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Sediment transport analysis as a component of coastal management—a UK example

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Abstract Detrimental effects of engineering works on the coast and a wish to conserve parts of the coastline have increased realization among coastal managers of the need to examine shoreline problems and proposals for protection in a wider spatial context than the site itself and over a longer time scale than the past few years. This paper outlines the approach taken in one region of the United Kingdom, the central south coast of England, to provide that wider perspective. Authorities responsible for coastal protection and sea defenses formed a coastal group, which, among other activities, commissioned research aimed at providing a greater understanding on which to base shoreline management decisions. A major project undertaken was a sediment transport study in which all existing information relating to coastal sediment processes in the region was collated and analyzed. All inputs, flows, and outputs of sediment were documented. Links between processes were examined for each part of the region. Finally, nine littoral cells of sediment circulation were identified and were suggested as forming a framework for shoreline management. The methods of compilation and analysis are outlined here and are exemplified for one area in the region. The approach is recommended as a cost-effective basis for strategic management of the coast in developed regions.

Key words Geomorphology · Shoreline management · Littoral cells · Data base · Southern England · Coastal processes · Sediment sources · Sediment supply · Coastal engineering

Introduction

In the United Kingdom in recent years, concern over problems of physical management of beaches and other types of shoreline has increased. Among the problems has been the apparent depletion of sediment from beaches and spits (Clayton 1989), the effects on the shoreline of coastal defenses, the decrease in length of natural and ecologically rich coastline, and the loss of wetlands. Evidence of engineering works having detrimental effects on the coastal system is increasing, and this has led to the growing realization that shoreline problems should be examined in a wide spatial context and that natural processes need to be understood and considered in any management scheme. This paper describes a strategy adopted in one region, the central south coast of Britain, to provide that process context and so mitigate some of these problems. It demonstrates the way in which scientific information has been used at both local and regional levels in coastal management. As Fleming (1992) points out, analysis and management of coastal problems at a regional level was rare, previously.

In the United Kingdom at present, local authorities (mainly district councils) have statutory responsibility for coastal protection and the National Rivers Authority (NRA) is responsible for the prevention of sea flooding along low-lying frontages. The county councils play a role at the level of strategic development planning and minerals policy and have increasing landscape/habitat conservation interests. English Nature (and its equivalents outside England) exercise statutory controls via SSSIs (sites of special scientific importance), many of which have coastal locations. Various harbor and port authorities and central government agencies (e.g., Ministry of Defense) have rights or controls in specific areas. The Crown Estate Commissioners administer the seabed seawards of mean low water, which includes control of access to aggregate dredging. Thus, there is a plethora of organizations responsible for certain uses and functions of the coast and immediate offshore area, although usually only for particular sectors delimited by administrative boundaries. Such a situation is not conducive to management based on natural processes (Evans 1992; Lee 1993).

As a result of the physical problems that were being experienced, and because of the limitations of the existing

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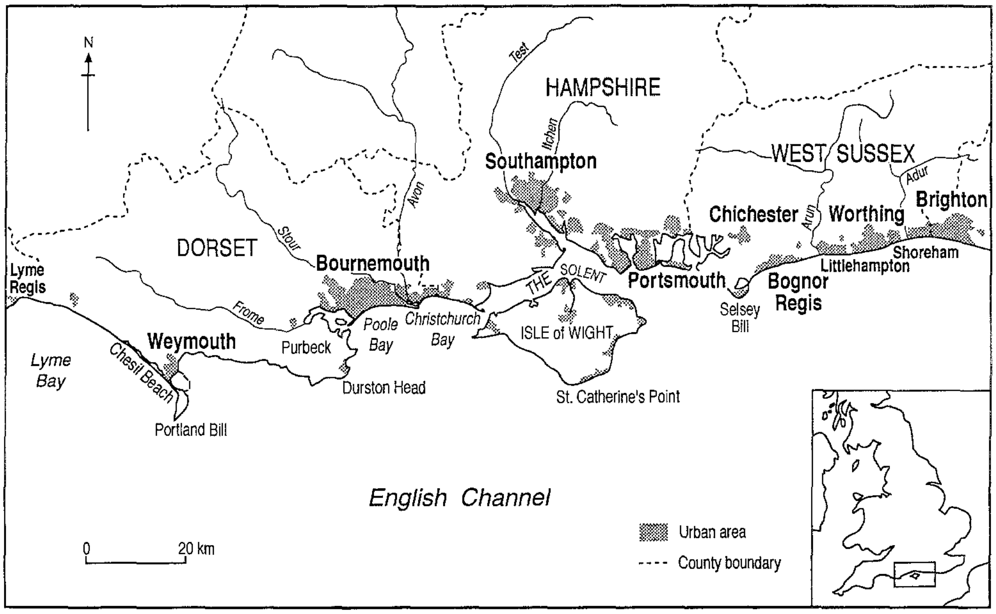

Fig. 1 Map of the study area of the south coast of England with major urban areas and county boundaries

administrative units as a framework from which to tackle the problems caused by process interactions across authority boundaries, a forum for discussion and action was created by the authorities involved in the south coast of England. This coastal group, called SCOPAC (Standing Conference on Problems Associated with the Coastline) and established in 1986, comprises the local authorities, the NRA, English Nature, and others in the area extending from Dorset in the west to West Sussex in the east and including the Isle of Wight (Fig. 1). The aims of the group are set out in Table 1. SCOPAC itself comprises officers of the authorities and elected members (councillors) from the local authorities. From its inception, SCOPAC has established a budget to allow it to commission research and determine its aims. Since the formation of SCOPAC, other coastal groups have been established, now totaling 18 and covering 98% of the coastline of England and Wales (Oakes 1994; Hooke and Bray 1995).

