Impacts of Coastal Region Management on Water Quality

by

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"I hereby declare that, except where specifically indicated, the work submitted herein is my own original work."

Signed ______________________________ Date ______________

Management on Water Quality
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Technical Abstract

The aim of this project is to analyse the occurrence of algal blooms by way of looking at a Case Study in the Solent region, and analysing the conditions through run off and coastal processes - which trigger and lead to conditions conducive to algal blooms. Firstly from runoff, sediment loadings were generated, these can be looked at in a coastal balance to determine the likely amounts of sediment and hence nutrient loadings, alongside climatic features which contribute towards the algal blooms. Together with past meteorological and discharge data simulating the conditions of being able to simulate algal bloom, and non algal bloom events, has led to the predicting of the conditions that will lead to blooms in the future.

Algal blooms and specifically Harmful Algal Blooms have become a regular feature in the UK and around the world. They are particularly prevalent in coastal regions, one such Case Study that is explored in this project is the Portsmouth, Solent and Chichester Harbour. Things such as the volatile and changing nature of the geomorphological region effects including climate change have been monitored. Found already contribute and produce these bloom events. In the past decade there has been increased monitoring through use of satellite radar technology to track and monitor these changes more accurately. This has lead to mapping land use and the ability to extract catchment areas from Geographic Information System (GIS) software.

Nitrates and Phosphates are the main nutrients which contribute towards Algal Blooms; these nutrients come from agricultural and urban land in general. In order to do analysis on these nutrients, it is assumed that sediment is the main carrier for the nutrients and in order to analyse sediment loadings it is necessary to look at water flow. Streams of discharge data are modelled as carrying bed load and suspended sediment along with dissolved nutrients. To generate flow data, a tool called SHETRAN was chosen since it runs simulations on catchment areas and can simulate the hydrological cycle using a physical model scheme.

SHETRAN required input files of the catchment area, which were created using inputs GIS software. A sensitivity analysis on a runset was used to gain an indication of the reliability and functionality of the tool, on a preliminary case region: Gais Gill - leading to a full Case Study region, for which the sediment loadings which produced algal blooms could be analysed.

Calibration of SHETRAN to the measured discharge of data meant that, simulations can be run to determine the discharge for difference climate scenarios providing an

indicator was algal blooms, implying that higher discharge increases the likelihood of bloom events due to higher nutrient concentrations building up downstream. The years 2006 – 2011 were simulated and when this was compared with the bloom years and non bloom years, it was found that higher discharge corresponded to algal blooms and lower discharge rates corresponded to non bloom years.

A coastal balance was then deduced whereby, sea conditions: wind, waves, turbulence and tidal activities were the drivers to coastal processes: such as Long Shore Drift. By making relevant assumptions based on the (Standing Conference on Problems Associated with the Coastline) SCOPAC and (United States Army of Corps Engineers) USACE literature reviews -for analysing the sediment loadings due to climatic events - the assumption would be made to see the effect that changes in coastal processes, which would be instigated by coastal region management to alter conditions which could encourage algal blooms, due to excess nutrient loading.

In the case study region it was found that the harbours behave as a sink, however when run off and precipitation of sufficient intensity occur, a flushing of the harbour can occur signally an increase nutrient loading in the sea, which can lead to the build up the algal blooms.

A way of quantifying the occurrence of algal blooms via coastal region management has been developed, and can be used and applied to various coasts around the world for engineering practices, to manage and assess the relative measure of the impact of coastal region management on algal bloom events which can be more safely managed.

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Acronyms:

HAB	Harmful Algal Bloom
DEM	Digital Elevation Model
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
TOPAZ	Topographic Parameterization
USGS	United States Geological Survey
CEH	Centre for Ecology & Hydrology Home
UTM	Universal Transverse Mercator
PE	Potential Evaporation
NSE	Nash Sutcliffe Efficiency
GIS	Geographic Information System
SCOPAC	Standing Conference on Problems Associated with the Coastline
USACE	United States Army Corps of Engineers

1 Introduction

Harmful Algal Blooms, otherwise known as Red tide and Green tide have been occurring around the world, including the UK (Figure 1). The purpose of this project is to explore the occurrence of algal blooms and the conditions that are likely to produce the algal blooms. Algal Blooms have been a topical issue; making headlines and being documented in the news [see Appendix 2].

Investigations have previously been done into algal blooms, exploring the different aspects, both biological and physical, which contribute to the algal blooms. One such case that has been explored is the link between Zostera (weed) - which geese feed on – providing an indirect measure of the bloom activity in the target region. (VALIELA et al, 1997 [1]). Additionally upwelling in England Channel has also been shown to contribute towards the occurrence of blooms (S. B. Mitchell ,2006).

Factors such as the population historical human population growth have increased the level of nutrients in the soil which will potentially contribute to the blooms. Contributing more nutrients potentially to in a catchment area, leading to higher concentrations of nutrient loadings. An algal bloom event is characterised by a rapid increase or accumulation in the population of algal, due to factors such as population growth and popularity of things favouring phosphates and nitrates; it has been hypothesised that there has been increased loadings from human activities which has been said to go into the run off and sea and hence result in algal blooms.

Most Algal Blooms are not harmful, but 2% are harmful (SMAYDA, 1997 [2]). Blooms have become more prevalent, due to the increased nutrient loading particularly phosphates and nitrates in coastal waters, caused by Eutrophication. Eutrophication is when aquatic life end up depleting oxygen levels within the water; killing fish, creating odours ‘and reduced attractiveness of the water for recreation and other public uses. The full extent of the bloom can be seen and been observed through use of aerial and satellite technology as shown in Figure 1.

Figure 1: Diagram showing Algal Bloom off the Coast of South West England
Source:

2 Case Study Region: Chichester, Solent, Portsmouth Region

Figure 2: Map of Case Study Region: Portsmouth, Chichester, Solent Region
Source: Google Maps

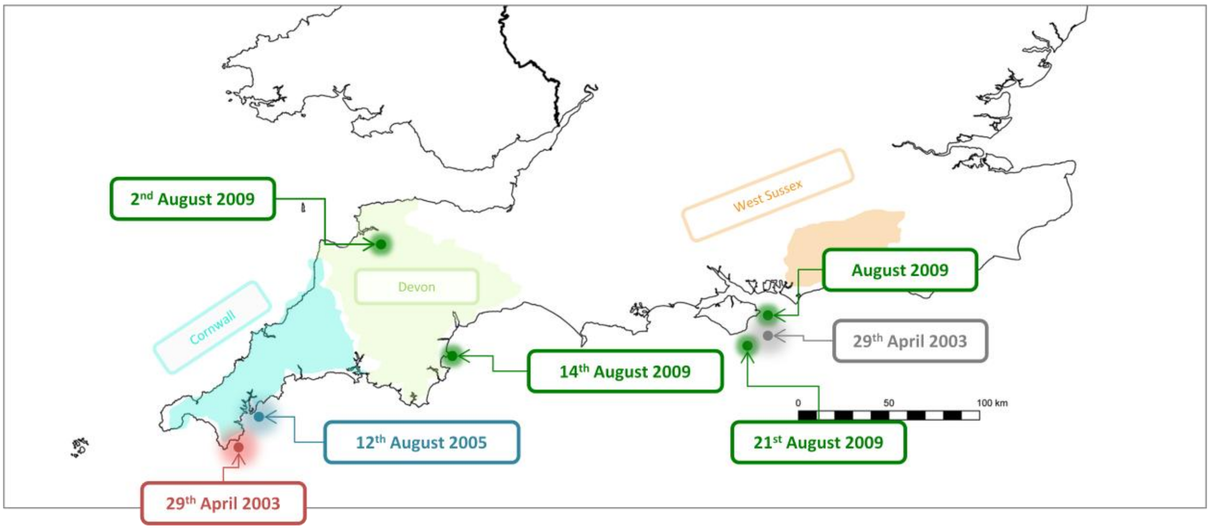


Figure 3: General Bloom Events in South England

See Appendix 2 for source

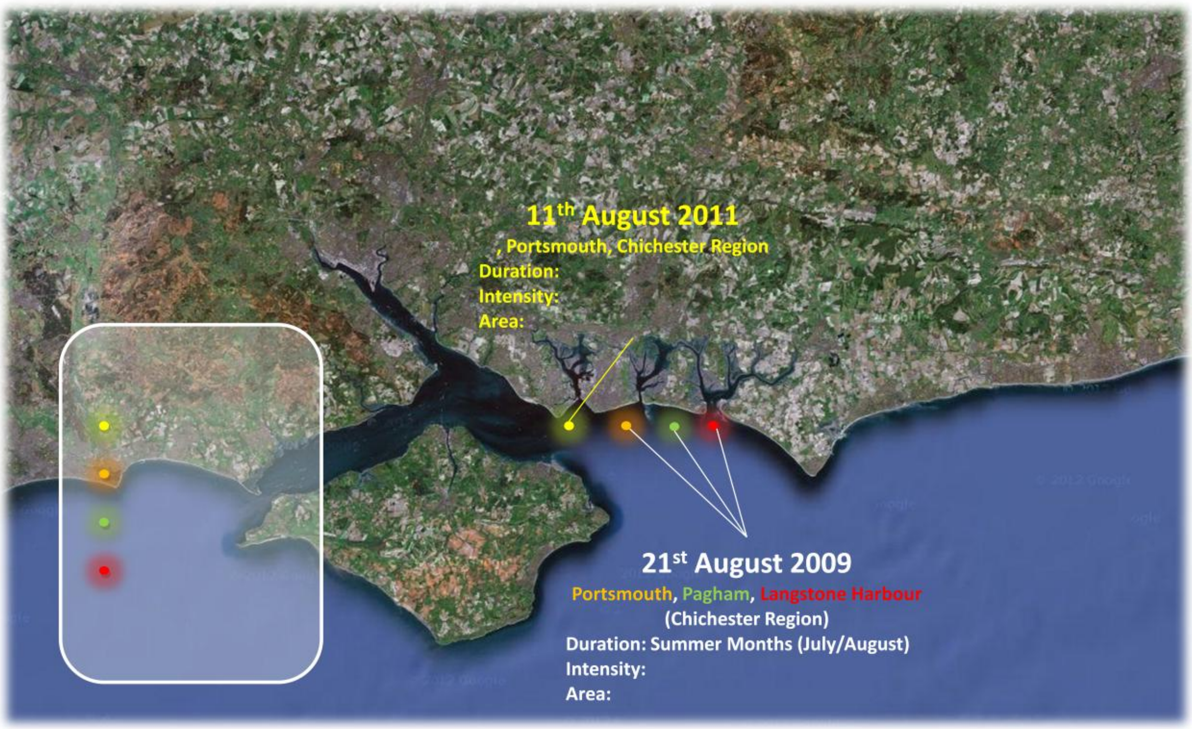


Figure 4: Time map of algal bloom events

around South England

Source: Googlemaps

The coastal system in the Solent region of the South of England was chosen to be used as the main case study for the presence of algal blooms due to the historical occurrences of algal blooms. Algal Blooms have occurred historically and have been documented and reported in the news for various points around the English Channel see in Figure 3 and **4** for algal bloom dates.

