# CHAPTER 343

## An Attempt to Determine the Spanish Public Domain Border

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**Abstract**

In this paper the problem of the determination of the Spanish maritime-land public domain border is analyzed. The Spanish public domain border is defined by the Spanish Law as the limit where the waves reach during the worst storm in the area. The law also establishes that this limit must be calculated taking into account the effects of the astronomical tide, the storm surge and the wave run-up. Since the storm surge and the wave run-up are random variables, the extreme flooding level determination is carried out by means of an extension of the joint probability method, first proposed by (Pugh and Vassie, 1978), which includes the effect of the wave run-up. The proposed theoretical approach is applied to a case study of a beach located in the North Coast of Spain.


**Introduction**

In Spain not only the sea, but also the shoreline is considered to be public property. This consideration is linked to our cultural and legal tradition and can be found in the ancient Roman and medieval Spanish Law.

In the 6th century, for instance, Justiniano established that: *"According to the natural law, the air, the running water, the sea and its shore are common to everybody. These shores have no owner... "*. Later, in the 13th century King Alfonso X, also known as Alfonso "The Wise", ruled that: *"The things that communally belong to all creatures living in this world are: the air, the rainwater, the sea and its shore. No building can be undertaken on the seashore that could restrain the communal use of the people"*.

The present Spanish Legislation on Coasts, passed in 1988, also protects the shore-line and defines what is called the Maritime-Land Public Domain: "The public domain stretches as far as the waves reach (maximum flooding level) during the worst storm in the area, and it includes beaches, dunes, cliffs, swamps and other low wetlands".

No type of trade activities can be allowed in this property. The Legislation on Coasts extends its influence to the private lands adjacent to the public property, Fig. 1,

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to avoid any use carried out on those areas which could be harmful to this space of high environmental value, (M.O.P.T.M.A., 1994). Therefore, in order to implement this policy, the Ministry of Public Works has undertaken a series of programs of actions with the first being the need to complete a precise indentification of the public domain maritime-land assets in accordance to the definition set down in the Legislation on Coasts. This process has given rise to the current Property Survey Plan, whose purpose it is to fix public domain boundaries throughout the whole of the Spanish coast. This approach to the management of the coast in an integral manner has to embrace all territorial and political levels of government such as central government, states and city councils, as well as any individual with private interest on the coast.

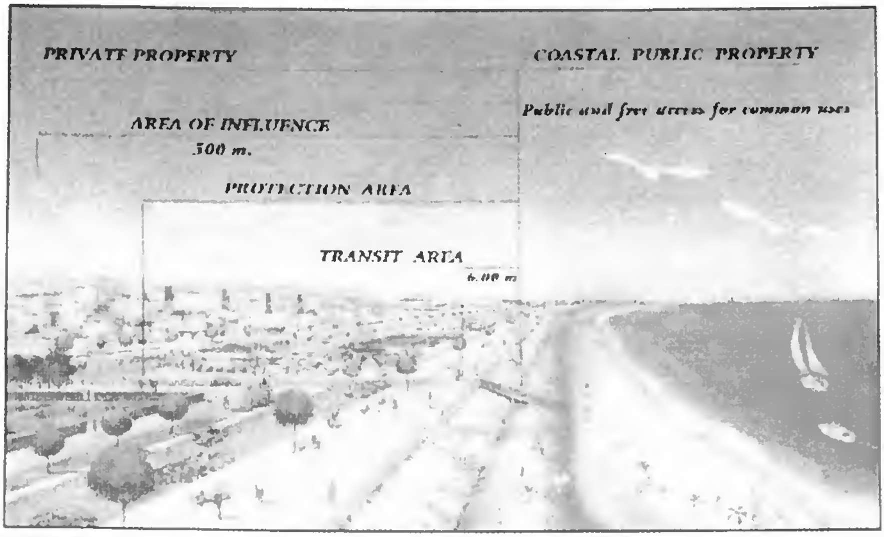


**Figure 1. Public and private uses of shoreline**

For this reason, the determination of the Spanish maritime-land public domain border is an extremely important element in the Program of Coastal Actions initiated by the Spanish Government, and in the last years it has become a key reason for many law suits between the different agents with interest in the coastal area.

