ECONOMIC IMPACTS OF ANTHROPOGENIC ACTIVITIES ON COASTLINES OF THE UNITED STATES

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Anthropogenic activities primarily impact our coastline by reducing sediment inputs, altering sediment transport processes, and accelerating sediment losses to the offshore. These activities include: sand and gravel extraction; navigation and shore protection works; non-structural shoreline management strategies such as beach nourishment, sand by-passing, and beach scraping; dams and flood control works; channel and inlet dredging; subsidence caused by fluid extraction and reduction of carbonate beach material. Although many of these activities have improved the quality of life, they also have had unintended effects on the coast. The issues that arise from human alterations of the coast are common to many coastal regions around the world; this paper draws from several areas of the United States to present an overview and provisional assessment of the economic consequences of anthropogenic activities along the coast.

1. General

In addition to the almost constant attack on coastlines by waves and currents, anthropogenic activities or "works of man" have produced serious impacts, resulting in both short term and long term erosion. Most often this is caused by the reduction of sediments to and along coastlines (Douglas 2003). This paper will present an overview of some of these unintended impacts to the coastlines which often result in the loss or reduction of protective and energy dissipative beaches which allow storm waves to attack and generally accelerate erosion of coastlines.

In early published literature on the subject of anthropogenic activities on the California coast, Gilbert (1917) reported on the effects of hydraulic gold mining in California on the supply of sediment to San Francisco Bay and the nearby beaches. In discussing coastal sediment supply to southern California beaches, O'Brien (1936) stated, "For the most part, the streams are torrential in character, flowing for only a few days of the year but then discharging relatively large quantities of water and debris. In the vicinity of Los Angeles one of the important engineering problems at the present is the control of floods and the accompanying debris. Measures taken to reduce flood hazards and intercept the debris promise to reduce the supply of beach material and bring about a general recession of the beach. Although some suggestions have been made regarding the inter-relationship between flood control and beach preservation, the subject has not received the careful study which it deserves". These papers along with the work of Professor Douglas Inman (1978) of Scripps Institute of Oceanography and Professor Gary Griggs of the University of California, Santa Cruz, are the foundation of this current work. There is a very large body of literature on this subject and it is not possible to cite all these references or acknowledge all of the personal communications from investigators who contributed to the material presented. With the exception of the economic analysis, no new research was conducted but rather the authors attempted to consider the more significant elements in the published literature to synthesize the conceptual components on which an economic analysis could be based.

Although the focus of this effort was on the Pacific Ocean coastline of the continental United States, the anthropogenic factors were generally in effect in other sections the United States coastline as seen in Louisiana (Williams 1991, 1994, 2003) and elsewhere as well as coastlines of other nations including Japan (Itibashi and Uda 1998), Portugal (Borges et al. 2002), and Egypt (Inman and Jenkins, 1984).

2. Alterations To Fluvial Sediments

Rivers and streams are the main sources of sediment for the Pacific Coast. Along the northern portion of the coast, in Washington, Oregon and northern California, the rivers and streams tend to be large watershed systems, like the Columbia, the Klamath, and the Eel that provide millions of cubic meters of material to the coast. In Southern California, the watersheds are small, but still these are the key contributors of new beach material for most of the coast. The long-term sustainability of Pacific coast beaches depends on periodic deliveries of sand and gravel from coastal rivers and streams. The main activities that have altered fluvial sediments are (1) sediment and debris basins that intercept sediments before they can reach the fluvial system; (2) dams that intercept sediment within the fluvial system and (3) sand and gravel mining that remove sediment from the fluvial system.

2.1. *Debris Basins*

Debris basins are typically used in southern California to protect urban development from the effects of intense rainfall (Sherman 1999). "Debris basins are designed to trap sediments being transported by debris flows…. As of 2000, 162 debris basins trapped a total of more than 13,761,900 cubic meters of debris… Assuming a 50% sand content for these deposits, the basins have trapped about 6,881,000 cubic meters of sand. It is assumed that little of this sand is returned to the drainage system, and therefore this impoundment represents a loss of sand from the coastal budget." (Ellis et al. 2001). Debris basins are also discussed in Herron (1956). For this paper, the cumulative loss estimated through 2003 is 7.3 million cubic meters with an annual rate of loss of about 100,000 cubic meters.

