A Delaware Sea Grant Technical Report

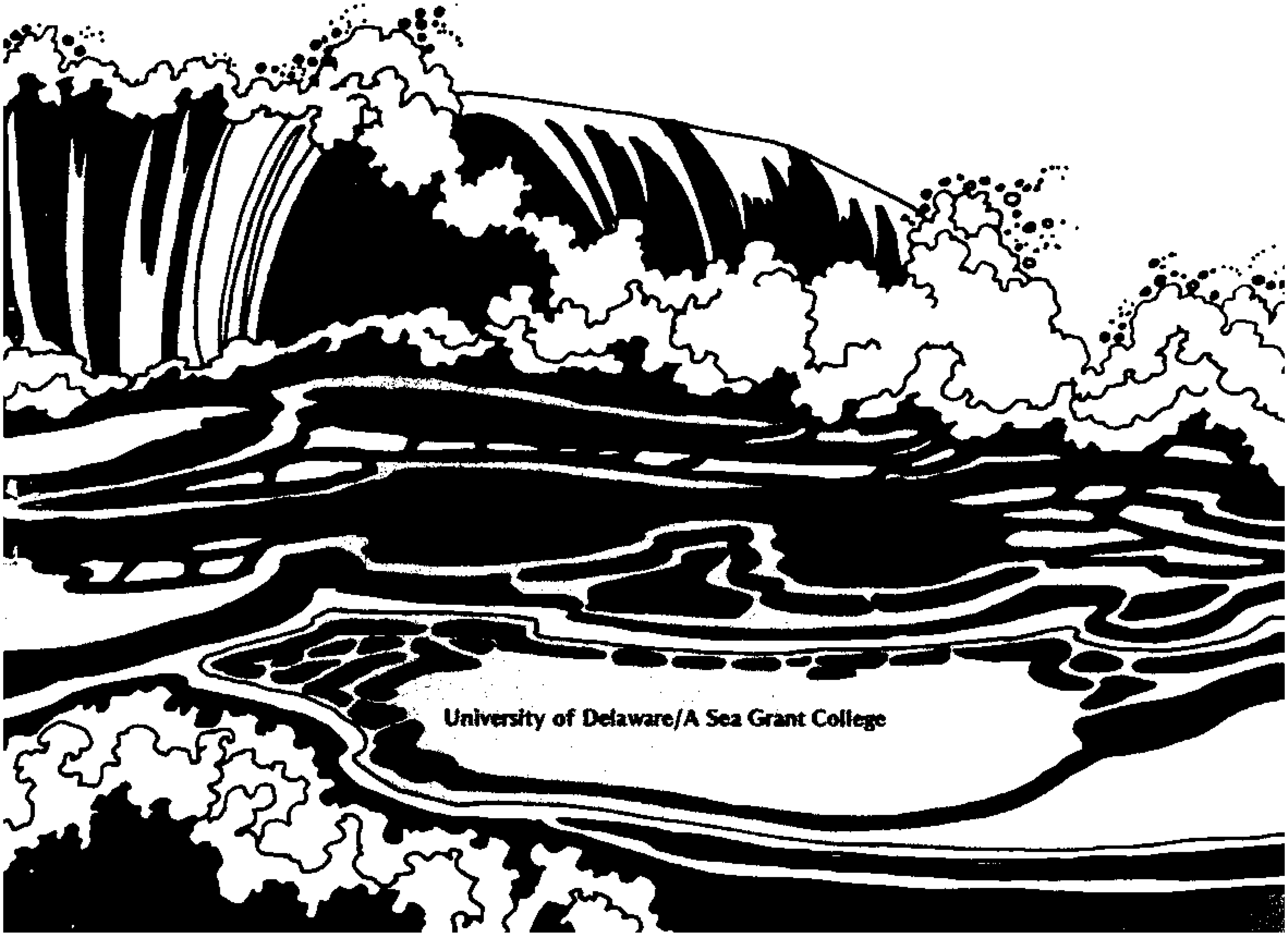
$2.00

ECONOMICS OF STORM PROTECTION

by

Lee G. Anderson and Christopher Kellogg

DEL-SG-20-76



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Produced by

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SUMMARY

In the past 50 years, large storms have been causing increasing damage to coastal areas in Delaware. Now is the time for additional storm protection to be considered because:

- *The last major storm that struck the Delaware coast (1962) caused 10 deaths and $16.6 million in damages. It is hard to imagine how much damage a similar storm would cause to the same area today given the increased development, building costs, property values and population.*
- *These growth trends are likely to continue and may even accelerate in the future.*
- *With meteorologists' predictions of a change in global weather trends, severe storms may occur more frequently in the near future.*

There are two fundamental steps in the design of any storm protection system — predicting the frequency and severity of large storms and designing and implementing an appropriate protection plan. The first alternative for improving weather prediction is to increase the lead time provided by existing storm warning systems. Unfortunately, this type of improvement would not prove useful for Delaware because protection measures that would be effective against large coastal storms require more time than could possibly be provided by any improvements in existing warning systems. Better weather information is useful only to the extent that it allows things to be done differently. If a better storm warning system could provide even a week's lead time (which is very unlikely), that would still not be enough time to implement any but the most marginal protection measures.

The key to improving storm protection in Delaware is to use historical weather data to evaluate the cost effectiveness of long-run protection methods such as building revetments, maintaining sand dunes and adopting building codes and zoning laws. This study develops a method for evaluating the cost effectiveness of any type of long-run protection measure. Demonstrations of that method show that more restrictive zoning or building codes would cost more than they would save, and that there is some indication that variances in certain cases may lead to net savings. The method also was used to analyze a proposed Army Corps of Engineers project for the Delaware coast.

INTRODUCTION

In August 1933, a hurricane with wind velocities of 75 miles per hour severely damaged shore structures, beaches and roads along the northeast Atlantic Coast. Excluding beaches and roads, total estimated damage in Delaware was $40,000.

In September 1944, a hurricane wreaked similar destruction on the Delaware coast, but this time, it destroyed gravel streets as well and caused $206,000 worth of damage.

