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Analysis of Beach Nourishment Schemes

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ABSTRACT

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The erosion of a nourished beach may be conveniently described as the sum of the linear coastal retreat and a surcharge which decreases exponentially in time. Application of this model to the data from eight nourishment projects in north-western Europe has shown that on average only 52 percent of the nourished volume becomes a permanent part of the coastal volume. Allowing for an initial loss of some 10 per cent, the results obtained indicate that in practice computed nourishment volumes should be multiplied by a factor of about 2.2, somewhat higher than previous recommendations.

ADDITIONAL INDEX WORDS: *beach replenishment, coastal erosion, artificial beaches, coastal management.*

INTRODUCTION

For the design of an artificial beach nourishment, it is possible to follow the straightforward method as described by VERHAGEN (1992). This method is only valid in those cases where the coastal erosion is large with respect to the quantity of the nourishment. Also, data have to be available regarding the previous erosion rate. In the method, a multiplier is used to account for all "losses" of sand. A value of 40% extra is suggested. In this note, the results from a number of nourishment projects are evaluated in order to obtain support for the suggested value of 40% and further insight into the behaviour of nourishment as a function of time.

The method described in this note is limited to the evaluation of a restricted part of the beach. Usually nourished sand moves out of the nourishment area to neighbouring coastlines or to somewhat deeper water. This is called a "loss", although in the long term this sand still contributes to the stability of the coastline in general, but not at the desired location. From a geomorphological point of view the sand is not lost, because it is still a part of the littoral system, but from a point of view of the beach-manager it is a loss, because fewer square meters of dry beach are available for recreational use.

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MATHEMATICAL DESCRIPTION

The erosion of a nourished beach consists of two components: (a) the linear component of the erosion (the linear regression of the volume of sand in the coastal profile); and (b) extra erosion, arising from the new coastline being more exposed than the neighbouring profiles.

In fact, the extra erosion mentioned under (b) is caused by both longshore losses as well as adaptation of the profile in the cross-shore direction. This last phenomenon can be decreased numerically by selecting a deeper closing depth of the balance area. Unfortunately, this approach is not always possible because of non-stable breaker bars.

For a nourishment extending over a relatively long stretch of beach (the same length as the eroding area) without "adaptation losses" in the cross-shore direction, only the linear erosion needs to be taken into account:

$$V_t = V_0 - at \qquad (1)$$

In this formula, V_0 is the volume of the nourishment and V_t is the volume at given time t. For a "stable" coastline (*i.e.*, a coastline with a coastal erosion of zero m^3/m/year), with only losses in the longshore direction and "adaptation losses" in cross-shore direction, the erosion rate may be assumed to be a linear function of the extension of the nourishment into the sea. This assumption results in an exponential decay of the nourished volume (FÜHRBÖTER, 1991):

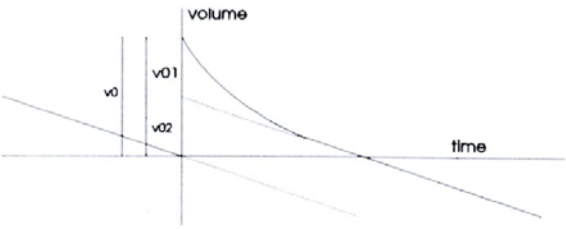

Figure 1. Change of nourished volume over time.

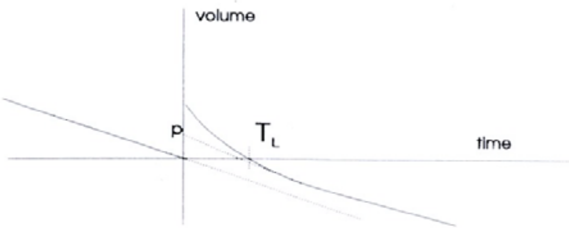

Figure 2. The value of T_L in relation to p.

$$V_t = V_0 e^{-t/T_c} \quad (2)$$

The value of T_c is a constant to be determined. Usually both situations occur at the same time:

$$V_t = V_{02} - at + V_{01} e^{-t/T_c} \quad (3)$$

with the nourished volume now partitioned into two components, V_{01} and V_{02}, as presented graphically in Figure 1.

For convenience, a parameter p may be introduced, giving the fraction of the nourished volume that becomes a permanent part of the coastal volume:

$$V_{02} = pV_0$$
$$V_{01} = (1 - p)V_0 \quad (4)$$

and consequently: Eq. (3) now becomes:

$$V_{02}(t) = pV_0 - at \quad (5)$$
$$V_{01}(t) = (1 - p)V_0 e^{-t/T_c}$$
$$V_t = pV_0 - at + (1 - p)V_0 e^{-t/T_c} \quad (6)$$

in which:

V_t = Volume of nourishment at time t (m^3/m)
V_0 = Nourished volume at t = 0 (m^3/m)
p = Fraction of the nourished volume corresponding to the natural (linear) erosion of the coastline (−)
a = Linear component of the coastal erosion (linear coastal regression) ($m^3/m/year$)
t = time (years)
T_c = Characteristic decay time of the nourishment (years), *i.e.*, after T_c years still e^{-1} = 37% of the nourishment remains. Instead of T_c the 50% or the 10% value can be used: $T_{50\%} = 0.693T_c$ and $T_{10\%} = 2.3T_c$.

The most effective beach nourishment is that which requires exactly the yearly loss, averaged over the erosion previous to the nourishment. Hence, a nourishment with p = 1 is the most effective. However, nourishment with p = 0 is not the least effective. Therefore, p is not a good efficiency parameter.

In order to develop a term for efficiency, E, a variable T_L is introduced, defined as the time until the moment when all nourished sand washed away (or in special cases, the moment that V_t becomes less than a predefined minimum V_{min}). The most effective nourishment has a volume $V_E = a \cdot T_L$. The efficiency is therefore:

$$E = \frac{V_E}{V_0} = \frac{aT_L}{V_0} \quad (7)$$

T_L can be calculated from:

$$pV_0 - aT_L + (1 - p)V_0 e^{-T_L/T_c} = 0 \quad (8)$$

The relation between T_L and p is sketched in Figure 2. In case of an evaluation, the unknown parameters in equation (6) are p, a and T_c. It can be assumed (VERHAGEN, 1992) that the erosion rate before and after the nourishment is the same. In some cases, the erosion rate before the nourishment is known and can be used. If linear erosion rate is not known, the assumption may be applied that near the end of the lifetime of the nourishment, there is only linear erosion left, giving a value of a. The other two parameters (p and T_c) can be determined by curve fitting (note: p is not determined by simply dividing V_{02}/V_0).

