Fairlight Cove: Managing the coastline in the context of natural processes and human activity - Supporting activity: Planning coastal intervention – predicting erosion rates and potential future impact of defences on sediment budgets.

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Erosion of coastal cliffs is typically seen as problematical to society as it poses threats to the hinterland. However, erosion doesn't necessarily mean the imminent loss of properties, but could highlight a potential issue which can be left until a future date to tackle. By doing this, allowing erosion to continue allows the continued input of sediment into the coastal sediment budget. Such management of erosion on cliffed coastlines can be made easier if we are able to predict the rate at which the cliff in question will eroding in the future. Predicting this rate means that we would be able to estimate how soon cliff-top properties will become threatened by the encroaching sea. Following from this, if we can predict rates of erosion, we can also then predict annual sediment volumes being input into the coastal sediment budget.

The aim of this activity is to plot lines which represent the predicted future positions of the cliff edge (erosion lines). Students can then discuss possible intervention/management strategies (including a 'do nothing' scenario) against a time scale, and also consider the impact intervention could have on sediment input from the eroding cliff. The detailed methodology below is provided as background and is not, necessarily, aimed at students themselves, but more at informing class leaders of how data was derived. The data table can be used to produce the map.

1. Prediction of cliff erosion and future cliff-edge position

The rate at which the seaward edge of a cliff erodes is of key importance when managing the coast. By predicting this rate, a coastal manager can determine how soon cliff-top development will come under threat from erosion, and thus, plan a defence strategy accordingly. There are published rates for cliff retreat, such as 'This cliff is retreating at an average of 'X'm per year'. Simply taking the value of X and marking a series of lines on a map is insufficient, as we also need to consider that over time, rising sea levels (plus other associated factors) will increase the rate of erosion.

Bray & Hooke (1997) developed a model by which this retreat can be predicted. Although a little simplistic (in that the model assumes the only controlling factor is SLR), it can be used to gain an insight into the extent of a cliff erosion problem[1] and also facilitate discussion of possible intervention strategies and their impacts on both the coastline and sediment budgets.

[1] *Bray M.J. & Hooke J.M. (1997) Prediction of soft cliff retreat with accelerating sea-level rise. Journal of Coastal Research **13(2):** 453-467*

The model:

$$R_2 = (R_1 / S_1) \times S_2$$

where:

R_1 = historical retreat rate (m a^{-1})

R_2 = future coastal retreat rates (m a^{-1})

S_1 = Historical sea level rise (m a^{-1})

S_2 = Predicted future sea level rise (m a^{-1})

Example:

A study undertaken in 2000 revealed that a cliff of uniform lithology has experienced an average retreat rate of 1.5 m a^{-1} over the past 100 years. Sea level rise over this period has averaged 4mm a^{-1}. Predicted future sea level rise is a further 2mm by 2060, giving a rate of 6mm a^{-1} by 2060. The closest cliff top development occurs 50m from the cliff edge.

Questions:

1. How long will it take for the development to become threatened and what will be your management strategy?
2. What volume of material does this erosion contributed to the sediment budget annually?

<u>To answer question 1:</u>

1. Determining retreat rate in 2060

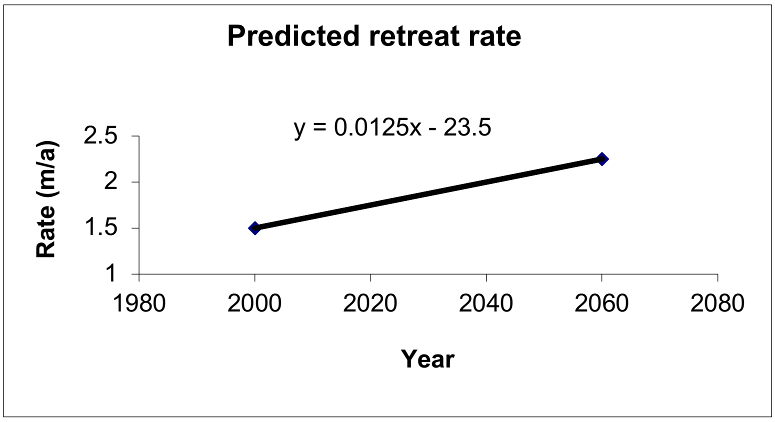
using the model, R_1 = 1.5m a^{-1} ; S_1 = 4mm a^{-1} or 0.004m a^{-1} ; and S_2 = 6mm a^{-1} or 0.006 a^{-1}

retreat rate in 2060 (R_2) = (1.5 / 0.004) x 0.006

= 2.25 m a^{-1} by 2060

2. When will cliff top development be threatened?

To determine this, you need to predict the future positions of the coastline for selected years – typically every 10, 25, for example. By plotting your existing two data points (existing rate plus historic sea level rise) on a graph (2000, 1.5) & predicted erosion rate and sea level rise in 2060 (2060, 2.25), plotting the regression line and calculating the regression equation (excel is good for this!), you are in a position to plot cliff position for any year between your start and end dates.