In March 1962, a late winter storm, proceeding slowly northward along the Atlantic coast, was blocked by a high pressure air mass centered over Labrador. Unable to move, the storm generated hurricane-force winds, concentrating its fury over the same stretch of water for two and one-half days instead of the usual 12 to 24 hours. Together with already high spring tides, it drove 20-to-30-foot waves on top of a storm surge five to six feet above normal to batter the coastline from New Jersey to North Carolina. In Rehoboth, buildings and the boardwalk were carried out to sea. Tons of beach sand were washed away and new inlets were cut through barrier islands, leaving inland areas vulnerable to record high flooding. Ten people died. Damage to the Delaware oceanfront was $16.6 million. Even an estimated 1.5 million broiler chickens were lost because of a power failure in the Delmarva production area.

While such storms are rare events, they emphasize a number of problems concerning shoreline protection. As the coastline continues to be developed, large storms could cause increasing damage to property and possible loss of life, especially since meteorologists now predict an increased frequency of severe storms. As a result, the need for improved shoreline protection is becoming a growing concern. With new and better information about the probabilities of severe storms, additional storm protection is being examined in terms of cost effectiveness, (i.e., is the extra protection worth its cost?). Economists and statisticians are attempting to improve the method of translating existing information into decisions in the coastal area and to determine whether more money should be spent to improve weather forecasts.

This report will examine the economic aspects of storm and wave protection. First, it will describe some of the past and current trends affecting storm protection decisions and how weather information might be used to improve these decisions. Second, it will describe the types of conceptual models now being used to evaluate specific storm protection alternatives, such as building codes and construction methods, as well as general protection for the Delaware shoreline.

Past Resource Allocation Decisions: A Scenario

Storm protection decisions were once made on the basis of less complete information than is available today. In the past, after a coastal town was hit by a severe storm, the town fathers would probably adopt protection measures against future storms similar to the one that had just occurred. If they had just experienced a storm with a 3-foot tidal surge, then they might be expected to protect against the occurrence of another storm with 3-foot tidal surge. The town would then be safe – until it was hit by a storm with a 5-foot tidal surge. This type of decisionmaking could be expected to repeat itself until the town was hit by a storm so large that it could not afford to (or did not know how to) protect itself against such an event in the future. It is likely that very destructive storms were simply regarded as acts of God. People were faced with the alternatives of moving either to a more protected coastal area or farther inland, or putting up with periodic destruction. As it happened, coastal towns tended to locate where there was some natural protection. While this scenario may not be entirely factual, the point is that in the past, storm protection decisions were probably made on an ad-hoc basis.

Modern Trends

Recently, a number of trends have improved the process by which decisions are made about storm protection. Our knowledge of the frequency of large storms has increased – a result of records kept of weather information during the past 100 years. With the help of statisticians, meterologists have been able to translate the data into probabilistic predictions of the occurrence of different sized storms. In addition, their ability to determine the frequency of large storms is improving as the amount and time span of data continue to grow. Meteorologists can now predict with a fair amount of certainty the long-run probability that a specific coastal area will be hit by a hurricane or a very large extra-tropical storm.

By examining the historical deposition of sediments, geologists have expanded knowledge of coastal processes.

Their work has been particularly useful in two ways. First, we have learned the short-term dynamics of how sand is transported along the beach and in nearshore waters, a critical step in understanding how to prevent the erosion of sand dunes important for storm protection. Second, coastal geologists have identified and projected long-term trends in the development of coastline configurations caused by the rise in sea level and changing wind and water currents.

In the past century, advances in technology have enabled men to construct massive artificial barriers, such as stone revetments, that would have been too expensive years earlier. With these new methods and the ever-increasing demand for commercial, recreational, and residential services, development of coastal resources has proceeded at a rapid pace.

Depending upon the size and the nature of the area, various methods of protection have been used. These methods could be grouped into those that enhance existing natural means of protection and those that have been developed by man. The enhancement of natural barriers against storm waves and tides can be further divided into methods of maintaining sand dunes and beaches and methods of maintaining marshland. The maintenance of dune and beach barriers includes planting dune grass, sand fencing, restricting commercial development and traffic from vehicles and pedestrians, replenishing dunes with sand transported from other areas, and sand bypassing. [Sand bypassing refers to the use of dredging equipment to transport sand across inlets (particularly if man-made) to minimize the disturbance of existing coastal patterns of sand transport.]

Methods for maintaining marshland range from restrictions on commercial development that would directly destroy marshland, to restrictions on pest control techniques, such as ditching and diking, that could be harmful to marsh ecology in general, and ultimately perhaps, to the existence of the marsh.

Protection methods devised by man can be classified as the construction of artificial barriers or legal restrictions. Artificial barriers include beach groins (jetties) perpendicular to the shoreline and bulkheads or revetments (seawalls) parallel to the shoreline. Legal restrictions range from building codes, which specify types of construction methods to be used in coastal areas, to zoning, which may simply prohibit buildings in areas that may be severely damaged by large storms.

Modern Problems

Despite the increase in number and effectiveness of storm protection techniques, critics complain that many of the artificial devices create more long-term problems than they solve. While bulkheads and revetments provide protection for significant periods of time, natural forces such as changes in sea level and coastal erosion may ultimately prevail. For example, the city of Rehoboth has resisted erosion of its shorefront area by constructing groins and bulkheads. However, the prevailing longshore drift has pushed back the neighboring shoreline to the north and south by washing more beach sand northward than is being replenished from the south. As a result, Rehoboth juts out from the surrounding coastline, leaving itself more vulnerable to wave and tide attack from more directions, particularly the northeast.[1] While the groins and bulkheads may provide needed protection today, their mere existence may encourage increased development in an area particularly vulnerable to large storms tomorrow.

