CHAPTER 116

REALISTIC ECONOMIC BENEFITS FROM BEACH NOURISHMENT

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ABSTRACT

A method is presented and illustrated with examples to establish appropriate storm damage reduction and recreational benefits from beach nourishment projects. Unlike previous methods, benefits to project adjacent areas are recognized due to sand transport out of the project area and deposition on adjacent beaches. Assuming homogeniety along the shoreline, the character of storm damage reduction and recreational benefit relationships are such that sand transported from a project area and deposited on adjacent beaches always results in an <u>increase</u> rather than a reduction in benefits. A central element in calculating storm damage reduction benefits is the establishment of a proportional damage curve for upland structures as a function of beach width and storm return period. To illustrate the method, limiting cases are presented in which (A) all sediment remains within the area placed, and (B) all sediment spreads out immediately over a long segment of shoreline. Using Monte Carlo simulation to represent the random character of the storms, the method is applied to 15 realistic cases with varying project lengths, representative wave heights, added beach widths and interest rates. The present worth storm damage reduction and recreational benefits are calculated to demonstrate the effects of the various parameters. It is found that for short project lengths and relatively large wave heights, the benefits from project adjacent areas exceed those in the project area where the sand is placed. Although no littoral control structures, such as jetties are included in the present application, the method could be extended readily to include their effects.

INTRODUCTION

Policies and methodologies should evolve continuously to remain consistent with modern understanding of coastal processes and the true equities of those residing along the shoreline. Several changes have occurred in the last few decades that argue for an examination and modifications of present economic analysis procedures relating to beach

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nourishment: (1) It is now clear that on a long, uninterrupted shoreline, good quality sand placed in a beach nourishment project will eventually be transported out of the region placed, but will remain within the active nearshore system, (2) Sand transported from a project area and deposited on project adjacent areas provides not only continuing damage reduction and recreational benefits, but provides enhanced benefits, and (3) With increasing concern over the use of "hard structures" as a means of shoreline control, beach nourishment will play an increasing future role.

This paper considers the economic consequences of sand eroded from a beach nourishment project area and deposited on project adjacent areas. Realistic damage reduction relationships and recreational benefits for a widened beach are utilized to demonstrate that this evolution process actually results in a net increase in project benefits. Benefits from simple limiting cases are examined in which (1) the sand remains in the area placed, and (2) the sand spreads out immediately. A direct procedure is presented to account for total present worth project benefits. The procedure utilizes Monte Carlo simulation to faithfully represent the probability of storm occurrences.

Although the methodology presented here is not applicable to shorelines which include features which would cause longshore sediment transport interruptions, the concepts could be extended readily for such cases.

CONCEPTS

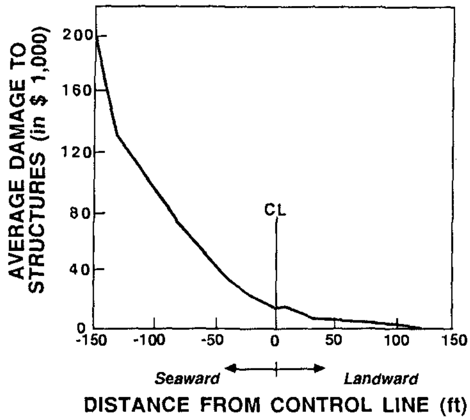
There are two simple concepts which are critical to the methodology presented here:

(1) Good quality sand placed in a beach nourishment project will be eroded from the area placed but will remain indefinitely in the active nearshore region, and

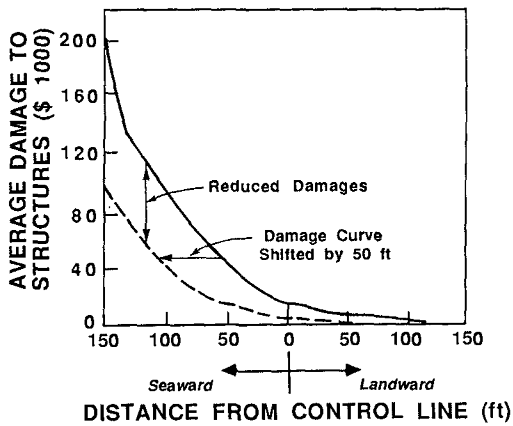
(2) The greatest storm damage and recreational benefits are generally realized for the initially narrower beaches.