Using the regression equation. It's then easy to calculate the cliff retreat rate for each successive year. [formula in excel = ((0.0125*{year})-23.5)

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Table 1: Predicted rates of cliff recession per year from 2000 until 2060

Year	***Rate***	***Year***	***Rate***	***Year***	***Rate***	***Year***	***Rate***	***Year***	***Rate***	***Year***	***Rate***
2000	1.50	2010	1.63	2020	1.75	2030	1.88	2040	2.00	2050	2.13
2001	1.51	2011	1.64	2021	1.76	2031	1.89	2041	2.01	2051	2.14
2002	1.53	2012	1.65	2022	1.78	2032	1.90	2042	2.03	2052	2.15
2003	1.54	2013	1.66	2023	1.79	2033	1.91	2043	2.04	2053	2.16
2004	1.55	2014	1.68	2024	1.80	2034	1.93	2044	2.05	2054	2.18
2005	1.56	2015	1.69	2025	1.81	2035	1.94	2045	2.06	2055	2.19
2006	1.58	2016	1.70	2026	1.83	2036	1.95	2046	2.08	2056	2.20
2007	1.59	2017	1.71	2027	1.84	2037	1.96	2047	2.09	2057	2.21
2008	1.60	2018	1.73	2028	1.85	2038	1.98	2048	2.10	2058	2.23
2009	1.61	2019	1.74	2029	1.86	2039	1.99	2049	2.11	2059	2.24
										2060	2.25

In essence, it is now possible to say that in 2030, for example, the cliff is predicted to retreat by 1.88m, and in 2045, by 2.06m.

Discussion Question: Is the concept of cliffs eroding gradually year on year a true concept, or is the process more punctuated?

To calculate how far the cliff goes back before a specified date, it is simply a case of adding up the retreat rates between the two dates. For example, how far inland will the cliff move between 2000 and 2010?

In 2000, the cliff retreats 1.50 m, in 2001 it retreats 1.51m …… in 2009 it retreats 1.61m . Hence, by 2010, the predicted cliff position will be:

1.50+1.51+1.53+1.54+1.55+1.56+1.58+1.59+1.60+1.61 = 15.56m further inland

Table 2: Cumulative erosion rates (m/year)

Year	***Dist.***	***Year***	***Dist.***	***Year***	***Dist.***	***Year***	***Dist.***	***Year***	***Dist.***	***Year***	***Dist.***
2000	1.50	2010	17.19	2020	34.13	2030	52.31	2040	71.75	2050	92.44
2001	3.01	2011	18.83	2021	35.89	2031	54.20	2041	73.76	2051	94.58
2002	4.54	2012	20.48	2022	37.66	2032	56.10	2042	75.79	2052	96.73
2003	6.08	2013	22.14	2023	39.45	2033	58.01	2043	77.83	2053	98.89
2004	7.63	2014	23.81	2024	41.25	2034	59.94	2044	79.88	2054	101.06
2005	9.19	2015	25.50	2025	43.06	2035	61.88	2045	81.94	2055	103.25
2006	10.76	2016	27.20	2026	44.89	2036	63.83	2046	84.01	2056	105.45
2007	12.35	2017	28.91	2027	46.73	2037	65.79	2047	86.10	2057	107.66
2008	13.95	2018	30.64	2028	48.58	2038	67.76	2048	88.20	2058	109.89
2009	15.56	2019	32.38	2029	50.44	2039	69.75	2049	90.31	2059	112.13
										2060	114.38

(Dist = distance in metres)

Given that the data dates back to 2000, we are in a position to 'test' the accuracy of the prediction – for example, the model predicts that by end of 2021 the cliff would have retreated by 35.89m from its 2000 position. We could determine how accurate this prediction was by field measurement.

This is a simple example; in that it assumes that the whole cliff is retreating at a uniform rate. In reality, cliff recession is measured with reference to a number of marker points on top of the cliff, and so there may be a series of different values for R_1. In such cases, the above process needs to be repeated for each of these marker posts, giving each data point its own set of erosion data for plotting.

So, in answer to question 1, asking how long it will take for a development, 50m from the cliff edge to become threatened, we can estimate from the table above that 50m worth of erosion will occur between 2028 and 2029, *BASED ON PREDICTED ESTIMATES OF CLIFF EROSION.* Based on this, what will be your defence strategy?

Student Activities

1. Using the base map, plot the predicted cumulative erosion distances from Table 2 and estimate when each of the buildings and road will be lost. Start by using every 10 years, then plot other lines to fine tune predicted 'loss-by' dates.

Discussion question: When will each development come under threat? What are potential management scenarios? How might defence strategies differ depending on what the buildings are.

You could suggest different types of building and how cost benefit analysis could be used to determine whether defence will proceed e.g. how might students see the need for defence if the buildings were related to a farm or to a factory? How important is it to protect the road? This may depend on how important it is (a dead end to the site in question, or a coastal through road). The importance may also relate to what is below the road surface (main utilities/ sewerage, etc).

How long could the cliff be left to erode before defences are needed? It is worth remembering that the longer erosion continues, the longer sediment will be added to the sediment budget from this erosion and help maintain coastlines downdrift.