Enter the Economist

Increased government intervention in the management of natural resources for the public welfare brought with it the need for refined techniques to measure the benefits of government projects. As long ago as 1936, a Congressional act required federal authorities to compute special or local benefits as a means for charging local interests with part of the costs. Under the New Deal, federal participation in flood control projects prompted the need for broader social justification for these projects.[2] "The benefits to whomsoever they may accrue" had to exceed estimated costs. The purpose of determining benefits and costs was not only to justify the worth of the projects, but also to help decide who should pay. Since that time, economists have not only added to the techniques of calculating benefits, but have integrated them into a theoretical framework. As a result, economists and policymakers have learned to ask pointed questions about the benefits of resource allocation decisions, encouraging more efficient use of the existing information relevant to storm protection.

THE USE OF WEATHER INFORMATION

One fundamental principle in the use of weather information is that added or expanded information is beneficial only to the extent that it allows for things to be done differently. For example, consider an apple grower who is concerned with freezes and receives 24-hour forecasts of their arrival – ample time for him to set out heat pots. If he can do nothing else but use the heat pots (i.e., there is no other technology that he can use) then a 48-hour or a 72-hour warning would be of no value to him. The 24-hour warning gives him adequate time to prepare, given the existing state of technology. Now consider an individual who desires to build a structure in a flood plain. He has two different construction methods from which to choose: method A which will produce a structure secure in a flood of up to three feet and method B which will produce a structure secure in a flood greater than three feet. (This simple example ignores the problems of duration of flood or the velocity of the water.) Weather information that distinguishes between floods with one and two foot depths will be of no use to him because it will not allow him to make a choice between the two methods. As far as his decisionmaking is concerned, there are only two discreet weather events (floods of less than and greater than three feet in depth, respectively) and they are determined by the technological options open to him. Information concerning other categories of weather activity are of no value to him. This same principle holds true in more complex examples. A decisionmaker is concerned with discreet weather events, one for every possible management option open to him. Breakdowns into finer events are of no value because they do not allow him to do things differently.

Although storms or weather events may have a number of effects, only one of the effects may cause significant damage or be relevant in considering the value of a specific storm protection device. It is obvious that certain methods of protecting against water damage, like building bulkheads, will do little to prevent wind damage, while other protection methods such as the use of stronger building foundations may protect against both. However, if a decisionmaker is considering a specific protection alternative, then only those effects which the alternative protects against are relevant to its evaluation. If the decisionmaker is concerned with wave and tide damage, the weather event must be defined in terms of these variables. The storm's wind speed, whether 55 or 75 knots, does not matter, if the duration and height of the surge is the same at both speeds. For instance, the March 1962 storm caused greater flood tides than many hurricanes with higher wind speeds but shorter durations. Consequently, if the critical consideration is potential flood damage, the March 1962 storm is a rarer event than many tropical storms. The importance of this distinction will become more evident in the next section.

A final point is that existing storm warning systems do not provide enough lead time to adopt the most effective protection measures. It may take months, even years, to build a stone revetment or to correct the erosional patterns of a dune barrier. A few days or a week clearly is not enough time to implement any but the most marginal measures, such as building sand bag barriers, boarding up windows or evacuating residents. And since it is unlikely that it will ever be possible to determine two weeks in advance a particular storm's intensity or its specific path, a different type of weather information is needed to provide enough lead time both to evaluate and to implement protection measures.

Probabilistic Information

For the decisionmaker, the most helpful weather information available is statistical estimates of the probability of occurrence of different sized storms. For example, using historical information, meteorologists are able to predict that storms the size of the March 1962 storm or larger, will occur on the average of one time in every 25 years. For this reason, the March 1962 storm (and others of the same size) are referred to as "one-in-25-years" storms. It must be remembered that what determines storm size is the height of the storm's tidal surge above mean sea level (MSL). For instance, on the mid-Atlantic coast, the one-in-25-years storm has a tidal surge of 7.3 feet above MSL. On the average, this area will experience a storm with a tidal surge of *at least* 7.3 feet above normal once in every 25 years. Or from another viewpoint, the same area has a 1 in 25 chance (or a probability of .04[3]) of being hit by a storm with a tidal surge of 7.3 feet *or greater* in any single year.

With this type of information the minimum average expected yearly damage from this range of storm sizes can be calculated. Note that some of the storms included in the range of sizes having a .04 annual chance of occurrence are larger than just the one-in-25-years storm, but for ease of explanation this will be ignored for the moment. Suppose the March 1962 storm had caused $10 million damage to Atlantic City. Because it was a one-in-25-years storm, Atlantic City could be said to suffer an average of at least .04 x $10 million ($40,000) in annual damages from storms of that size or *larger*. This figure of $10 million is an estimate of minimum potential damages; while the one-in-25-years storm might cause $10 million in damages, the .04 probability range also includes the one-in-50 or the one-in-100 years storm which would cause more than just the $10 million in damages. If, instead, the March 1962 storm had an annual chance of occurrence of 10% instead of 4% (1 in 25), then the average annual expected damages would be at least .10 x $10 million or $100,000 instead of just $40,000. In statistics, such probabilistic estimates are referred to as *expected values*; in reference to storm protection problems, they are known as *expected damages*.

To see how the idea of expected damages is useful to storm protection decisions, suppose a specific protection project was designed to prevent at least 80% of the damage to Atlantic City caused by our once-in-25-years storm. If the method worked as predicted, it would prevent .80 x $10 million or a minimum of $8 million in damages one time in every 25 years. Expected damage reductions would equal at least $8 million x .04 or $32,000 annually. These savings from potential damages are the benefits of the project. To determine whether the project would be worthwhile, the decisionmaker simply has to calculate the costs of the project and subtract them from its benefits. If the net figure is negative, then one-in-25-years or larger storms would actually cost the city less if it did nothing to prevent damages than if they adopted the storm protection measure. If the net figure is positive, then based just on that information, it would be worthwhile to build the project.

If, for example, the project was the construction of a revetment with a properly discounted annualized cost of $24,000, net annual benefits would be $8,000 – expected yearly savings of $32,000 minus annualized costs of $24,000. In contrast, if the project had annual costs of $36,000, net benefits would be $32,000-$36,000 or a negative $4,000, indicating that the project should not be built. To extend this type of analysis, it is helpful to formalize it into a decisionmaking model.