The first concept will be considered as valid without much discussion. Although "good quality sand" is a matter of degree, here it refers to sand that is greater than 0.14 mm or so in diameter and that is coarser than or as coarse as the material originally present on the beach. For those nourishment materials in which the above is not the case, this paper refers to that sand fraction which is compatible. Monitoring results from a number of beach nourishment projects have demonstrated the first concept, for example at Port Canaveral, FL (Dean, 1988) and Captiva Island, FL (Tackney and Associates, 1983).

The second concept is illustrated by Figure 1a which represents a survey (by Shows, 1978) of the structural damage caused by Hurricane Eloise (1975) in Bay County, FL as a function of proximity of the structures relative to a jurisdictional control line which is generally parallel to



a) Damage to Structures in Relation to their Location with Control Line (Resulting from Study of 540 Structures in Bay County after Hurricane Eloise, by Shows, 1978).



b) Damage Reduction Due to Beach Nourishment Advancing the Profile Fifty Feet Seaward.

Figure 1. Structural Damages Due to Hurricane Eloise (1975) and Example of Reduced Damages by Beach Nourishment Advancing the Shoreline Seaward by Fifty Feet.

the shoreline. Of particular significance in Figure 1a is the steeply sloped portion of the damage curve near its seaward end and the relatively mild slope near its landward end. It is instructive to consider the effect of a beach nourishment project which displaces the beach seaward by a certain amount such as 50 ft as shown in Figure 1b. It is seen that due to the slope characteristics discussed above, the greatest damage reductions occur for those structures which initially have very little beach in front of them. Figure 2 presents the damage reduction per structure associated with an additional one foot of beach width. For the narrower initial beach widths, the reduction is approximately $3,000 per structure whereas for greater initial beach widths, the damage reduction per structure is less than $500. In summary, the damage reduction benefits are greater for beaches which are initially much narrower.

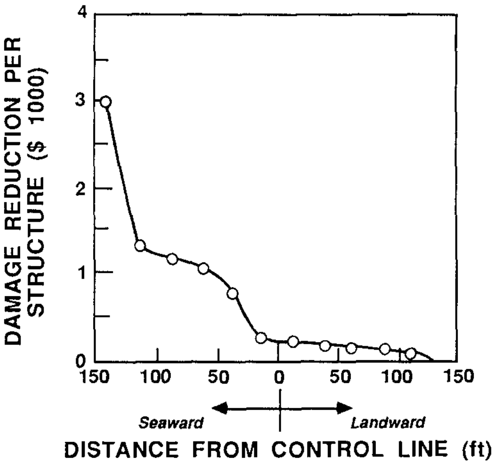
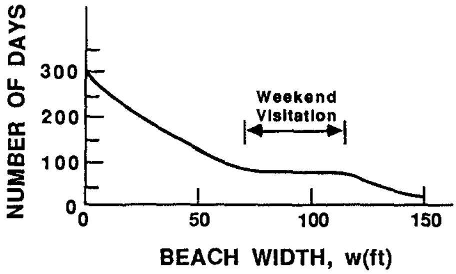


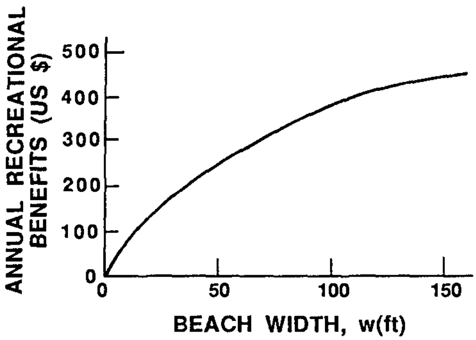
Figure 2. Damage Reduction Per Structure Resulting from a One Foot Wide Additional Beach, as a Function of Structure Location Relative to Control Line. Based on Hurricane Eloise Data.