From an early stage, SCOPAC realized that understanding of supply and transport of sediment was fundamental to dealing in an effective and sustainable way with the shoreline problems, and so they commissioned research that would increase that understanding in the region. A basic assumption of the approach taken was that there was a connection in processes along the coast and that littoral sediment was transferred in identifiable patterns. Carter (1988) suggested that coarse material is circulated in almost closed cells that are separated by boundaries across which little beach material is transferred. Based on a systems framework, inputs, outputs, stores, and sinks of sediment can be identified (Clayton 1980). Sediment budgets can be constructed if quantities of all elements are known, as long advocated, for example, by Bowen and Inman (1966), Krumbein (1968), Davies (1979), Lakhan and Trenhaile (1989). By the late 1980s, the sediment cell as a concept was being discussed in relation to its practical application (Brunsden 1992), particularly its potential value for management in elucidating the extent and nature of interdependence along the coast and thus in providing a basis for assessment of impact of structural works. The assumption is that, if sources, directions, and amounts of sediment transport can be identified, then the effect of interference in those flows at any point can be predicted.

Table 1 SCOPAC: Aims and objectives

To ensure a fully coordinated approach to all coastal engineering works and related matters between neighboring authorities on the south central coast of England
To eliminate the risk of coastal engineering work carried out by one authority adversely affecting the coastline of neighboring areas
To exchange information on the success or failure of specific types of coastal engineering projects
To establish a close liaison with government and other bodies concerned with shoreline management
To identify aspects of overall shore management where further research work is required and to promote such research

Methodology

Sediment cells and patterns of circulation as a whole had not previously been identified for the SCOPAC region, although it was suspected that much relevant data existed in the form of individual consultancy and research studies. SCOPAC therefore commissioned construction of a bibliographic data base to compile sources of sediment transport information, including unpublished material located in authority, company, and institution offices. Contact with over 150 organizations revealed a wealth of material being held by these bodies. An interactive data base was constructed containing standard bibliographic reference details and key-worded according to subject matter over a wide range relating to sediment transport and according to location (Carter and others 1989). After compilation, copies of the data base were provided to SCOPAC authorities for direct interrogation, and it is now used in baseline studies for local schemes. After two further updates, the data base in 1994 comprised over 4000 separate bibliographic entries. Coverage of topics and geographical areas is varied, depending on the physical nature of the coastline, the pressures of development, and the amount of investigation.

The abundance of unconsolidated source material having been confirmed, the next phase of research was to analyze the information contained in the documents. The region was subdivided into 20 areas, based on known physical characteristics of the coastline, and analysis was carried out on each. This entailed obtaining, and reading all relevant documents and extracting all items of information that related to any component of the sediment system, recording not only types, directions, and quantities of flows and processes but also details of dynamics and variability. The time scale did cause some problem where major recent changes had taken place, but the aim was to identify the contemporary situation. Historical data were compiled and the coastline was also classified according to the long-term trend of type of change (Hooke and Riley 1991). Data were evaluated and classified for their reliability according to predetermined and standard scientific criteria. Conflicting evidence was carefully assessed and disparities were highlighted (Bray and others 1991). The level of detail emerging for each area was entirely dependent on the amount and quality of previous work.

All reliable evidence of sediment transport pathways was plotted on large-scale maps for each area. These were specifically designed to show: (1) the types of process involved, e.g. longshore drift, offshore/onshore transport, cliff erosion; (2) the composition of sediment in fluxes; (3) the directions of movement; and (4) volumes of sediment (where quantitative data were available). A system of colored arrows (key in Fig. 2 below) was differentiated according to sediment transport mechanism and each arrow was coded (for labeling and use in black and white reproduction); this was used to cross-reference with accompanying text. Reliability was indicated by the density of the outline of the arrows so that a general visual impression commensurate with the quality of information is produced. Quantities of transported sediment (in cubic meters per year) were indicated by the addition of scale bars. An example of an area map is given in Fig. 2, referred to in detail later.

Case example

The SCOPAC region coastline encompasses a wide range of coastal environments from eroding cliffs to enclosed harbors with salt marshes, and includes major shingle beaches and spits, such as Chesil Beach, and the peculiar feature of the Solent, between the mainland and the Isle of Wight with its double-peaked tides [Natural Environment Research Council (NERC) 1980]. The coastline varies in degree of protection and development, these generally increasing towards the east of the region. The analysis of one sample area is outlined briefly here to indicate the type and nature of information provided by the study and summarized for SCOPAC in maps and a detailed report (Bray and others 1991). The area selected is that of part of West Sussex. The sediment fluxes identified are shown in Fig. 2 with the key to the transport codes given in Table 2.