A SIMPLE MODEL

The basic model for decisionmaking with long-range weather information uses game theory. Consider a coastal area providing a single service and assume that there are two methods of constructing the necessary physical facilities. Both are generally suitable in use but the second costs more and is able to withstand "heavy weather" with reduced damages. The following gamebox describes the expenses of the two methods in given types of weather.

The rows signify construction methods and the columns represent weather events. The term in each box represents the expense that will result from a given weather event using a certain construction method. If Method 1 (M_1) is used there will be no expenses in fair weather (W_1), but there will be a heavy loss (L_{12}) from damages in heavy weather. If Method 2 (M_2) is used, which costs more than the first method on an adjusted yearly basis (C_2), the expenses will be (C_2) in fair weather and in heavy weather will be the sum of the cost for the construction method and, hopefully, resulting lower losses in heavy weather, $C_2 + L_{22}$ (L_{22} represents losses from damages in heavy weather). Before we can even

Weather Event

	Fair Weather (W_1)	Heavy Weather (W_2)
Method 1 (M_1)	No Extra Cost (0)	Heavy Loss (L_{12})
Method 2 (M_2)	Some Extra Cost (C_2)	Some Cost + Lower Loss ($C_2 + L_{22}$)

consider using the second method of construction, it is necessary that we have some reason to believe that losses in heavy weather will be reduced (i.e., L_{22} is less than L_{12}). Note that the weather events are being defined in terms of the construction methods - heavy weather occurs when losses of a certain magnitude occur from using M_1.

The expected annual cost of using a given construction method is the sum of the expected cost for each of the two weather events. It makes sense to undertake the extra costs entailed in M_2 only if the expected costs of using it are less than those of using M_1. Letting P_1 and P_2 represent the probabilities of weather events 1 and 2 respectively, Method 2 will be advantageous when

$$P_1(o) + P_2(L_{12}) > P_1C_2 + P_2C_2 + P_2L_{22}$$

or

$$P_2L_{12} > C_2 + P_2L_{22}$$

This can be simplified to

$$P_2 > \frac{C_2}{L_{12} - L_{22}}$$

M_2 should be used only if the long run probability of heavy weather is greater than the ratio of the extra cost of M_2 to the reduction in losses that result from using M_2. This means that as far as the decisionmaker is concerned, research should only be undertaken to find the probability of heavy weather with respect to this ratio; any further breakdown is of no value to him.

Application of Model

One of the alternative methods for protecting against storm damage is for builders to use extra strong foundations for buildings in the coastal area. To see how the conceptual model might be used, some actual estimates of construction costs are helpful. For example, two builders have independently estimated that on the average, increased foundation costs added about 4% to the total cost of buildings constructed in nearshore areas,[4] (over what the cost would be elsewhere). Using this figure as a first approximation and then arbitrarily assuming that special foundations will prevent 90% of damages to structures caused by a specific size of storm, the decision gamebox would be filled in as follows:

		W_1 (fair weather)	W_2 (heavy weather)
Construction Methods	M_1	0	aC
	M_2	.04C	.04C + .1 (aC)

C = the annualized cost of structure. For example, if a building which cost $160,000 to build and $40,000 to finance was expected to last for 40 years, then its annualized cost would equal ($160,000 + $40,000)/ $40 or 5,000.

a = the annualized loss from damages due to heavy weather if the cheaper method of construction, M_1 is used. "a" is expressed as a percentage of the annualized cost and can exceed 100%.

Other than the fact that they are expressed in percentage terms of building costs, the entries in this gamebox correspond exactly with those in the preceding one. In terms of the original decision criteria that expected savings must exceed costs, M_2 should be used only if

$$P_2 (aC) > .04C + P_2 .1 \; (aC),$$

that is, only if the expected yearly cost of M_2 is less than that of M_1. This inequality can be modified by dividing through by C and then rearranging terms.