The same concepts demonstrated above for damage reduction benefits apply for recreational benefits. Figure 3 presents the hypothetical usage and associated recreational benefits for beaches of varying widths. The number of people using the beach will increase with beach width; however, the rate of increase decreases for the greater widths. The results in Figure 3b are based on a visitation value of $6.00 per visitor per day and a plan area visitation requirement of 200 square feet. The annual recreational benefits associated with an additional foot of beach width versus initial beach width, based on Figure 3, are presented in Figure 4. As before, it is seen that the greatest benefits occur for the initially narrower beaches.

Referring to Figure 5, the significance of greater benefits for initially narrower beaches is that as a beach nourishment project evolves with the beach fronting the project area narrowing and the project adjacent beaches widening, benefits are lost in the initially wider project area. This loss of benefits is small compared to the gain of relatively large benefits in the initially narrow project adjacent areas. Assuming that the value of the upland structures protected by the project and the initial beach



a) Number of Days Per Year that Full Beach Width is Used.



b) Annual Recreational Benefits vs Beach Width Per Foot of Beach Length.

Figure 3. Hypothetical Usage and Recreational Benefits of Sandy Beaches.

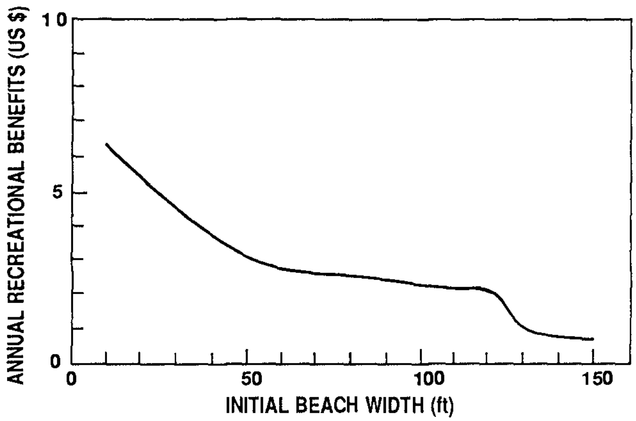


Figure 4. Annual Recreational Benefits Per Additional Foot of Beach Width as a Function of Initial Beach Width, Per Foot of Beach Length. Developed from Figure 3b.

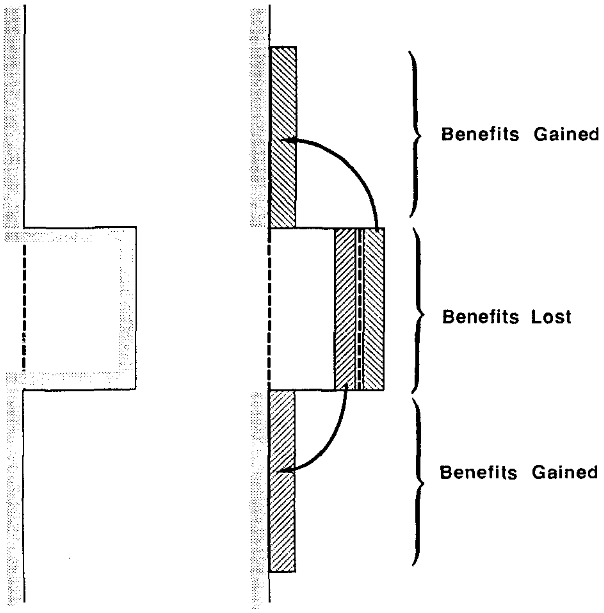


Figure 5. Schematic of Erosion of Nourished Area and Deposition in Project Adjacent Areas.

widths in project adjacent areas are uniform along the beach, there is always a net gain in storm reduction benefits as a result of project evolution. Similarly with respect to recreational benefits, assuming that the need for and access to recreational beaches are uniform, etc., the net effect of project evolution is a gain in recreational benefits.

