell dynamics, backbarrier morphology, incident wave energy and clast characteristics, overall barrier evolution on either side of the Var delta over the last few thousand years was such as to maintain a coherent, essentially concave, plan-view shoreline configuration. The two embayment beaches on either side of the Var river, their major gravel supplier in the past, were characterized by sporadic, essentially storm-controlled and slow up-and-down longshore movement of sediments within 'closed' bay systems (in terms of longshore drift), with the two hard-rock headlands bounding the Baie

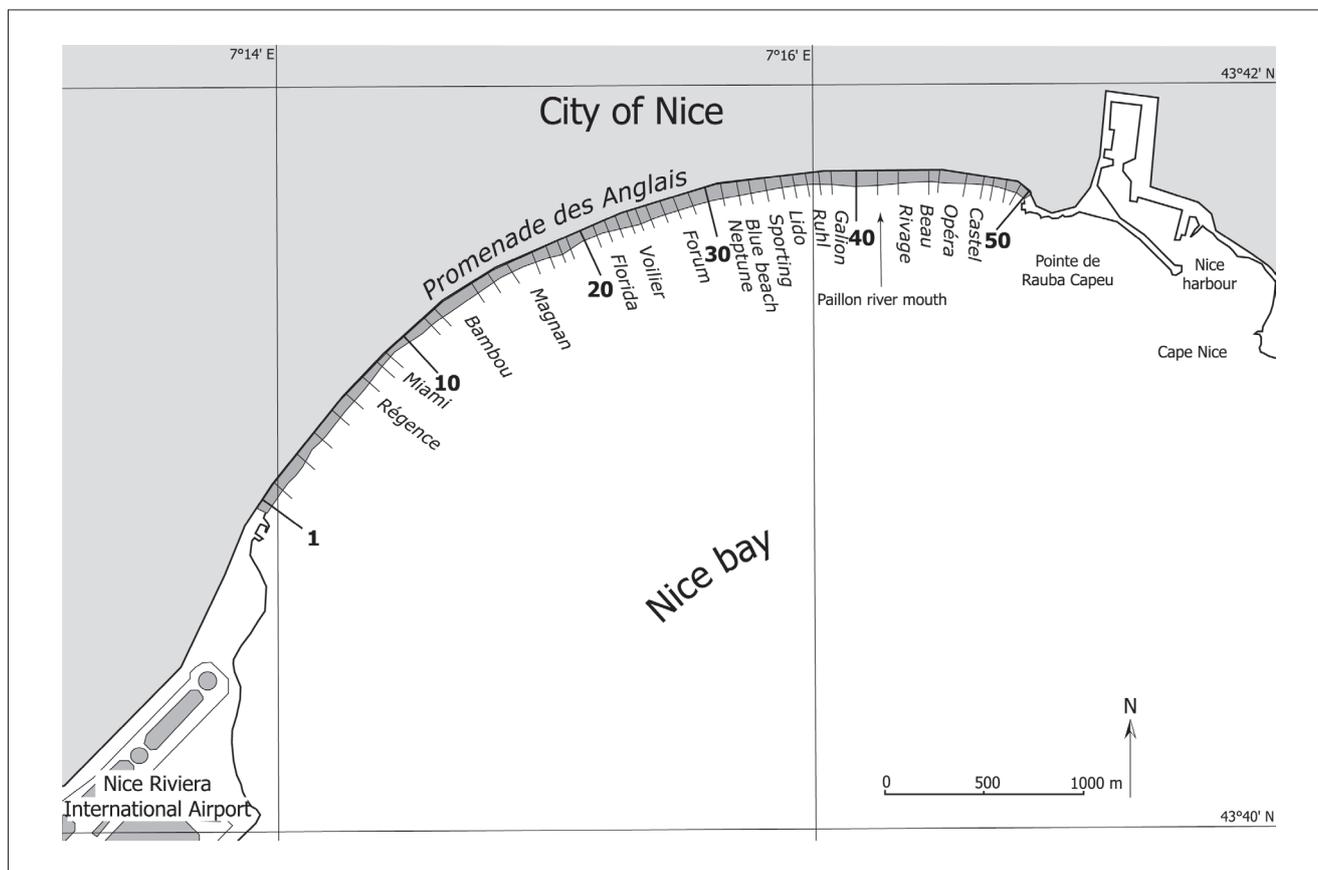


Fig. 3 - Location of beach width monitoring transects (names of beach sectors are indicated).
Fig. 3 - Localisation des transects de mesure de la largeur de la plage (avec les noms des secteurs de plage).