$$P_2 (a) > .04 + P_2 (.10a)$$

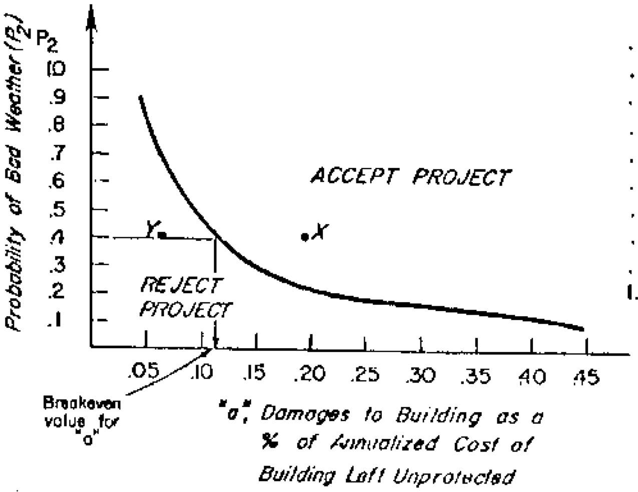
$$P_2 (a) - P_2 (.10) \; (a) > .04$$

$$a \, [P_2(1 - .10)] > .04$$

$$a > \frac{.04}{P_2 (1 - .10)}$$

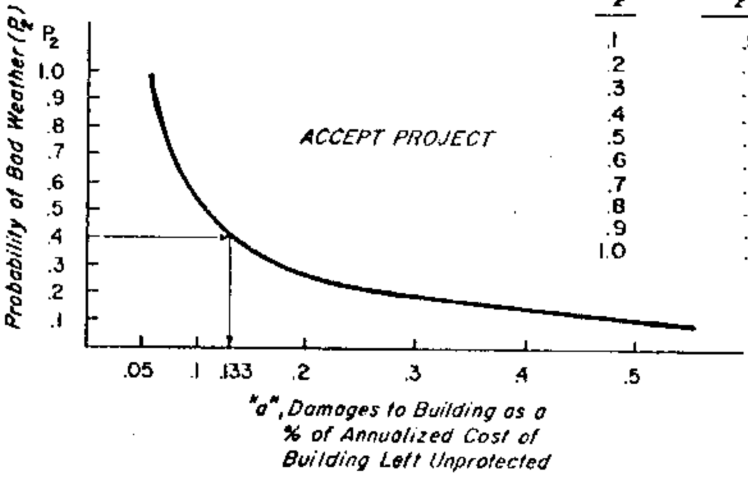
In other words, knowing the percentage increase in foundation costs and what percentage of the building a more expensive foundation would protect, we can compute "a." "a" represents what the damage to an unprotected building, as a percentage of annualized cost, would have to be before it would be worthwhile to use construction alternative M_2 for any probability that the particular size storm in question will occur. This relationship is graphically depicted in Figure 1. The graph can be used in the following manner: The curve represents the break-even points where the expected savings from using the more expensive foundation would just equal its cost. The area above and to the right of the curve represents those combinations of probability of heavy weather and "a" values where the more sophisticated construction method would be worthwhile. This graph can be used as follows: Given the values for increased construction costs (4% annually) and the amount of protection provided (90% of the total annualized costs), suppose that (1) the decisionmaker is concerned with storms causing a tidal surge three-feet above MSL, (2) the U. S. Weather Bureau informs him that storms of that size have an annual chance of occurrence of .40 (making them once in 2-1/2 years storms). By finding the point where P_2 = .40 on the vertical axis, and reading horizontally across to the appropriate point on the curve and then vertically down, the decisionmaker can then locate the corresponding breakeven value for "a" such that expected savings from using the stronger foundations would equal their extra costs. In this case, the breakeven value of "a" equals .111 of total annualized costs. If it happened that the actual value for "a" (the damages to the buildings if the cheaper foundations were used) exceeded .111 of the structures' annualized costs (let's say a = .20), then the buildings in the area under consideration would correspond to point X on the graph, and the more expensive foundations would be worthwhile. In contrast, if the actual value of "a" were .05, (i.e. point Y), the expensive building foundations would cost more than they would save in terms of wave and tide damage associated with the size of the storm in question. In this last example, the more expensive foundations may be worthwhile if criteria such as wind protection or increased life for the buildings due to added structural soundness were considered. But based solely on wave and tide damage prevented, these foundations should not be used.

It should be remembered that these damage amounts are in annualized figures. To get a picture of their total dollar amounts, it is necessary to reconvert the figures to lump sums. With the example of the $200,000 building and a breakeven point of damages without protection equal to .111 of annualized costs, the model implies that the storm in question would have to cause more than .111 x $200,000 or $22,000 worth of damage to the building without protection. In addition, the more expensive foundation would cost .04 x $200,000 or $8,000 more than the cheaper one.



P_2	$a = \frac{.04}{P_2(1-.10)}$
.1	.444
.2	.222
.3	.148
.4	.111
.5	.088
.6	.074
.7	.063
.8	.055
.9	.049
1.0	.040

Figure 1. Decision Graph When Special Foundations Prevent 90% of Damages.



P_2	$a = \frac{.04}{P_2(1-.25)}$
.1	.533
.2	.266
.3	.177
.4	.133
.5	.106
.6	.088
.7	.076
.8	.066
.9	.059
1.0	.053

Figure 2. Decision Graph When Special Foundations Prevent 75% of Damages.

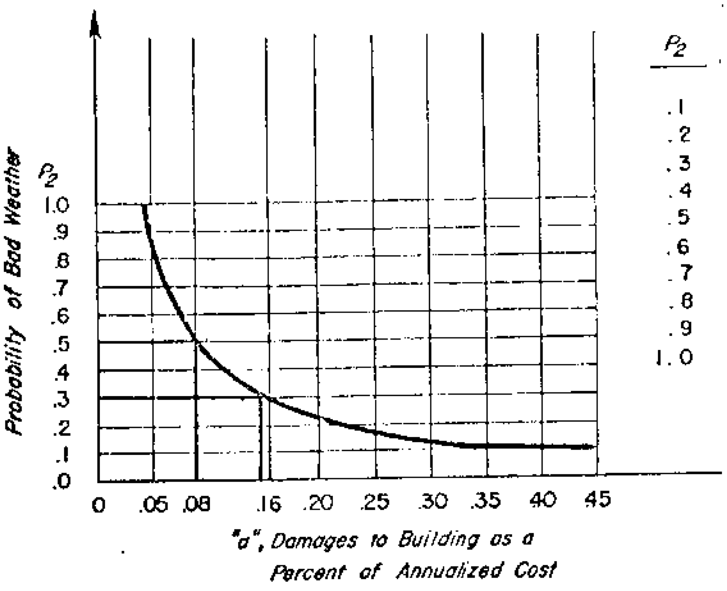
Implications

The implications for the decisionmaker are that if the situation under consideration corresponds with point X in Figure 1 (i.e. P = 4 and a = 27), savings could be realized by using the more expensive construction method. If building codes were written so that builders had to construct foundations in this manner, savings would be automatic. Of course, this is not to say that building codes are based on this type of analysis, but that this would be an economic basis for determining them.

If the parameter values were different, we would get different results for our 2-1/2 years storm. Suppose the more expensive foundation prevented only 75% instead of 90% of the damages that would have occurred to the buildings without protection. As can be seen from Figure 2, damages to the unprotected building would have to be 13.3% of annualized costs, or a lump sum of $26,000 in reference to our $200,000 building, before the stronger foundation would be worthwhile.

It is apparent that for a decisionmaker to use this type of analysis for a particular area, he would have to plot his own graph, taking into account the effects of the local environment on the parameter values. However, the resulting amount of net benefits is very sensitive to estimates of the amounts of protection actually provided by improved construction alternatives. For this type of analysis to work, the decisionmaker would have to have a high level of confidence in the estimates of protection provided by different alternatives. As builders will testify, such estimates are far from exact, but they may be accurate enough to greatly improve decisionmaking.