Since the cause of algal blooms has been from excessive nutrient loadings. a catchment representative of the region will be chosen to build a model, in which simulations can be run based on historical data, In order to build a predictor / warning system, for how the expected changes in climate or human activity can influence and create conditions conducive to algal blooms.

Sediment loadings which are an indirect measure of algal blooms will be used to investigate the occurrence of algal blooms. [Ewen, 2000[3][4] The sediment loading itself is not of a primary concern to algal blooms; it can be used as an indicator of nutrients such as Phosphorus and Nitrogen which can be attached to the Sediment. In order to determine the sediment loadings, clear run off and discharge rates must be determined since from that the amount of suspended sediment, bed loading can be calculated.

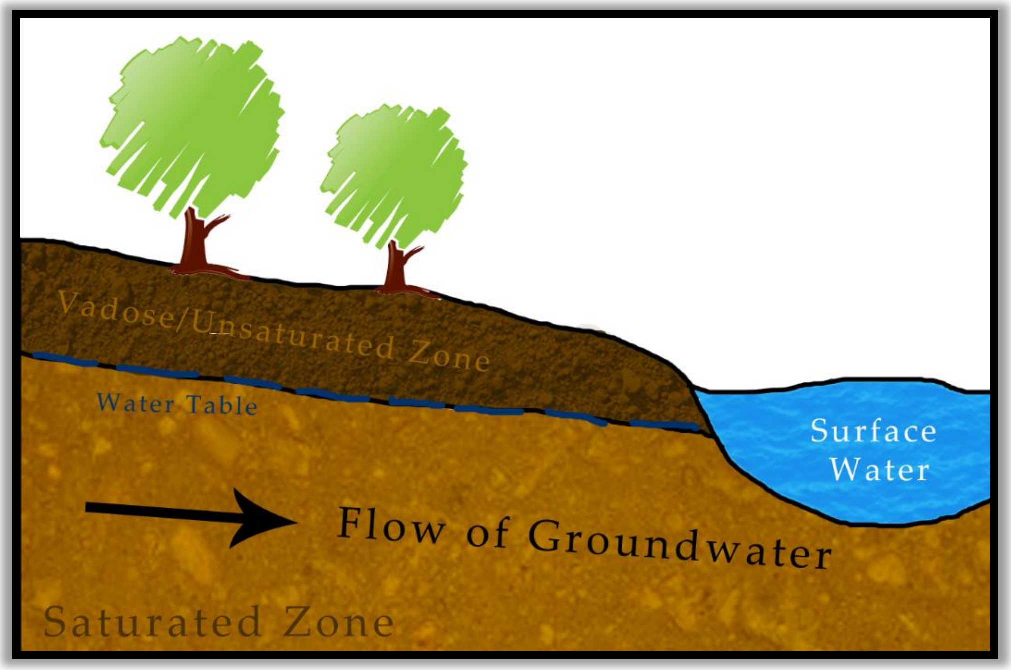


Figure 5: Ground and Surface Water Flow, Adapted from:
US Geological Survey

2.1 SHETRAN

A catchment hydrology model can be used to investigate the sediment loadings as shown in Figure 6, using a physical model basis. The model that has been chosen is SHETRAN which uses the physical basis for modelling the hydrology of the region. Historically catchment modelling has evolved with the rise of computation and being able to make more computations faster and run simulations over hundreds of years.

What distinguishes SHETRAN is its ability for it to be used as a model for flows between each segment of the DEM due to the river links function. It models its operation flow using a polynomial to describe the output:

SHETRAN *is a* physically based spatially distributed PBSD river basin modelling system; it uses the following data inputs as shown in figure 6: digital elevation models (DEM), precipitation.

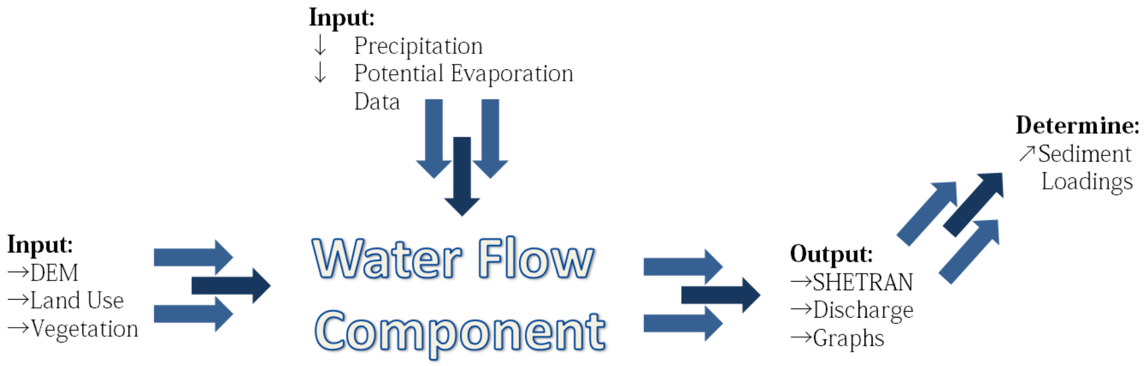


Figure 6: SHETRAN Function overview, Adapted from Ewen and Co. [1]

3 Preliminary Case Study: Gais Gill

A Sensitivity Analysis was conducted for the Gais Gall Region, North England:

Showing the region and determining to degree the accuracy and validation of the results of this project would show, by use of the Nash Sutcliffe Efficiency.

		Nash Sutcliffe Efficiency	Cumulative Discharge
Base Calibrated	Silt Loam Clay	0.496	58.4
Change in Vegetation	(Reduction in Storage Capacity)	0.227	63.1
Additional Soil layers	Changing the Saturated Conductivity between soil layers	0.886	210
Increasing Number of River links/ Channel	Implied discretising into smaller areas.	0.905	120

Table 1 – Results from Preliminary Case Study: Sensitivity Analysis on Gais Gill Region

4 Background of Catchment Regions

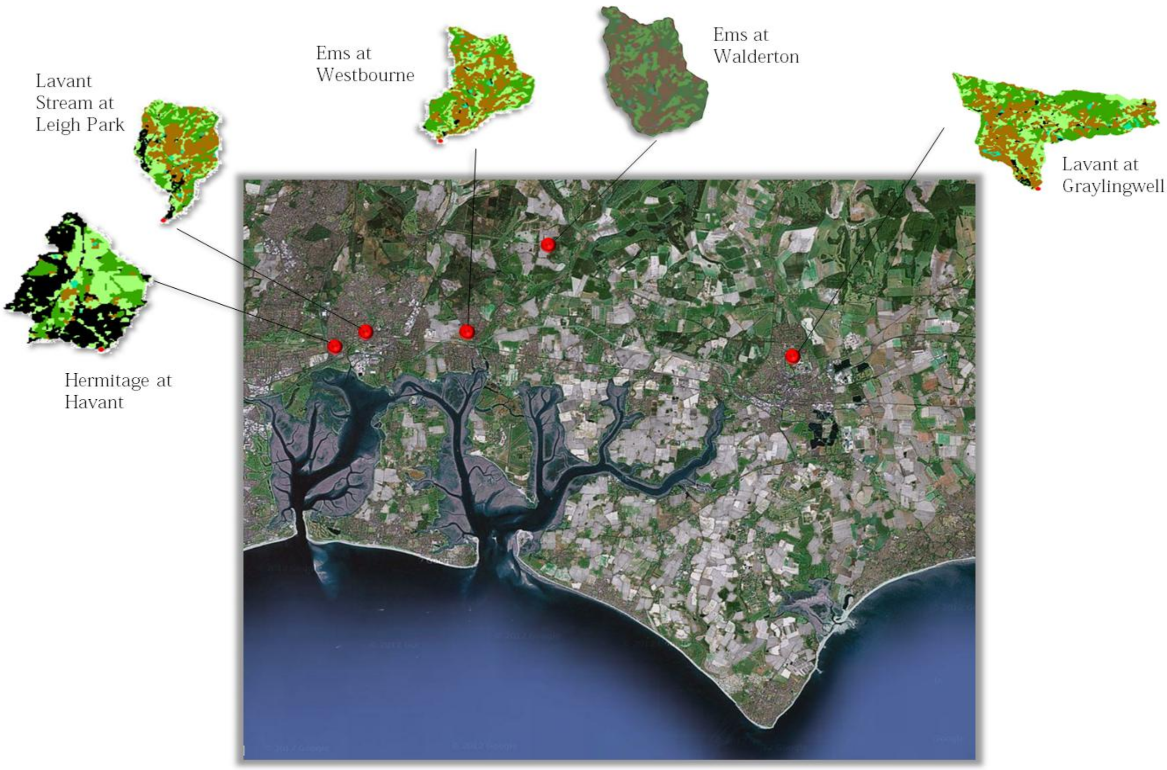


Figure 7: Catchment Areas, Source: Google Maps, Source: CEH website Land Use Catchments

Hermitage Stream is an ephemeral stream within a catchment of 19km[1] only visible when precipitation is high; therefore it is not a consistent stream. Literature review from SCOPAC suggests that the sediment yields due to transport are low and possible negligible. It is on tertiary deposits of London Clay and Reading Beds, with some upper chalk outcropping on the coast; on a section of the 3.2 kilometres of concrete lined channel with bank revetment in concrete blocks shown on the map below. With a mean annual rainfall of $0.28m^3/s$, it source is Queens Inclusive at Cowplain.

The River Lavant is a ephemeral stream 14.5km in length and has a catchment of $87.2km^2$ and "drains the dip-slope" South Downs Chalk region.[2] It has a mean annual precipitation of 958 mm and for this reason the precipitation values have been scaled to account for the higher precipitation for the regions such as that. In the Roman times the River Lavant was diverted to from its original course to Pagham but now is diverted to Chichester Harbour:

River Ems is ephemeral over its length it is also a "Chalk draining the South downs"[3] [Reference =] Land use: Woodland and Scattered Settlements Rephrase Paragraph

River	Mean Annual Rain (mm)	Percentage Run Off (%)	Mean Annual Runoff (mm)	Mean Flow (m^3/s)	Mean Annual Loss (mm)
Ems, Westbourne	932	28	265	0.47	687
Ems, Walderton	976	6	54	0.07	922
Lavant Stream, Leigh Park	938	5	46	0.07	892
Hermitage Havant	806	60	483	0.28	323
Lavant Graylingwell	958	11	110	0.3	848[4]

[1] (http://www.havant.gov.uk/havant-9872)

[2] http://www.ceh.ac.uk/products/publications/documents/HydrometricRegister_Final_WithCovers.pdf

[3] http://www.ceh.ac.uk/products/publications/documents/HydrometricRegister_Final_WithCovers.pdf

[4] **http://www.ceh.ac.uk/products/publications/documents/HydrometricRegister_Final_WithCovers.pdf**

Table 1 - Summary of Catchment Flow Characteristics –
Used to give preliminary calibration for SHETRAN Flows

For the annual rain is within the range 800 -1000 mm. From this preliminary analysis it is clear that Hermitage gives the most run off. It gives the most run off and least loss. A calculation using the Length of River, Discharge assuming uniform stream, with factor of 1.5 for non linearity, gives approximately 3 - 4 hours for precipitation to drain into the river. It would be necessary to use this level of resolution of data in order to factor for the time lag in precipitation and measurement at the outlet discharge.