PROTOTYPE CASES

In order to evaluate out the mathematical scheme mentioned above, eight nourishments in Germany and the Netherlands were analyzed. Data from Germany were provided by KAMP (*personal communication*), data from the Netherlands from ROELSE and HILLEN (1993) and from RAKHORST (*personal communication*).

The Dutch nourishments were made in the

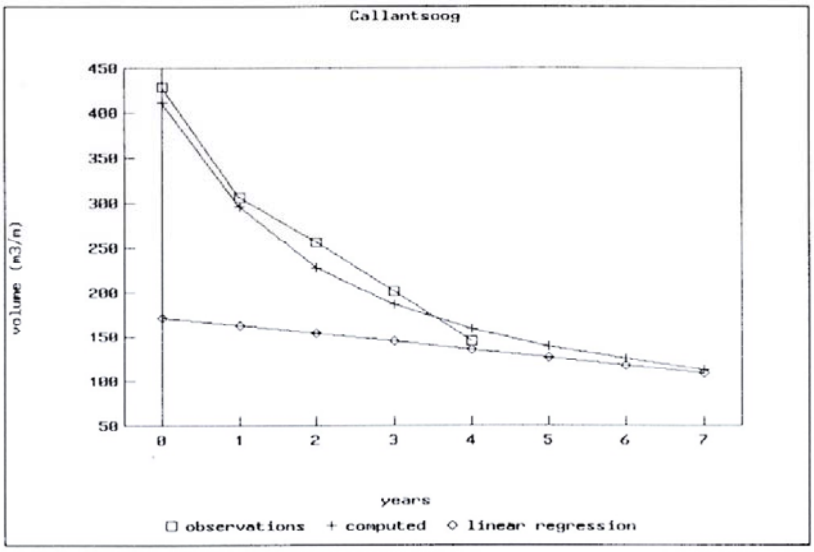

Figure 3. Nourishment at Callantsoog.

northwestern part of the country, near the villages of Callantsoog (1986), Zwanewater (1987) and De Koog (1984). The coast near Zwanewater is nearly 5 km long, and a total quantity of 1.85 million m^3 of sand has been placed. The grain size of the sediment was 270–300 μm; the original beach sand was 255 μm. The slope of the nourishment was approximately 1:20 (under water) and 1:35 on the beach. The coast at De Koog (6 km) was nourished with 3 million m^3 of sand with a grain size of 180 μm, while the original beach consisted of sand of 200 μm. The slope under water was 1:25, the beach slope was 1:40 to 1:60. At Callantsoog, (3 km) 1.3 million m^3 of sand has been placed with a grain

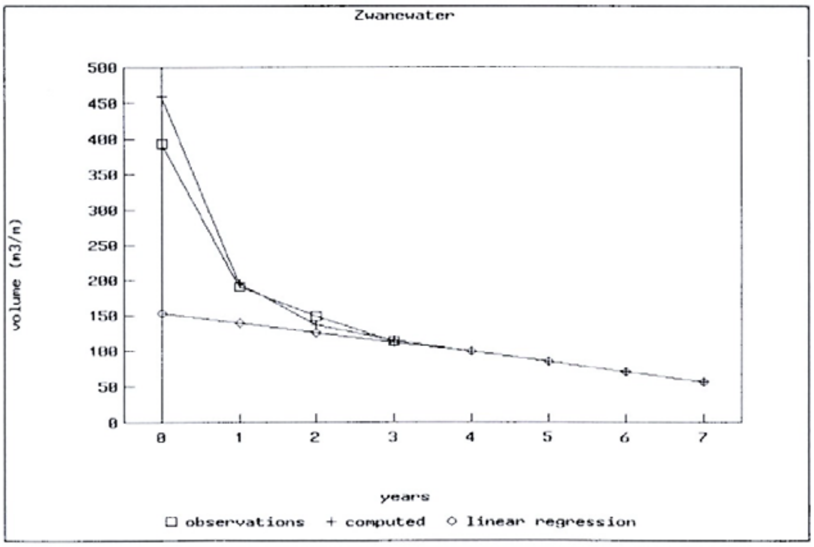

Figure 4. Nourishment at Zwanewater.

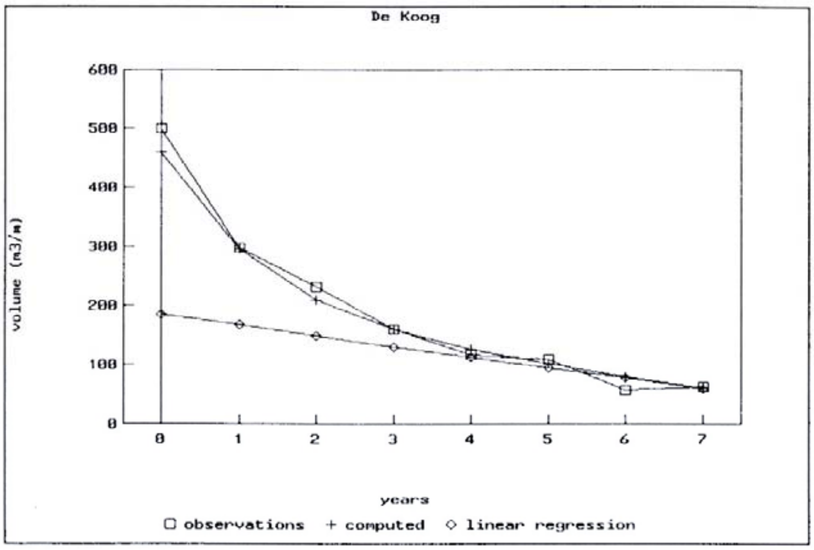

Figure 5. Nourishment at De Koog.