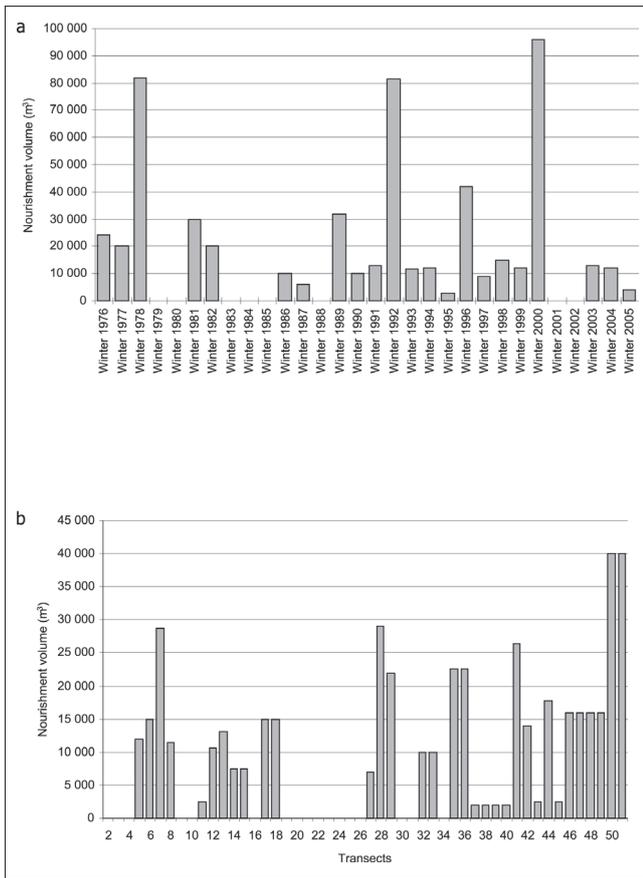


Fig. 4 - Nourishment volumes (a) and nourished transects (b) on Nice beach since 1976.
Fig. 4 - Volumes de rechargement (a), et transects rechargés (b) de la plage de Nice depuis 1976.

des Anges allowing for no gravel leakage into adjacent embayments east and south of the Baie des Anges.

The present status of these gravel beaches is one of destabilization, not as a direct result of internal barrier dynamics but as a consequence of human interference in the last hundred years (ANTHONY, 1993; ANTHONY and COHEN, 1995). The erosion and fragile status of the present gravel beaches are due to a combination of several interacting factors that include past direct beach aggregate extraction, the construction of barrages in the lower Var river, drastic reduction of beach width due to the growth of urban fronts and the construction of the famous Nice sea-front Promenade des Anglais, and destabilization of the beach face and back-barrier water table as a result of the construction of roads, a major rail link and various other infrastructure, including sea walls. The implantation of artificial shorelines associated with leisure ports and reclamation fill, especially the Var delta fill for the construction of Nice-Riviera airport (see Anthony, this issue), and the emplacement of groyne fields by local government authorities not working in concert, and showing no concern for the downdrift consequences, have also been important factors. Paradoxically, some of these structures were constructed to stave off beach erosion. The net effects include zero natural sediment inputs and consequent erosion, as well as modification of the sediment drift structure and the beach morphodynamics. The conjunction of a sediment deficit, of an increasingly polycellular drift system induced by artificial shoreline development, and of barrier constriction through infrastructural implantations on the upper beach has led to beach narrowing and steepening, enhancing the already