The coastal frontage of this area of West Sussex has an approximately east-to-west orientation for most of its length, except for the projection of the Selsey peninsula. Coastline continuity is interrupted in only three other places by inlets, viz., Pagham Harbour, the mouth of the River Arun at Littlehampton, and farther east by the Adur Estuary at Shoreham-by-Sea. The coastline and immediate hinterland have negligible relief, with low cliffs developed only in the vicinity of Selsey Bill. The coastal plain is built of Tertiary (Eocene) rocks with an overburden of Quaternary sediments. The distinctive salient of the Selsey Peninsula is the result of relative protection from wave erosion provided by the Isle of Wight and several more resistant, but partly eroded limestone reefs a short distance offshore. The entire coastline has retreated rapidly as a result of Holocene sea-level transgression.

Beaches along this coastline are characteristically shingle (steep upper foreshore) and sand (more gently sloping lower foreshore), with well-defined spits at East Head, Pagham, and Shoreham-by-Sea. Long sectors are heavily defended by groins and seawall, giving protection to the several settlements that make up the westward extension of the south coast conurbation. The following are the major component processes in the coastal sediment system of the area.

Inputs

Coast erosion (E1)

Virtually the entire coast between East Head and Brighton is protected by groins and seawall, so contemporary shoreline recession is now constrained. Coast erosion can supply sediment to the littoral zone only from a short unprotected segment to the west of Selsey Bill (E1). Supply is small, being 6100 m^3 yr^{-1} of all sediment grades, of which about 5400 m^3 remains on the beach (Harlow 1980). Sandy sediments also appear to be eroded from the lower foreshore throughout the region resulting in a general steepening of the active shore profile (Beazley 1982).

Feed from offshore (F1–7)

In the absence of coast erosion, feed from offshore comprises the major supply of fresh material to the beach and

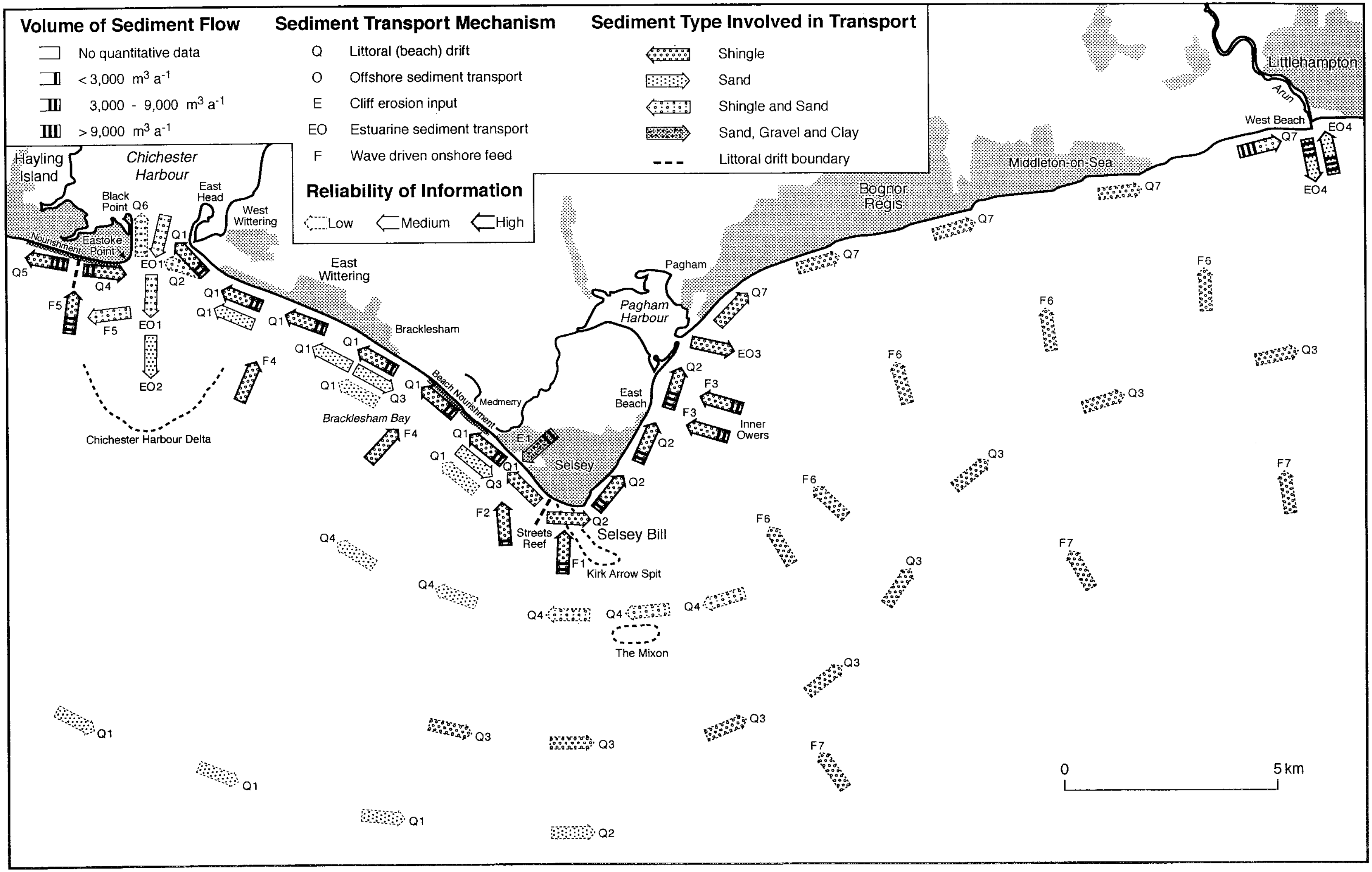
Volume of Sediment Flow
No quantitative data
< 3,000 m3 a-1
3,000 - 9,000 m3 a-1
> 9,000 m3 a-1
Sediment Transport Mechanism
Q Littoral (beach) drift
O Offshore sediment transport
E Cliff erosion input
EO Estuarine sediment transport
F Wave driven onshore feed
Sediment Type Involved in Transport
Shingle
Sand
Shingle and Sand
Sand, Gravel and Clay
Littoral drift boundary
Reliability of Information
Low
Medium
High
Hayling Island
Chichester Harbour
Black Point
Eastoke Point
Nourishment
East Head
West Wittering
East Wittering
Bracklesham
Bracklesham Bay
Chichester Harbour Delta
Beach Nourishment
Medmerry
Selsey
Selsey Bill
Streets Reef
Kirk Arrow Spit
The Mixon
East Beach
Pagham Harbour
Pagham
Inner Owers
Bognor Regis
Middleton-on-Sea
West Beach
Arun
Littlehampton
0
5 km

