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GLOBAL WARMING: ITS IMPACT ON HYDRAULIC ENGINEERING IN THE CARIBBEAN

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This paper is a revised and improved version of a paper which was presented at the CIB-W65 Symposium on Construction Engineering & Management, in Port of Spain, Trinidad, West Indies, September 1993.

SUMMARY

It is now believed, amidst some uncertainty, that the anticipated global warming will cause average temperature to increase by 3 to 5 degrees centigrade, and sea level to rise by about 60 to 70 centimetres over the next century. Other meteorological events such as the amount and spatial distribution of precipitation are also expected to change. It is envisaged that these changes will affect hydraulic engineering design and construction activities in the Caribbean in a number of ways. Sea level rise and altered precipitation patterns, in particular, would significantly impact on the adequacy of the existing and currently proposed hydraulic engineering systems. This paper shows, by means of a design example, that the cost of building a bridge today, incorporating the provisions for the anticipated sea level rise, is considerably less compared to the cost of retrofitting the same structure in future. This paper, therefore, concludes that in spite of the uncertainty and the long term nature of global warming, the prudent approach is to recognize the uncertainty but not allow it to forestall action and forward planning.

Keywords: Caribbean, Global Warming, Sea Level Rise, Hydraulic Structures, Economic Implications.

1.0 INTRODUCTION

Global warming (GW), resulting from the accumulation of carbon dioxide and other greenhouse gases in the atmosphere, is one of the most important environmental issues in the world today (11). The predictions of the resulting climatic changes are based on atmospheric General Circulation Models (GCM's). At this time a sea level rise of approximately 0.65 m , and an increase in the mean annual temperature of 3 to 5 degrees centigrade are predicted to take place on a global basis during the course of the next century (3). There is a considerable uncertainty associated with these predictions for the following main reasons. Firstly, the scale of events and the available computational resources require the use of a coarse numerical grid. Secondly, because of varying responses to a perturbation, the interaction between the ocean and the atmosphere is as yet difficult to simulate with reasonable accuracy, and finally it is believed that there may be alternative Geo-Physical and Astro-Physical explanations (1,6). It is generally believed, however, that the prudent course of action is to carry out advance planning inspite of the uncertainty (2,3,5,9).

2.0 IMPLICATIONS IN THE CARIBBEAN

Predictions for the Caribbean region, from the GCM's which assume a doubling of carbon dioxide, are based on relatively coarse spatial resolutions of the order of 5 degrees latitude by 8 degrees longitude (8). Thus specific predictions for the small Caribbean islands are not now possible. Available information shows that for the entire Caribbean region, temperatures are projected to rise by approximately 3 degrees on a mean annual basis. The mean annual precipitation is projected to increase by approximately 6 % in the western Caribbean and decrease by approximately 4 % in the eastern Caribbean (4,8). It is anticipated that the decrease in precipitation in the eastern Caribbean would take place in the dry season, which would mean a more severe and longer drought conditions. The projected increase in precipitation in the western Caribbean would also take place in the dry season,which would mean a reduction in the severity of the dry season in islands such as Jamaica. The frequency of occurence of hurricanes and tropical storms, as well as their intensity, are likely to increase due to the increase in sea level temperature and humidity.

One of the major direct implications of GW in the Caribbean is in the domain of hydraulic engineering, and therefore, this paper concentrates on this aspect. The likely hydraulic impacts range from retrofitting irrigation, drainage and water supply systems to the need for coastal defence works for protecting low lying areas. In addition, the potential for a severe contamination of aquifers by increased sea water intrusion gives cause for much concern, keeping in view the critical dependence of many small Caribbean islands on groundwater resources.

The central problem surrounding GW is the dilemma of what actions ,if any, should now be taken to mitigate it. The possible options are: (i) to control the emission of greenhouse gases, (ii) to provide for GW in the

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contemporary hydraulic engineering design, and (iii) to retrofit the hydraulic engineering systems in the future, when GW effects become undeniably evident and must be reckoned with (7,9). The first option, control of emissions of greenhouse gases, is considered beyond the scope of hydraulic engineering, since it has broad social, technological and political dimensions; and as yet has an uncertain time frame. Therefore it will not be considered here.