5 Methodology

In order to run and generate discharge flow simulations of run off on SHETRAN, there is a need to create input files for catchment information on SHETRAN. A Digital Elevation Model - a numerical representation of terrain of earth is needed consisting of Raster Grid Squares of height and catchment shape - built via remote sensing technology.

A SHETRAN Model with a 30 m grid size was created for each catchment area being examined as shown in Table 3. In order to do this a Digital Elevation Model as shown in figure 10 and figure 12 using the Global Data Explorer courtesy of the U.S. Geological Survey (USGS). Outlet points were located using the CEH website and locating the outlet coordinates in order to extract the relevant regions. The DEM downloaded for the region was of a 30 metre resolution DEM which provided good accuracy for the target regions to be extracted and delineated and then output in ASCII format for use with SHETRAN.

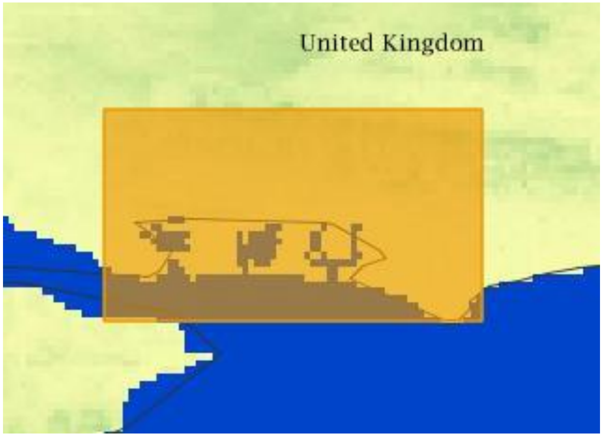


Figure 8: Download of DEM for Entire Area

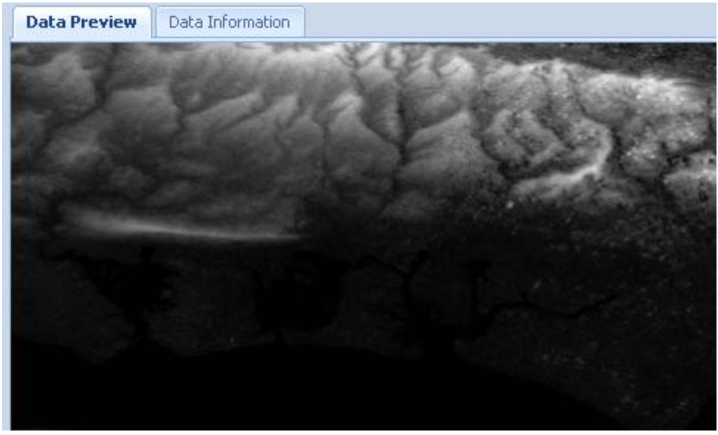


Figure 9: Data Preview for Catchment Regions

Using a grid size ranging from “116m to 462m” a river basin flow model, SHETRAN was set up for the 5 catchment regions as shown in Table 3. The following procedure was used data originally as ASTER DEM V2 data, which takes regions of the earth at 30 metre resolution using the USGS website - specifically using the UTM (Zone 30) since the region being delineated gives pixels which have equal sides in length This aspect is useful, as it ensures the linearity of the region.

From there, the data files (JPEG, GEOTIFF and ARCASCII) were downloaded from the USGS website for the target region of a large section of South England:
An example of delineated regions is shown in Figure 10 and Figure 12.

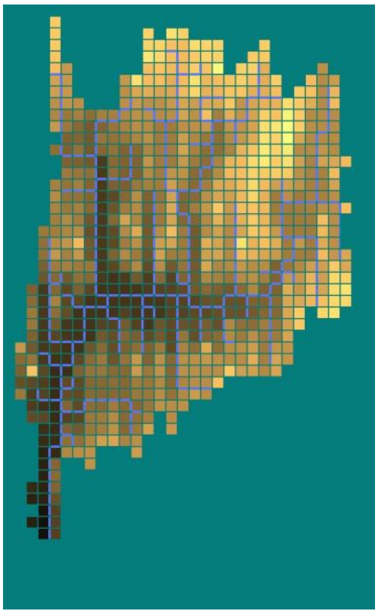


Figure 10: Delineated SHETRAN HD5 Output, Ems at Westbourne

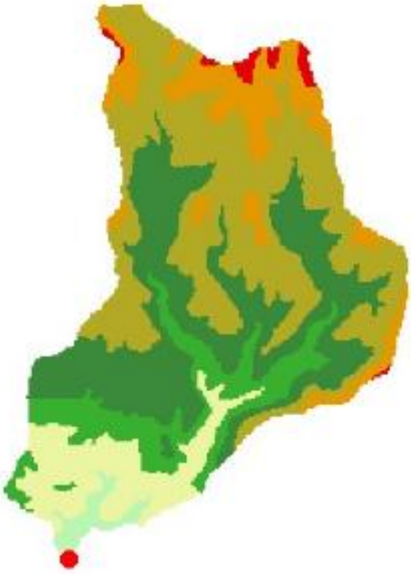


Figure 11: Elevation of Ems Westbourne (CEH Website Data)

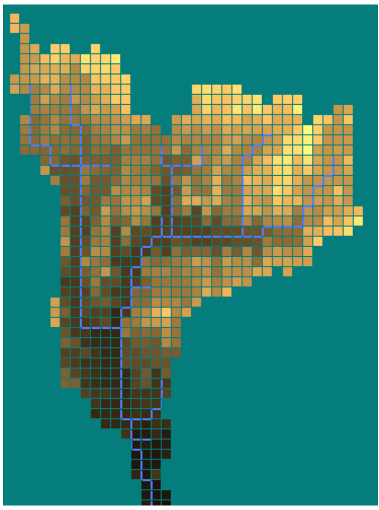


Figure 12: Delineated SHETRAN HD5 Output, Lavant at Graylingwell

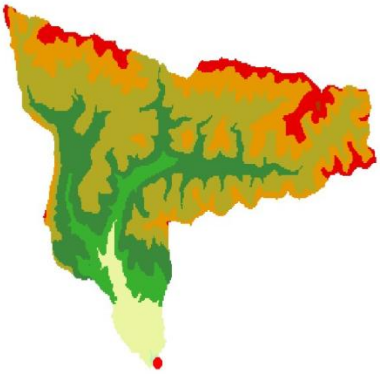


Figure 13: Elevation of Lavant Graylingwell (CEH Website Data)

Here is a summary for the regions:

Catchment Name	River	Area (km^2)	Max Elevation (m)	Minimum Elevation (m)	Max River Length (km)	CEH Reference
Westbourne	Ems	58.3	240.8	9.6	9.7	41015
Graylingwell	Lavant	87.2	253.6	20.7	14.5	41023
Walderton	Ems	41.5	240.8	34.3	9.7	41034
Havant	Hermitage	17	82.2	8	5	42017
Leigh Park	Lavant Stream	54.5	269.1	11.9	7	42025

Table 3 – DEM Characteristics of Region
Source: CEH website

6 Land Use

Catchment Name	River	Catchment Area	Woodland	Arable/ Horticultural	Grassland	Mountain/ Heath/ Bog	Urban Extent
		km^2	%	%	%	%	%
Westbourne	Ems	58.3	28.5	42.4	25.6	0	0.4
Graylingwell	Lavant	87.2	31	37.2	26.9	0	0.8
Walderton	Ems	41.5	27	43.7	26.6	0	0.3
Havant	Hermitage	17	18.7	4.1	31	0	23.8
Leigh Park	Lavant Stream	54.5	24.3	39.8	25.3	0.1	4.2

Table 4 – Land Use for Catchment
Source: CEH website

Looking at the catchment areas, Lavant at Graylingwell is the largest catchment region of 87.2km^2. Mainly compromising of Arable Land, (42.4% of the land is arable) ,In addition to this, all the regions are similar in their land uses, which suggests overall that it is the best catchment area for discharge was demonstrated by the graphs of the discharge versus time,

“The River Ems, Westbourne is 58.3km, however looking at the run off [this could feed into the below (height, land use & shetran) analysis. The run off percentages are higher for Lavant at Graylingwell this 28% vs 11% with Ems Westbourne (showing run offs." Explain. From a magnitude of size this means that more sediment and hence more nutrient is being transported from the region, meaning that the nutrient loading in the English Channel and harbours is likely to be more represented by that of Lavant at Graylingwell compared with other regions. However both regions can be used a relative comparison as good flow data exists for both regions. Focus is given to the Lavant at Graylingwell catchment in this report with Ems Westbourne used as a comparison.

6.1 Precipitation Data

In order to drive the SHETRAN simulation, daily precipitation values are needed. These were obtained from the Met Office 'South of England' region dataset for the 2006-2011 period examined here, [5] to construct the model dataset; it was assumed that this regional precipitation data was representative and uniform over the catchment study regions.

6.2 Potential Evaporation Data

Potential evaporation data values were also needed to drive SHETRAN, using data from[6] the Met Office Website to calculate the dataset. Since the values for Potential Evaporation are not recorded by the MET Office it was computed through the use of the Thornthwaite equation:

$$PET = 16\,(\frac{L}{12})(\frac{N}{30})(\frac{10T_{\propto}}{I})^{\propto}$$

$L =$ Average Number of day Length(hours)

$N =$ Number of Days in the Month

$T_{\propto} = Average\ Daily\ Temperature\ (\ Celcius)$

$$I = Heat\ Index = \sum_{i=1}^{12}(\frac{T_{ai}}{5})^{1.514}$$

$$\propto = (6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I + 0.49239$$

Equation 1: PET formula Thornwaite Method

[5] http://www.metoffice.gov.uk/hadobs/hadukp/data/daily/HadSEEP_daily_qc.txt
[6] http://www.metoffice.gov.uk/climate/uk/stationdata/hurndata.txt

6.3 Calibration Data

For the calibration process, data was inputted with respect to the land use as per the CEH data website. Specific land use classes were classes to certain regions (As shown in Figure 6 .These land use types were used in the analysis as per the CEH website Woodland, Arable, Grassland, Water, Built Up, Coastal. Runoff characteristics could be selected as per the literature review suggested by, (Uttormark, et al.) four calibration characteristics for land use could be implemented with respect to the land use: “Urban”, “Agriculture”, “Forest” and “Wetland”, as per a first guess of the calibrated land use figures.