METHODOLOGY

The methodology will be described and illustrated for idealized cases of no project evolution and rapid project evolution and general cases of benefits due to project evolution over realistic time frames.

Shoreline Evolution Model

The shoreline evolution model adopted here will be that due to Pelnard-Consideré for an initially rectangular planform as presented in Figure 6. The factor G is the so-called "longshore diffusivity" and for small angles of wave incidence is

$$G = \frac{K\, H_b^{5/2}\, \sqrt{g/\kappa}}{8(s-1)(1-p)(h_* + B)}$$

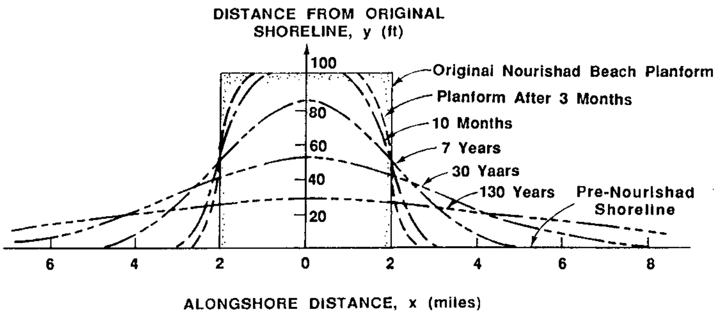


Figure 6. Example Solution of Evolution of Initially Rectangular Beach Planform. Pelnard Considere Method. Wave Height, H_b = 2.0 ft, Initial Nourished Beach Width = 100 ft, Fill Length, ℓ = 4 miles, t = time.

in which K is the sediment transport factor usually taken as 0.77, H_b is the representative breaking wave height, g is gravity, κ is the spilling breaker ratio (on the order of 0.8), s is the ratio of sediment specific gravity to that of the water in which transport is occurring, p is the in situ porosity and (h_*+ B) is the vertical extent of beach profile response.

Storm Damage Reduction Benefits

Development of storm damage reduction benefits commences with the establishment of the relationship of a proportional storm damage factor, D, as a function of beach width fronting the structure, w, and storm return period, T_R. Figure 7 presents one example of such a relationship which has been used in the state of Florida Beach Management Plan. Development of this relationship is by no means trivial and should be based on an analysis of the expected damage to a range of representative structures as well as calibration with available storm results if such data are available. The proportional storm damage factor, D, depends on the foundation and structural and elevation characteristics of the buildings as well as the beach morphology, and presence and integrity of coastal protection structures, etc.

With the availability of $D(w,T_R)$ it is possible to predict the present worth damage reduction benefits PWDRB(N) during N years by the following equation

$$PWDRB(N) = \sum_{n=1}^{N} \frac{1}{(1+I)^n} \int_{\substack{\text{Project}\\ \text{Area}}} V(x,n)\left[D(w(x,n)T_R(n))-D(w_o,T_R(n))\right]dx$$
$$+ \sum_{n=1}^{N} \frac{1}{(1+I)^n} \int_{\substack{\text{Project}\\ \text{Adjacent}\\ \text{Areas}}} V(x,n)\left[D(w(x,n),T_R(n))-D(w_o,T_R(n))\right]dx \qquad (1)$$