Table 2 Sediment inputs, flows and outputs: Chichester Harbour entrance–Littlehampton

Coastal erosion	
E1[a]	Selsey Bill—300 m long unprotected section
Feed from offshore	
F1	Onshore feed from the Kirk Arrow Spit
F2	Onshore feed from the Streets Reef
F3	Onshore feed from the Inner Owers
F4	Diffuse weed-rafted shingle feed between Bracklesham Bay and eastern Hayling Island
F5	Onshore shingle feed from Chichester Harbour tidal delta
F6	Diffuse feed by kelp-rafted shingle between Pagham and Brighton
F7	Kelp-rafting in water depths to 40 m
Littoral drift	
Q1	Bracklesham Bay
Q2	Selsey to Pagham
Q3	Reversed sand drift in Bracklesham Bay
Q4	Eastward drift from the Beach Club, Hayling Island to Eastoke Point
Q5	Westward drift from the Beach Club, Hayling Island
Q6	Northward drift of shingle and sand from Eastoke Point to Black Point
Q7	Eastward drift of shingle from Pagham
Transport in the offshore zone	
O1	Eastward sand transport southwest of The Mixon
O2	Eastward sand transport south of The Mixon
O3	Eastward moving kelp-rafted shingle
O4	Westward moving kelp-rafted shingle off Selsey Bill
Estuarine transport	
EO1	Chichester Harbour entrance and inner bar
EO2	Chichester Harbour tidal delta and outer bar
EO3	Pagham Harbour entrance
EO4	Littlehampton Harbour entrance and bar

[a] Letters and numbers refer to arrows shown in Fig. 2

nearshore systems. The supply is composed of three main mechanisms.

1. Wave-driven onshore feed from inshore shingle banks. Feeds of this nature exist in the vicinity of Selsey Bill from the Kirk Arrow and Inner Owers spits. These feeds comprise a significant shingle input to the coastal segment and their combined mean supply has been estimated at 10,000 $m^3\ yr^{-1}$, although this is variable (Lewis and Duvivier 1976).

2. Wave-driven diffuse onshore creep of shingle. Feed of this type was determined in water of less than 18 m depth off Shoreham (Crickmore and others 1972). The volume involved was up to 1500 $m^3\ km^{-1}\ yr^{-1}$. If this process was common to the entire coastal segment, some 57,000–86,000 $m^3\ yr^{-1}$ of shingle could be supplied to beaches in the area (57 km frontage). Actual supply is almost certainly much less due to the discontinuous extent of suitable offshore shingle deposits.

3. Diffuse feed of kelp-rafted shingle. This process has been observed underwater, but not quantified (Jolliffe and Wallace 1973). In fact, the West Sussex coast would appear to be one of the few sites along the southern English coast where this process could be important. Rough calculations at Worthing suggested supply volumes of 94–234 $m^3\ km^{-1}\ yr^{-1}$ based upon observations of major incursions of weed (Binnie and Partners Ltd. 1987). This translates to 5360–13,340 $m^3\ yr^{-1}$ for the whole coastal segment, but supply at this rate is unlikely for weed incursions are particularly severe at Worthing. Further west at Hayling Island, Harlow (1980) calculated kelp rafting supply to average only 20 $m^3\ km^{-1}\ yr^{-1}$ (equivalent to only 1140 $m^3\ yr^{-1}$ for the entire coastal segment). Total input by this mechanism is probably intermediate between these figures and is site-specific.

