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DYNAMIC EQUILIBRIUM IN APPLIED GEOMORPHOLOGY: TWO CASE STUDIES

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Abstract

Engineering works and agricultural activity which change the relationship between rainfall and river flow lead to modifications of river channels with attendant erosion and deposition problems. In the Swiss Jura Lakes area, the natural flooding of the River Aare became such an acute problem by the mid-nineteenth century that extensive engineering works were carried out to alleviate flooding. The land thus reclaimed became a valuable agricultural asset, but the fall of the water table following removal of the annual flood risk, led to a fall in the level of the land as peat was changed into humus. Renewed flooding occurred. The natural readjustment following the first series of flood alleviation works reproduced the original problem and a second series of engineering works has had to be undertaken to remedy the situation. On the Belgian coast, harbour construction and the spread of buildings over the sand dunes have resulted in severe beach erosion in the eastern seaside resorts.. Extensive engineering works have had to be undertaken to restore the beach. These examples illustrate how man's challenges to nature are often recurrent phenomena, and how the alteration of one aspect of the physical environment may lead to a succession of readjustments. Each phase of engineering activity may be considered a break in natural equilibrium, and each period of natural erosion or deposition a trend towards a new equilibrium.

INTRODUCTION

In his recent review of the state of physical geography Chorley (1971) suggests that physical geographers might concentrate on the equilibrium relationships of process-response systems and their disturbance, regulation and control by human intervention. Such studies imply shorter time scales than the purely physical process-response systems involved in the dynamic equilibrium interpretation of topographic forms (Hack, 1960), according to which landforms adjust to changes in any aspect of erosional energy, and every slope and channel in a drainage basin tends to become adjusted to every other.

Short time spans allow steady state conditions to develop in drainage systems (Schumm and Lichty, 1965), but when man intervenes, by changing vegetation or beginning construction works, such a dynamic equilibrium is broken (Wolman, 1967). The process of land clearance and urbanisation develops a systematic response in the sediment yield of the drainage system. Studies in Maryland suggest that following agricultural development, the drainage basin adjusts to a new equilibrium state with a sediment yield of between 100 and 350 tons/km^2. The drastic exposure and loosening of soil during construction works increase sediment yield to over 1000 tons/km^2, but the final urban surface provides a new equilibrium with yields of less than 50 tons/km^2, (Wolman and Schick, 1967).

In long term process-response systems, climatic changes introduce sequences of disruption of equilibria, such as those envisaged in cylic concepts of various scales (Davis, 1899; Butler, 1959). Erhart (1966) expressed shorter term stability-instability phases as a biostasy and rhexistasy. In the man-environment process-response model, similar sequences of relative stability and disruption occur. One way of establishing these phases is to examine the costs and benefits of disruption of geomorphological systems.

A concept of sequent benefit and cost phases of exploitation of river and coastal areas.

The achievement of a satisfactory exploitation of a physical resource involves some initial costs in making that resource more readily available, such as the cost of making tourist access roads to an attractive area of coastal or mountain scenery, and a larger benefit, either in strictly economic terms or in social and cultural terms, from the enjoyment of that resource. Many phases of exploitation, however, see the benefits being eroded as new costs arise. The massive effects of air pollution, and the costs society has to face in reducing air pollution could be regarded as an example of this change from a phase of benefit to a phase of cost in the exploitation of the atmosphere. These phases of benefit and of cost may be regarded as phases of quasi-equilibrium, and of disruption and effort to adjust to a new equilibrium, respectively.

In this paper, two such cases of sequent benefit and cost phases in the exploitation of the hydrological and geomorphological resources of Europe are discussed. In the Swiss Jura Lakes area, successive phases of drainage have been required in response to a constantly changing dynamic equilibrium between agricultural activity and lake evolution. On the Belgian coast, competition for the exploitation of the coastline by different economic activities has aggravated the side effects produced by harbour works at Zeebrugge. In both cases, the second phase of high cost construction has provided additional recreational benefits as a side effect of basic protection and preservation aims.