size of 270 μm. The original beach material here was also 255 μm. Slopes were 1:20 under water and 1:35 on the beach. The German nourishments are made on the island of Sylt, near the Danish border. The nourishment at Westerland (1972) consisted of 1 million m^3 of sand, and was placed as a stockpile of only 300 m wide. The next nourishment in Westerland (1978) was also 1 million m^3, but was placed over a total length of 900 m. In 1984 the nourishment was repeated in Westerland, 1.1 million m^3 over a total length of 1.5 km. The nourishment of Rantum was placed in

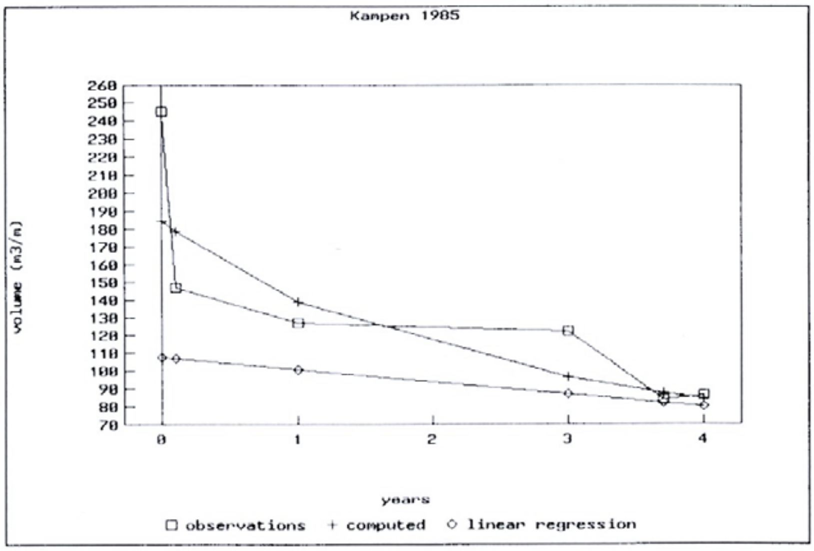

Figure 6. Nourishment at Kampen.

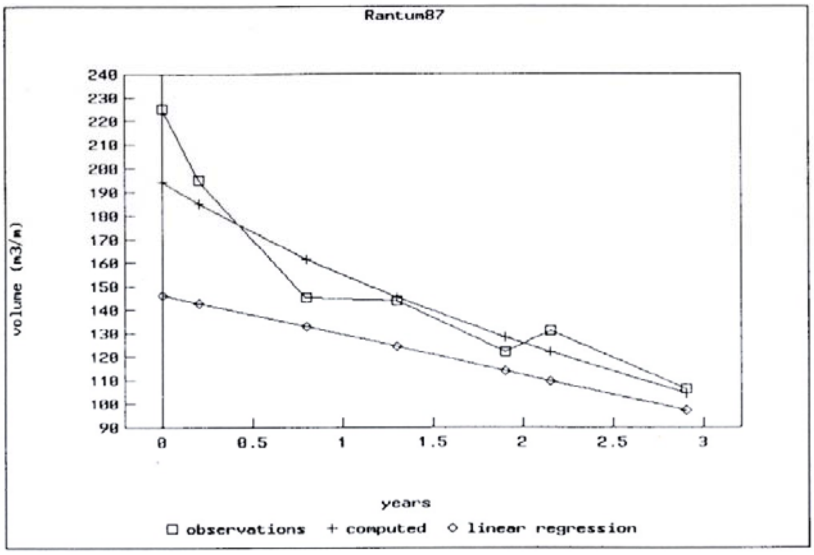

Figure 7. Nourishment at Rantum.

1987 and consisted of 1.44 million m^3 placed over a beach length of 3 km. The area near Kampen was nourished in 1985 and consisted of 1.97 million m^3 placed over a beach length of 4.6 km.

In the Dutch cases the erosion before the nourishment was known in detail. The following values were measured:

Callantsoog	9 m^3/m/year
Zwanewater	14 m^3/m/year
De Koog	18 m^3/m/year

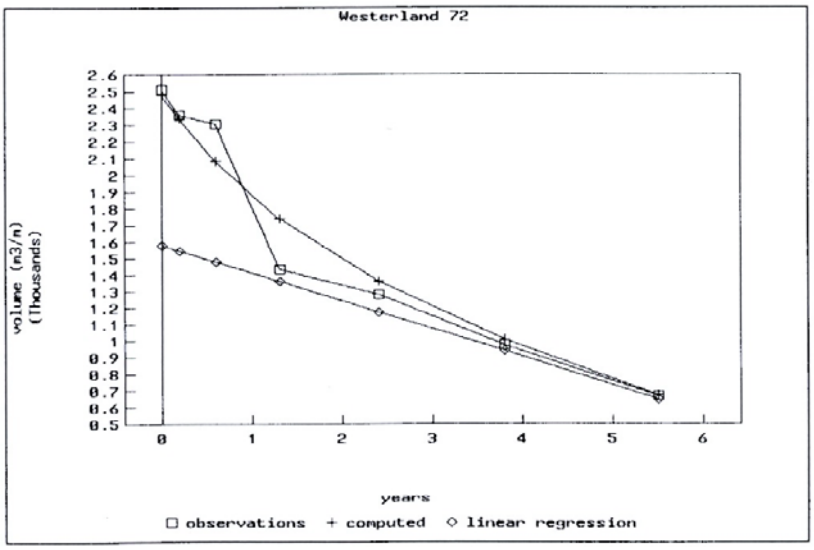

Figure 8. Nourishment at Westerland (1972).

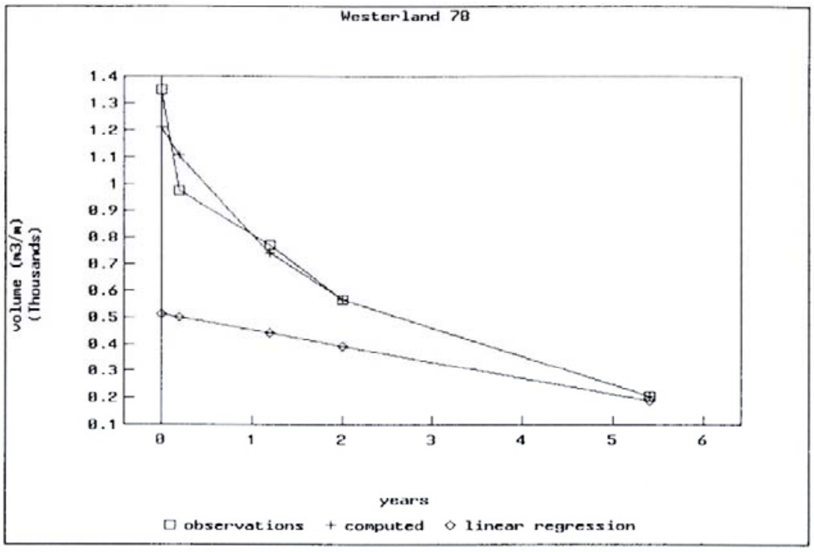

Figure 9. Nourishment at Westerland (1978).