*Public Domain Border Determination*

In order to determine the limit where "the waves reach during the worst storm in the area", the 1988 Law established the maritime and meteorological dynamics that must be taken into account. In particular, the law established that the calculation of the maximum flooding level must account for the effects of the: (1) astronomical tide, (2) storm surge and (3) wave run-up, Fig. 2. Episodic events such as tsunamis must be omitted from the calculation, and the influence of long term effects such as sea level rise is not explicitly considered in the law.

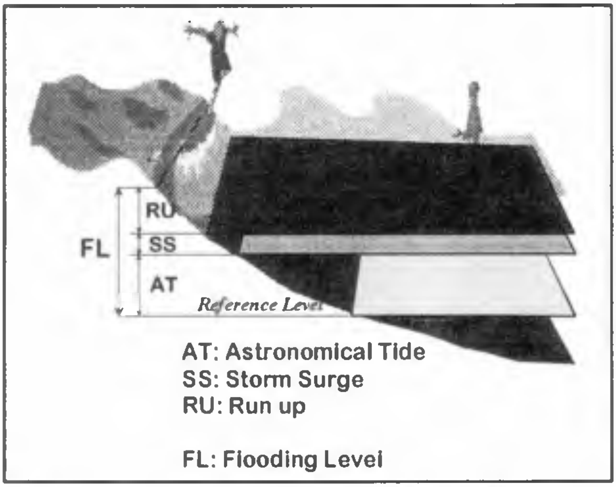


**Figure 2. Dynamics to be considered in the determination of the public domain border**

Since the storm surge and the wave run-up are random variables, the flooding level is also a random variable. Consequently, the determination of the public domain border is a stochastic extreme problem.

One of the consequences of being a stochastic problem is that there is not a deterministic "limit where the waves reach during the worst storm" but each level will have "a probability of being exceeded during a given storm". This probabilistic aspect is not considered in the law in which the public domain border is thought of as a deterministic line.

In this paper the extreme flooding level determination problem is analyzed by means of the joint probability method, (Pugh and Vassie, 1978), which has to be modified to include the effect of the wave run-up. The theoretical approach proposed to determine the public domain border is then applied to a case study in a beach located in the North Coast of Spain. In this case study, the probabilistic problem is also analyzed and a maritime-land public domain border is proposed.

## Theoretical Aproach

The existing methods for estimating the distribution of extreme sea-level at a site, using field data, can be divided into: (1) Direct Methods - in which extremes of the observed water level are analysed-, and (2) Indirect Methods - in which the constituent processes (i.e. tides, surges and waves) are modeled separately and the extreme water level is inferred.

### *Direct Methods*

The direct methods are, mainly, the classical annual maxima approach and the r-largest annual events method.

Annual Maxima Method: The best known, simplest, and most widely used method of analysis of extreme distributions is the annual maxima method, (Gumbel, 1958). This approach has been previously used by several investigators to determine extreme sea-levels, eg. (Lennon, 1963), (Suthons, 1963) and (Graff, 1981).

According to (Tawn and Vassie, 1991), this method is highly inefficient in its use of data and provides inaccurate results. These authors remarked that the assumptions made in using the annual maxima method are namely that hourly sea level heights are (1) independent, (2) identically distributed, and (3) that the number of hours in a year is large enough for the asymptotic approximations to hold. However, because of the nature of the tide and the dependence on the surge sequence, it is clear that (1) and (2) do not hold.

R-largest Annual Events Method: Several proposals have been made to extend the annual maxima method to incorporate all independent extreme sea-level observations into the estimation of the annual maxima distribution: (1) the peaks over thresholds method, (Davison and Smith, 1990); (2) the r-largest events method, (Tawn, 1988); and (3) the point process method, (Smith, 1989).