FLOOD PREVENTION IN THE SWISS JURA LAKES AREA

The first flood alleviation scheme

Until less than a century ago, the waters and sediments of the Aare, draining from the Bernese Oberland, discharged into the broad structural trough occupied by glacial sediments and Lakes Neuchâtel, Morat and Bienne, building up an alluvial fan with its apex at Aarberg and toe near Büren. This deposition on the bed of the Aare partially blocked the channel of the Thielle, the tributary carrying

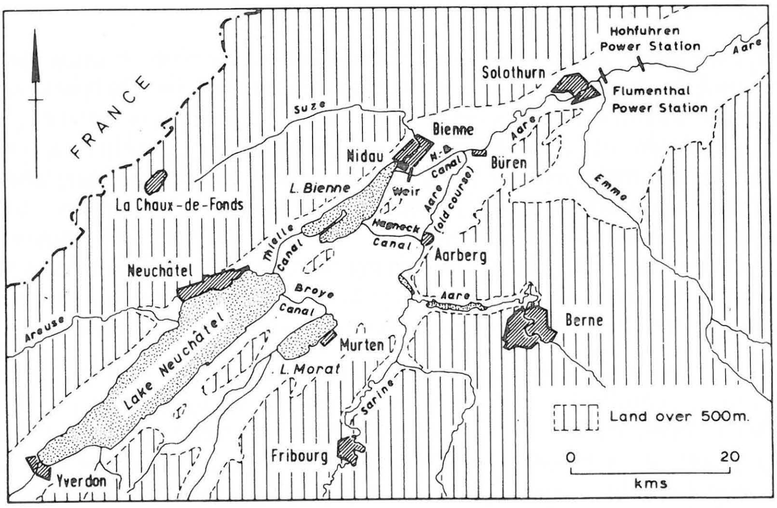

Figure 1. General map of the Swiss Jura Lakes showing the waterways of the Jura Water Correction.

water from the three lakes and the surrounding plain, causing a rise in the levels of the three lakes in time of flood. Below the confluence of the Thielle and Aare above Büren (Fig. 1) the gradient of the Aare was very gentle as far as Solothurn, where the Emme built up another fan diverting the Aare on to a rock bar which controlled river levels upstream. By the mid-nineteenth century, the reduction in channel capacity had led to acute flood problems on the plains around the Jura Lakes.

To prevent a further increase in the height of the bed of the Aare and to decrease the risk of flooding, the First Correction of the Jura Waters was carried out between 1868 and 1891 (Chavaz and Gygax, 1964). Lake Bienne was made to act as a trap for the sediment of the Aare by diverting the river to flow directly into the lake through the Hagneck Canal. The Nidau-Büren canal provided a shorter and more efficient channel for the Thielle and the three lakes were linked by the Broye and Thielle canals. The fall in lake levels of 2.5 metres which resulted from the construction of these canals enabled the riverine and lacustrine plains to be drained without pumping.

The land thus protected from flooding was reclaimed for agriculture, largely by individual farmers or small groups of entrepreneurs. The cereal crops and potatoes grown there became a valuable part of the Swiss rural economy. The break in the natural trend towards an equilibrium state was followed by renewed adjustments in hydraulic and geomorphic conditions. Around the three lakes the level of the land surface began to fall as water tables were lowered and peat transformed into humus. Although the floods no longer reached the previous maximum levels, the fall in land level of almost 1.5 metres created a new flood risk, with widespread inundation following the exceptional floods of 1910, and the risk of 100km^2 of this valuable land reverting to marsh conditions.

The second flood alleviation scheme

The problem to be solved by the Second Correction of the Jura Waters arises from the role of the lakes as a great flood basin into which water flows at rates of 1400 to 1700m^3/sec but out of which the maximum rate of discharge, from Lake Bienne, is only 700m^3/sec. Flood protection, the main aim of the Second Correction, is being achieved by increasing the maximum outflow from Lake Bienne to 750m^3/sec., at a water level of 430.25m, 1.05m lower than the 1944 flood level. The capacity of the Aare below Nidau is being increased by lowering the channel bed, and by removing part of the rock bar at Solothurn, below which the gradient of the Aare steepens. As excessive channel erosion will threaten riparian towns and lower water tables, the natural tendency for the channel profile to adjust to the removal of the Solothurn nickpoint will be avoided by a new hydroelectric power station, which is being constructed at Flumenthal, just below Solothurn, both to use combined hydraulic energy of the Aare and Emme, and to control the discharge of the river at low flows. Further deepening of the channel is taking place between Nidau and Büren, but erosion of the fluvioglacial materials of the channel bed between Büren and Solothurn is being left to natural channel processes (Müller, 1959).