Discussion question: What are the limitations of this approach?

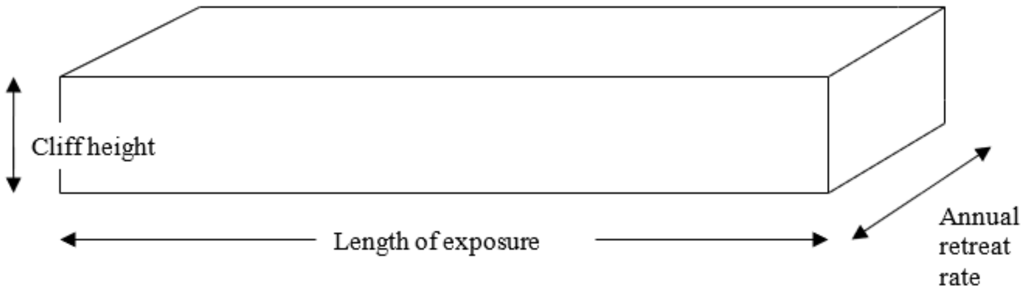
One obvious issue is that the cliff is an embayed coastline and so in reality, the embayment's are going to erode at a faster rate than predicted for a linear coast. Hence, underlining the need for multiple erosion monitoring points.

Also, cliffs do not retreat as a uniform entity, but as a series of successional failures, making the input punctuated.

2. Prediction of sediment budget contribution from cliff erosion

We have seen from the prediction of cliff edge position how the cliff edge retreats inland over time. Each erosion event represents an input of sediment into the sediment budget; hence the longer erosion continues, the greater this contribution will be. To predict the volume of sediment input, we need to know cliff dimensions.

The cliff exposure studied earlier is uniformly 25m high and the length of the exposure is 120m. The lithology is weakly consolidated sandstone.



Average volume per year = length x height x predicted annual retreat rate (depth lost in 1 year)

Length of cliff exposure = 1**20m**
Cliff height = **25m**
Predicted retreat rate in 2010 = **1.63m**

Hence, volume eroded (predicted) from the cliff in 2010 = 120 x 25 x 1.63 = **4890m^3**

This volume makes one invalid assumption, that all of the volume calculated above is sediment. The cliff is composed of sandstone – sand grains. These will have pore spaces between them which is, in reality, air (or water of the cliff is saturated). Hence, the value of 4890**m^3** is clearly an over estimate. We need to correct this value to account for the porosity if we are to reliable assessment budget inputs.

We could accurately determine how much pore space is present through laboratory measurement. However, for our purposes, we will estimate and use the average porosity value for sandy sediment (0.6) This means that for any given volume, 40% is sand and 60% is pore space.

To correct for porosity, therefore, only 40% of the above value is sand, so:

Volume of sand = 4890 X 0.4 = 1950**m^3**

The next step is to predict future budgets. Returning to Table 1, it is simple to calculate the values for each year

Table 3: Associated sediment volumes (corrected for porosity) (cubic meters per year)

Year	Rate	Input	Year	Rate	Input	Year	Rate	Input	Year	Rate	Input	Year	Rate	Input
2010	1.63	1950	2020	1.75	2100	2030	1.88	2250	2040	2.00	2400	2050	2.13	2550
2011	1.64	1965	2021	1.76	2115	2031	1.89	2265	2041	2.01	2415	2051	2.14	2565
2012	1.65	1980	2022	1.78	2130	2032	1.90	2280	2042	2.03	2430	2052	2.15	2580
2013	1.66	1995	2023	1.79	2145	2033	1.91	2295	2043	2.04	2445	2053	2.16	2595
2014	1.68	2010	2024	1.80	2160	2034	1.93	2310	2044	2.05	2460	2054	2.18	2610
2015	1.69	2025	2025	1.81	2175	2035	1.94	2325	2045	2.06	2475	2055	2.19	2625
2016	1.70	2040	2026	1.83	2190	2036	1.95	2340	2046	2.08	2490	2056	2.20	2640
2017	1.71	2055	2027	1.84	2205	2037	1.96	2355	2047	2.09	2505	2057	2.21	2655
2018	1.73	2070	2028	1.85	2220	2038	1.98	2370	2048	2.10	2520	2058	2.23	2670
2019	1.74	2085	2029	1.86	2235	2039	1.99	2385	2049	2.11	2535	2059	2.24	2685
												2060	2.25	2700

[Excel Formula = ((120*25*{erosion rate})*0.4)]

Key considerations:
How important is this sediment to the budget?
Are currents strong enough to move it?
Where will it go – Down drift/offshore/sediment store – i.e. how useful is it to coastal functioning?
What happens if half the cliff is defended? All the cliff?

The key thing is that having this information, you will be in a stronger position to assess the budget and the impacts of defending, thus cutting off input. The same process can be carried out for salt marshes, to determine inputs to estuarine budgets, or to calculate pollutant fluxes. Similarly, composite cliffs – sand and clay, sand and pebbles can be treated in the same way, but you will need to determine how much sand, how much pebble material, and the porosity for each cliff.

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