2.2. *Coastal Dams*

The reduction of supply of sediments to the California coast due to the construction and operation of dams (Brownlie and Brown, 1978) as treated by Willis and Griggs (2003) notes that "The long-term sustainability of California's beaches depends on periodic deliveries of sand and gravel from coastal rivers and streams. To assess the long-term health of California's beaches, this study characterized the current state of fluvial sediments delivery and quantified on a littoral cell basis, the cumulative impacts of dams on decreasing annual discharge. Presently, more than 500 dams impound more than 42,000 square kilometers or 38% of California's coastal watershed area. Flow modeling suggests that by diminishing flood hydrographs, these dams have reduced the average annual sand and gravel flux to 20 major littoral cells by 2.8 million cubic meters per year or 25%." For the economic impacts, we use this estimate and a cumulative loss since 1963 of 113.2 million cubic meters.

The Columbia River is one of the dominant watersheds for the Washington and Oregon Coast. Research estimates from Gelfenbaum et al. (1994), Mortiz (1999), and Allan (2002) suggest a range of 1.4 to 4.4 million cubic meters per year. Kaminsky (2004) reports that "Flow regulation has been estimated to reduce the sand carrying capacity of the river by 2/3, and the present estimated rate of supply of sand from the lower river to the estuary is 1.4 million cubic meters per year (or less as estimated by the Corps). ….. There is a large uncertainty in the changes to sediment volume in the Columbia River area. It is difficult to say whether the estuary exports this sand to the coast, or if the estuary actually imports more sand from the coast than is supplied by the river." As a conservative estimate, this study assumes that the reduction had been 2.0 million cubic meters annually, due to dams and regulated dredging for navigation. For the coasts of Oregon and Washington, Komar (2004) also notes that "other than the effects of the dams on the Columbia River, this not a particular issue on the coasts of Oregon and Washington."

2.3. *Fluvial Sand and Gravel Mining*

Many beaches are impacted by reduction of sediment delivery to the coastal zone caused by gravel and sand mining from coastal watersheds. In the United States, approximately 1.3 x 10^9 metric tons of aggregate was produced in 2003 at an average price of $5.14 per metric ton (Bolen 2004, Kohler 2002),.

Streams and rivers are the transportation systems that deliver sediments to the coastline. The rivers act as "conveyor belts" that move sediment from areas of weathering and erosion in the headwaters regions through middle reaches where little erosion or deposition occurs to regions of deposition in the lower reaches of rivers and then ultimately delivered to below sea-level sites. The time scale of sediment movement down this system is measured from decades to centuries (Kondolf et al. 2001). Movement of sediments is not a constant event but controlled by episodic peak flows during extreme rainfall events that often trigger floods. Additionally the reduction of peak flows by dams along rivers reduces the ability of the system to move sediment.

Transportation of sediment helps to dissipate energy in a river system. If sand and gravel is removed from deposits within the river channel then “hungry water” is created by reduction of sediment available for downstream transport (Kondolf 1997). This creates disequilibrium in the fluvial system and may cause erosion of gravel bars downstream from the mine site. Off-stream mining in floodplain terrace gravel deposits creates large pits next to dynamically changing river channels. These pits may capture the river during peak flows. If this occurs, then these pits act as sinks for bedload sediment, robbing the lower reaches of the river of sediment.

The concept of “safe yield” of aggregate mines encompasses the argument that states: As long as the volume of sand and gravel that is mined annually from river channels is less than the annual replenishment of sediment from natural erosion then the effect on river channels is negligible. This argument may hold true for local reaches of rivers close to mining sites, however, the total sediment in the fluvial system is reduced and ultimately that volume of sediment is not delivered to the coast.