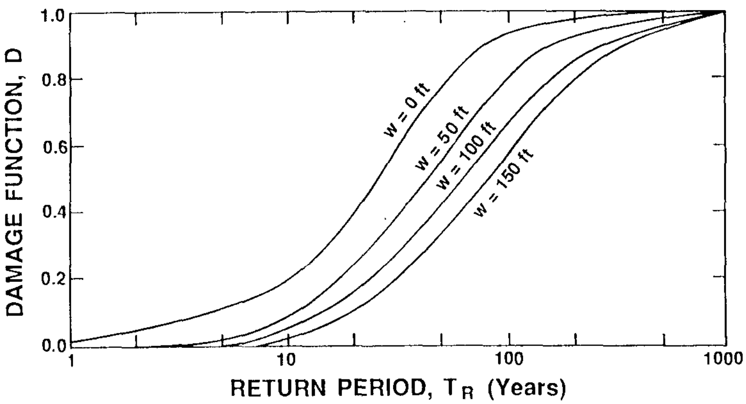


Figure 7. Hypothetical Proportional Storm Damage, D, as a Function of Storm Return Period, T_R, and Beach Width, w.

in which I is the interest rate and V(x,n) represents the structure value at a location, x, at a time n years into the future. $T_R(n)$ is the storm return period n years into the future. The two integrals differ only in their respective intervals of integration and are written separately here to illustrate the contributions from the two areas.

Eq. (1) accomplishes the objective of providing methodology for quantifying storm damage reduction. However, it is instructive to develop concepts further. Referring to Figure 7 which presents the proportional storm damage factor, D, the expected damage by a single storm $\bar{D}(w)$ as a function of beach width, w, is

$$\bar{D}(w) = \int_0^1 D(w,T_R)\,p(D)\,dD \tag{2}$$

in which p is the probability density function and is related to the cumulative probability distribution P by

$$p(D) = \frac{dP}{dD} \tag{3}$$

and noting that

$$T_R = \frac{1}{P} \tag{4}$$

Eq. (2) simplifies to

$$\bar{D}(w) = \int_0^1 D(w,T_R)\,\frac{dP}{dD}\,dD = \int_0^1 D(w,T_R)\,dP \tag{5}$$

Figure 8 presents $\bar{D}$ as a function of beach width as developed from Eq. (5). It is noted that this distribution is qualitatively similar to damages experienced in Hurricane Eloise (Figure 1) which was approximately a 70 year storm.

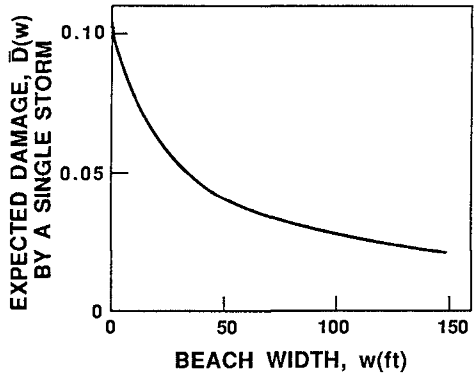


Figure 8. Expected Damage $\bar{D}(w)$ Due to a Single Storm as a Function of Beach Width, w.

Assuming that the value of the upland structures remain constant with time and that damaged structures are rebuilt to the same standards (both considerable assumptions), the present worth damage factor, PWDF(w) as a function of beach width for N years into the future is

$$PWDF(w,N) = \sum_{n=1}^{N} \frac{1}{(1+I)^n} \bar{D}(w) = \frac{1}{I} \left[1 - \frac{1}{(1+I)^N}\right] \bar{D}(w) \quad (6)$$

and again, I is the interest. The bracketed factor in Eq. (6) approaches unity with large N. Table I presents values of PWDF(w,∞) for several beach widths interest rates. It is noted that the present worth damage factor can range as high as 1.31 for the case of zero beach width and an interest rate of 8%.