This model could also be used to determine the range of weather data relevant to the choice of a particular protection alternative if the builder has a fair idea of which construction alternatives are feasible and the approximate amount of protection they provide against a given amount of flood exposure. Suppose a builder is considering using an extra strength construction method which would prevent damages from storm surges between four and six feet above MSL. The additional strength provided by this alternative would not be needed if the storm surge were less than four feet, and it would be useless in preventing damages from a surge greater than six feet above MSL. Knowing the range of weather events relevant to the decision, the



P_2	$a = \frac{.04}{P_2(1-.10)}$
.1	.444
.2	.222
.3	.148
.4	.111
.5	.088
.6	.074
.7	.063
.8	.055
.9	.049
1.0	.040

Figure 3. Decision Graph Showing Range of Weather Probabilities.

meteorologist would then be able to narrow his efforts in reviewing and interpreting data. For example, if it were known with a high degree of certainty that the value of "a" for the Delaware coast was between .08 and .16, then according to the graph in Figure 3, the important range of probabilities is between .3 and .5. If meteorologists believe P_2 is somewhere between .1 and .2, then for economic considerations alone, we have enough information. It would be a waste of money and manpower to refine the estimate. However if P_2 was thought to be in the .3 to .5 range, it would be worthwhile to narrow the estimate to a shorter range to improve decisionmaking.

The above discussion must be put in proper context with respect to meteorological research. The value of pure research is not being impugned. The above does not mean that such research should stop in those instances where the known probability of a weather event falls outside the critical range determined by the economic analysis. It just says that the results of that research will not improve decisionmaking in the area under consideration.

This discussion describes a useful model for individual decisionmaking. However, it is highly likely that, given existing building codes and zoning laws, when the model is used to test new construction methods beyond these legal constraints, few will pass the test. There are three reasons to believe this is so.

Zoning laws prohibiting new construction in areas less than eight feet above MSL have eliminated most of the storm protection problem. Based on Corps of Engineers tidal data, these zoning laws theoretically protect all new buildings from all weather events with an annual chance of occurrence greater than about 2%.[5] In other words, buildings now being built would only be damaged by the most extreme storms, such as once-in-60-years storms or larger. Under existing laws, construction techniques would produce net savings only to the extent that they prevented damage in addition to existing zoning laws.

Builders claim that new buildings are now constructed with foundations that already provide more than the optimum amount of protection from a cost benefit viewpoint. Existing building codes, in order to meet conditions of soft and sandy substrata, require deeper foundations than are necessary for just storm protection considerations. Also, because of the economics of commercial construction and land values in the coastal area, most new structures are multi-story, so that structural soundness requirements because of height more than meet those of storm protection.

Builders feel that there is little they can do to improve storm protection other than provide adequate foundations. Protecting against direct wave attack would be prohibitively expensive and is not even considered as a remote possibility. Similarly, it would be hopeless to protect against water damage from tidal inundation, short of making buildings watertight -- an unrealistic measure. Foundations protect only against limited structural damage, as opposed to that caused by direct wave attack, or water damage to the interior.

Interestingly, existing zoning laws protect against all types of damage. Yet many builders claim that the degree of storm protection written into zoning laws and building codes is excessive. They generally agree that better storm information would not allow them to save more money given the existing zoning laws. Even if they knew for sure that no storm damage would occur to buildings currently under construction, they could not reduce construction costs without violating existing building codes.

As stated earlier, added or expanded information is beneficial only to the extent that it allows things to be done differently. Under existing building codes, builders would not be allowed to do things differently despite improvements in weather information which could lead to possible savings. The efficiency of these codes and zoning laws theoretically could be improved by making them more flexible and by making sure that they provide the same level of protection. In the past, laws were designed to provide a certain minimum amount of protection -- the way to compensate for the uncertainty of weather events was to add an extra margin of safety to this minimum level. However, improved information reduces the need for this safety margin since it reduces the uncertainty about the effects of future weather events. By reducing the uncertainty about weather events, the amount of risk embodied in building codes and zoning laws could be reduced. Theoretically, buildings could be designed more precisely to provide a specific amount of protection according to expected probabilities of serious weather events. The cost for achieving a minimum level of storm protection is the cost of extra strength construction where it is not really needed, and the opportunity cost of not being allowed to build in low-lying areas even though extra strength construction methods could compensate for the more destructive storm effects on these areas. In other words, laws and building codes could require a specific amount of protection, allowing construction methods to be varied in order to produce that amount of protection. Less expensive construction methods could be used to achieve savings in areas where probability of damage is low.

However, there are a number of drawbacks to such flexible building codes. First, they would have high enforcement costs which could very likely outweigh their increase in benefits. Second, storm protection still remains a very inexact science and where questions of public safety or consumer ignorance are concerned, it is probably better to err on the side of more protection than less. Third, under the proposed flexible zoning scheme, public authorities would have to depend on builders for expertise. Since builders would benefit from increased coastal development, they may not be impartial in their advice.

In summary, requiring improved construction methods or further refinement of weather data would most likely not lead to any increase in savings from storm damage because existing building codes and especially zoning laws already provide more than the optimum amount of protection.

If savings are possible they will come from the ability to use less stringent zoning laws in areas where improved predictions show that it would be worthwhile. However, it should be noted that this conclusion applies only to the construction of new buildings, and does not eliminate the need to consider additional protection for existing structures. The question of additional protection for existing structures will be discussed in the next section.

SHORELINE PROTECTION

The foregoing decision model can be expanded to include shoreline protection problems of heavily developed areas by taking into account a range of different sized storms and expected damages. To see how this is done, a model will be used to evaluate an early version of a comprehensive protection plan for the Delaware coast developed by the Army Corps of Engineers.[6] Because of Corps policy, data on the present version were not available. First, a set of simplifying assumptions will be made in order to calculate the amount of damages that the project will prevent. Then a more complex model will be developed by making the assumptions more realistic and by using a more precise method to calculate expected damage.