Based on county level information available on the Internet, sand and gravel mining in northern California from the Russian River to the Oregon border is approximately 6.1 million cubic meters per year (California Coastal Commission 2001, County of Humboldt 1994, 1999, County of Sonoma 1996). No recent site specific statistics for sand and gravel mining in southern California are available. Taylor (1978) reports an annual loss of 10 million cubic meters for a 400 km reach of the southern California coastline from Point Conception to the Mexican border. Miller (1993, 1994, 1995, 1996) reports that sand and gravel mining in southern California produces an average of 55.8 million tons (31.6 million cubic meters) of sand and gravel annually. Willis (2004) suggests that “maybe the best thing to do is to err on conservative side and select 25 to 50% of total gravel mining number.” For purposes of this paper, it is estimated that 50 percent of this material may be from or associated with coastal watercourses in the first flood plain and we roughly estimate that annual sand and gravel extraction in coastal watersheds in southern California is 15.3 million cubic meters and in northern California 6.1 million cubic meters to estimate the economic impacts.

2.4. *Coastal Sand Mining*

Although coastal sand mining was occurring along the coasts of California and Oregon by the late 1800s, coastal sand mining along the Pacific coast ended by 1991. Komar (1998) reports that some 84,100 cubic meters of sand were removed from the beach near the mouth of the Siletz River in Oregon between 1965 and 1971. Hotten (1988) reports that between 7,700 and 11,500 cubic meters of sand were removed from the Mission Bay littoral in conjunction with removal of kelp from beaches.

The major California coastal sand mining operations have been along the southern portion of Monterey Bay. Based on the estimates of Magoon (1972) and Kendall (1991), approximately 6.3 million cubic meters of coastal sand has been mined in the vicinity before coastal sand mining seaward of the shore ceased in 1991. However, mining of near coastal dunes in the southern Monterey Bay region continues and is not considered in this paper.

2.5. *Seawalls and Armoring*

Although the loss of sediments to the coast due to construction of seawalls or coastal armoring is locally important (Komar 2004, Hampton 2004), it has a relatively minor impact considering the west coast of the United States. Griggs in California Department of Boating and Waterways (2002) estimates that for the Santa Barbara and Oceanside littoral cells in Southern California, coastal armoring reduced the supply of sediments by 2,000 cubic meters and 9,500 cubic meters per year respectively resulting from 68.6 kilometers (42.6 miles) of armoring. Averaging and projecting the sediment reduction from these reaches of coast to the entire state in order to estimate the effect of armoring in California (seawalls and breakwaters) for this paper we estimate 50,000 cubic meters per year is lost in the State of California due to armoring. For Oregon, the estimate is 2,290 cubic meters per year (Komar 2004).

2.6. *Navigation Maintenance Dredging*

Modern practices of navigation channel maintenance generally include the placement of suitable beach material on the nearby shores or in sufficiently shallow water that keeps the dredged material in the littoral system (Douglas 2003). The two major exceptions to this practice are the navigation channels at the entrances of Humboldt Bay and the Columbia River (the latter was considered earlier in this paper).

Since 1990, material removed from the entrance and navigation channel of Humboldt Bay in northern California has been deposited in deep water thereby removing the material from the littoral system. By 1998, approximately 10.7 million cubic meters of material had been deposited in water depths of 49 to 55 meters and lost to the coastal. The cumulative loss through 2003 is an estimated 16.9 million cubic meters, while the ongoing annual rate of loss is 1.3 million cubic meters.

2.7*Subsidence*

Land subsidence can be a gradual settling of the land surface due to consolidation and compaction of subsurface sediments or sometimes a sudden sinking due to faulting or slumping. Subsidence due to natural geologic processes is common for many coastal regions, especially delta plains such as south-central Louisiana, the Sacramento-San Joaquin delta, California, and Venice, Italy. Subsidence combined with global sea-level rise (~20 cm rise in the last century) can yield rates of relative sea level rise in excess of 1cm/yr, resulting in significant coastal erosion, inundation, and loss of wetlands. Man-induced subsidence, due to causes such as hydrocarbon production, excessive ground water pumping, underground mining, and drainage of organic soils, is often difficult to detect, map, and quantify, but is a significant factor contributing to coastal erosion and land loss for many regions of the United States.