Fig. 2 Sediment transport map of eastern West Sussex; key and symbols are as used in the complete sediment transport study

Beach replenishment

This must now be recognized as a significant input to the sediment budget in this area as it most frequently comprises introduction of marine dredged sand and gravel from offshore. Several such operations have been undertaken between Bognor Regis and Littlehampton. As in most schemes, there was rapid initial diminution of beach volume, probably due to offshore transport of fines, in situ compaction, and abrasion of less-resistant constituents, but with increasing stability thereafter. Material is also recycled from zones of accretion (e.g., to the west of the River Arun) to replenish eroding beaches. However, this must be treated as a redistribution of existing sediment rather than a fresh input. Replenishment has also been undertaken just west of Selsey Bill in 1976 using coarse, angular material from an inland source. Further maintenance replenishments have subsequently continued at many sites. Total sediment input has been about 400,000–500,000 m^3 since the mid-1970s.

Flows

Littoral drift (Q1–7)

To the east of Selsey Bill, net shingle drift is eastward while to the west of the bill net drift is westward. There is therefore a major drift parting and cell boundary at this point. The drift divide lies approximately 1 km to the west of Selsey Bill. This is a feature of the protection from prevailing southwesterly waves afforded by the Isle of Wight (Fig. 1). Quantitative information in Bracklesham Bay and at East Beach, Selsey, was derived from analysis of beach volume changes over the past 50–100 years. A natural rate of 7000 $m^3\ yr^{-1}$ was calculated for Bracklesham Bay (Harlow 1979) and 15,000–20,000 $m^3\ yr^{-1}$ for East Beach to Pagham (Lewis and Duvivier 1976). These natural drift rates are modified by coast protection structures (groins) which extend along virtually the entire coast. In Bracklesham Bay, input of fresh shingle is strictly limited (except for a beach replenishment scheme) so that groin compartments are not often filled sufficiently for bypassing to occur. Thus, present day rates of drift rarely attain the potential rate. By contrast, supply is much greater to the eastern side of the Selsey peninsular and bypassing of groins is more frequent, so that present-day drift can reach 10,000 m^3 yr^{-1} (Lewis and Duvivier 1976).

Littoral drift along the remainder of the coastal segment has only been quantified at Littlehampton (65,000 m^3 yr^{-1}) using a wave power approach (Hydraulics Research 1987) and at Shoreham (14,000–14,500 m^3 yr^{-1}) based upon beach volume changes (Halcrow and Partners 1989; Chadwick 1989). Both of these estimates refer to natural drift uninterrupted by coast protection structures. Drift is undoubtedly much lower elsewhere due to the high concentration of groins.

Transport in the offshore zone (O1–4)

Relatively little information is available regarding offshore transport parallel to the coast, i.e., sediment transport pathways not involving direct feeds/losses to beaches. Eastward sand transport has been inferred from study of bedforms (British Geological Survey 1990) and numerical modeling (Hydraulics Research 1993). The other major information sources were the diving observations of Jolliffe and Wallace (1973) and Wallace (1990), which primarily concerned shingle transport by kelp rafting off Selsey Bill. The main trend identified by these studies was that sediment transport was eastward throughout most of the offshore area where transport was possible, except for a zone of westward transport within 5 km of the shore in the vicinity of Selsey Bill. Shingle is immobile over large areas of the seabed and is only moved by waves and tidal currents in the more shallow parts, such as around the reefs off Selsey Bill (Hydraulics Research 1993).

Estuarine transport (EO1–4)

This process comprises sediment transport by strong tidal currents at harbor entrances and estuaries. Transport is both into and out of the inlets, but at Chichester and Pagham harbors net transport is seaward because the ebb current is more powerful (Harlow 1980; Wallace 1988; Barcock and Collins 1991). The direction of net transport has not been analyzed at the other major inlets, but tidal considerations suggest a fine balance exists at Littlehampton and a tendency for sediment to be transported into the Shoreham Harbour entrance (Wallace 1988).

The strong tidal currents generated at the inlets act as barriers to littoral drift. Studies by Harlow (1980) at Chichester revealed that material supplied from East Head was flushed offshore to form an extensive delta deposit (Fig. 2). These studies also suggested that shingle could be transported onshore from the delta to supply Hayling Island; thus a sediment circulation system was identified. Littoral drift was interrupted by the inlet but resumes at a point further along the coast. It can be postulated that a similar circulation system could operate at Pagham Harbour, although on a smaller scale and involving eastward drift (Barcock and Collins 1991). The inlets at Littlehampton and Shoreham are both flanked by training walls and breakwaters that prevent much shingle from entering and reinforce the barrier effect on littoral transport. Sand transport on a large scale has been determined off the Littlehampton inlet (Hydraulics Research 1987), so drift of this material may simply be interrupted rather than prevented by the inlet. This demonstrates that littoral transport boundaries differ with respect to their effect upon different sediment sizes. Coarse sediments are more effectively partitioned by boundaries, while fine materials are more easily transported and can bypass boundaries.