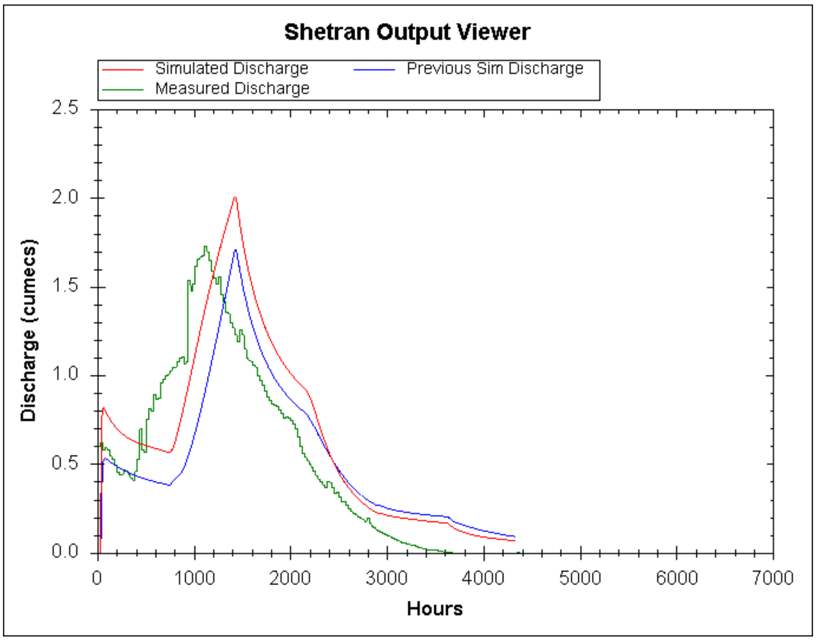


Figure 15: Calibration of Ems Westbourne Graph January 2006 – June 2006

The SHETRAN values were calibrated such that the calibrated values were adjusted to the actual flow data. Runoff parameters were allocated to check that it gave a representation of the behaviour of the flow at the specified outlet as shown from Figure 15 .

From the graph peak discharge occurs towards the end of January. However this was run for the purposes of calibration. The red line gave a Nash Sutcliffe Efficiency (NSE) of 0.7207 and the blue line gave a NSE of 0.6967. All the run offs were calibrated for the NSE greater than 0.7 as this would give a well correlated run off stream.

In addition the calibration the runoff percentages have been taken from the generic run off for the Precipitation data set since not all the measured discharges were known and measured as in figure 15.

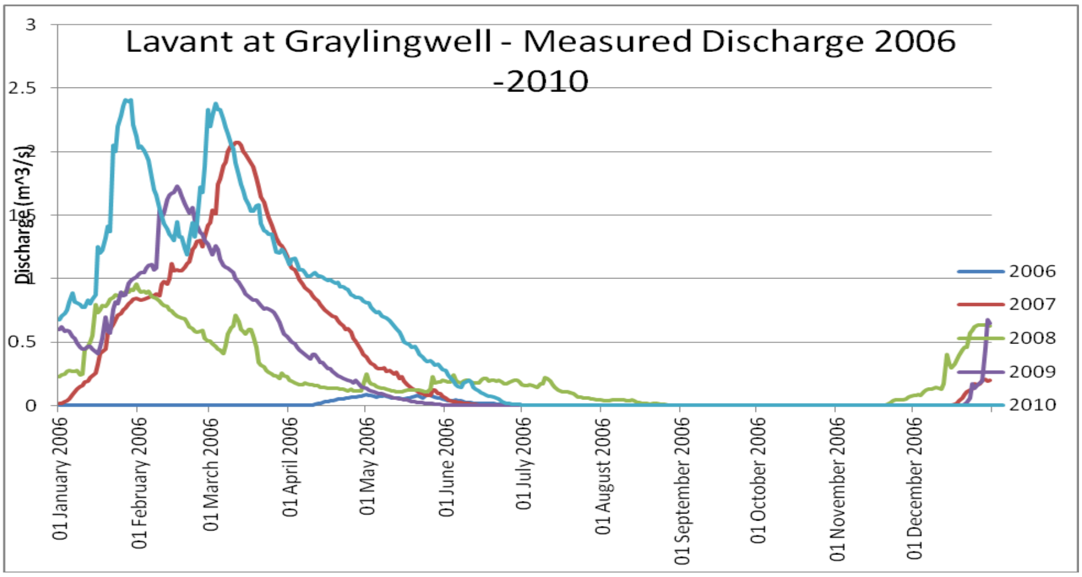


Figure 16: Measured Discharge,
Lavant at Graylingwell

From figure 16 this one can make the assumption nearly all sediment transport occurs in January – June ie 80-90% of sediment will occur in these months therefore makes sense that balance is done on a yearly cycle basis due to the ephemeral nature of the catchments.

The measured discharge for Lavant at Graylingwell is shown here (source CEH website). An analysis reveals the differing levels of discharge varying each year. Since the general shape is similar year by year the calibration will be valid for future years. The peak discharge provides a good indicator for the predictability of algal blooms, in that in 2009 a high discharge was shown, One can make the assumption that if a predicted case were to give a peak discharge greater than that of 2009, it is likely algal blooms will occur.

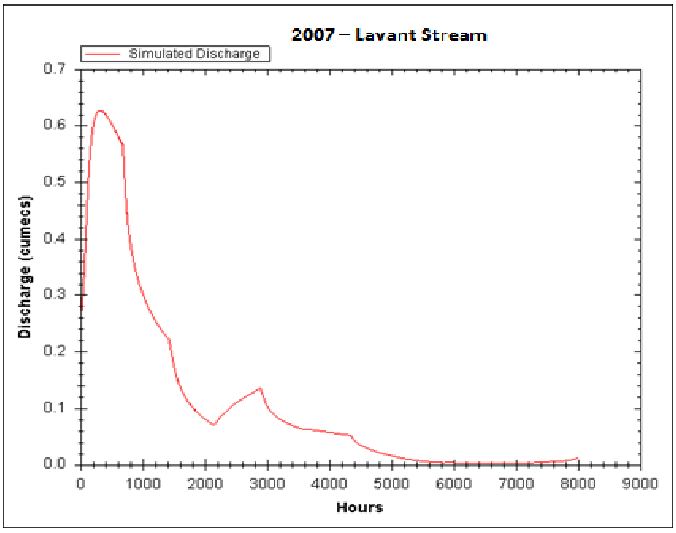


Figure 17: SHETRAN Calibrated Simulation (January – December 2007) Lavant Stream

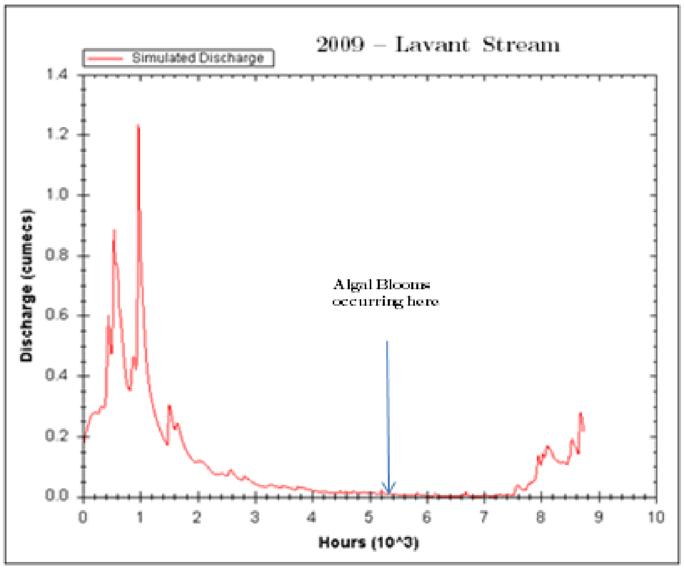


Figure 18: SHETRAN Calibrated Simulation (2009) Lavant Stream

From the graphs of Lavant Stream showing that the higher discharge of 1.2 cumecs is measured in the 2009 (January and February) when algal blooms occurred. However the peak discharge was measured to be 0.6 cumecs in 2007, algal blooms did not occur. In addition, in 2009 there was more flow occurring earlier so a greater proportion of sediment would have reached the coastal system meaning that a greater proportion of nutrient loading could occur much earlier than 2006.

Figure 19: Ems Westborne 2008

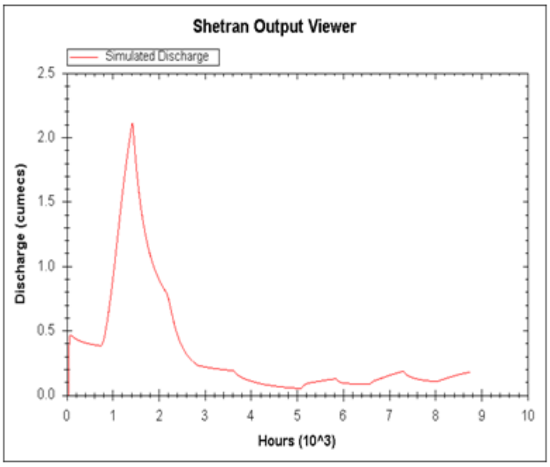
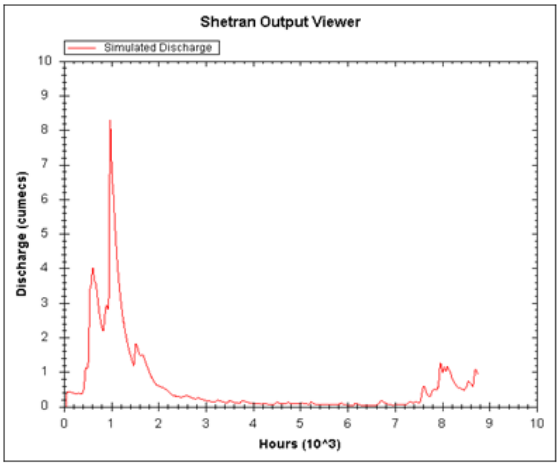


Figure 20: Ems Westborne 2009



The peak discharge of Ems Westbourne in 2009 is significantly higher than Ems Westbourne 2008. In addition during the year 2009 which algal bloms were produced the discharge graph is clearly more peakier. This implies that there are more etremes of precipitation. As well as higher discharge more volatile weather conditions are likely to trigger higher sediment loadings since there are more "turbulence" in the way the water runs off, implying greater bedload and suspended sediment loadinsg.

The results are reinforced by figure 18 and figure 17, showing the discharge for the Lavant Stream whereby 2007 is compared with 2009. Howeveer when looking at the Hermitage at Havant discharge the indicator of peak discharge is not clear – this was to be expected because from review of literature in (SCOPAC) it suggested that very low sediment transport took place – hence the lack of well defined sediment which was shown in SHETRAN.