Studies of coastal erosion and wetland loss in south-central Louisiana by the USGS and others over the past 20 years show that the highest rates of geologic subsidence (< 3mm/yr) correspond with the thickest Holocene-age deltaic sediments (Williams et al. 1994, Penland 2002). These sediments are young and undergo natural dewatering compaction and consolidation. However, the highest rates of wetland loss over the past 50 years are associated with delta plain areas having historical rates of subsidence as much as 23 mm/yr. Recent studies of four large oil and gas fields in south-central Louisiana by (Morton, et al. 2002, 2003), using regional releveling geodetic profiles, tide gauge records, and hydrocarbon production data demonstrate close correlations between high rates of subsidence, rapid wetland loss, and hydrocarbon production. Significant in trying to extrapolate these correlations to other parts of the Louisiana delta plain is that the period of most rapid wetland loss (1956-1974) corresponds with highest production of hydrocarbon fluids. Additional studies are needed in other Louisiana wetlands to test if hydrocarbon-induced subsidence correlates closely with rapid wetland loss. Results of these studies should be used as an input to the $14 billion restoration program underway.

The extraction of water and oil in the Port of Long Beach has resulted in subsidence of up to 9 meters. The subsidence contours resulting from fluid extraction indicate that the subsidence occurred over a relatively large area, perhaps 52 square kilometers based on estimates from the Port of Long Beach. The cost of monitoring and stabilizing this area from further subsidence is estimated to be in the range of one half to one billion dollars ($750,000,000 is used in this paper to estimate economic impacts) (Knatz and Goldman 2004).

3. Economic Issues

The dominating concept in understanding the economics of these activities focuses on unpriced externalities. In each of the activities examined here, changes to the sediment budget resulted from activities not directly related to the coast. Sediment is removed to clear channels for commercial shipping, sediment is contained behind dams to provide water and power, sediment is mined as an input to construction, etc. While each of these activities was undertaken at some expense, the cost of the activity did not include the cost to the coastline of removal of the sediment. The failure of the market to include the cost of interference in the shoreline results effectively in a subsidy to the action, as the activity is being undertaken at less than the real cost. The cost is external to the decision to undertake the activity, resulting in the potential over consumption of sediment further compounding the problem.

Three approaches are offered to estimate the economic value of sediment losses to the Pacific coast as a result of engineered interferences in the sediment system. First we examine the replacement cost of lost sediment. Second we estimate the remediation cost, i.e., the cost to offset past and future damages caused by the sediment loss. Finally, we look at the repair cost, examining the estimated cost to 'fix' the shoreline to protect against future damages.

A simple approach is used to estimate the replacement value. In Table 1, the measurable loss of sediment from debris basins, dams and flow regulation, sand and gravel mining, seawalls and other armoring, harbor dredging and harbor deepening are valued based on a generic estimate of $12 per cubic meter with the exception of the subsidence at California-Long Beach where the cost shown is based on the cost currently allocated for restoration. Accordingly, the estimated cumulative sediment loss along the Pacific shoreline (Washington, Oregon, California) is 1.4 billion cubic meters. The estimated value of this sediment plus the costs of ongoing mitigation California-Long Beach are $16.4 billion. The estimated ongoing annual loss of sediment is 29 million cubic meters, valued at $333 million, excluding any ongoing subsidence losses for California–Long Beach. Note that these estimates are solely for illustration, were sizeable efforts initiated to mitigate the cumulative or annual sediment losses, the actual cost would be much higher as the tremendous demand for sediment would drive up the cost significantly.