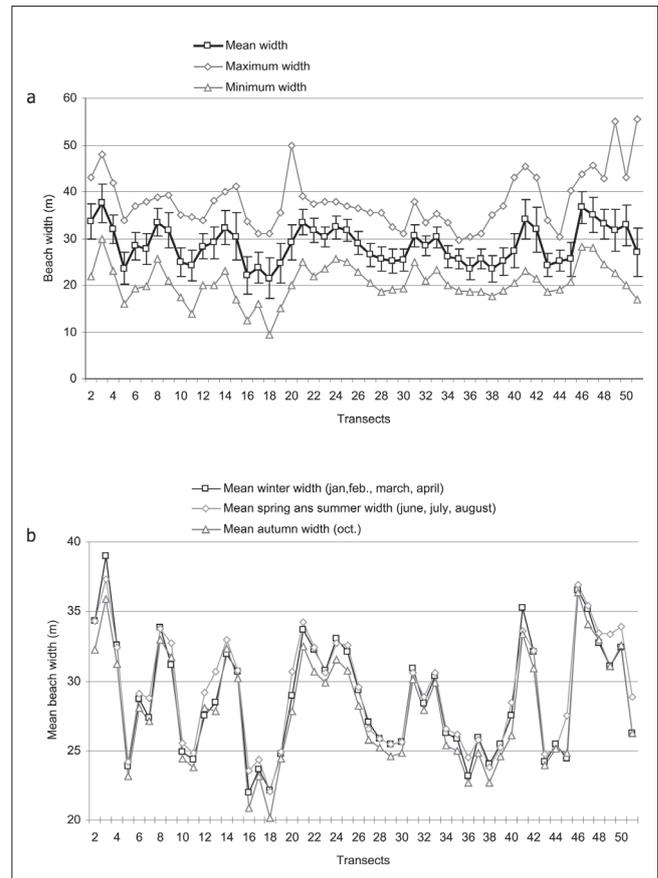


Fig. 5 - Mean, maximum and minimum beach widths (a), and mean seasonal widths (b) of the 50 transects.
Fig. 5 - Largeur moyenne, maximum et minimum (a), et largeur saisonnière (b) des 50 transects de la plage.

highly reflective morphodynamic conditions prevailing on these beaches and on the steep inner shoreface.

3 - Beach nourishment

The gravel for beach nourishment is provided at virtually no cost for the city of Nice by flood-prevention operations on the gravel-rich bed of the nearby Paillon river, as well as from building sites on the puddingstone geological formations that constitute the hilly foundations of much of the city of Nice, and which are rich in rounded gravel clasts. The nourishment spots have been empirically determined by the environmental services of the city of Nice from data acquired two to four times a year on beach width from a total of 50 transects (Fig. 3) spaced 40 to 250 m apart (mean spacing = 90 m) over the 4.5 km-long beach. This yields a dataset of 87 beach width measurements since 1976.

4 - Results

The nourishment has fluctuated significantly over time with annual volumes ranging from nil in certain years (1979, 1980, 1983-85, 2001-2002) to a peak of over 97,000 cubic meters in 2000 (Fig. 4a), depending on the rhythm of the river-bed operations and of ready availability of clasts from the building industry. There has been a significant concentration of nourishment in the western half of Nice bay compared to the