For the German cases this value was not known, but from observations long after the nourishments, the following values have been deduced:

Kampen	7 m^3/m/year
Rantum	17 m^3/m/year
Westerland 72	170 m^3/m/year
Westerland 78	60 m^3/m/year
Westerland 84	37 m^3/m/year

The extremely high erosion rate at Westerland in 1972 is not reliable. This is mainly caused by the nourishment being executed as a stockpile over a very short beach length. The data of the measured volume were analyzed using equation (6). Standard linear regression analysis was used to find the coefficients. In case of Westerland 72 and Callantsoog, the line through the points was deter-

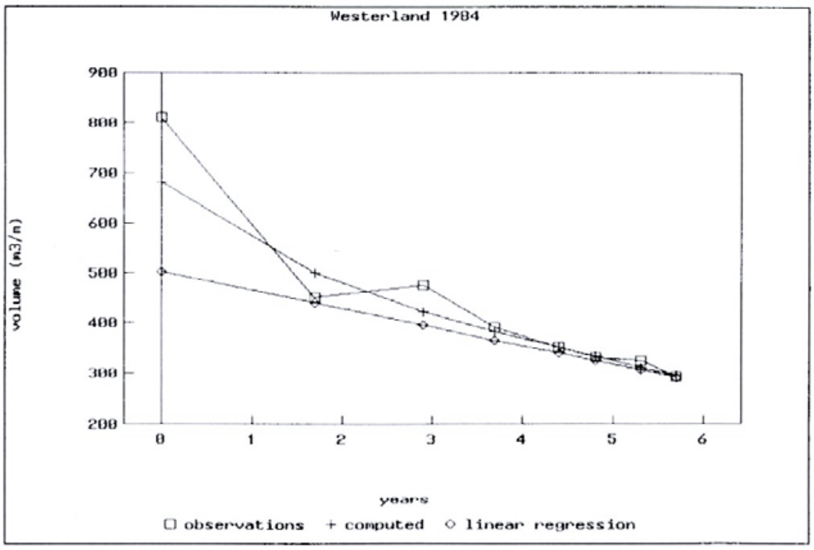

Figure 10. Nourishment at Westerland (1984).

Table 1. *Data from the analysis.*

	p	a	V_{02}	V_{01}	T_c	Corr	Initial Loss
Callantsoog	0.40	9	160	240	1.70	0.92	4%
Zwanewater	0.56	14	140	119	1.54	0.98	4%
De Koog	0.51	18	178	205	1.67	0.93	8%
Kampen	0.44	7	108	77	1.41	0.62	24%
Rantum	0.65	17	146	48	1.55	0.58	14%
Westerland 72	0.63	170	1,583	900	1.50	0.85	1%
Westerland 78	0.38	60	513	700	1.43	0.99	10%
Westerland 84	0.62	37	502	179	1.56	0.61	16%
Average	0.51				1.55		
Stand. dev.	0.11				0.10		

mined visually, not mathematically. In all cases, the correlation coefficient was determined. The results are presented in Figures 3 to 10.

SOME RESULTS

The following nourishments were analyzed with the method described above, resulting in the data of Table 1. As can be seen from the figures, in nearly all cases the computed volume at time $t = 0$ is less than the measured value on the beach (so it is less than the real nourished quantity). This initial loss is also indicated in the table above. As an average this loss is in the order of 10% of the total quantity. An extreme case is the nourishment in Kampen, where this percentage is up to 24%. This initial loss is decreased significantly by using deeper closing depth (in the German cases the closing depth is always 1 m below mean sea level), in the Dutch cases the closing depth is placed at approximately 5 m below mean sea level.

It is also clear that the variations in the values of p and T_c are quite small. For the design of a beach nourishment, this is an important finding. The average value of p is 0.52, which means that only 52% of the nourished sand contributes to combat the long term erosion. Because of all inaccuracies in the above analysis, one can say that the multiplier for the design is a factor of 2. However, one should add the 10% initial losses, as calculated in the last column of the table. So finally the multiplier in the cases analyzed is approximately 2.2 (the highest one is 2.9, Westerland 1978; the lowest one is 1.7 at Rantum).

CONCLUSIONS

The mathematical description of the change of a nourishment, using a linear component and an exponential component fits quite well with the observed decay of nourishment schemes in northwestern Europe. The characteristic decay time T_c is for all nourishments on the order of 1.5 years. The linear retreat is highly variable for each coast, but is rather independent from the nourishment schemes performed. The initial loss (loss in the first year) varies from 1–25 percent. This quantity, however, depends very much on the method of execution of the nourishment, as well as the closure depth for the volumetric analysis.

For a practical design of nourishments, when no data are available, the suggestion in VERHAGEN (1992) to apply a surcharge of 40% on the quantity required to combat the linear coastal regression, is not contradicted by the results from the data presented here.

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TECHNICAL COMMUNICATION

Assessment and Prediction of Poole Bay (UK) Sand Replenishment Schemes: Application of Data to Führböter and Verhagen Models

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ABSTRACT

COOPER, N.J., 1998. Assessment and prediction of Poole Bay (UK) sand replenishment schemes: application of data to Führböter and Verhagen models. *Journal of Coastal Research*, 14(1), 353–359. Royal Palm Beach (Florida), ISSN 0749-0208.