The proposed shoreline protection plan includes all of the Delaware coast and employs numerous protection methods such as sand fencing, planting dune grass and transporting beach fill from other areas to nourish the existing dune system. For our purposes, we will focus attention only on those specific projects for the developed areas of Rehoboth, Dewey, and Bethany Beach. The protection methods will be limited to the construction of bulkheads and revetments, and will be designed to prevent 100% of the direct wave damage and a conservatively estimated 50% of the tidal flooding from a one-in-100-years storm. The Corps estimated the annualized cost of construction and maintenance for these projects was $420,900 for Rehoboth and Dewey Beach and $103,200 for Bethany Beach.

To get a rough idea of the value of this project, one can calculate savings from potential damages due to the March 1962 storm. Corps of Engineers' data, presented in Table 1, show that this storm caused $3.53 million worth of damages to Rehoboth and $3.14 million to Dewey Beach, or a total of $6.67 million. To make this amount comparable to the project's estimated costs (in 1972 prices), the $6.67 million in actual damages is multiplied by a Department of Commerce price correction factor of 1.79, yielding a figure of $11.939 million. Therefore, in terms of 1972 prices, annual expected damages from the once-in-25-years storm would be at least .04 x $11.939 million or $478,000 per year. If in fact all these damages were prevented by the proposed structures for Rehoboth and Dewey, then there would be a net yearly savings of $478,000-$420,900 or $57,100. Although it is unlikely that 100% of the damage will be prevented, the percentage of potential damages that the project must prevent to make it worthwhile can be computed by simply calculating costs as a percentage of total potential damages. For instance, since $420,900/$478,000 equals about 88%, the project would have to prevent 88% of potential damages for savings to at least equal costs. If it prevents more than 88% of potential damages, it will produce positive net savings.

For Bethany Beach, the Corps estimated that a similar project would cost $103,200 annually. Damages to this area from the March 1962 storm were $2.39 million (see Table 1) or $4.278 million when corrected to 1972 prices. Expected annual damages in 1972 prices are .04 ($4.278 million) or $170,100 per year. Maximum annual savings would then be $170,100-$103,200 or $67,900 if 100% of the damages are prevented. Also, annual savings will be positive as long as the damage reduction is at least $103,200/$170,100 or about 61%. However, projects should not be judged on the basis of such simple calculations -- a more detailed analysis is needed.

One major flaw in this method of calculating expected damages is that it fails to include additional savings from storms larger than those with a 7.3 foot storm tide and it completely ignores savings from potential damages from smaller storms. It is clear that if the project prevented all or part of the wave and tide damage from the one-in-25-years storm, then it would also reduce damages caused by smaller storms. Similarly, the projects would give some protection from larger storms. These extra savings can be calculated by using estimates of the probability of different sized storms and accompanying damages, and then summing the products of the probability and the damages.

The Corps has provided estimates of these two parameters for the Delaware coast north of Indian River Inlet. The first three columns of Table 2 give storm descriptions by height of the storm tide, for each individual size storm's probability of occurrence and expected damages. However, since we are only interested in the areas of Rehoboth and Dewey, the Corps damage estimates will have to be adjusted to reflect the correct amount of damages to these two areas in particular instead of damages to the whole coast north of Indian River Inlet.

The March 1962 storm falls into the range of storms in Table 2, column 1, with storm tides between 7.3 and 8.05 feet above MSL. The Corps of Engineers has estimated that storms of this size would cause $5.33 million in damages to the whole coast north of Indian River Inlet (see Table 2, column 3). However, even taking into account price level changes and the fact that damages to Dewey and Rehoboth accounted for about 80% of the damages to this area, the $5.33 million estimate cannot be reconciled with the $11.939 million in actual damages also calculated by the Corps and presented in Table 1. It was not possible to obtain the explanation for this discrepancy. However, if it is assumed that the data presented in Table 2, column 3 gives the correct relative weights to damages from different sized storms, then damages to Dewey and Rehoboth from these different sized storms can be estimated by multiplying each figure in Table 2, column 3, by 2.24 (i.e. 11.939/5.33). The results of this computation (a corrected damage

Table 1

DAMAGES RESULTING FROM STORM OF MARCH 1962 CAPE HENLOPEN TO FENWICK ISLAND (JULY 1962 PRICES)

Location	Estimated Damages
North of Indian River Inlet	
Fort Miles	$ 270,000
Fort Miles to Rehoboth Beach	640,000
Rehoboth Beach	3,530,000
Dewey Beach	3,140,000
Dewey Beach to Indian River Inlet	890,000
Total Damages	$8,470,000
South of Indian River Inlet	
Indian River Inlet to Bethany Beach	630,000
Bethany Beach	2,390,000
Bethany Beach to Fenwick Island	3,110,000
Fenwick Island	2,060,000
Total Damages	$8,190,000

Source: Delaware Coast Beach Erosion Control and Hurricane Protection. Gen. Design Memorandum, Phase I, Department of Army, Philadelphia District, Corps of Engineers.

Table 2

REHOBOTH AND DEWEY BEACH STORM DAMAGES

(1) Storm Description (Height of Tidal Surge in Feet Above MSL)	(2) Probability of Occurrence	(3) Estimated Damages in Millions 1962 Dollars for North of Indian River Inlet	(4) Corrected Damage Estimates for Rehoboth and Dewey in Millions 1972 Dollars	(5) Expected Damages to Dewey and Rehoboth in Millions 1972 Dollars
> 10	.01	12.5	28.00	.280
8.05 - 10.0	.01	9.06	20.16	.202
7.3 - 8.05	.02	5.33	11.939	.239
7.1 - 7.3	.01	4.13	9.512	.095
6.95 - 7.1	.01	3.33	7.459	.075
6.73 - 6.95	.02	2.00	4.480	.090
6.55 - 6.73	.02	0.80	0.792	.016
6.07 - 6.55	.10	0.22	.493	.049
5.5 - 6.07	.30	0.08	.179	.054
			Total	1.10