7 Sediment Loading

Firstly the “Design Curves for Suspended Load Estimation” (G Fleming,1969), were used to get find a relationship between the discharge velocities of water at an outlet compared with sediment discharge. In order to determine this, an adjusted equation of: $y = 123x^{0.78}$

This was on the assumption that the relation between catchment area and velocity could be linked and that this relationship was not known but to be determined.

	Suspended Load	Average Flow Rate
	(tonnes /km^2/ year)	(m^3/s)
River Ems	1450	0.47
River Lavant	2400	0.298

Table 5– Sediment loading Calibration factor

Source: (Rendel Geotechnics)

From this the sediment loadings from the Design Curves and the sediment loading in this region were calibrated and extrapolated to determine how this would change as a function of the catchment and flow data from since flow data can be simulated from the calibrate SHETRAN outputs.

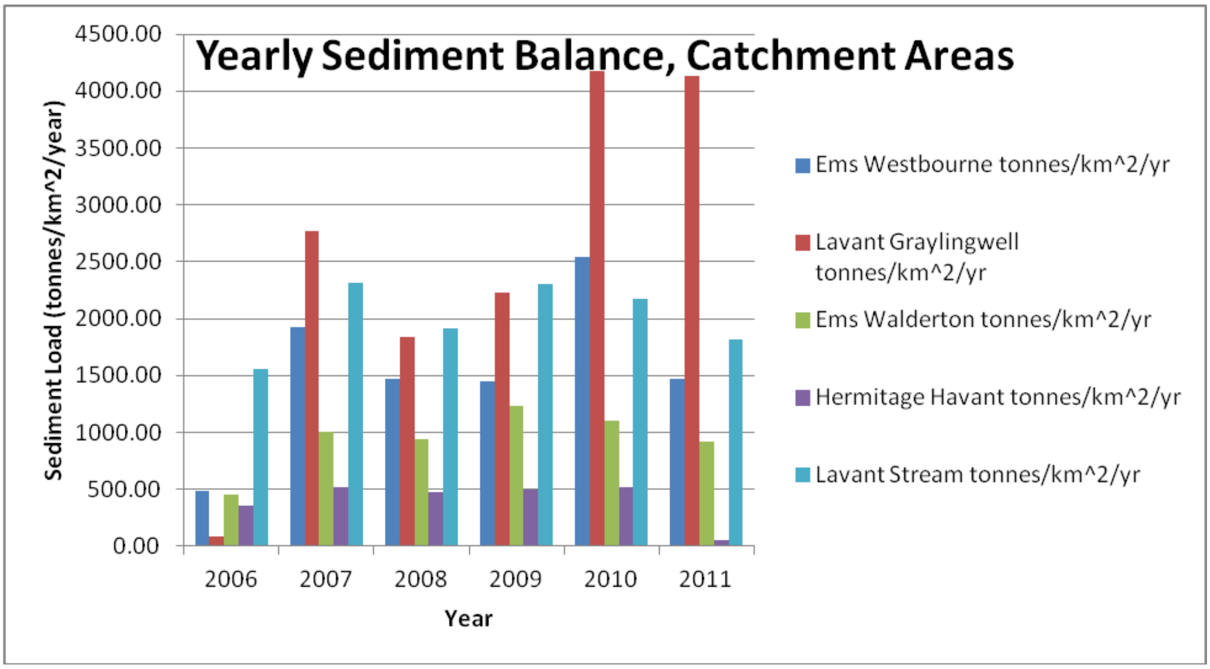


Figure 21: Sediment Balance Loading for the regions per km² per year

From the above graph, the loadings per metre squared have been plotted and the loadings are significantly higher in the 2009 – 2011, compared with 2006 – 2008. This is significant because higher run offs occurring have produced more sediment loading. This provides evidence that when algal blooms occurred in 2009 there were higher nutrient concentrations being transported to the coastal region.

8 Introduction to Coastal Region Management

This part of the project seeks to look at how the coastal elements, climatic factors, coastal processes and the general management of the coastal region is summed up in the case study region as a whole. The overall aim would be to see the effects of how the management of coastal regions will improve or exacerbate through the trigger of algal bloom events.

First a literature review was conducted to form a coastal balance. Unlike the modelling of runoff stream flow where sediment was only transported one way, the coastal system can be seen as a two way system, comprising of accreting sediment rates and flushing sediment rates in this way a net loading can be made to find the net loading within each time step.

8.1 Literature Review

The coastline in the South of England is primarily a function of the complex geological history in this area. During the Cretaceous Era 65 (Allen and Gardiner, 2000) million years ago the land was subjected to a period of uplift and down warping which produced the English Channel. Chalk beds were lain in the Upper Cretaceous Era (84 million years ago) (Allen and Gardiner, 2000). And also in the lower Cretaceous Era approximately 52 million years ago Clay, Sand and Silt was deposited on top the area.

The Neogene Period erosion, uplift and folding[7] (See Long et al. 2000) which was 2 – 23 million years ago. In the Holocene period a warm period of 10,000 years ago, after the last ice age it was a period of erosion for the unsheltered parts of the Solent and accretion of soil whereby the some parts of the coast were eroded and others sheltered experienced accretion of mudflats. The Isle of Wight became separated from the mainland UK which itself provides a significant shelter for the Solent region. Today there are estuaries, harbours, deltas which are looked at as the input and output from the sea from the coastal process: turbulence, waves, tides, and the hydrology of the inland regions bringing water to the sea. (As can be shown from **figure 22**)

[7] http://www.estuary-guide.net/pdfs/southampton_water_case_study.pdf (Townsend I,

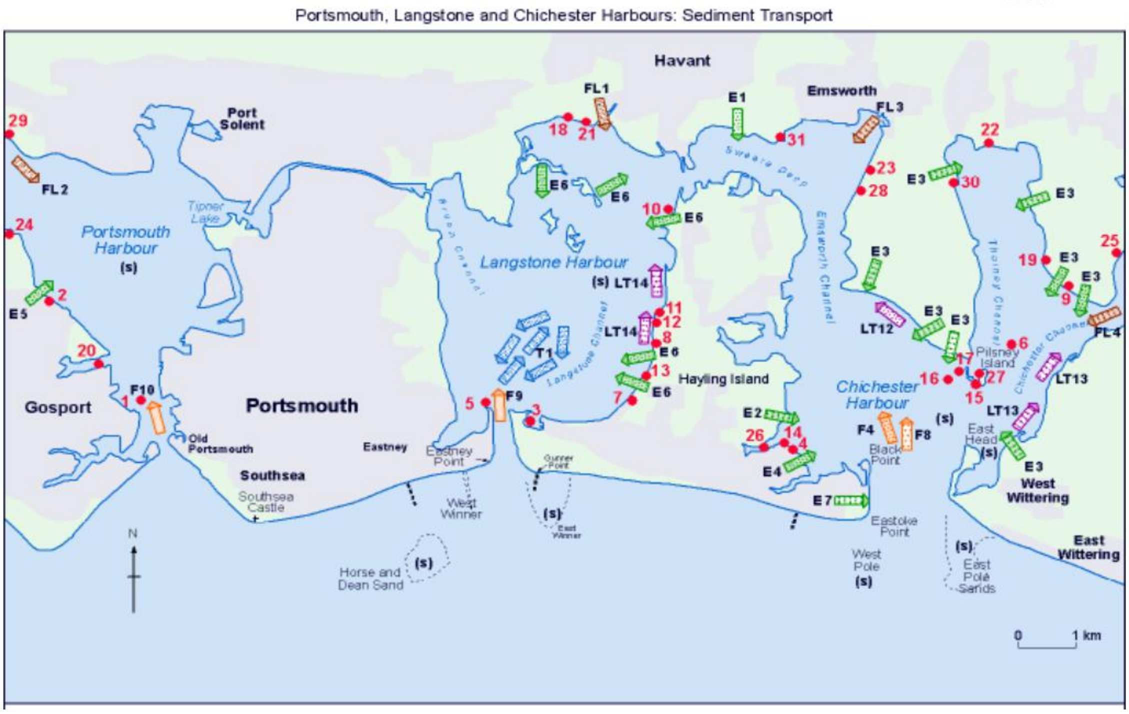


Figure 22: SCOPAC MAP of Sediment of Sediment Inputs, Source: http://www.scopac.org.uk/scopac_sedimentdb/hbrs/

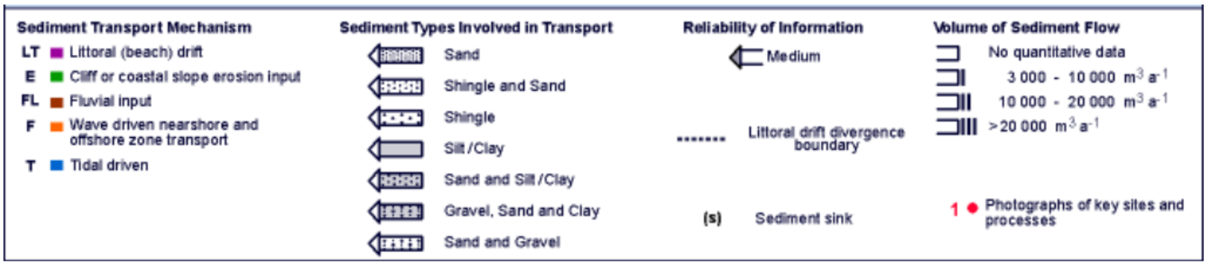


Figure 23: Key showing types of sediment transport with indicative volumes: http://www.scopac.org.uk/scopac_sedimentdb/hbrs/

Sediment Transport Mechanism	Number of Arrows
Littoral (beach) drift	5
Cliff or coastal slope erosion input	18
Fluvial input	4
Wave driven nearshore and offshore zone transport	4
Tidal Driven	6

Table 6: Showing development of coastal balance using relative factors of sediment

8.2 Physical Climatic Processes

The area of the target region is a low lying area as can be seen from Figure 22, it is fed by streams into the harbour. From the Coastal Features and looking at the analysis from the SCOPAC website there is sediment net sediment contribution to the Chichester Harbour – net transport from the “Wave Driven Current” into the harbour. In addition to the factor of the sediment into the harbours the harbour appears to be acting as a sink for the region. By modelling the accumulation and flushing rate associated with these processes as can be seen from figure 25 it is possible to see how often this occurs at each time step respectively and an estimate can be made of how often it will be flushed out.

8.2.1 Waves

Literature review suggests that waves which have a height of greater than 4 metres would have a substantial contribution (20%) to the net accretion rates in the harbour. However in the region from the SCOPAC website, waves do not co tribute far into the region and are ineffective. Waves are approximately 1 metre in height and literature review suggests 1) in the extreme cases of events the Predictive Case: 1 in 50 year event(1.1metre) (HR Wallingford, 1995) 1 in 100 year event (1.9m) (HR Wallingford, 1995).