3.0 IMPACT ON DESIGN, CONSTRUCTION AND MAINTENANCE

GW is likely to impact on hydraulic engineering construction activities in two different ways; firstly, through changes in the precipitation patterns, and secondly, due to the sea level rise. For the Caribbean region, storms are likely to be less frequent but more intense (4). This would mean that a fifty year storm may occur with a smaller recurrence interval. As a consequence existing design criteria will require changes, and the design of spillways, bridge water ways, culverts and drainage channels will be significantly affected.

Sea level rise will affect construction activities in an adverse manner. The cost of constructing hydraulic engineering systems would be higher due to larger dimensions of flow elements and control structures, required to mitigate the effects of sea level rise. Examples of hydraulic engineering structures that would require either initial design changes or retrofitting are: bridge waterways, culverts, well fields, sea walls, and storm and land drainage systems. Coastal drainage systems are specially vulnerable to the sea level rise. The decrease in hydraulic gradient, due to the sea level rise, would reduce the flow velocities in open channels. This would cause an increase in sediment deposition, further reducing capacity or necessitating more frequent maintenance. Furthermore, as sea level rises, some areas that currently have gravity drainage may require pumping. Finally, sea level rise and its interaction with groundwater flow would raise the water table. This would make excavation works more expensive and difficult in coastal areas. It may be stated that, in general, the additional construction costs may cause a delay, deletion, or scaling down of projects due to financial constraints.

It should be noted that GW has impacts on hydraulic systems, other than that due to the concomitant sea level rise. These are anthropogenic impacts derived from devegetation, modified slope angles, accelerated erosion and deposition rates, changing runoff and evapotranspiration co-efficients and changing coastal geomorphology attendent on development. However, this paper does not consider these impacts.

4.0 ILLUSTRATIVE EXAMPLE

A comparative look, at the options (ii) and (iii) - stated in section 2 of this paper, is presented in this section; with reference to an example on the hydraulic design of a bridge. The proposed location of the bridge is in the north west peninsula of Trinidad (Figure 1). It is to be noted that both the hydraulic analyses and cost estimates, pertaining to the illustrative example, are neither complete nor rigourous, and are briefly stated only to complement the discussion on the impact of GW on hydraulic engineering design and construction.

The area of the catchment of the stream that flows under the bridge is approximately 100 hectares. The catchment is located near the coast, and would comprise a sub-urban housing development. Approximately 70 % of land would be occupied by 0.2 hectare residential lots, and the remaining 30 % would be reserved for open space with trees and lawns. The average land slope is 0.01, and the estimated time of concentration of the peak runoff in the catchment is 1.5 hours. The 25 year design peak flow for the bridge was estimated to be 10 cubic metres per second, by using the Soil Conservation Service Method (10).

The design life of the bridge is 50 years, but it is relevant to note that with good maintenance similar

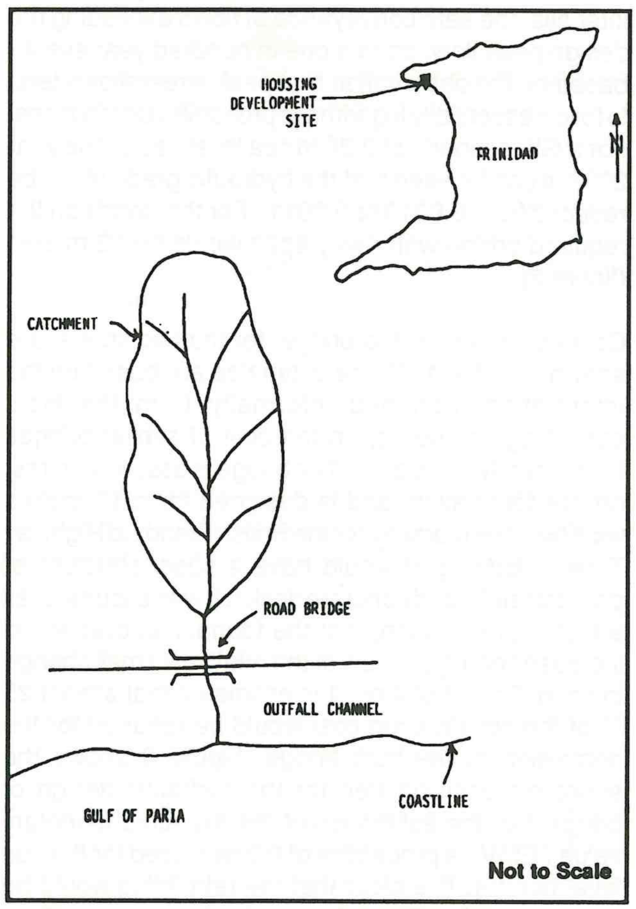

Figure 6. Location of Bridge & Catchment

Span	Foundation	Super structure cost	Total Cost	Demolition	Additional
(1)	(2)	(3)	(4)	(5)	(6)
10m	$150,000	$45,000	$195,000	$48,750	$282,750
12m	$180,000	$54,000	$234,000	Not Required	Not Requ ired