Table 1. Coastal Sediment Losses and Costs

(Millions of Cubic Meters, $Millions)

FACTOR	ESTIMATED ANNUAL LOSS (Millions of Cubic Meters)	TOTAL LOSS (Millions of Cubic Meters)	TOTAL COST ($MILLIONS @$12/CUBIC METER)	FUTURE ANNUAL COSTS
Debris Basins				
Southern California	0.1	7.3	$87.5	$1.7
Coastal Dams and Flow Regulation				
Oregon/Washington - Columbia River*	2.0	106.0	$1272.0	$24.0
California	2.8	113.2	$1,357.9	$33.9
Sand and Gravel Mining				
Land Based				
Northern California	6.1	324.2	$3,890.3	$73.4
Southern California	15.3	810.9	$9,730.8	$183.6
Coastal				
Oregon	NA	0.1	$1.0	$0.0
California – coastal general	NA	NA	NA	$0.0
California – Monterey	NA	6.3	$76.2	$0.0
Seawalls and Other Armoring				
California	0.05	1.23	$14.8	$0.6
Oregon	0.003	0.07	$0.8	$0.0
Ongoing Harbor Dredging*				
California - Humboldt Bay	1.3	16.9	$202.8	$15.6
Harbor Dredging: Deepening				
California - Humboldt Bay		4.0	$48.0	NA
Subsidence				
California-Long Beach	NA	NA	$750.0	NA
TOTAL	**29.8**	**1,390**	**$17,432.1**	**$332.9**

- Impacts of Harbor Dredging for the Columbia River are included in Coastal Dams and Flow Regulation

In a second attempt to look at the economic value, we examine the remediation cost by using estimates of economics losses reported from recent studies along the lines of American Trader Case (Chapman 2001) wherein the courts upheld the concept in shoreline pollution that 'the polluter pays.' In the "Evaluation of Erosion Hazards," (John Heinz Center 2000) the researchers estimated 4,600 structures, or 5-10% of structures within 500 feet of the shore are in the 60 year erosion hazard area (EHA). The authors estimated an additional 600 structures could be constructed on currently open lots in the EHA, bringing the total of structures susceptible to erosion within 60 years to 5,200. The average annual expected loss to property along the Pacific Coast over the next 60 years is estimated as $110 million. Using a discount rate of 3.5%, the net present value of these losses is $2.7 billion. This estimate is only for loss of structures and property. The State of California (California Boating and Waterways 2002) estimated the net recreation benefits of proposed beach nourishment projects (again using a 3.5% discount rate) at $367 million. The total of these two estimates, or $3.1 billion, represent another method of calculating the economic losses related sediment loss along the Pacific Coast.

Little is available for repair costs, as only a very limited portion of the shoreline has undergone repair. The U.S. Army Corps of Engineers has undertaken five nourishment projects beginning in 1959 'putting back' about 56 million cubic yards (U.S. Army Corps of Engineers, 2003) along the California coast. Note that most of the sand that was 'put back' utilized nearshore dredged material which was simply replacing what would otherwise have been counted as a loss to the system. The projects costs for this nourishment totaled $258 million (U.S. Army Corps of Engineers, 1994, 2003).

Although some of the important anthropogenic activities that impact on the coast have been summarized, review of the literature suggests no agreement regarding who or what body is responsible for implementing and paying for the remedial actions necessary. Stone (1998) summarized past legal actions and proposed at least three potential legal avenues for integrating into the decision - making process a recognition of the effect of a project on beach erosion. First, the courts could do so by recognition of sand as an interest to be protected under the California Constitution by the public trust doctrine. Second, the State Legislature and Congress could mandate consideration of the affect of a project on sand supply. Third, public agencies could administratively recognize and deal with the problem.

4. Summary and Conclusions

The limited research in this effort indicates that about 1.4 billion cubic meters of sediment have been lost to the Pacific Coast since 1950. Separate studies estimate $3.1 billion in lost structures, infrastructure and recreation benefits in this region. During the same period, the Corps has ‘put back’ 56 million cubic yards, leaving a net deficit of at least 1.4 billion cubic meters, a larger deficit as much of the sediment placed was from dredged material in the nearshore system. The project costs for nourishment totaled $258 million while the $3.1 billion in losses are expected in spite of the nourishment projects. Although there are many limitations related to these estimates, they are offered to establish an order-of-magnitude understanding of the economic effects of sediment loss along the Pacific coastline.

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