8.2.2 Tidal Current:

From the diagram the size of the entrance to the harbour coupled with the shelter of Isle of Wight restricts the influence of waves but increases the “tidal velocities”. (SCOPAC) From HR Wallingford procedure, flooding occurs: On a seasonal basis, this would be a long term issue being modelled. Specifically the Spring Tide tends to be at the highest which corresponds to the time which the flow of water from sediment transport will be at the highest. Unique to this area is a double tidal system which is the feature of the tide.

For analysis be done it was necessary to split .so time scale a review if this is found on the scopac website.

8.3 Coastal Processes vs Time:

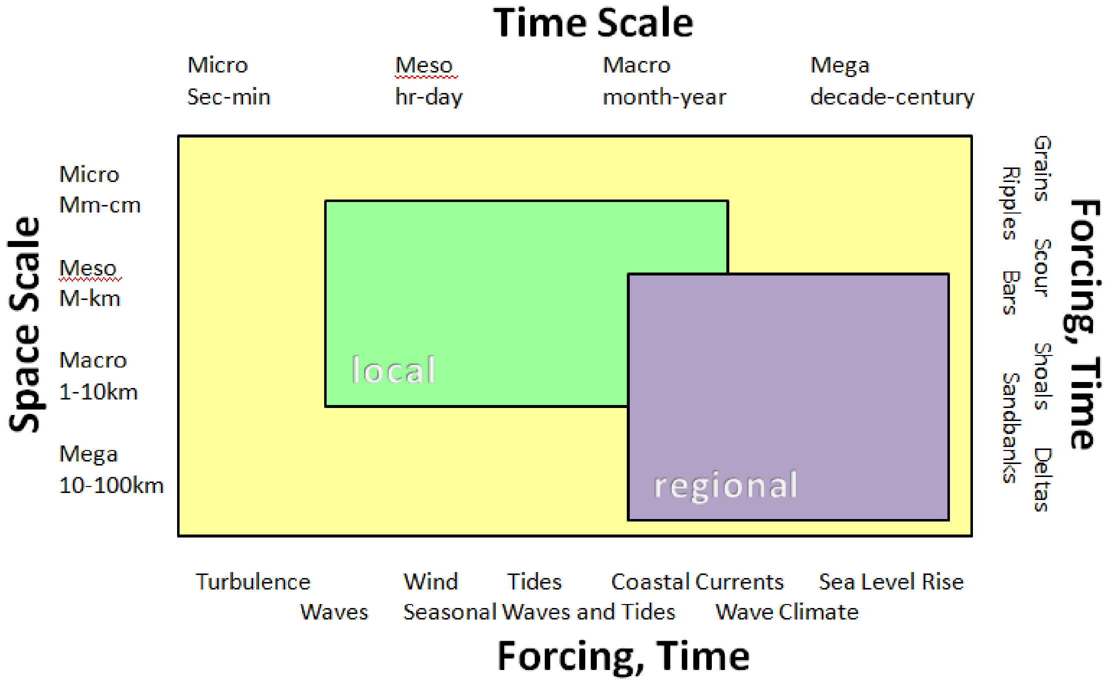


Figure 24 Classification of coastal processes with respect to time and space scales
Source: USACE

The coastal processes have been analysis in the form of a table by looking at figure 22 (SCOPAC) analysis and converting these values into relative sums of sediment loading for the balance. Since the time scale of which would be most significant would be within a year's time frame because each year can be looked at as a unit therefore issues such as Sea Level rise which give a change of 1 – 4mm per year, although a sediment balance could be applied the sediment is low enough to be neglected.

The following processes were looked at in the analysis (see Appendix)

- Littoral Beach Drift
- Off Shore Sediment Transport
- Cliff or Coastal Slope Erosion Input
- Estuarine Sediment Transport
- Wave Driven Nearshore and Offshore Zone Transport
- Fluvial Input

- Suspended, Flood Tide
- Tidal Driven

8.4 Assumption of Sediment Balance:

In order to do the mass balance the SCOPAC information research on sediment movement in this area was used as a starting point. The arrows of transport processes can give a relative scaled measure of sediment loading. Some sediment loading rates were missing but an extrapolation could be made as to the possible range of sediment loadings and the number of arrows and a approximate flushing and accretion rate calculated from the direction of the relative moment of sediment loading.

As well as this literature rates from USACE were chose, and then the contribution percentage of sediment that would contribute to the accumulation and flushing rate was considered. From the yearly balance a daily and monthly amount could be inferred.

From this sediment balance, coastal region management methods can be calculated by considerations such as the addition of a groyne which would decrease the loading due to Long Shore Drift and this is modelled in figure 25 and the results shown in Table 8 where the impact of Longshore Drift is reduced by 50% to factor in the use of groynes in this area.

From this model changes in climate such as increase or decrease in wind speed of 30% waves by which would have the impact of increasing the accretion and flushing rate by different factors respectively and are shown in Table 7 and Table 8.

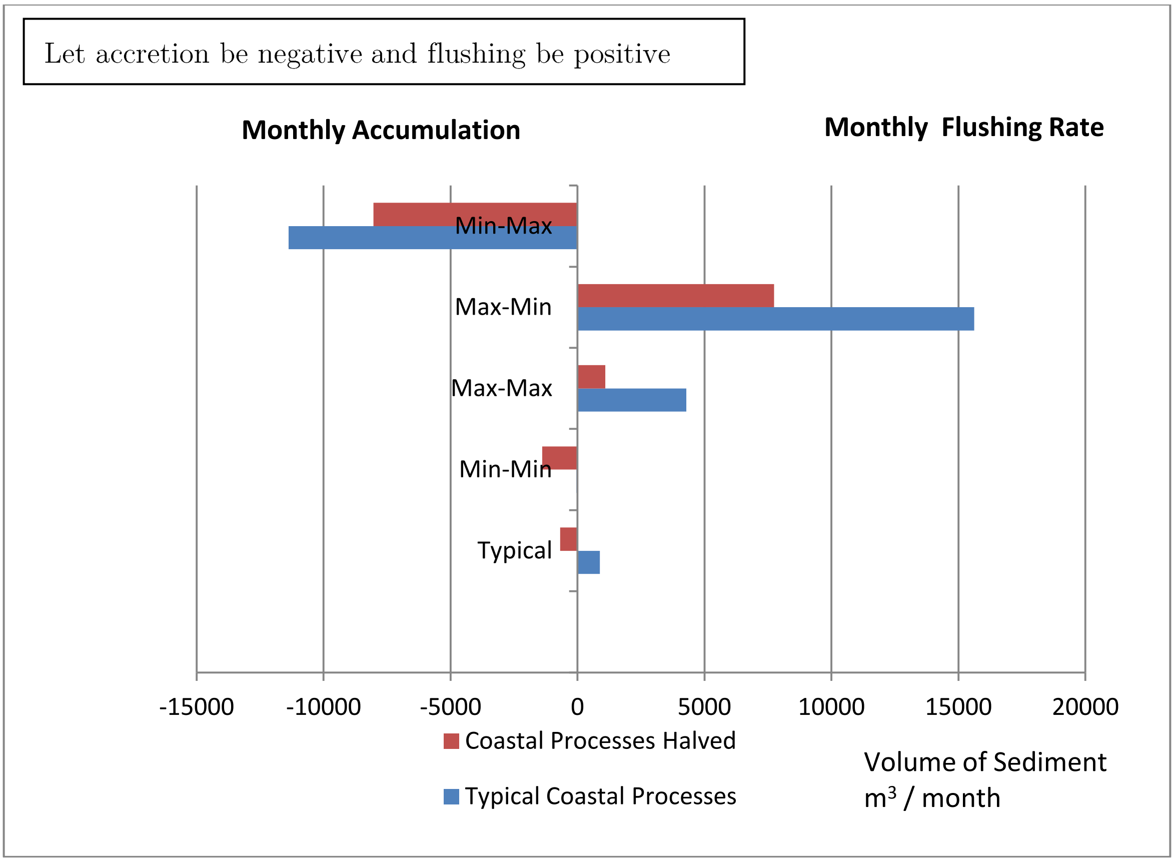


Figure 25: Result of Sediment Balance based on: Monthly Accumulation and Flushing Rates

This graph demonstrates the key assumptions from the sediment balance in that assuming all things minimum accumulation and flushing there is a tendency for sediment to accumulate in the harbours overall.

Let Case 1: Min – Max
Let Case 2: Max-Min
Let Case 3: Max - Max
Let Case 4: Min – Min
Let Case 5: Typical

On a monthly basis from the analysis of different rates of accretion and flushing rates, four bounds of typical loading rates would be possible in a month. Typical case is small sediment transfer to Sea or Small sediment transfer into the harbour of + or - 65m^3 due to the coastal processes that take place in this zone – this is related to the theory of the harbour acting as an exchange due to the sediment loading s from inland and the sediment loadings from sea. In addition the monthly accumulation could be much higher due to the harbour regions acting as a sink as a lot of sediment is stored during periods of high discharge from rivers (months December – June). The sediment loading in the peak months could be as high as 11,378m^3 per month.

At times of algal blooms when the flushing processes are highest, due to high periods of rainfall Intensity draining water, sediment and hence nutrients loads and higher erosion rates in the sediment transport high loads of 15,623m^3 per month could be transported into the sea which is a big potential sediment load for the sea. This high nutrient loading case is a scenario for setting for algal blooms.

Case 1, Case 4 and Case 5 would appear to match the literature review (table 8) for the sediment accretion however in the algal bloom events it is to be expected that case 2 and case 3 would be the algal bloom events.

8.5 The effect of coastal management on Case Study:

In order to do a coastal sediment balance, firstly the load conditions were determined for the typical case from the Literature USACE data suggested values and SCOPAC initial research conditions. Since these sources have looked at the coastal processes and tried to model them to analyse the relative impact of each process as a whole to the system. Then as each process is modelled as s a function of wind, wave, and tidal features in the sediment.

Net Balance of Sediment Loading	Typical Volumes (m^3)	Wind Factor 30% Increase (m^3)	Wave Factor 30% increase (m^3)	Tidal Factor 30% increase (m^3)
Yearly Loading	98,000	104000	110000.	120,000
Monthly Loading	-65	500	1100	1600
Daily Loading	27	46	65	82

Table 7: Predicted Scenario for Climatic Increase

Net Balance of Sediment Loading	Typical Upper Bound (m^3)	Wind Factor 30% Decrease (m^3)	Wave Factor 30% Decrease (m^3)	Tidal Factor 30% Decrease (m^3)
Yearly Loading	230,000	55,000	84,000	120,000

Monthly Loading	1,300	-10,000	-1,203	-9,800
Daily Loading	450	-300	-11	-283

Table 8: Predicted Scenario for Hypothetical Coastal Management Sediment Decrease

The above procedure above is a procedure to control coastal strategies in general. The coastal defence strategies such as breakwater and groynes, all have an effect on the effective sediment transport load. They can be modelled by such things as the reduction in arrows therefore each change can adjusted in the coastal balance model.