These methods are based on extreme value limit theory for stationary random sequences and, consequently, it is assumed the r-largest annual extreme levels are from stationary data. This assumption is critical since, due to the tide, the water level is highly non-stationary. According to this argument, the r-largest annual events method is not appropriate to determine extreme sea-levels, (Dixon and Tawn, 1994).

*Indirect Methods*

The existing indirect approaches, the joint probability method (Pugh and Vassie, 1978) and the revised joint probability method, (Tawn and Vassie, 1991) are the only viable options for estimating extreme levels when short data sets are available.

The main advantage of these methods is to exploit our knowledge of the tide in short data sets to which the annual maxima method could not be applied. Basically, these methods seek the probability distribution function (p.d.f.) of the different variables involved and calculate the sea level p.d.f. by combining those p.d.f.s The nature of the combination of the p.d.f.s depends on whether there is dependence between the variable sequences.

The joint probability method assumes that extreme hourly water levels are independent. Clearly hourly water levels are not independent, but extreme levels may be only weakly dependent. (Tawn and Vassie, 1989) studied this feature and found that the assumption was false but led only to small overestimation of return levels.

In the revised joint probability method the temporal dependence of the variables is considered to be a parameter, called extremal index, $\theta$, which is determined empirically from the data.

Although the revised joint probability method results hold for temporal dependence between variables, the existing records are not long enough to have data in the regions of both extreme tides and surges and, consequently, the external index determination is, many times, impossible.

From the previous analysis it can be concluded that direct methods cannot be used to determine extreme sea levels due to the lack of long records. Furthermore, the revised joint probability method also needs a long enough series in order to estimate $\theta$. Consequently, the only methodology capable of giving reasonable results to the problem under study is the joint probability method.

*The Joint Probability Method (J.P.M.)*

This method was first introduced by (Pugh and Vassie, 1978) to calculate extreme sea-levels due to the combined effect of tides and storm surges. At any time the observed sea level, after averaging out surface waves, has three components: mean sea level, tidal and storm surge level. Using standard methods, the first two of these components can be removed from the sea level sequence leaving the surge sequence.

Because the tidal sequence is deterministic, the p.d.f. for all tidal levels can be generated from tidal predictions, while the p.d.f. for the surge level is determined from the nontidal residual.

The p.d.f. of the sea level is finally calculated using the tidal and surge p.d.f.s'. Assuming that the tide and the surge can be considered independent, then

$$p(z) = \int_{-\infty}^{\infty} p_T(z - y)\, p_S(y)\, dy$$

where $p_T(z - y)$, $p_S(y)$ and $p(z)$ are the probability density functions for tide, surge and sea levels respectively.

## Wave-Surge Joint Modelling

As stated previously, wave run-up is an important factor that must be included when determining the maximum flooding level on a beach. The inclusion of wave run-up leads to a two stochastic variables problem, surge and wave run-up, extending the J.P.M. developed by (Pugh and Vassie, 1978), which considers the surge only.

This new problem is one of bivariate extremes and the extrapolation of the distribution tail is required for both the surge and the wave run-up. Furthermore, the dependence between the extremes of theses variables must be accounted for.

If surge and wave run-up are related, the probability density function for the sea level (flooding level) can be written as:

$$p(z) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p_T(z - y - x)\, p_{S,Ru}(y, x)\, dx\, dy$$

where $p_{S,Ru}(y, x)$ is the combined p.d.f. of surge and wave run-up.

If surge and wave run-up are independent, then

$$p(z) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p_T(z - y - x)\, p_S(y)\, p_{Ru}(x)\, dx\, dy$$

It should be noted that the availability of wave run-up data for a particular beach is usually scarce and, consequently, wave run-up p.d.f. must be inferred from wave data and wave run-up theory.