The performance of two major sand replenishment schemes in Poole Bay has been assessed based upon a long-term beach monitoring record. Analyses of post-replenishment volumetric decay trends have enabled a prediction of when a future replenishment scheme will be needed in Poole Bay. The ability to undertake such a prediction has altered the management philosophy in Poole Bay from a reactive to a pro-active one, and the benefits of such a change are discussed. The Poole Bay data are also applied to mathematical models that have been derived by Führböter (1991) and Verhagen (1996). These models express the volumetric decay of a replenished beach with respect to time. The site-specific modelling parameters derived from the first Poole Bay scheme have been compared with those used to calibrate the Verhagen model, and significant differences are observed. Despite this, both models provide a good fit to the measured field data. Consequently, both models have been used to extrapolate the current post-replenishment volumetric decay, to allow additional dates for a future Poole Bay replenishment scheme to be predicted with confidence, and compared with the previously predicted data.

ADDITIONAL INDEX WORDS: *Beach replenishment, coastal erosion, sediment transport.*

INTRODUCTION

Beach replenishment has gained in popularity as a shoreline management tool since the first reported case in the USA in 1922 (HALL, 1952). This is largely because it is the only form of shoreline management which directly introduces fresh sediment to the littoral budget. As such, beach replenishment has both coast protection and amenity benefits. However, despite great increases in its worldwide use, particularly since the 1970s, the understanding of the performance of replenishment schemes remains relatively poor. This is largely due to insufficient pre- and post-scheme monitoring to allow for objective project appraisal (DAVISON *et al*, 1992). Such a deficiency hinders the efficient design of new schemes and makes it difficult to "fine-tune" existing ones. Indeed, the standard traditional design practice has been simply to add an empirical multiplier factor, commonly 40%, to the required fill volume in order to account for material "losses" (VERHAGEN, 1992).

FÜHRBÖTER AND VERHAGEN MODELS

FÜHRBÖTER (1991) attempted to improve the understanding of the performance of a replenished beach by deriving a formula which related to the exponential decay in material volume with respect to time:

$$V_t = V_o e^{-t/T_c}$$

Where:

- V_t = Volume of replenishment material remaining after time t (m^3/m)
- V_o = Nourished volume at t = 0 (m^3/m)
- t = time (years)
- T_c = Characteristic decay time of the nourishment (years), *i.e.* when $t = T_c$ the equation becomes $V_t = V_o e^{-1}$ (*i.e.* 37% of the replenishment material remains on the beach).

Recent research by VERHAGEN (1996) has described a math-

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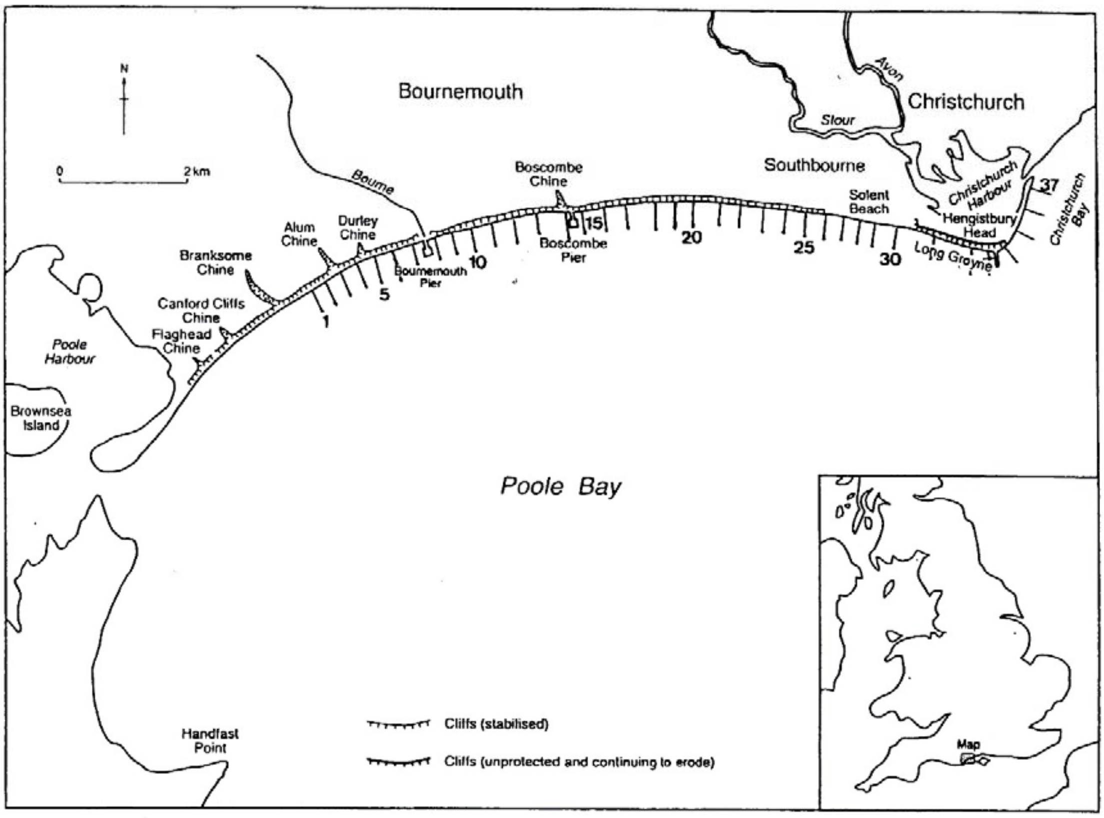

Figure 1. Location map of Poole Bay, UK.

ematical model which, in addition to a similar exponential decay component, incorporates a component relating to the linear background erosion of the coastline:

$$V_t = \text{(exponential component)} + \text{(linear component)}$$

$$V_t = ((1 - p)V_0e^{-t/T_c}) + (pV_0 - at)$$

Where:

p = Fraction of material loss attributable to linear coastal erosion (−)
a = Linear coastal erosion rate (m^3/m/year).

This latter model has been calibrated against field data from eight replenishment schemes in Germany and the Netherlands and has been proven to fit the measured data well. However, the data sets used only range between 3–6 years in duration. In an attempt to further calibrate the Verhagen model, and to compare its validity with the Führböter model, data derived from a higher intensity and longer-term beach monitoring record in Poole Bay, on the south coast of England, are applied to both.