Notes 1. Superstructure Cost based on the cost of precast reinforced concrete decks at $450/m^2$

2. Estimates based on 1992 $

Table 1 - Cost Estimates for Bridge Construction

bridges are known to last up to 100 years. The outfall channel to the sea has a length of approximately 670 metres, a slope of approximately 0.0016, and the estimated Manning's friction factor of 0.025. The stream bed elevation at the bridge location is 1.07 metres above the mean sea level. The appropriate bridge water way span for the afore-mentioned peak flow, for uniform flow in a trapezoidal natural channel is 10 metres. The one metre freeboard is to provide for, inter alia, the safe conveyance of flows exceeding the design peak flow; up to a one in hundred year event - based on the observation that peak streamflows tend to follow essentially logarithmic probability distributions. For a GW scenerio of 0.30 m sea level rise by the year 2032, it can be seen that the hydraulic gradient will be reduced from 0.0016 to 0.0011. For this condition the required bridge water way span would be 12 metres (figure 2).

Cost estimates for the bridge, for the two spans, are shown in Table 1. These estimates are based on the information, obtained informally from the local consulting engineers, on the cost of similar bridges built recently in the area. The bridge is assumed to rest on pile foundation, and is designed for a 10 metres wide two lane roadway for the British Standard Highway Type A loading. It would have a super-structure of precast reinforced concrete decks. It was assumed, as a first approximation, that the foundation cost would increase linearly; in view of the relatively small change in span. For retrofitting, it is estimated that almost 25 % of the construction cost would be required for the demolition of the built bridge. Figure 3 shows the economic decision tree for the hydraulic design of bridge. For the estimation of the expected monetary value (EMV) a probability of 0.3 was used for the sea level rise (9). It is clear that the retrofitting would be more expensive. This inference is of course specific to

CONVEYANCE CAPACITY OF BRIDGE WATERWAY

Span (m)	Area (m2)	Wetted Peri-meter (m)	Hyd. Radius (m)	Velocity (m/s)	Discharge (m3/s)
(1)	(2)	(3)	(4)	(5)	(6)
10	8	10.5	0.75	1.3	10.6
12	10	12.5	0.8	1	10