The study of wave run-up on artificial and natural beaches has received considerable attention by researchers over the last several years; e.g. (Guza and Thornton, 1981), (Holman, 1986), (Nielsen and Hanslow, 1991), (Holland and Holman, 1993).

In this study, (Nielsen and Hanslow , 1991) results for wave run-up distribution on a natural beach are used. Using run-up distributions measured on a wide spectrum of sandy beaches, these authors showed that, for a sea state, the Rayleigh distribution is a reasonable statistical model for the maximum level reached by individual waves. This result was also obtained theoretically by (Battjes, 1971) for the special case of perfect correlation between wave height, $H$ and wave period, $T$. That is,

$$F(R_{wm} \geq R) = \exp\left[-\left(\frac{R - R_{100}}{L_{Rwm}}\right)^2\right]$$

where $R_{100}$ is the highest level transgressed by 100% of the waves and $L_{Rwm}$ is the vertical scale of the distribution.

For extreme wave conditions, the beach can be assumed to be dissipative and, $L_{Rwm} \approx 0{,}05\ (H_{rms}\, L_o)^{0,5}$ where $H_{rms}$ is the mean squared root wave height and $L_o$ is the deep water wave length. Notice that for a typical relationship $T_S = \alpha_1\, H_S^{0,5}$, $L_{Rwm} \approx \alpha_2 H_S$, where $\alpha_1$ and $\alpha_2$ are two constants, depending on the wave climate of a given region.

Notice that the wave run-up p.d.f. is a Rayleigh distribution that depends on a random variable $H_S$, which has its own p.d.f. (e.g. Weibull), consequently the flooding level p.d.f. can be written as:

$$p(z) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p_T(z - y - x)\, p_S(y)\, p_{Ru}(x)\, dx\, dy$$

with

$$p_{Ru}(x) = \int_{-\infty}^{\infty} p^*_{Ru}\,(x,\, H_s)\, p_{H_S}(H_S)\, dH_S$$

$p^*_{Ru}$ ( ) where is the Rayleigh $p_{H_S}$ ( ) p.d.f., and is the significant wave height p.d.f.

## Application

In this section, the wave-surge joint modelling is applied to a beach located on the North Coast of Spain.

*Study Site*

The study site is Oyambre Beach, located close to the city of Santander, on the Cantabrian coast of Spain, Gulf of Biscay, Fig. 3.

The northern coast of Spain is divided into a series of pocket beaches and small inlets isolated between rocky headlands. Most of the headlands extend into deep water and appear to be effective in confining littoral sand to the embayments. Therefore, the coast can be analyzed as a series of littoral cells.

One of these littoral cells is the beach of Oyambre. The beach is bound westward by Cape Oyambre and eastward by Cape El Moro. Several reefs can be found in intermediate water as part of Cape Oyambre along the northwest part of the beach (e.g. La Molar Shoal, San Francisco Shoal, Fig. 3).

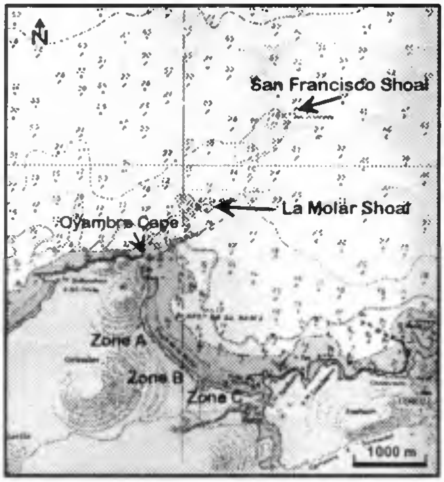


**Figure 3. Location Map**

More than three-quarters of the deep-water waves approach Oyambre Beach from the northern - northwestern sector. The annual average significant wave height is about 1 m with typical winter storms waves of $H_S \sim 4 \div 6$ m. Tides at Oyambre Beach are semidiurnal with a mean tidal range of 3 m and spring tidal range of 5 m.