POOLE BAY REPLENISHMENT SCHEMES AND BEACH MONITORING DATA

Poole Bay comprises the shallow embayment bounded by Handfast Point to the west and Hengistbury Head to the east (Figure 1). The characteristic beach material is fine sand in western and central parts, but it becomes coarser at Hengistbury Head where shingle dominates. The majority of this frontage has experienced a progression of protection measures to control erosion and safeguard the sandy beaches that are so vital to its tourist economy (Bray and Carter, 1996). The historical protection measures of seawalls and groynes had limited success in retaining beach material and the conventional philosophy of "hard" protection altered following a period of damage in the 1960s (Lelliott, 1989) to establish, in 1974, one of the largest and longest running programmes of beach replenishment in the U.K. (May, 1990). This programme has included three phases of sand replenishment.

BIS1

A pilot replenishment scheme (Beach Improvement Scheme 1—or BIS1) was carried out in 1970, involving the emplacement of 84,500 m^3 of dredged sand at MLW along a 1.8 km frontage (LELLIOTT, 1989).

BIS2

The experience gained from this pilot scheme gave the Local Authority confidence to undertake a full-scale scheme in 1974–1975. This involved pumping directly onto the beaches, over a 8.5 km frontage, some 654,200 m^3 of marine-dredged sand specified to replicate the indigenous material (D_{50} = 0.33 mm). This was the largest scheme of its kind at this time in the U.K. (MAY, 1990). Due to the two-stage placement operation adopted, a further 749,300 m^3 of dredged sand was left in artificially created nearshore dumpsite pits, but ultimately a large proportion of this material moved onshore to further nourish the beaches (HODDER, 1986). After remaining effective for about 13 years, critically low beach levels recurred in 1987, damage to seawalls occurred, and MHW migrated landward to intercept the seawall itself.

BIS3

Subsequently a third sand replenishment scheme was undertaken in three phases from 1988–1990, involving the deposition of 998,730 m^3 of dredged fill directly onto the beach. This material was pumped onshore above MHW and allowed to form its own profile. The coincidental dredging of the Poole Harbour entrance at the same time as the need for beach replenishment material substantially reduced the costs of BIS3 (TURNER, 1994).

A bi-annual beach profiling survey was instigated in July 1974, and has been maintained to date. Suitable sites for profile lines were chosen at regular intervals along the coast (numbers 1 to 37 in Figure 1) and surveys on fifty dates have so far been processed and analysed (Table 1). The beach profiles are in two parts, a topographic survey above MLW and a hydrographic survey that extends from MHW to 450 m seaward of the origin. This seaward limit of 450 m is approximately the point at which the 1:400 offshore gradient changes to 1:40 and represents the "closure point" for erosion (*i.e.* no significant changes occur beyond this point). The surveying methods adopted were the best available technology and have been steadily updated with technological advances. The most recent surveys have been undertaken using a Global Positioning System. Since the origin (a pin in the seawall) and orientation of each profile line has been fixed and consistent measurement procedures have been maintained throughout, the data sets are of extremely high quality (GAO and COLLINS, 1994). The availability of such a long-term monitoring record is very rare and must be considered a valuable asset.

The total net beach volume in Poole Bay (*i.e.* the volume of beach material overlying the *in-situ* geological substrate) has been calculated from these data. It can be seen from Figure 2 that both BIS2 and 3 produced major volumetric improvements, followed by a two-phase decay. BIS2 increased the total net beach volume from a low of about 6 million m^3 in early 1975 to a peak of 7.7 million m^3 in 1979, after which the volume decreased to 6.9 million m^3 in 1988. The peak volume associated with BIS2 occurred some four years after direct replenishment stopped. This was due to the continued

Table 1. *Dates of Poole Bay beach profile surveys.*

Survey Date	Survey No.	Remarks	Survey Date	Survey No.	Remarks
01/07/74	1		27/03/82	26	
01/08/74	2	Incomplete data	03/11/82	27	
26/11/74	3	Topographic	15/04/83	28	
14/12/74	4	Incomplete data	12/11/83	29	
26/01/75	5	Topographic	19/03/84	30	
13/02/75	6	Incomplete data	12/10/84	31	
25/02/75	7		08/05/85	32	
13/03/75	8	Incomplete data	15/10/85	33	
28/03/75	9		23/06/86	34	
12/07/75	10		01/03/87	35	
05/09/75	11		01/10/87	36	Incomplete data
18/11/75	12	Partial survey	01/05/88	37	
30/03/76	13	Incomplete data	13/09/88	38	
23/09/76	14		19/04/89	39	
05/04/77	15	B6&7 data lost	30/09/89	40	
13/09/77	16		07/12/89	41	
01/04/78	17		27/03/90	42	Partial survey
17/10/78	18		01/05/90	43	
27/04/79	19		29/11/90	44	Partial survey
11/09/79	20		17/04/91	45	
29/04/80	21		11/09/91	46	
30/10/80	22	Topographic	05/05/92	47	
13/11/80	23		10/10/92	48	
06/04/81	24		26/03/93	49	
16/10/81	25		04/11/93	50	

onshore migration of the dredged material which was left in nearshore dumpsite pits, a process which continued until the stock was exhausted. The post-peak volumetric decay comprised two phases, an early rapid loss rate of 286,700 m^3a^{-1} for two years, followed by a slower rate of 26,100 m^3a^{-1} for the following seven years until BIS3 was commenced in 1988. BIS3 increased the volume to a peak of 8 million m^3 in 1990, and thereafter it decreased to 7.89 million m^3 in late 1993, following a similar trend to the BIS2 post-peak decay.

Due to the consistency in the rate of beach volume change after both replenishment schemes, the date for a future beach replenishment scheme (BIS4) can be anticipated using an extrapolated rate of volumetric decline from the present day. After BIS2 in 1974–1975, unacceptable damage to the seawall began to re-occur in 1988, when the total net beach volume was 6.9 million m^3. Assuming this volume to be a critically low volume (V_c) at this particular time, and (for modelling purposes) assuming sea-level rise to be the primary factor in causing beach erosion, it can be anticipated when BIS4 will be required. In order to maintain the existing beach levels relative to sea-level rise, a certain quantity of beach material will be required. This quantity can be calculated by multiplying the assumed rate of sea-level rise (6 mma^{-1} onset in 1996 (BRAY *et al.*, 1992; 1994)) by the length of coastline considered (11,143 m) by the active width of beach profile (450 m). Consequently, a critical volume baseline can be created which increases from the V_c value recorded in 1988 (6.9 million m^3) by a rate of 30,086 m^3a^{-1} (Figure 3). This graph illustrates that the extrapolated net beach volume decline rate intercepts the critical volume baseline in 2003. However, this critical volume baseline has been based upon the V_c which was a threshold that led to seawall damage. Conse-