Stores

The beaches and shingle spits comprise the major sediment stores in this region. The contemporary beaches are probably remnants of previously much larger shingle barrier beaches that developed and migrated onshore during the early to mid-Holocene marine transgression (Jennings and Smyth 1987, 1990). Flint shingle dominates, but little quantitative analysis of beach sediments has been undertaken, although regular qualitative assessments and some beach profile measurements are recorded by the local authorities. The most comprehensive sedimentological survey relates to a restricted area around Pagham Harbour entrance (Barcock and Collins 1991).

The major data source for beach stability analyses was the Southern Water Authority Beach Monitoring (Beazley 1982). Although doubts have been expressed as to absolute accuracy, profile comparison over successive surveys appears valid and trends are likely to become more significant and reliable as the length of the record increases. The most thoroughly analyzed areas were Pagham (1973–1987) and Shoreham (1983–87), and in both cases highly significant trends for both accretion and depletion were established. At both sites accretion occurred to the west of a harbor entrance and depletion occurred to the east. This is attributed to interruption of net eastward littoral drift by tidal currents and protection works causing accretion (updrift) and depletion (downdrift). Most other areas are less intensively studied, and zones of accretion (Littlehampton, Worthing, and Brighton) and depletion (Selsey, Middleton and Lancing) are less easily distinguished from the 1973–1982 data (Beazley 1982). This survey did, however, identify a general trend for accretion of the upper (shingle) beach and depletion of the lower (sand) beach, although no further studies have been conducted to establish the reliability/longevity of this trend, the contributing factors, or the possible implications.

Conclusions of the local study

Analysis of this area therefore shows there is a major cell boundary at Selsey Bill. There is a general lack of sediment supply in the areas of both cells due to coastal protection that greatly reduces coast erosion inputs and a severe problem of beach depletion and vulnerability of spit structures. The compilation showed a need for further research on littoral drift and an offshore–onshore feed. Recently, a major seabed mobility study (Hydraulics Research 1993) has shown that gravel is usually immobile over most of the offshore area, but sand is potentially mobile throughout. There is, however, a lack of sand cover offshore and sand transport pathways are largely offshore or parallel to the coast, except near Selsey where they are more complex.

A site east of Bognor Regis is now the location of an innovative "soft engineering" scheme comprising an offshore rock breakwater and beach replenishment (Holland and Coughlan 1994). This is being carefully monitored to assess whether it produces the predicted accretion, and its performance will be evaluated in relation to position and processes in the sediment cell.

Regional synthesis

Once the aforementioned type of analysis had been completed for the full extent of the SCOPAC coast, the information was brought together as a regional synthesis to identify the sediment cells and subcells, the principal pathways of sediment transport, the nature of the sediment budgets, and their interrelationships. Several types of sediment transport boundaries were recognized, based on alterations or discontinuities in rates or directions of transport (or both) (Bray and others 1995a). Fixed boundaries are those with a documented record of stability over at least the past 20–100 years. Absolute and partial fixed boundaries are recognized according to their barrier effect; partial boundaries intercept coarse sediments but allow bypassing of finer grades. Fixed boundaries are primarily of two natural physical types: headlands and inlets. Artificial structures themselves can create fixed boundaries, but are often dependent upon continued maintenance and would otherwise cease to operate. Transient boundaries are generally of a more diffuse character, limited temporal stability, and show propensity for longshore migration. These comprise littoral drift divides, convergences, and abrupt changes in transport rates. They are frequently marked by zones of accretion or erosion and delineate subcells within larger compartments.

The major boundaries identified are indicated in Fig. 3, producing nine macrocompartments. There are some zones where boundaries are poorly defined either because of limited information, e.g., the Purbeck coast and the south and southwest coasts of the Isle of Wight, or because of the complex nature of the coastline, e.g., the major harbors. The latter are treated as separate budgetary units but have some connections with the open coast. A noticeable regional feature is that, to the west, compartments and their subcells are primarily defined by hard rock headland barriers, while along the softer rock shores of the Solent margins and eastwards, inlet and sediment sink boundaries predominate. Although these different boundary types have similar net effects on sediment transport, they give rise to compartments of differing relative stability. Headlands generally retain stability when subject to environmental forcing (especially hard rock coasts), so that the compartments they define have high overall stability. Inlet and sediment sink boundaries are, by contrast, very sensitive to change resulting from human activity