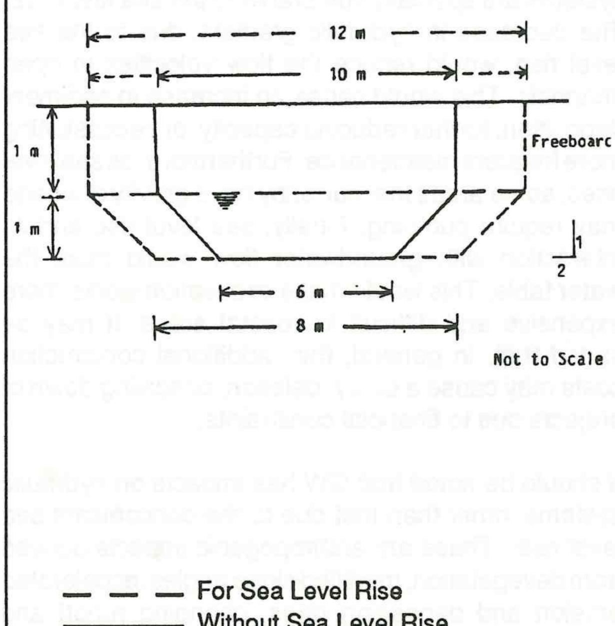

Figure 2 Schematic of Bridge Waterway

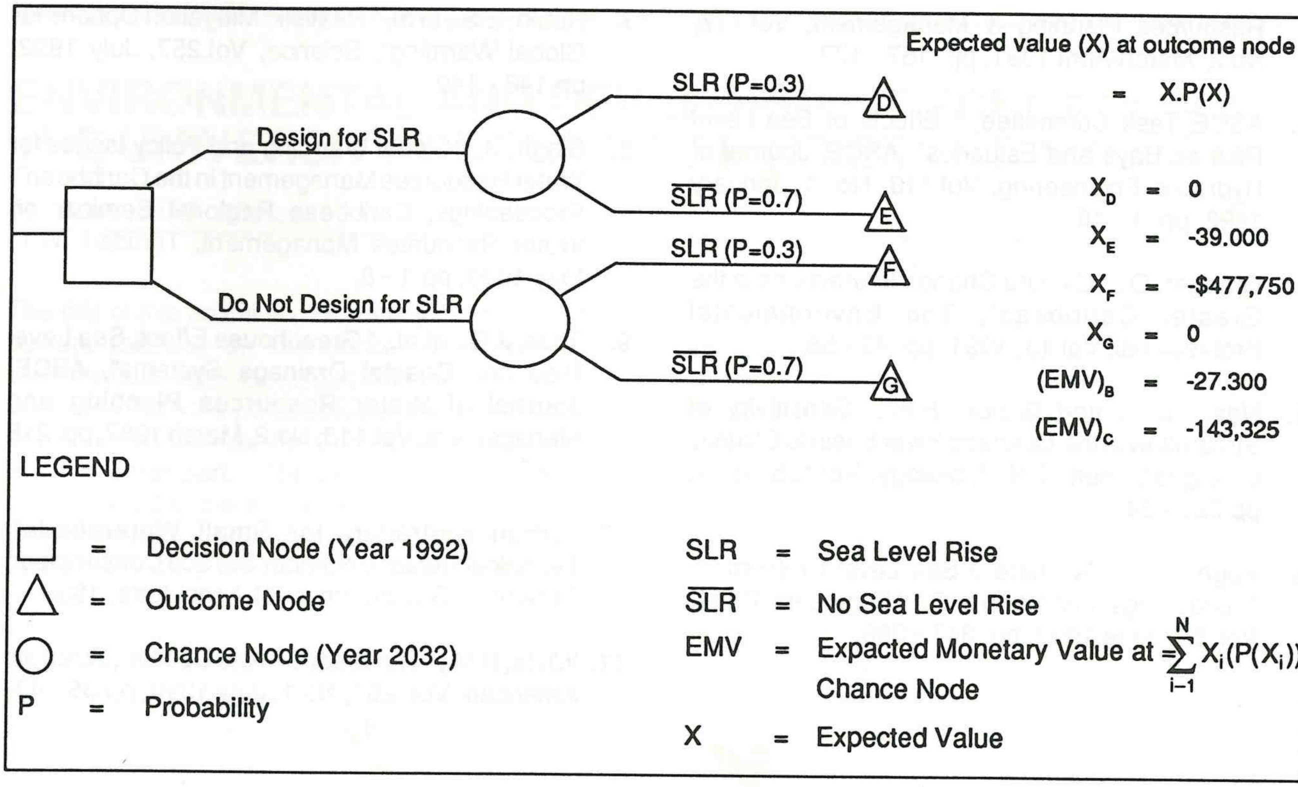

Figure 3. Decision Tree for Economic Analysis

the example presented. However, the order of cost implications should be true, in general, for similar projects.

5.0 CONCLUSIONS

In view of the foregoing analysis and discussion, the following conclusions may be made:

(i) The prudent course of action, for dealing with GW and sea level rise, is to recognise the present uncertainties, and at the same time to commence forward planning.

(ii) It is cost effective to incorporate GW implications in the contemporary design of Hydraulic Structures. It should be noted, however, that while cost effectiveness should be a key measure for deciding on a course of action for the mitigation of GW, the economic cost of any response should be considered with other claims on a country's resources.

(iii) The Hydraulic Engineering Design Standards should be reviewed, as soon as possible, for incorporating the GW implications. For example, it may be prudent to consider, inter alia, a design standard that ensures that buildings and roads are not put so close to the drainage channels that future widening is impossible.

(iv) The contemporary provisions for mitigating GW should be considered an investment in a country's future. For example, increased capacity of drainage systems would provide a higher factor of safety, if GW fails to occur, and would prolong the usefulness of the system, in view of the land use changes and population increases in the future.

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