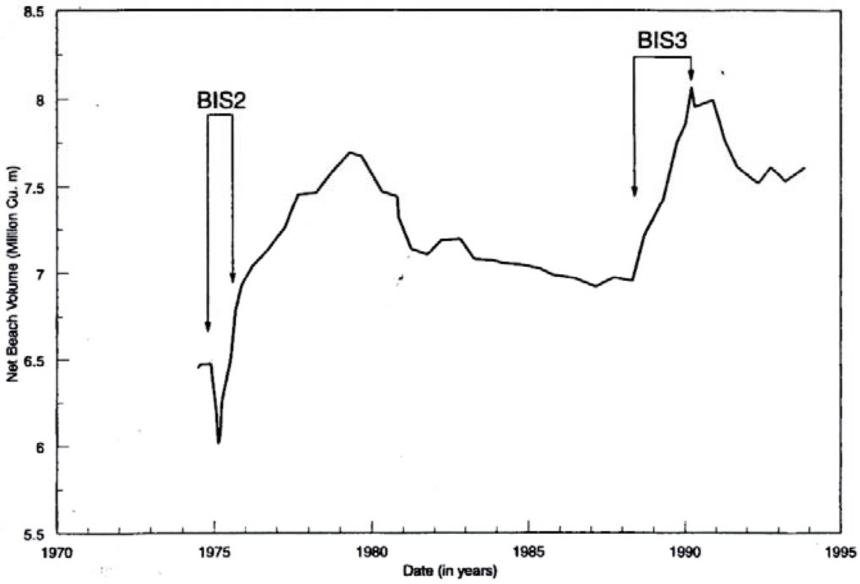

Figure 2. Monitored net beach volume in Poole Bay.

quently, in order to prevent such damage occurring, BIS4 will be required before this date. It may also be possible to define a V_c value and critical volume baseline with respect to the loss of tourist revenue due to the decline in amenity value of the beach, although inadequacies in current economic assessments of environmental and social issues such as these at present hinder such an analysis. Continued monitoring of beach volume should identify whether the predicted rates of

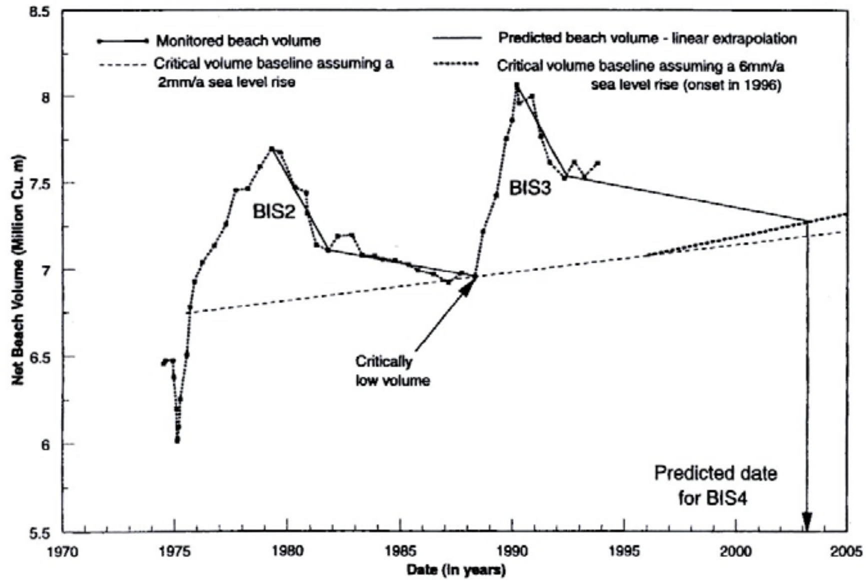

Figure 3. Net beach volume predicted.

Table 2. *Modelling parameters related to BIS2.*

Parameter	Definition	Value
V_o	Nourished volume at $t = 0$	66.5 $m^3 m^{-1}$
V_{37}	Nourished volume at $t = T_c$	24.6 $m^3 m^{-1}$
T_c	Characteristic decay time	1.68 years
a	Linear coastal recession	2.08 $m^3 m^{-1} a^{-1}$
p	Fraction of decay corresponding to natural linear coastal recession	0.28
t	Time increments used in models	0.1 years

volumetric decline are reliable, or whether they might be sensitive to changes in external regulators (*e.g.* wave climates, sea-level rise, and most importantly storm frequency). The advantage of replenishment is that it can be adjusted to cope with unforseen situations provided that adequate monitoring is undertaken (STIVE *et al.*, 1991).

APPLICATION OF DATA TO FÜHRBÖTER AND VERHAGEN MODELS

The predicted date for BIS4 was based upon a two phase post-peak decay pattern suggested by the author. Each phase of the decay assumes a linear decline, each comprising distinctly different rates of material loss. The initial relatively rapid phase of volumetric decay is attributable to "profile adjustment" during which dynamic equilibrium conditions are re-established, whilst the longer duration second phase exhibits slower rates of decay attributable to background erosion. However, the predictive models proposed by FÜHRBÖTER (1991) and VERHAGEN (1996) assume the post-peak decay to follow an exponential pattern. Therefore, the raw data have been applied to both models in order to determine whether any improvement in the accuracy of the previously predicted date for BIS4 can be achieved. The site-specific parameters required to run both models have been derived by analysing the BIS2 post-peak volumetric decay (Table 2).

Figures 4 and 5 demonstrate that both models provide relatively good fits to the data which were directly measured after BIS2, although the two-phase linear decay fits these data equally well. The statistical coefficient R^2 (the sum of the squares of the differences between predicted and actual volumes, divided by the number of data points) yields values of 6.3 for the two-phase linear decay, 7.3 for the Verhagen model, and 11.3 for the Führböter model. This suggests that it is justifiable to employ the two-phase linear decay technique when the change between decay rates is so distinct. Of the two exponential decay models adopted, the Verhagen model provides the better representation of the slower rates of material loss which are substantially attributed to linear background coastal erosion, indicating that this model is the more representative of the two.