*Maritime and Meteorological Data*

In order to apply the methodology presented in section "Wave-Surge Joint Modelling", different data sets of waves and sea-level were analyzed. These data sets are continuously recorded by the Spanish Network for Maritime Recording and are presented in several publications from the Ministry of Public Works, Transportation and Environment, called R.O.M., (Losada et al, 1996).

*Sea-Level Data*

Sea-level data used in this study were recorded at Santander. This sea-level data set consists of hourly sea-level measured during the last five years and include three additive components: mean sea-level, tidal, and surge level.

Standard tidal analysis, (Godin 1978), is used to separate the astronomical tide and the surge from the sea-level data. The astronomical tide distribution shown by a probability density function in Fig. 4, is bi-modal. This kind of distribution is typical of semi-diurnal dominated tides, with the modes ocurring at levels corresponding to mean high and low water tides.

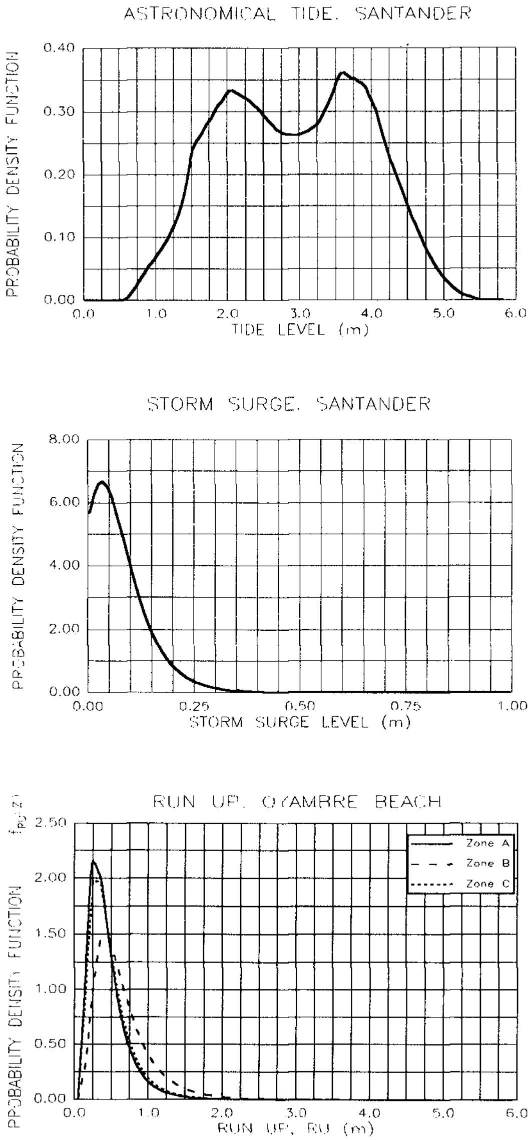


**Figure 4. Tide, surge and wave run-up p.d.f.'s**

The surge series is defined as the residual of the tidal series; i.e. the difference between the observed sea-level and the predicted tide. The difference between observed levels and tidal predictions is due to meteorological forcing in the form of changes in air pressure and winds which constitutes the surges forcing.

Due to the location of the tidal gauge, inside Santander Bay and in water depth of about 10 m, most of the surge is caused by air pressure. This hypothesis was further corroborated by correlating the 5 year surge data to air pressure data. Using this correlation, a probability density function of the surge was estimated by means of pressure data from the last 50 years, Fig. 4. The surge distribution is uni-modal, with the mode close to zero, and is positively skewed, leading to large positive surge levels being more likely than large negative surges (not shown).

Wind surge cannot be determined from Santander sea-level data. Furthermore, since the variability of wind-surge from coast to coast due to local bathymetry is so high, theoretical wind-surge estimation from wind data is the only feasible way to determine wind-surge at Oyambre Beach. Different simulations were run to estimate the combined surge due to air pressure and wind at Oyambre Beach. The main conclusion was that wind surge can be considered negligible when compared to air pressure surge, especially in extreme events when a low pressure is close to Oyambre. This characteristic of the surge at Oyambre Beach is due to the kind of low pressure reaching the northern Spanish coast and the bathymetry of Oyambre Beach and cannot be generalized for other locations.