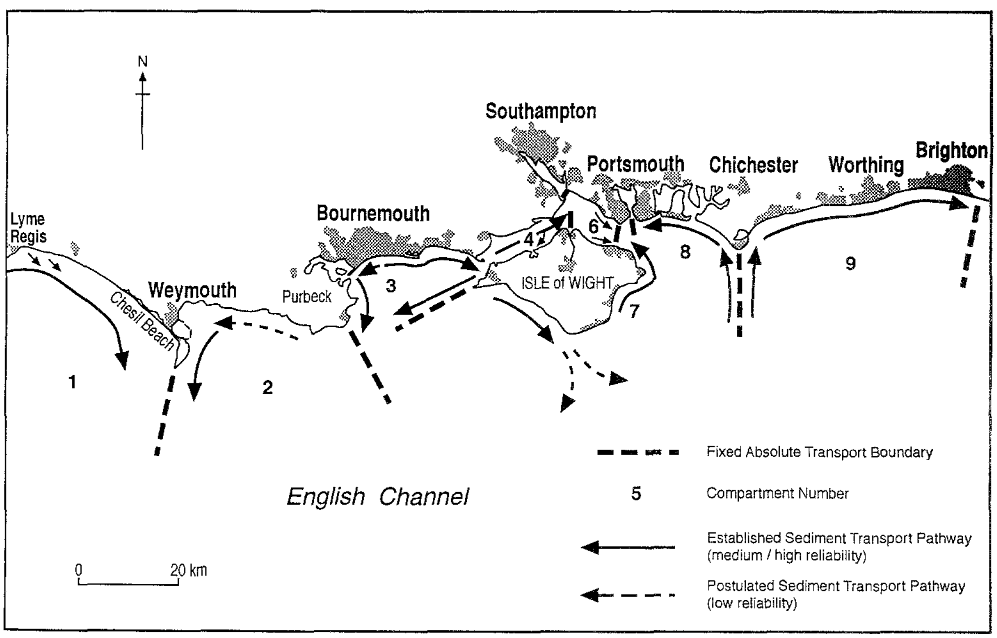

Fig. 3 Major littoral cells and sediment pathways in the SCOPAC area of the south coast of England

(e.g., dredging, reclamation) or variable physical boundary conditions (e.g., climate change and sea-level rise). Thus, it is envisaged that compartments in the east of the SCOPAC area have less natural stability. To some extent this critical difference is offset by widespread protection and artificial maintenance of shoreline stability.

For each macrocompartment a sediment budget has been analyzed, and several distinct types are identified. High-flux budgets are characterized by rapid coast erosion input, throughput, and loss. These are important contemporary sediment source areas and comprise the West Dorset, Purbeck, and South, South-West, South-East Wight Isle of Wight compartments. Moderately dynamic systems with well-defined sources, transport pathways, and sinks are generally quite finely balanced with respect to overall sediment budgets. These are therefore sensitive to interference by coast protection, e.g., Poole Bay, or by aggregate/navigation channel dredging, e.g., West Solent. Budgets characterized by relatively low rates of sediment flux are generally in sheltered locations and characterized by long-term accretionary budgets, e.g., Southampton Water and the major harbors. However, it appears that slow process rates make these budgets particularly sensitive to variations in natural factors and artificial interference. Stability of low-flux systems therefore appears marginal and easily disturbed, but due to their positive budgets and sediment sink status, their impacts on adjoining compartments are limited. By contrast, high-flux budgets are themselves relatively stable in form so long as their component processes can continue to function.

Although budget status differs between cells, certain major sources and sinks have been identified and the regional sediment transport pathways have been mapped on this basis (Fig. 3). Overall, the major sediment source in the region is from erosion of cliffs. Transfers are generally eastwards in the dominant direction of drift, but there are reversals of this direction along certain parts of the coast. The amount of offshore–onshore sediment transport is difficult to assess from available data, but it appears to be relatively small in eastern parts of the study area (Hydraulics Research 1993). Important additions to the natural system now take place by beach replenishment, and this is likely to become even more significant in future as this becomes an increasingly popular strategy for tackling problems of beach sediment depletion (Riddell and Young 1992). Many of the major sediment accumulations in the region, particularly the shingle features are early-mid Holocene in origin and are essentially finite residual features (Carr and Blackley 1974; Bray 1992; Nicholls 1992). They therefore pose particular problems of vulnerability to sediment depletion. Net losses to the sediment system through dredging are difficult to quantify because of confidentiality of offshore aggregate dredging figures and the scarcity of information relating to navigational dredging in harbors and channels. The concern over unknown quantities and impacts of dredging raised by SCOPAC has caused some increase in release of information, so that local government authorities are now informed of licences granted for offshore dredging in their area.

Evaluation and utility of results

This approach of compiling, analyzing and synthesizing existing information has several advantages. It is relatively cheap and very cost-effective compared with original research. It enables the large-scale patterns to be identified and facilitates an overview of sediment dynamics in a region. It also allows identification of gaps in understanding so that further research can be carefully targeted. Notwithstanding deficiencies in data, enough information was available to provide a valuable basis for planning and management at local and regional levels.

The analysis demonstrated that on the central south coast of England, cliff erosion is the major source of sediment and thus further protection could have detrimental consequences for beach supply within the same cell. The analysis also showed how certain structures act as barriers and how modification of the coastline has altered the amount and even, sometimes, the direction of flows of sediment. Transport boundaries of various types and stability were recognized and further work is needed on these drift divergencies or discontinuities and their variation over time. It also emerged that even some apparently sophisticated numerical modeling studies must be interpreted with care, especially in relation to assumptions on average and extreme conditions.