TABLE I

PRESENT WORTH DAMAGE FUNCTION, PWDF(w,∞)
VERSUS BEACH WIDTH, w, FOR ALL FUTURE DAMAGE

Interest Rate	Present Worth Damage Function, PWDF(w,∞) For Beach Width, w			
	0 ft	50 ft	100 ft	150 ft
6%	1.75	0.67	0.47	0.35
8%	1.31	0.50	0.35	0.26
12%	0.88	0.33	0.23	0.18

Idealized Cases

In contrasting project benefits realized within the project area to those outside the project area, it is instructive to consider two simple cases:

Case (A). All sediment remains within the area placed, and

Case (B). The sediment placed spreads out immediately over a long segment of shoreline.

Case (A).

The expected storm damage reduction benefits due to a single storm are

$$(SDRB)_A = [\bar{D}(w_o + \Delta w) - \bar{D}(w_o)]\ell \tag{7}$$

Case (B).

Denoting the (long) distance over which the sediment has been distributed as ℓ' and the associated additional width as $\Delta w'$, we have

$$(SDRB)_B = -\left(\frac{\partial \bar{D}}{\partial w}\right)_{w_o} \Delta w'\ell' \tag{8}$$

and since sediment is conserved $\Delta w\ell = \Delta w'\ell'$,

$$(SDRB)_B = -\left(\frac{\partial \bar{D}}{\partial w}\right)_{w_o} \Delta w\ell \tag{9}$$

The ratio, R_{SD}, of storm damage reduction benefits for the case of sand spreading out immediately to the case in which sand remains where placed is

$$R_{SD} = \frac{-\left(\frac{\partial \bar{D}}{\partial w}\right)_{w_o} \Delta w}{[\bar{D}(w_o + \Delta w) - \bar{D}(w_o)]} \tag{10}$$

It is noted that the ratio R_{SD} is always greater than unity. As shown in Figure 9, the interpretation is simple with the numerator representing the tangent of the damage curve at w_o and the denominator the secant slope between w_o and $w_o + \Delta w$. Due to the character of the curve, the ratio will always exceed unity. Figure 10 presents the ratio R_{SD} vs w_o for several values of Δw.

The same general discussion presented above applies to recreational benefits relationships. The ratio of benefits R_{RB} for a project that spreads out immediately to one that remains in place is

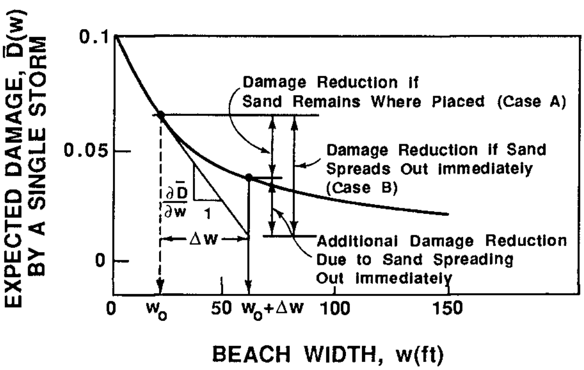


Figure 9. Interpretation of Damage Reduction Benefits if Sand Remains Where Placed (Case A) and if Sand Spreads Out Immediately (Case B).

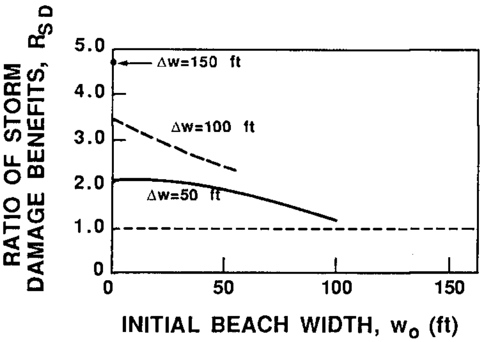


Figure 10. Ratio of Storm Damage Benefits, R_{SD}, vs Initial Beach Width, w_o, and Additional Beach Width, Δw. R_{SD} is Ratio of Storm Damage Benefits for Sand Which Spreads Out Immediately to Those for Which Sand Remains Where Placed.

$$R_{RB} = \frac{\left(\frac{\partial R}{\partial w}\right)_{w_o} \Delta w}{\left[R(w_o + \Delta w) - R(w_o)\right]} \tag{11}$$

and this ratio will always exceed unity by the same argument as for the damage reduction benefits. For the recreational benefits shown in Figure 3, values of the ratio, R_{RB}, are presented in Figure 11.