*Wave Data*

Wave data used in this study was recorded at Gijón (about 100 km west of Oyambre). These data are deep water measurements of wave characteristics monitored by the Spanish Network mentioned above. Wave characteristics were propagated to the study area using a numerical wave propagation model. The model used, called REF/DIF, (Kirby and Dalrymple, 1985), solves the parabolic approximation of the mild slope equation and is adequate to estimate the effect of the different shoals located northwestward the beach, Fig. 3.

Since the wave characteristics varies from point to point along the beach, a zoning was made in order to set zones in which the wave characteristics can be assumed to be homogeneous. At Oyambre Beach this classification led to three areas called A, B and C, shown in Fig. 3.

For these three areas, different combinations of wave height, $H_S$, and wave period, $T$, at deep water were propagated in order to obtain the wave height distribution at shallow water in front of zones A, B and C. Using this wave distribution and (Nielsen and Hanslow, 1991) empirical distribution for wave run-up, the wave run-up p.d.f. at the different zones is calculated Fig. 4. The wave run-up distributions are also uni-modal and positively skewed. Zone C, which is exposed, has higher run-up probabilities than zones A and B.

*Maximum Flooding Level*

Using the p.d.f.s shown in Fig. 4 and the Joint Probability method described above, the flooding level p.d.f. is estimated, Fig. 5. The probability that the flooding level is less than $x$ is:

$$F(z) = \int_{-\infty}^{z} p(x)\, dx$$

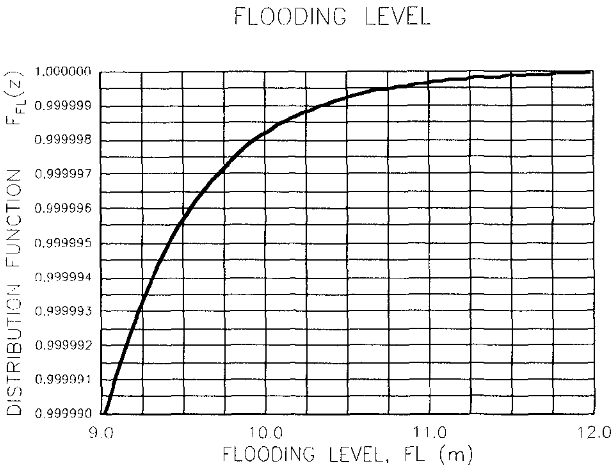


**Figure 5. Flooding level p.d.f.**

This distribution function *F(z)* is shown, for the maxima, in Fig. 6.

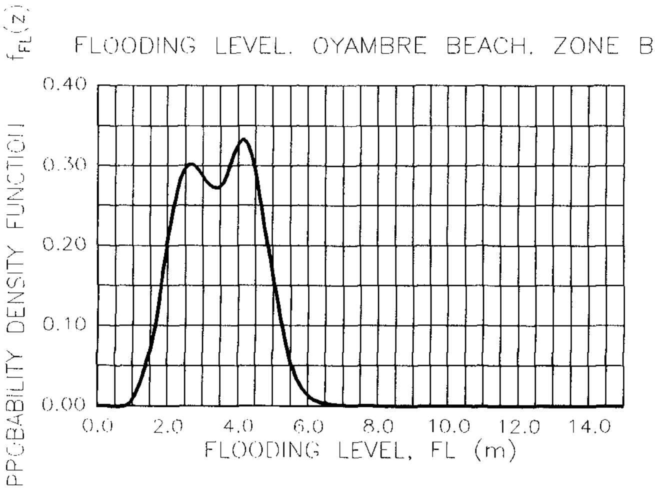


**Figure 6. Flooding level distribution function**

Although the probability of a level to be exceeded by the combination of tide, surge and wave run-up can be determined from Fig. 6, the application of the results to the determination of the public domain border is not straightforward since the law is not expressed in terms of probability but in terms of number of waves. ("The limit as far as the wave reach during the worst storm").