The exponential decay curves that have been calculated based upon BIS2 scheme parameters have also been applied to BIS3 in order to obtain predicted dates for the requirement for a future replenishment scheme. Since the Verhagen model yields a better representation of the slower rates of decline towards the tail of the curve, it is likely that it will also result in the most realistic predicted date for BIS4. Indeed, the predicted date of early 2002 fits closely to the value obtained from the two-phase linear decay predictions (early 2003). However, the Führböter model predicts a date for BIS4 of late

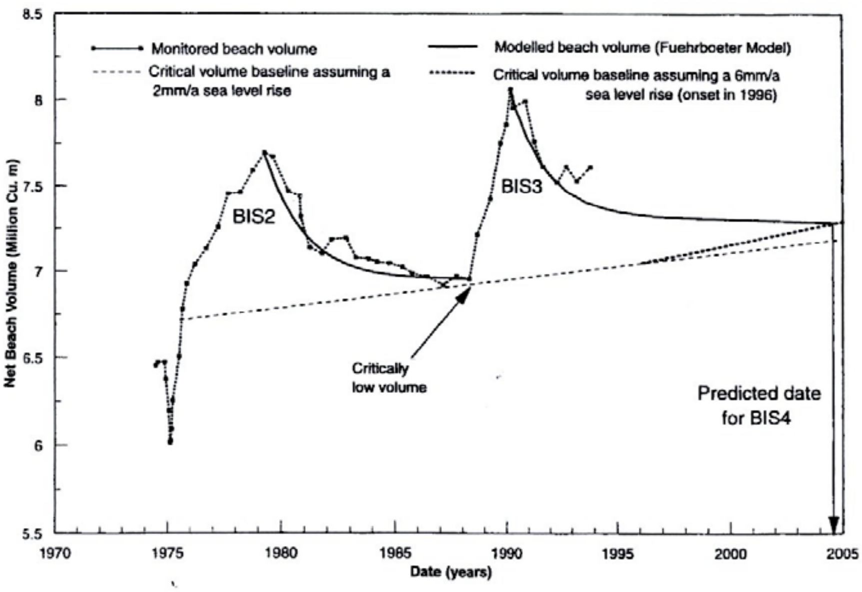

Figure 4. Net beach volume predicted: Führböter model.

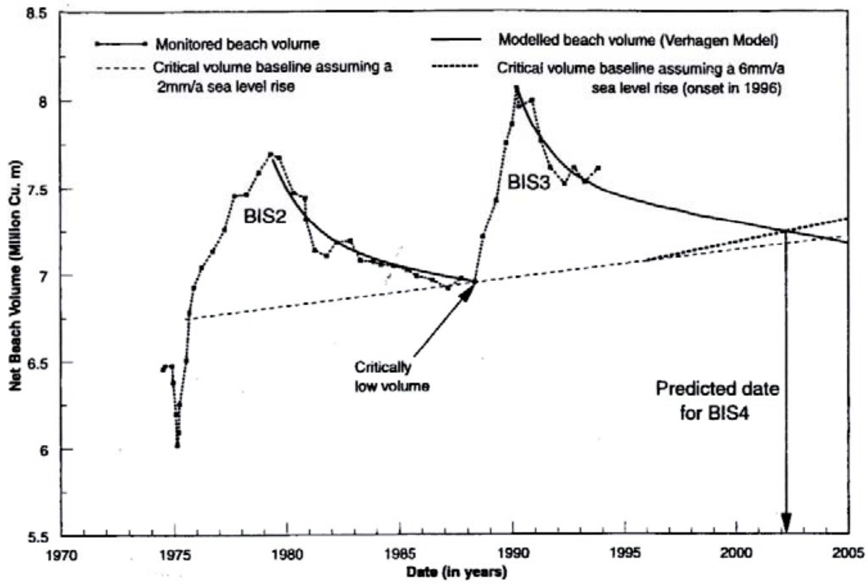

Figure 5. Net beach volume predicted: Verhagen model.

2004 which, although not significantly different, is likely to be an over-estimate since it doesn't fit the measured data so closely.

CONCLUSION

Table 3 demonstrates that the linear background coastal erosion (a) in Poole Bay is smaller than the values derived by VERHAGEN (1996) from the German and Dutch replenishment schemes. Additionally, the parameter p, representing the proportion of material loss attributable to this linear erosion is smaller for Poole Bay. This suggests that the Poole Bay frontage may have experienced less severe storms during the monitoring period than the schemes reported on by VERHAGEN (1996), although no data were presented on storm frequencies.

Despite numerous previous attempts to model the performance of replenished beaches (DEAN and YOO, 1992; VERHAGEN, 1992; WORK and DEAN, 1995), the general consensus is that there is little or no correlation between modelled and actual scheme performance (PILKEY and CLAYTON, 1989; LEONARD *et al.*, 1990a,b). One reason for such a finding is that site-specific conditions are believed to play a far greater role in determining the performance of beach replenishment schemes than for other forms of coastal defence, and as such the most accurate technique for predicting beach response to, and lifespan of replenishment schemes is previous experience on the same beach (PILKEY *et al.*, 1994). Long-term beach monitoring is, therefore, critical if accurate and reliable models concerning replenishment scheme longevity are to be developed. The presence of such a long-term high quality beach monitoring record in Poole Bay, and the strong correlation between modelled and observed volumes after BIS2, enables the BIS3 data to be applied to the models with a relatively high degree of confidence, and therefore reliable dates for the time at which BIS4 will be required can be predicted. This has resulted in a change the management philosophy in Poole Bay from a reactive one (previous replenishment schemes were prompted by seawall damage) to a proactive one (sources of fill material for BIS4 are currently being sought in advance of the predicted date). This will, in the long run, have the economic benefits of saving on seawall damage and allowing finding for future replenishment schemes to be sought in advance. It should also help to ensure that consistent beach volumes can be maintained for amenity purposes.

Table 3. *Comparison of modelling parameters derived from field data.*

	P (−)	T_c (years)	a (m^3 m^{-1} a^{-1})
Verhagen (1996) data			
Minimum value	0.38	1.41	7.0
Maximum value	0.65	1.70	170.0
Average value	0.51	1.55	41.5
Poole Bay data	0.28	1.68	2.1

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