Allowances for further land subsidence

The new weir at Nidau controlling discharge from Lake Bienne will regulate the levels of the three lakes. As the work of the Second Correction will increase the peak flows of the Aare by some 200 to 250m^3/sec., some problems may occasionally occur downstream when there are flood flows on the Emme. On such occasions the weir at Nidau will have to be closed for short periods, but such closures will not have any significant effects on the lake levels. The subsidence of the peaty plains around the lakes is expected to continue as a result of the further lowering of the water table, and is estimated by Chavaz and Gygax (1964) to amount to another half metre over 100 to 200 years. The Second Correction has been designed to cope with this subsidence, and the engineers are confident that this scheme represents a long term improvement of the flood conditions around the Swiss Jura Lakes.

Although the benefits of the Second Correction include navigation improvements, recreational facilities and nature reserves in addition to protection of agricultural land, the costs are high. The five Cantons bordering the three lakes, Fribourg, Vaud, Neuchâtel, Solothurn and Bern are controlling the project through an intercantonal public works commission, but 50 per cent of the total estimated cost of 88.7 million Swiss francs is being met by a grant from the Confederation.

COASTAL EROSION IN BELGIUM

A seaside resort depends basically on its physiographic qualities for its existence as a tourist centre. Although amusement parks, theatres, restaurants, casinos and sporting facilities such as yachting marinas, boating lakes, golf course, swimming pools and bowling alleys may offer alternative activities for the tourist, the juxtaposition of land and sea is the essential ingredient. The beach is the fundamental coastal tourist resource, and any loss of beach by erosion is a serious threat to the economic well-being of a seaside resort. Harbour and navigation improvements have produced such a situation which has needed costly remedies on the eastern sector of the Belgian coast in the vicinity of Knokke-le-Zoute.

The stability of the dunes of the Belgian coast

The present cordon of dunes along the Belgian coast was probably fully developed by the 7th century A.D. (Tavernier and Moormann, 1954). The dunes have expanded on their landward side and the coastline has tended to recede in

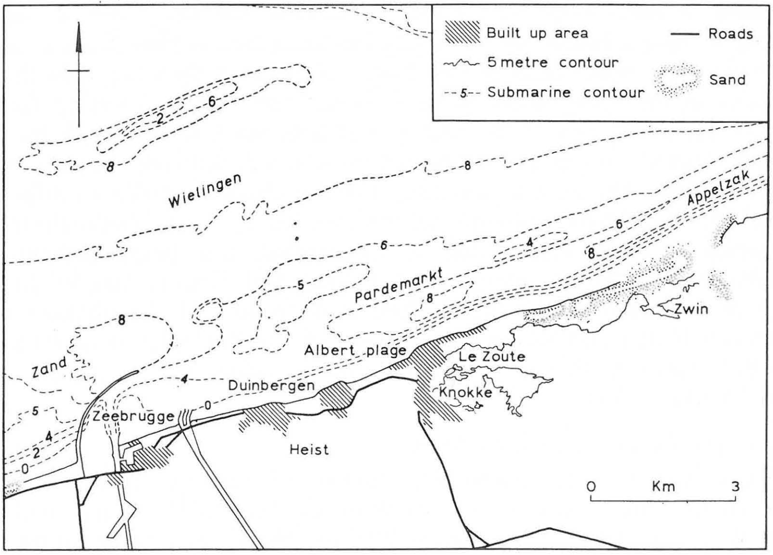

Figure 2. The eastern section of the Belgian coast showing the offshore submarine topography and main holiday resorts.

the Zeebrugge-Knokke section (Fig. 2). Mediaeval village sites are now several hundred metres out to sea. Major storm surges occasionally breached the dunes, and by the late sixteenth century groynes had been constructed at Heist.

The offshore gradient close to Knokke has become steeper in recent times and erosion has attacked submarine banks offshore, especially the Pardemarkt which was lowered by 2.9 metres between 1940 and 1955 (Verschave, 1961). This deepening of the zone immediately offshore has increased the exposure of the beach in the Knokke-le-Zoute area to storm waves, particularly from the north or northwest which have a longer fetch than waves from other directions.