Changing flooding probability into number of waves is a straightforward technique but it adds a new random variable to the problem; i.e. the number of waves in a given period of time. This new variable can also be determined by means of the data from the wave buoy network.

In Fig. 7, the flooding level distribution, in terms of number of waves, is presented for zone B of Oyambre Beach. If the number of waves is limited to "one wave" we will obtain the limit reached by one wave in a mean year.

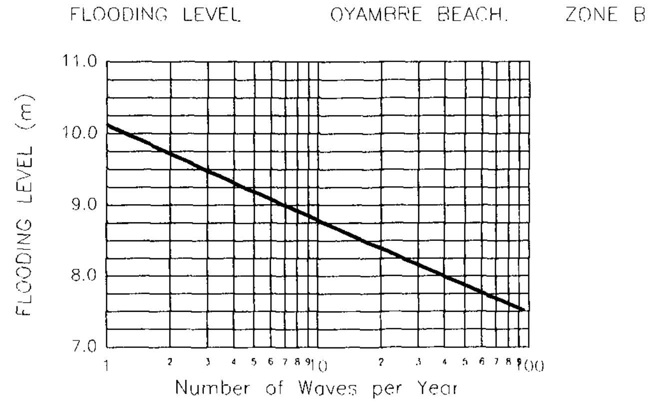


**Figure 7. Flooding level distribution in terms of number of waves**

Upper flooding levels will have an exceeding probability average less than "one wave per year" but they can be exceeded if we increase the number of years of observation. In this way we can determine the return period (years) of a level to be exceeded by one wave, Fig. 8.

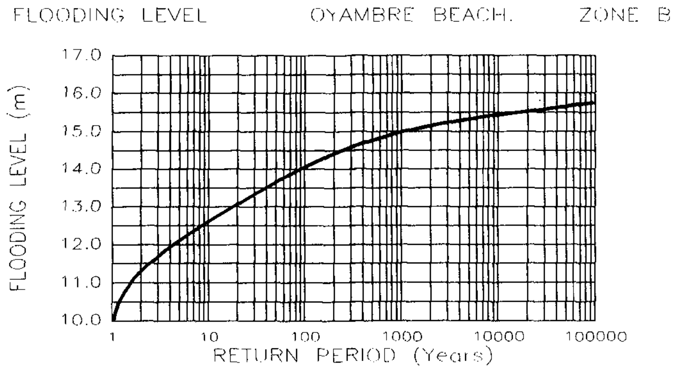


**Figure 8. Flooding level exceeder by one wave versus return period (years)**

*Public Domain Border*

From Fig. 8 it is clear that, a given flooding level will be exceeded if we have enough years of observations. At this point a criteria must be selected in order to establish the return period to be adopted in the calculation of the public domain border.

Since the Law of 1988 does not fix that criteria, the Spanish Recommendations for Coastal Works R.O.M. 02-90, (Puertos del Estado, 1990) is used. These recommendations give the designer an estimate of the minimum life and the risk to be adopted as a function of the type of maritime work and the security level demanded. With these two parameters, the return period can be calculated. For a public domain border determination, a mean return period of 500 years has been estimated.

## Conclusions

This paper presents a methodology to determine the Spanish public domain border, which is the theoretical line that separates the public and the private properties in the Spanish coastal zone.

The methodology is based on the joint probability method (J.P.M.) first introduced by (Pugh and Vassie, 1978) to estimate extreme sea-levels due to the combined effect of tides and storm surge. In this paper an extension of the J.P.M. has been developed in order to include the wave run-up on a beach.

To account for the probabilistic character of the problem a methodology is presented consistent with other Spanish coastal works recommendations. The given methodology provides an engineering tool to determine the public domain border based on available field data and on hand numerical models.

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