Time Period of Year	Sediment Accrual Rate
January – March	Sediment being accrued into the Harbour (small amounts
April – June	**Sediment being removed from Harbour**
July – September	Sediment being accrued into the Harbour (small amounts)
October - December	Sediment being accrued into the Harbour (small Amounts)

Table 8: Summary OF SCOPAC Literature Review

8.6 Hypothesis of Dry Springs:

Typically sediment accrues into the harbour as shown in figure 25. In drier springs less sediment is being flushed into the sea, however there will still be run off typically as shown in **Figure 17**. However discharge overall is lower hence, less precipitation but due to the sediment loading remaining in the harbour system, in years such as 2009 whereby there were much higher discharge, if Case 2 were to occur which implies a less dry spring this would produce extra high nutrient loading and hence Algal Blooms.

This actually supports the fundamental assumption that run off streams lead to 10: Algal Blooms occurred in 21st August 2009[8]: However the same was not reported for the same time period of August 2008. When comparing the sediment loadings for the same years there was less run off in 2008 which due to lower sediment loadings there has not been any algal bloom. For Lavant at Graylingwell the run off for 2009 was not substantially higher than previous years. As from the above, there are clearly other factors which contribute towards the bloom such as the climatic factors and the biological factors.

When considering the sunlight hours:

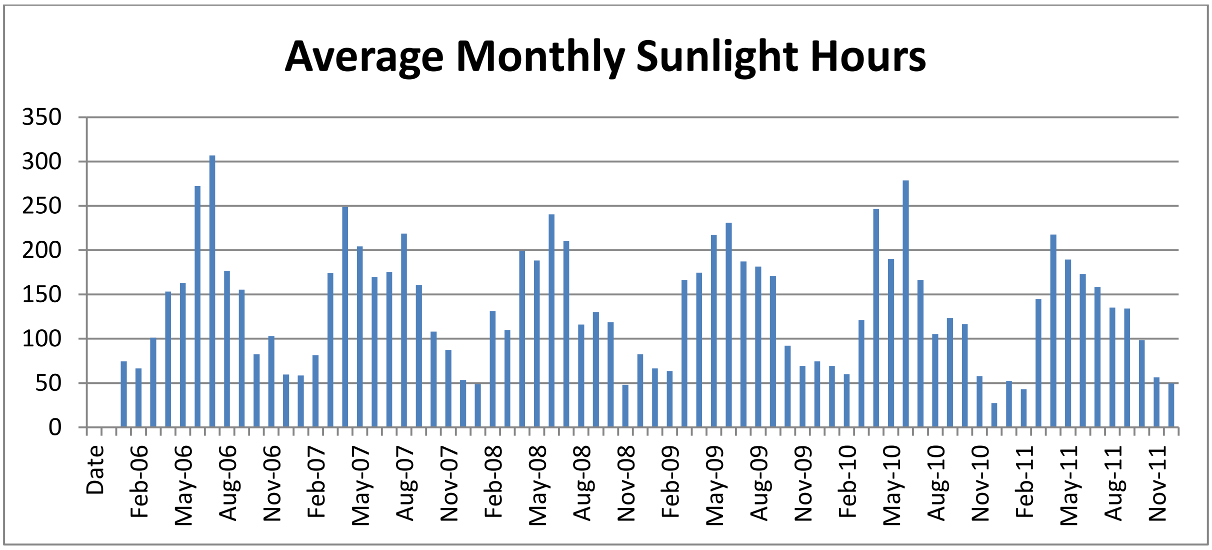
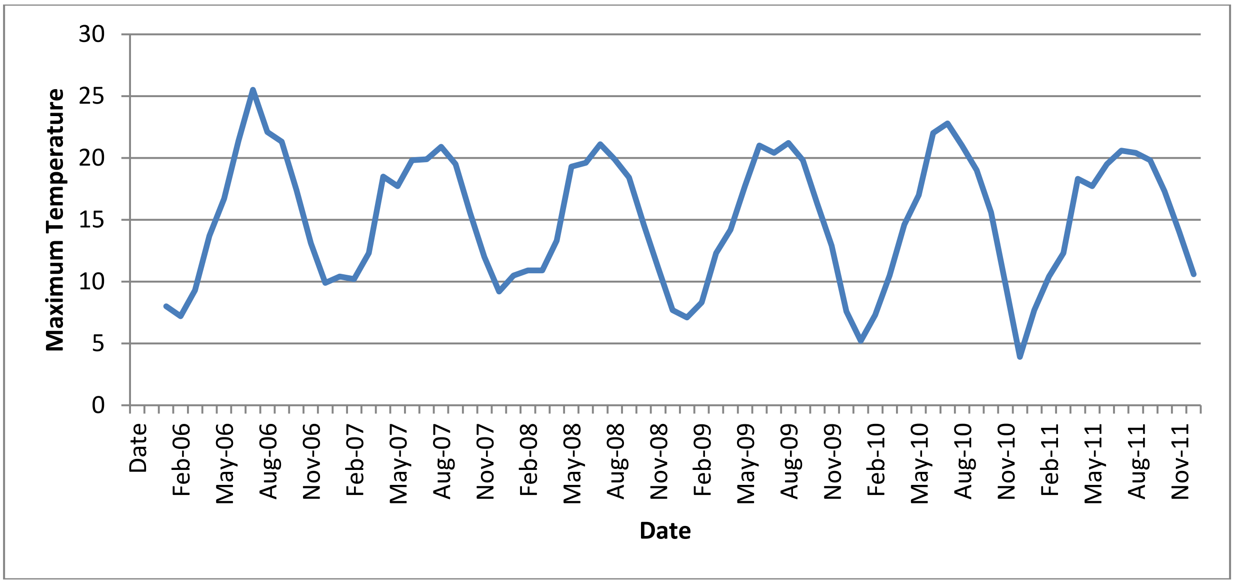


Figure 26: Showing the Average Monthly Sunlight Hours for Years 2006 - 2011

There is little significant about the sun light hours similar pattern, in year of algal bloom suggests (2009 and 2011) it suggests there might be algal blooms which occur when there is slightly less than average sunlight hours in a month. But this is clearly inconclusive in the sense that more sunlight and greater growth since more photosynthesis can occur. Suggesting the initial hypothesis is inconclusive. Since

[8] http://www.guardian.co.uk/environment/2009/aug/21/deadly-seaweed-chokes-solent

sunlight hours are fairly constant it can be assumed that the algal blooms produced are not limited by the sunlight in generals as this mechanism is always “switched on”.



Figures 27 showing Variation in Maximum Air Temperature between February 2006 – November 2011

Nothing significant about the maximum air temperature same as expected oscillating temperature as one might predict from being in this environment. Also the high maximum temperature corresponds with the high sunlight hours here. However the temperature being considered is the Air temperature. The sea temperature would be different due to the warming of the sea in the upper parts of it. One might expect that the higher temperatures in 2006 would correspond to algal blooms. Algal Blooms were discovered in Cornwall Devon (West of target region). So this does match the prediction in a sense, however the other factor is the flushing of sediment into the sea to cause the algal blooms in general.

This supports the idea that the Nitrogen and Phosphorus in the sediment loadings from the inland region contribute to developing algal blooms. Clearly run off from the Lavant at Graylingwell Figure is very low in 2006, hence although the conditions may be ideal for the run off of sediment the algal blooms have not developed in the Solent region, hence no news paper reports. However there were algal blooms in the Cornwall area in 2006 – but it could be shown from running simulations similar to that of this project to the catchment areas surrounding Cornwall that the high run offs contributed to the development of algal blooms.

9 Conclusions:

Ems at Westbourne and Lavant at Graylingwell are good predictors for Algal Blooms as they shown a distinct pattern of high runoff as shown from figures 15 – 20. Compared with the other catchments such as Hermitage at Havant where the runoff is sporadic in nature creates a stream flow which was a hard to calibrate on SHETRAN and determine accurately the run off. In addition the fact that much lower rates of runoff occur in the catchment zones such as Lavant Stream, less sediment is transported and hence less nutrient loads are gathered from this sediment transport processes.

The run offs are an input into the coastal system – hence the harbours will take sediment loadings during the winter/ spring months when run off is at the highest. However if the precipitation, coastal processes are relatively low or less effective the flushing effect will not occur hence, sediment from fluvial inputs will build up.

However when the wetter spring/winter occurs there will be much higher nutrient loading concentration and coupled with strong flushing effects this is evidence that leads to algal blooms. In this way algal blooms would be more likely when the flushing effect is higher. This was not proven by this investigation totally because there is uncertainty as to exact nature of the way in which sediment is accrued due to complexities of such a coastal system and many variations in factors that the loading could occur. This suggests more work should be done

The methodology developed in this data can be applied to other catchments in the world the run set created with the coastal balance can be used further to help engineers making design and engineering systems to make more efficient use of the coastal defensive strategy to avoid excessive sediment loading in similar coastal systems. This is of significance and novel nature of creating such a model is one that is adaptable.

The analysis for the sediment loadings was based on the SCOPAC data for the sediment loading in the region. Caution must be asserted in that the readings are not live values, but extrapolated based on the availability of limited information on historical readings. However the analysis provides a relative measure and can be verified by taking more readings and further in depth studies needed.

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Appendix 1:

Risk Assessment:

1) Identification the Risks:

Computer Risks: Hardware failure, electrical failure, electric safety
Ergonomics: The comfort level needed to be considered

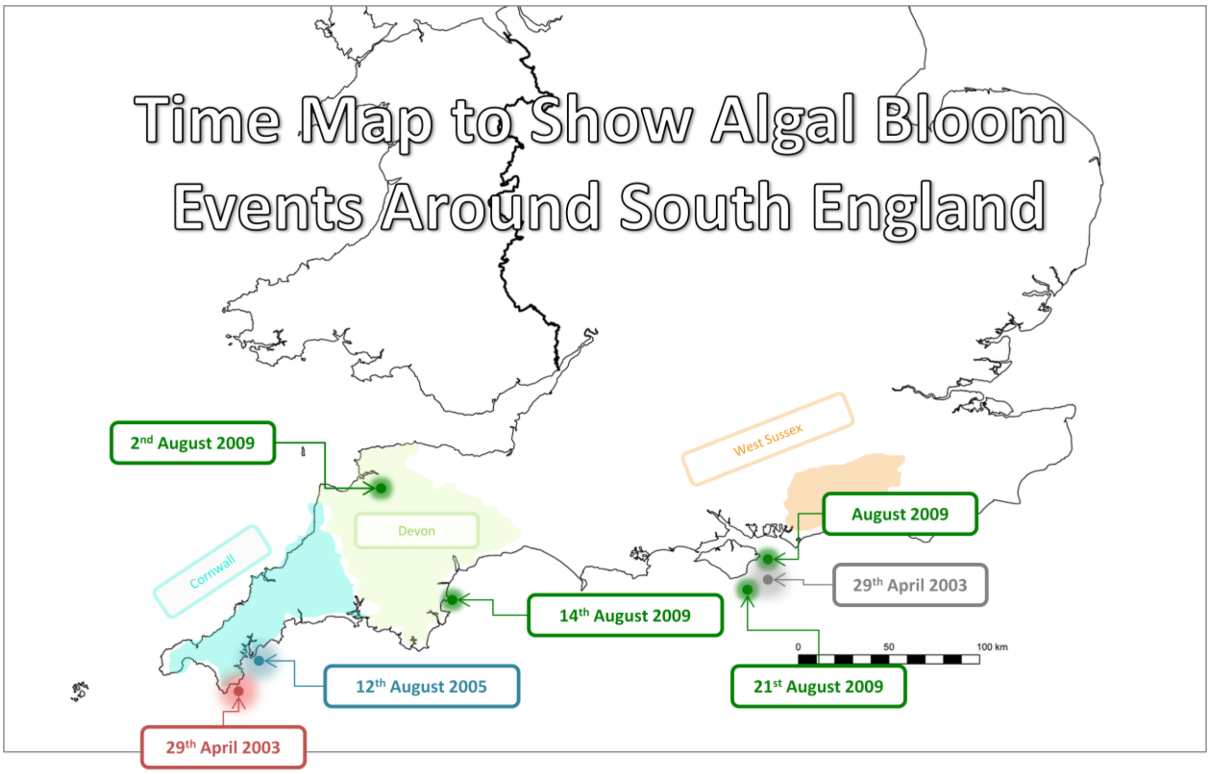
2) Who Might be Hazard:

Myself
People around me

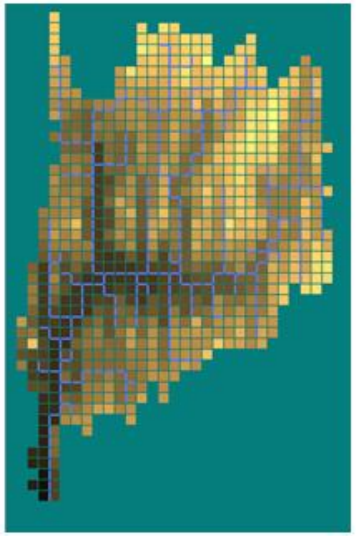
3) Implementation:

Made sure computer is used appropriately ie reduce electrical risk.
Having completed the project there were no significant risks from experimental procedure due to computer usage.

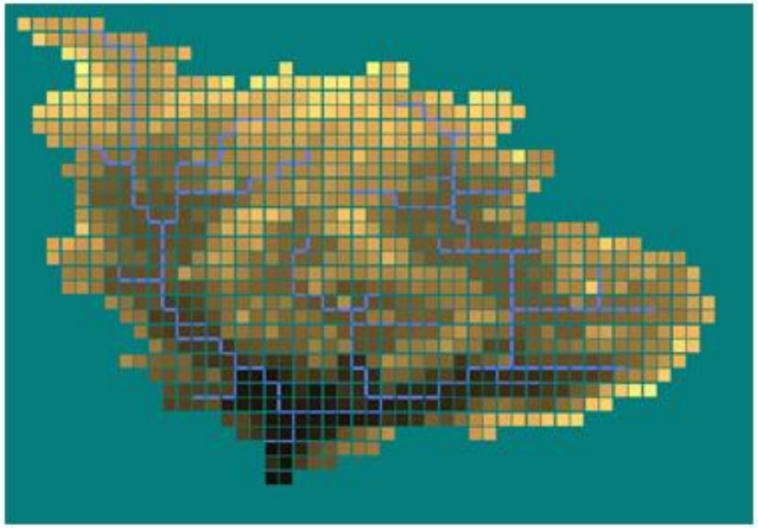
Appendix 2: News Articles Concerning Algal Blooms:



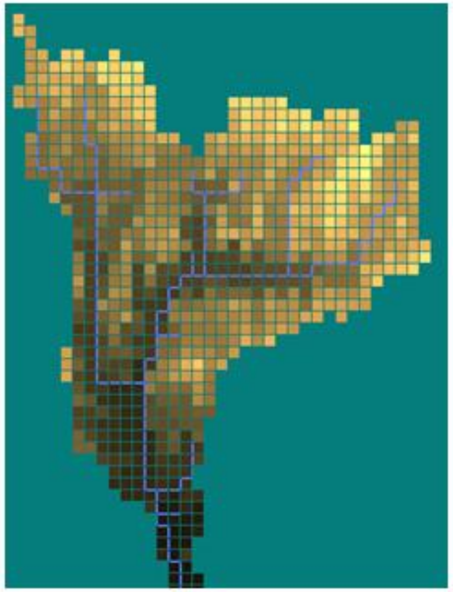
Appendix 3: Delineated DEM Output HD5 Format from SHETRAN



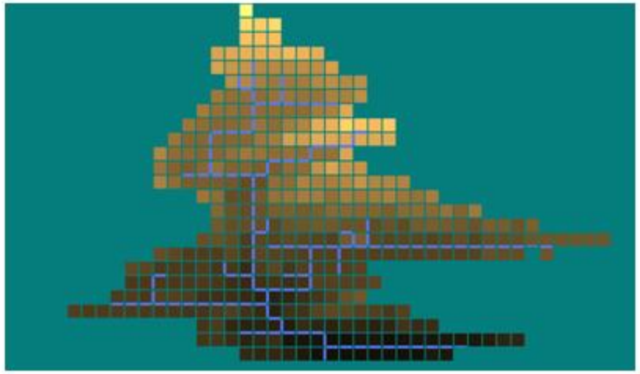
Ems Westbourne – Catchment HD5
Output from SHETRAN



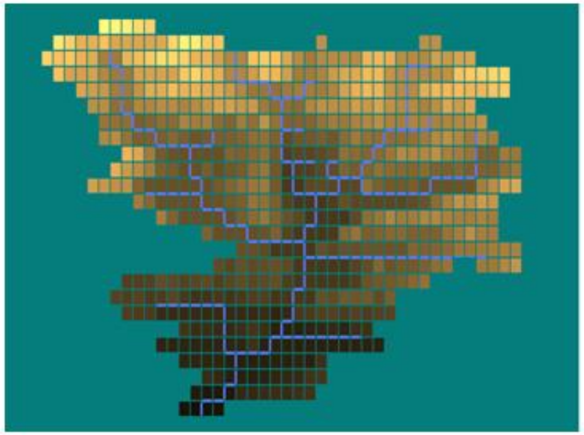
Ems Walderton– Catchment HD5
Output from SHETRAN



Lavant Graylingwell – Catchment HD5
Output from SHETRAN



Hermitage Havant – Catchment HD5
Output from SHETRAN



Lavant Stream – Catchment HD5 Output
from SHETRAN

Coastal Process ***Climatic Factors***	Frequency	Conditions from Lit review	Conditions in Target Zone	Time Zone	Sediment Balance Weighting %	Reference as Backup
Waves Very Short Term	High Daily Frequency	Greater than 4m will contribute 20% of Sediment Transport	Waves 1m in height Influences of **Isle of Wight Sheltering.** Harbour is relevantly Protected	Short Term, Hence Daily time frame so contribution of sediment transport in harbour very low	20%	Verhagen (1989) 100- 300m meters/ year
Tidal Impact	Twice Daily	Analytical model: morphological elements: ebb-tidal shoal, flood-tidal shoal, bypassing bar, and attachment bar.	Double Tide consider the impacts of that	Short Term		Kraus (2000a)
Sea Level Rise Impact	Continuous Low	1mm/ Year, relative small sediment yield impact negligible	Gradual impact	Long Term		Brunn Rule
Wind	Frequent	2.5 – 25m^3/m/year		Short Term	The Shore Protection Manual (1984)	Hull and Taylor (1999)
Storm	Infrequent but high impact	100% of yearly sand sediment for wave transport	1 in 50 year event(1.1metre) (HR Wallingford, 1995)	Middle Term/ Long Term	20% (Equal to sand)	Larson and Kraus 1994)
Tectonic Environment		Wide Contental Shelf implies less wave energy		Very Long Term	-	Inman and Nordstrom (1971)

In Shore Mechanisms

Sediment Transport Mechanism *(Physical Process)*	Arrows on SCOPAC website 1st Assumption	Percentage Weighting	Conditions from Lit review	Conditions in Target Zone	Time Zone	Reference as Backup	Volume of Sediment in a Year m^3
Littoral Beach Drift	5	125%		(Scaled Relative to Costal Slope Erosion Input)			5400
Cliff or Coastal Slope Erosion Input	18	450%	2 to 55cm. Year (average 18 cm/ year)		Each arrow corresponds to 1km therefore: (6m height)		19,440
Fluvial Input	**4**	100%			This is the sediment loading from the Outlets is equated		???
Wave Driven Nearshore and Offshore Zone Transport	4	100%		(Scaled Relative to Costal Slope Erosion Input)		(Larson and Kraus 2000)	4320
Tidal Driven	6	150%		(Scaled Relative to Costal Slope Erosion Input)			6480

Out Shore Mechanisms

Sediment Transport Mechanism	**Arrows on SCOPAC website**	**Conditions from Lit review**	**Conditions in Target Zone**	**Time Zone**	**Reference as Backup**	**Sediment Volume (m^3)/ year**	**Contribution (+ve or -ve to output)**
Littoral Beach Drift	21	1 Sand wave per 1.5 – m of shoreline Migrate at 0.5-1.5 km/year		Short	Sonu (1968) & Thevenot and Kraus (1995)	7560 **Estimation from diagram: 192,000m^3**/year	(+ve)20%
Off Shore Sediment Transport	10	Wind Contribution to this 2.5 to 2.5m^3			The Shore Protection Manual (1984)	3600 **Estimation from Scale: 91,000m^3/year**	(+ve) 80%
Cliff or Coastal Slope Erosion Input	3	2 to 55cm. Year (average 18 cm .year)	Each arrow corresponds to 1km therefore: (6m height)	Short	Moore, Benumof, and Griggs (1999)	1080 **Estimation from Scale: 27,2428m^3/year**	(+ve) 50%
Estuarine Sediment Transport	**13**	75% sediment source is due to coastal streams & 20% due to bluff erosion	: Coastal Streams (88,500m^3 approximately)		Best and Griggs (1991)	**118,000m^3/year**	(+ve) 100%
Wave Driven Nearshore and Offshore Zone Transport	11	Wind Contribution to this 2.5 to 2.5m^3			The Shore Protection Manual (1984)	3960: **Estimation from diagram: 80,000m^3** /year	(-ve) 80%
Fluvial Input	**4**	**From SHETRAN and suspended sediment analysis**	Epheral Streams	Jan – June (half the year)	(Inman and Jenkins 1999)	Worked out from the sediment discharge equation	???
Suspended, Flood Tide	4					**Estimation from diagram:**	(-ve)

						36,500m³/year	
Tidal Driven	6		Spring Tide is a Maximum			**Estimation from diagram: 54,900m³**/year	(+ve) 33%