1. Columns (1), (2), (3) from Army Corps of Engineers' data.
2. Column (4) = 2.24 x Column (3) $2.24 = \frac{11.939}{5.33}$
3. Column (5) = Column (2) x Column (4)

estimate for Rehoboth and Dewey) are found in column 4 of the same table. By multiplying this corrected figure by each storm's probability of occurrence, the annual expected loss for each size storm can be found (see column 5). Note that instead of combining all storms of the one-in-25-years and larger size into the category of storms with a tidal surge of greater than 7.3 feet, this table divides these storms into three classes: those with tidal surges between 7.3 and 8.05 feet; 8.05 to 10 feet; and greater than 10 feet. Also, the annual chance of occurrence for each of these narrower categories of storm size is given in column 2 of this table. With this more precise breakdown of events, storms which would cause $11.939 million in damages to Rehoboth and Dewey now represent only 2% of the whole spectrum of possible storm sizes instead of the 4% previously used. Expected damages from storms in this range of sizes would be .02 x $11.939 or $239,000 per year. This table also assigns more realistic damage estimates of $12.5 and $9.06 million to larger storms. Expected damages are $202,000 per year for one-in-50 to one-in-100-years storms, and $280,000 yearly for one-in-100-years storms and larger. As a result, expected damages from one-in-25-years and larger storms now equal $721,000 instead of $478,000 annually. The new figure is larger because it includes the additional expected damages from storms larger than the one in March 1962. (The first estimate was a minimum calculation of expected damages from these size storms.)

Using the same method, expected damages to Rehoboth and Dewey from smaller storms were calculated and are presented in the remainder of column 5 in Table 2. According to these calculations, the total amount of expected damages to this area from all size storms is $1.1 million per year versus the earlier estimate of $478,000. In other words, if the project would prevent 100% of these damages, the net savings would be $1.1 million minus the annualized costs of $420,900 or $679,100 per year. To take another point of view, the project must prevent more than $420,900/$1.1 million or 38% of all storm damages to be worthwhile.

The same procedure can be used to calculate expected damages for Bethany Beach. Bethany is close enough to Rehoboth that the same probability distribution of storm size as defined by the height of tidal surge above MSL is valid for both areas. However, due to differences in topography and in the levels of development between the areas north and south of Indian River Inlet, relative weights for damages caused by different size storms for Bethany listed in Table 3, column 3, are slightly different than those for Rehoboth. Estimated damages for Bethany in column 3 were adjusted in the same way as was done for Rehoboth, but using a correction factor of 4.28/5.46 to correct the first estimates in light of the damages actually experienced in the March 1962 storm. The expected damages from the one-in-25-years and larger storms are $99,000 + $69,000 + $86,000 or a total of $254,000 annually compared to the $171,000 per year predicted earlier. Expected damages from storms of all sizes are totaled at the bottom of column 5 and are $519,000 annually. Therefore, if the project was to prevent 100% of damages from storms of all sizes, net savings would equal $519,000 minus the annualized costs of $103,222 or $415,800 per year. For the project to be worthwhile it would have to pre-

Table 3

BETHANY BEACH STORM DAMAGES

(1) Storm Description (Height of Tidal Surge in Feet Above MSL)	(2) Probability of Occurrence	(3) Estimated Damages in Millions 1962 Dollars for South of Indian River Inlet	(4) Corrected Damage Estimates for Bethany in Millions 1972 Dollars	(5) Expected Damages to Bethany in Millions 1972 Dollars
> 10	.01	12.6	9.87	.099
8.05 - 10	.01	8.8	6.89	.069
7.3 - 8.05	.02	5.46	4.28	.086
7.1 - 7.3	.01	4.53	3.55	.036
6.95 - 7.1	.01	3.87	3.02	.030
6.73 - 6.95	.02	2.80	2.19	.044
6.55 - 6.73	.02	1.88	1.47	.029
6.07 - 6.55	.10	0.58	0.45	.045
5.5 - 6.07	.30	0.27	0.21	.081
			Total	0.519

1. Columns (1), (2) and (3) from Army Corps of Engineers' data.

2. Column (4) = $(\frac{4.28}{5.46})$ X Column (3)

3. Column (5) = Column (2) X Column (4)

vent $103,222/$519,000 or about 20% of expected losses.

On the basis of this information, it appears that the construction of the protection devices for these communities will generate savings in excess of their costs. Therefore on strict economic grounds it would be a worthwhile use of government funds to complete these parts of the project. However, this interpretation is only as valid as the data used in the analysis. Moreover, the purpose of this section is not to accept or reject any particular project, but rather to describe a method that can provide the necessary information to make the proper decision. It would be interesting to apply this method to the revised protection plan for the Delaware coast with full access to Corps data.

CONCLUSIONS

1. Greater use of coastal resources for both commerce and recreation as well as growing residential population have increased the need for storm protection measures.
2. Improved technology and greater knowledge about natural processes have increased the number and scope of available storm protection alternatives.
3. Using a fairly simple model, it is possible to compare the increased cost of building with the expected value of damage reduction that will result. This same model also will provide information regarding the critical range of probabilities of damaging storms.
4. Given only the assumptions used in this analysis, the shoreline protection projects proposed for Rehoboth, Dewey and Bethany beaches should produce savings from storm damage in excess of their costs. However, the analysis only serves to demonstrate that the method is capable of analysing the problem.

Footnotes

1. John Kraft. A Guide to the Geology of the Delaware Coastal Environment.
2. Prest and Turvey, "Cost Benefit Analysis: A Survey" in Economic Journal, December 1965, pp. 684-686.
3. .04 = 1/25.
4. Two builders estimated that foundation costs in coastal areas were about 40% more based on a $200,000 building. Since foundation costs represent about 10% of total costs, foundations built for coastal conditions add about 4% (.10 x .4) onto total costs of a building.
5. According to Army Corps of Engineers' data, a storm with a tidal surge of 8.05' above MSL has an annual chance of occurrence of .02 on the Delaware coast.
6. Delaware Coast Beach Erosion Control and Hurricane Protection, General Design Memorandum, Phase 1, Department of the Army, Philadelphia District, Corps of Engineers, Philadelphia, Pa. 1972.