RESULTS

Prior to presenting results for the general case, in which the beach planform evolves with time, it is worthwhile to consider the variables which will tend to favor Case A (sand remains in place) or Case B (sand spreads out immediately). Case A conditions would tend to dominate for:

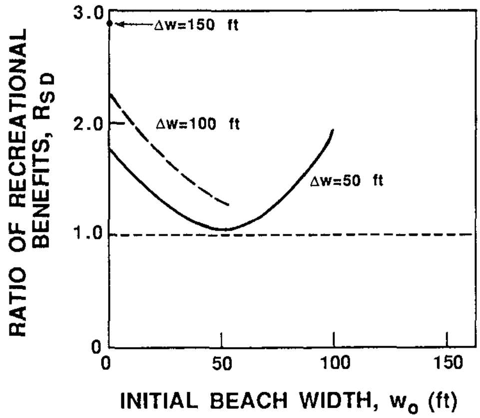


Figure 11. Ratio of Recreational Benefits, R_{RB}, vs Initial Beach Width, w_o, and Additional Beach Width, Δw. R_{RB} is Ratio of Recreational Benefits for Sand Which Spreads Out Immediately to Those for Which Sand Remains Where Placed.

Large Beach Fill Lengths, ℓ
Low Wave Height, H_b
Small Transport Coefficient, K
Small Additional Beach Widths, Δw
High Interest Rates, I

and vice versa for Case B.

The methodology described in the previous section was incorporated into a computer program which was "exercised" for the variable values shown in Table II. Results will be presented in two different forms.

Figure 12 presents variations of storm damage and recreational benefits with time for Run 5. The relatively large wave height and short beach fill associated with Figure 12 favors Case B conditions and it is seen that the dominant benefits occur within the adjacent project areas. It is also of interest to note that the benefits in the project adjacent areas lag those in the project area due to the time required for sediment transport to these adjacent areas. The longer project lengths and smaller wave heights would favor Case A conditions and the benefits inside the project area would dominate and commence quite early.

Table II summarizes results for all 15 runs conducted.

SUMMARY AND CONCLUSIONS

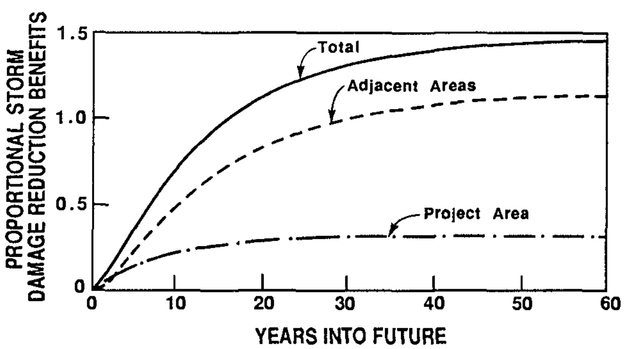
The methodology and results presented herein support the following statements.

Wider beaches seaward of structures perform as effective energy dissipators during storm conditions and, where

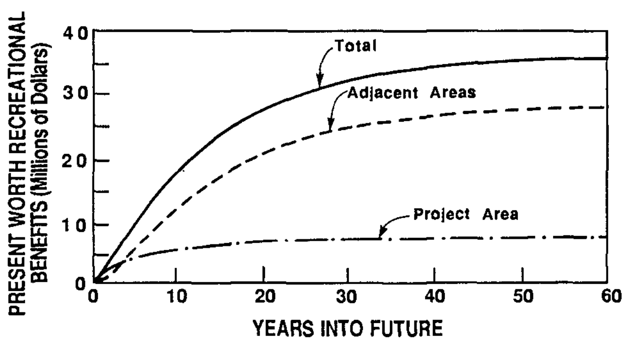
TABLE II. PRESENT WORTH STORM DAMAGE AND RECREATIONAL BENEFITS FOR VARIOUS WAVE AND PROJECT CONDITIONS