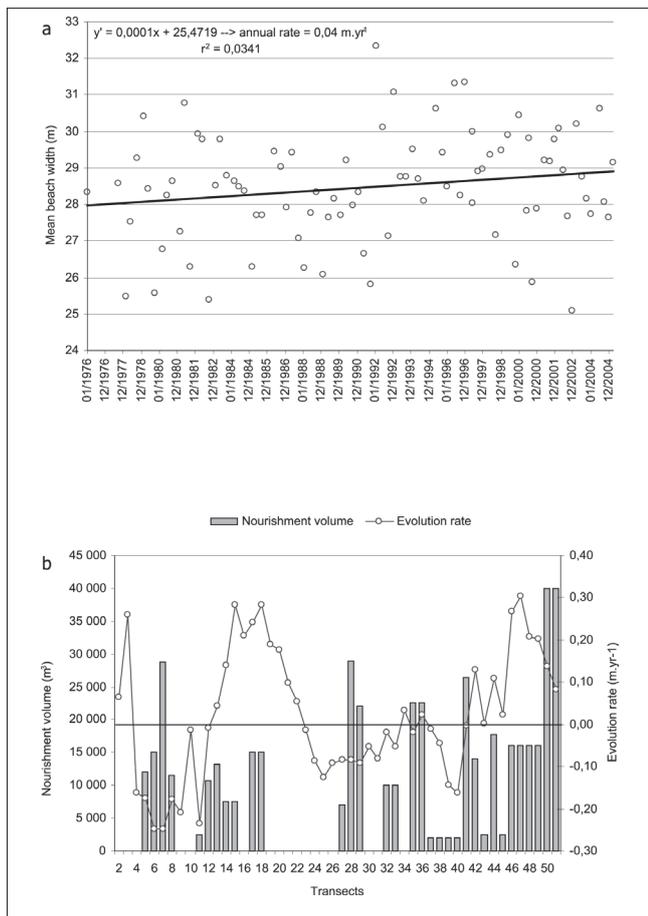


Fig. 6 - Mean beach width trends over time (a), annual width trends and nourishment volumes of the 50 transects (b).
Fig. 6 - Tendances de la largeur moyenne dans le temps (a), et tendances annuelles de la largeur et du volume rechargé des 50 transects (b).

eastern half, with hardly any nourishment in the central sector (Fig. 4b).

Simple statistical analyses of the results of this beach nourishment programme show that the mean beach width over the 30 year period is 28.7 m (Fig. 5a). The widest sectors attain a mean value of 37.5 m, while the narrowest do not exceed 21.5 m. The mean seasonal beach widths (Fig. 5b) highlight significant stability, the mean difference not exceeding 3 m. Inter-annual variations are more significant, with a mean of 17.6 m, but the maximum attains 38.5 m, which is quite considerable as it represents 1.3 times the width of the beach at its eastern extremity. However, the mean variability per transect is quite low (3.2 m on average), as shown by the error bars representing one standard deviation on either side of the mean (Fig. 5a). This variability is quite uniform, and highlights a particularly stable beach width in the central sector (transects 23 to 38). This relative stability is also brought out by regressing beach width over time (Fig. 6a), which yields a mean trend of only 0.04 m.yr⁻¹. This trend is confirmed by the linear regression analyses for each transect (Fig. 6b), which highlight relatively weak values (from -0.25 to +0.3 m.yr⁻¹). Nice bay thus shows three sectors of mild beach-width gains (transects 2 to 3, 13 to 22 and 41 to 51) and two width-decrease sectors (transects 4 to 12 and 23 to 40).

Figure 6b depicts, in addition to evolution rates, the relationship between the transect width trends and nourishment volumes since 1976. The results show that the overall massive