The work is being used to evaluate schemes and more widely as a baseline in coastal zone management plans and strategies (e.g., South Wight Borough Council 1994). It has the potential to be used in the evaluation of the impact of natural or process changes as well as direct anthropogenic impacts, e.g., sea-level rise (Bray and others 1995b). As a result of the study, SCOPAC confirmed that they advocated use of sediment cells as the framework for shoreline management. Specific management plans are now in preparation for each macrocompartment identified.

There are obviously some limitations on this approach and type of study. Most notably in this case, because of the limited finances, it was not possible to supplement documented information by field observations and morphological indicators (e.g., Taggart and Schwartz 1988). The analysis and synthesis are largely determined by the available data, but the study did add considerable value above simple collation of data, i.e., the whole was greater than the sum of the parts. This type of study could easily be adapted into a geographical information system for data manipulation and map production. It was considered in this case but rejected because few of the local authorities had compatible systems at that time.

Present situation

The Sediment Transport Report (Bray and others 1991) produced for SCOPAC demonstrated the basis on which management could be organized to form units compatible with physical processes on the south coast of England. It was an approach that had been gaining support for some time and shortly afterwards Hydraulics Research (Motyka and Brampton 1993) published their macroreview of the British coastline in which they identified 11 major cells around the coast of England and Wales. The pressure for revised, integrated administrative units for coastal management increased. This whole question was also addressed by a House of Commons Environment Committee (1992). All the expert advice given to the committee was in agreement on this issue, and a policy of formation of such units was recommended in the resulting Rossi report: "... *that the government consider how best to establish, resource and empower regional coastal zone management groups based on natural coastal cells as the linchpin of integrated protection and planning of the coastal zone.*"

The recommendation was rejected by the government, which has chosen to retain existing administrative units (Command Paper 2011 1992). However, the need for coordinated planning has now been recognized, and central government guidelines for the production of shoreline management plans have recently been issued (MAFF 1995) and the first plans have been commissioned. Plans are funded by MAFF through a lead local authority and are formulated and implemented by groupings of authorities based on subcells. This new management framework involves explicit recognition of the regional context, the sediment cell setting, the prevailing coastal processes, and the impacts of present and future structures and coastal strategies. The aims, objectives, and issues are given in Table 3. Analyses such as the one exemplified here are of great value for such strategic plans.

Major changes in attitude on strategies and policy have taken place at both the national and local level over the past ten years. It has now been officially recognized, through a ministerial statement (MAFF 1993) that the principle of working "with nature" should be applied to coastal management. A strategy of protection is no longer assumed, and techniques of soft engineering, e.g., beach replenishment, are being much more widely adopted. The effects of "hard" protection on sediment supply to beaches, as shown in this study, mean that continuation of such measures will not be a sustainable solution in the long term at many locations. Some modifications of planning policy, particularly to accommodate problems caused by coastal erosion and instability, have been incorporated in a Planning Policy Guideline, PPG 20 (Department of the Environment 1992), which should help to avoid some problems associated with development of coastal areas and sites in the future. Decision makers are now much more aware of the need for and the long-term advantages of taking a regional and historical perspective. However, in spite of all the progress made, the pressure for full coastal protection from the public and landowners is still high and often that political pressure prevails at local levels. Many decisions are still made on site-specific considerations alone and on limited information.

Table 3 Shoreline management plans: Aims, objectives, and issues[a]

Plans should aim to provide the basis for sustainable coastal defense policies within a sediment cell and to set objectives for the future management of the shoreline.

Main objectives of a plan

1. The main objectives in developing a plan are to
   Improve understanding of the coastal processes operating within the sediment cell
   Predict the likely future evolution of the coast
   Identify all the assets within the area covered by the plan that are likely to be affected by coastal change
   Identify the need for regional or site specific research and investigations
   Facilitate consultation between those bodies with an interest in the shoreline
2. The main objectives of a completed plan are to
   Assess a range of strategic coastal defence options and agree a preferred approach
   Outline future requirements for monitoring, management of data, and research related to the shoreline
   Inform the statutory planning process and related coastal zone planning
   Identify opportunities for maintaining and enhancing the natural coastal environment, taking account of any specific targets set by legislation or any locally set targets
   Set out arrangements for continued consultation with interested parties

Issues to be considered

3. Four key issues need to be addressed in the preparation of a shoreline management plan
   Coastal processes
   Coastal defences
   Land use and the human and built environment
   The natural environment

[a] Ministry of Agriculture, Fisheries and Food (1995)

Conclusions

This study demonstrates a cost-effective approach to construction of a framework of understanding of coastal sediment transport, which can then be used as the basis for shoreline management. It illustrates the value of secondary data, providing they are used in a critical manner, and the abundance of disparate information, which may typically be available on at least highly developed coastlines. It also allows further research to be targeted effectively. It has shown the immense value of a regional approach both in coordination and cooperation between organizations and in spatial analysis and how such information can form the basis for integrated shoreline management. It is an example of the use of scientific knowledge at a local, practical level and the translation of strategic planning to local action. It is suggested that such an approach may valuably be adopted elsewhere in the world.

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