Run	Characteristics					Storm Damage Reduction*			Recreational Benefits**		
	Project Length, ℓ, (miles)	Wave Height H_b (ft)	Initial Beach Width w_o (ft)	Added Beach Width Δw (ft)	Interest Rate I	In Project Area	In Project Adjacent Area	Total	In Project Area	In Project Adjacent Area	Total
1	1.0	1.0	0	100	0.08	0.368	1.037	1.405	4.4	12.7	17.1
2	1.0	2.0	0	100	0.08	0.176	1.434	1.610	2.1	17.8	19.9
3	1.0	4.0	0	100	0.08	0.072	1.561	1.633	0.9	19.7	20.6
4	2.0	1.0	0	100	0.08	0.592	0.532	1.124	15.4	13.0	28.4
5	2.0	2.0	0	100	0.08	0.323	1.136	1.459	7.6	27.9	35.5
6	2.0	4.0	0	100	0.08	0.148	1.470	1.618	3.6	36.7	40.3
7	4.0	1.0	0	100	0.08	1.009	0.084	1.093	55.9	4.2	60.1
8	4.0	2.0	0	100	0.08	0.525	0.672	1.197	26.6	32.7	59.3
9	4.0	4.0	0	100	0.08	0.280	1.234	1.514	13.0	60.7	73.7
10	2.0	2.0	0	150	0.08	0.388	.679	2.067	10.1	38.5	48.6
11	2.0	2.0	50	100	0.08	0.066	0.178	0.244	4.9	14.5	19.4
12	2.0	2.0	100	150	0.08	0.057	0.144	0.201	7.4	21.7	29.1
13	2.0	2.0	0	100	0.12	0.240	0.697	0.937	5.7	17.0	22.7
14	2.0	2.0	0	100	0.04	0.506	2.413	2.919	11.7	60.0	71.7
15	16.0	2.0	0	100	0.08	1.733	0.002	1.735	392.4	0.5	392.9

*Relative to immediately adjacent upland property values within project area
**Expressed in millions of dollars



a) Proportional Present Worth Storm Damage Reduction Benefit Components vs. Years into Future.



b) Present Worth Recreational Benefits vs. Years into Future.

Figure 12. Present Worth Storm Damage Reduction and Recreational Benefits. H_b = 2.0 ft, ℓ = 2.0 miles, w_o = 0.0, Δw = 100.0 ft., Interest Rate = 8%, Run No. 5.

the demand exists, also provide recreational benefits. These benefits can be enhanced through increasing beach widths by nourishment projects.

Beach nourishment projects conducted with good quality sand will evolve with erosion occurring within the project area and deposition in the project adjacent areas. Good quality sand will remain within the active nearshore region and provide continuing storm damge reduction and recreational benefits.

A simple method is presented for quantifying the benefits in and adjacent to beach nourishment project areas. Considering limiting cases in which (a) all sand stays within the area placed, or (b) all sand placed spreads out rapidly demonstrates that the potential benefits are greater for the latter. Example calculations for realistic cases demonstrate that the benefits for project adjacent areas can be substantial relative to those in project areas. The relative benefits in project adjacent areas increase with: short project length, large wave height, large sediment transport coefficient, low interest rate, and large additional beach width.

Accounting methodologies for benefits of beach nourishment projects should be representative of modern understanding of sediment transport processes and the equities of those residing along the shoreline and thus should recognize the benefits from sand transported from the project area and deposited in project adjacent areas.

Although the method presented here applies to the case of projects placed on long uninterrupted shorelines, similar procedures could be applied to situations where littoral controls exist, such as jetties at a channel entrance.

ACKNOWLEDGEMENTS

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