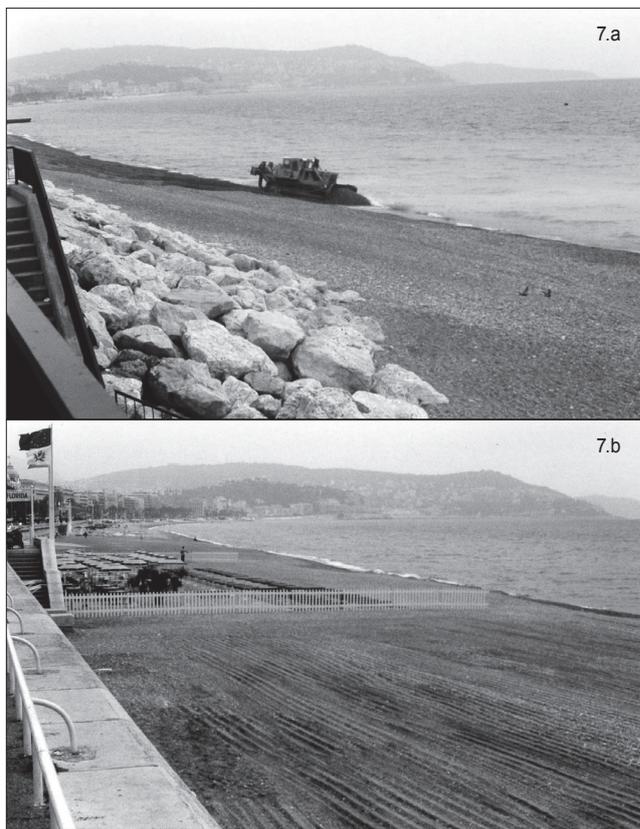


Fig. 7 - Photographs of Nice beach showing a nourishment operation underway (a), and flattening of the beach in order to enhance its carrying capacity (b).
Fig. 7 - Photographies de la plage de Nice montrant une opération de rechargement en cours (a), et l'aplatissement de la plage afin d'augmenter sa capacité d'accueil des estivants (b).

nourishment, representing the input of 123 cubic meters of gravel per meter of beach throughout Nice bay, has hardly resulted in significant beach width changes, both gains and losses (respectively for the three and two afore-mentioned sectors) being extremely mild. It may be emphasised that the two sectors of beach-width decrease received over 211,000 m³ of nourishment gravel.

5 - Discussion and conclusions

The results briefly presented above show that even massive nourishment on the narrow beach of Nice bay does not result in significantly larger beach widths, and has barely managed to maintain beach width over time. These results are hardly different from those reported by COHEN (1996) following the first 18 years (1976-1994) of nourishment, notwithstanding a nourishment of nearly 215,000 cubic meters of gravel over the last 11 years. This situation raises two questions regarding: (1) the relative 'inefficiency' of nourishment in significantly enhancing beach width, and (2) the fate of the beach without nourishment. In response to the first question, the treated nourishment data merely concern the nourished sectors and volumes without taking into account the spread of nourished material by bulldozers (Fig. 6b and 7). However, while this may constitute a limitation in the quality of the data, it is not likely to mask any significant increases in beach width,



were such increases to exist, given the relatively close mean spacing (90m) of the transects. A more likely explanation is that of gravel loss to the extremely steep nearshore zone, especially via the micro-canyons that practically impinge on the beach (ANTHONY, 1993; COHEN, 1996). The steep shoreface adjacent to the beach in the Nice embayment (Fig. 1) is an environmental factor of paramount importance in the dynamics and maintenance of these beaches. Nourishment practice on this beach generally involves spreading out the recharged materials and flattening the profile in order to extend the width of the beach and enhance its 'carrying' capacity during the summer tourist season (Fig. 7). However, while these operations may be efficient in summer, generally characterised by low-energy waves, they bring closer to the steep nearshore zone several cubic meters of beach gravel that may then be irreversibly evacuated downslope during storm conditions associated with surge levels. Autumn, winter and early spring storms with surges bring breaking waves high up the micro-tidal beach, resulting in the build-up of steep reflective berms. Energy reflection may

thus contribute in further transporting gravel downslope to depths from which it can no longer be recovered by fair-weather waves. The dominantly rounded nature of the recharged clasts may contribute to this offshore transport by encouraging rolling.

Experience gained from the morphodynamics of the gravel beach in the southern embayment of the Baie des Anges south of the Var delta (ANTHONY, 1993) shows that nourishment in Nice bay is an important means of containing the beach erosion hazard, at least contributing to stabilising beach widths. The beach south of the Var delta is extremely degraded in places by chronic erosion in the face of complete depletion of natural gravel supply by the Var river, and has all but disappeared in places. Unchecked beach erosion on this part of the French Riviera coast is thus an important potential hazard.

6 - Acknowledgements

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