Beach erosion as a consequence of human activity

The stability of the dune coastline has been further threatened by the slight general rise in sea level and by the fall in level of the polders of the maritime plain following the lowering of the water table by land drainage. The beach defences built to counteract the effects of these natural changes have not always been as efficient as intended. Groynes constructed between 1920 and 1939 were not long enough and resulted only in an acceleration of erosion of the beach at low tide on the southern slope of the Appelzak trench between Zeebrugge and the Dutch frontier. The construction of sea walls, roads and buildings on the dunes has broken down the dynamic equilibrium between the dunes and the beach, by restricting the supply of sand from the dunes to the beach. Thus instead of receding with constant, or nearly constant, profile, the beach has become steeper and erosion has been accelerated. Although the sea wall prevents storm waves attacking the dunes, the energy of wave impact against the artificial barrier is spent on undermining the beach at the base of the wall.

Further beach erosion problems have arisen from the creation of the port of Zeebrugge in the period 1890-1907, after the establishment of the major holiday resorts. By 1909, Heist, close to Zeebrugge, already had 170 hotels, far more than at present. The town began to suffer as its beach was eroded after the completion of the Zeebrugge mole. The stability of the beach depended on an eastward moving flood tide current which carried sand along the coast, replenishing that which had been carried off the beach by a westward ebb tide current. When the mole was completed, the sand carried by the eastward current accumulated on the western side of the mole, while the ebb tide current continued to erode sand from the beaches of Heist, Knokke and Le Zoute, depositing it in Zeebrugge harbour. As a result, at high tide, little beach is now exposed adjacent to the town centres of Heist and Knokke-le-Zoute. Only between Heist and Duinbergen, where the sea wall was built 150 metres further inland, and at Albert-Plage is the beach large enough for all the usual beach activity associated with a seaside holiday resort.

The attempts to restore the beach

The communes of Heist and Knokke endeavour to restore their vital beaches by bulldozing each spring, and have supported a beach protection programme undertaken by the coastal section of the Belgian Ministry of Works. The sea wall has been reconstructed between Zeebrugge and Knokke, and new groynes have been built to quicken the development of a less steep beach profile. Sand has been pumped hydraulically, from a deposit beneath the peat soil of the polders south-east of Knokke, on to the beach to assist the restoration work. The excavation of sand created a new lake 10 hectares in area which has become an additional tourist attraction for Knokke.

The results of these measures are striking. Between 1953 and 1959, 1,750,000m^3 of sand were gained naturally and a further 1,250,000m^3 were added by hydraulic pumping. The cost of the work was estimated at 354 million Belgian francs, which is only one per cent of the estimated value of the public and private investment along the sea front within 250 metres of the Zeebrugge-Knokke beaches. Alternatively, a crude estimate of the value of tourist activity for the two communes involved, Heist and Knokke, may be based on an average expenditure for each tourist per night spent in the resort of 200 Belgian francs. For the summer of 1960, when the restoration work was nearing completion, this suggests a tourist expenditure of 400 million Belgian francs, and thus the cost of the engineering works can be estimated as approximately one year's total tourist expenditure. The benefits of these works are difficult to measure, but despite changes in types of seaside holiday, the ten million people of Belgium need the maximum return from their 85km of coastline where tourism, industry and communications must co-exist. Under such circumstances, breaks in trends towards equilibrium states are likely to become more and more frequent until maintenance of the beach depends on continual human activity.

CONCLUSION

In the two process-response systems involving man and geomorphic and hydrologic processes examined here, the Jura Lakes area showed a single engineering process introducing quasi-natural re-adjustments which eventually required a second phase of construction activity to prevent the hydraulic processes destroying the benefits of the earlier works. This represents a simple analogy with Erhart's rhexistasy and biostasy, break of equilibrium trend being followed by trend towards new equilibrium.

On the Belgian coast, the man-made works are diverse, with building on the coastal dunes, establishment of groynes and the Zeebrugge mole all helping to disrupt the processes affecting the beaches. Here the relationship between man and the geomorphic process-response system is dynamic and continually changing. Every grab load of sediment dredged from the harbour, every repair to the sea wall, and every encroachment on to the dunes produce changes in beach stability.

Both examples suggest that management of the environment requires a thorough understanding of physical process-response systems as well as socio-economic analysis. They show that the often-invoked single phase of environmental disturbance, implied by Wolman's study of sedimentation in urban areas, does not apply for time spans of 100 years or more. Continued use of physical resources involves readjustments within what Chorley (1971) terms the geographic control systems. These readjustments are represented by additional investments in resource protection schemes, such as the Jura Waters Correction and the beach restoration works in Belgium. The study of complex man-environment relationships by an extension of well-established geomorphological theories of dynamic equilibrium may well improve the validity of cost-benefit analyses and the quality of resource conservation decisions.

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