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Catchment & Coastal Research

From Catchment to Coast: fluxes and transformations through the river-estuary system

An interdisciplinary conference for researchers & practitioners

January 8-10, 2012

Bangor University, North Wales

Abstract Booklet

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Compiled and edited by Jaco H. Baas

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SEDIMENTOLOGY OF TIDALLY-INFLUENCED FLUVIAL DEPOSITS

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Sediments deposited within the Tidally-Influenced Fluvial Zone (TIFZ) possess a complex internal heterogeneity due to the fact that this region experiences a combination of fluvial and tidal flows, which may also be influenced by waves. As a result, sediment transport and depositional rates within the TIFZ vary considerably both spatially and temporally, being controlled principally by the magnitudes of these river and tidal currents. Although the typical facies of *either* fluvial *or* tidal deposits are now well documented, little is known about the facies *changes* that occur though the fluvial-tidal transition. Here in the TIFZ, the dominance of either river or tidal flow: (a) controls the morphology, geometry and migration direction of resulting bed and bar forms, and (b) determines the distribution of grain sizes, such as discontinuous mud-sand deposits.

This paper will report on an integrated field and modelling programme in a 40 km reach of the Columbia River Estuary, USA. The Columbia is the 2nd largest river in the USA with a drainage basin of 660480 km^2 and mean discharge at the estuary mouth of 7280 m^3 s^{-1}. Tides in the Columbia River Estuary are of mixed diurnal and semidiurnal type with the semidiurnal wave 1.5 to 2.1 times larger in amplitude than the diurnal wave. The semidiurnal predominance increases in the upriver direction and the spring tidal range is 3.6 m with a large freshwater discharge. Peak river discharge occurs through spring snowmelt and from major winter subtropical storms.
Field data have been collected in year 1 of the project at both high (June) and low (September) river flow.

This paper will report on the first quantification of the sedimentary facies and heterogeneity of fluvial-tidal deposits both spatially (upstream to downstream) and temporally (from channel base to flow surface across the TIFZ). The TIFZ deposits are imaged, logged and quantified using Ground-Penetrating Radar (below exposed bar surfaces to depths of *c.* 10 m), Parametric Echo Sounding (penetration *c.* 6 m below the channel base) and vibracoring (depths to *c.* 4-5 m below the bar surface). Subsurface structure is related to channel morphodynamics through a time-series of historical aerial photographs. Results show eight key radar facies that typify the TIFZ and range in thickness from 1-4 m and length from 2-500+ m. Comparisons are made with ‘pure’ fluvial architecture from other large sandy anabranching rivers.

USING BED SEDIMENT COMPOSITION TO QUANTIFY THE ENERGY BALANCE BETWEEN FLUVIAL AND TIDAL PROCESSES IN THE DYFI RIVER AND ESTUARY

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The mineralogical composition of the bedload sediment in the Dyfi river (West Wales) is distinctly different from the bedload sediment in Cardigan Bay near the mouth of the Dyfi estuary. The river sediment is rich in dark-coloured rock fragments, while the marine sediment contains mainly light-coloured quartz grains. Bed sediment was sampled at 11 different locations along the river-estuarine transition zone of the Dyfi to investigate if the petrographical properties of these sediments can be used as a proxy for spatial changes in fluvial and marine influence on depositional processes. It is thus hypothesised that spatial variations in the energy balance between tidal, wave and fluvial processes are recorded in mixtures of fluvial and marine end-member sediments. The mixing process is thought to be not only effected by differences in hydrodynamic forcing, but also by mineralogical and textural maturation processes along the transport path of the bedload sediment.

The results of a comprehensive petrographical analysis of sand-sized sediment will be presented, which reveal that: (a) the *fluvial* end member is rich in rock fragments, derived from mudstones, siltstones, volcanic rocks and metamorphic rocks, whilst small amounts of polycrystalline and angular quartz were also found; and (b) the *marine* sediment is dominated by rounded and monocrystalline quartz, but it also contains biogenic components, feldspar and heavy minerals. This suggests that the marine sediment has a higher textural and/or mineralogical maturity than the fluvial sediment, because the marine sediment contains harder components that are more resistant to abrasion.

The fluvial and marine end members were found to mix in a predictable manner along the Dyfi river and estuary. The size of the fluvial end member population decreases in a seaward direction at the expense of the marine end member population. However, the data show significant variations in the trend lines for the different fluvial and marine grain types. For example, quartz percentage remains high well into the estuary until it decreases rapidly across the estuarine turbidity maximum (or bedload convergence zone) at the upper limit of the estuary. At this location, the percentage of rock fragments decreases in an opposite direction, but this trend is less distinct than for marine quartz grains. The energy balance between fluvial and tidal currents thus controls mixing processes of sand-sized sediment deposition most pronouncedly in the bedload convergence zone.

The petrographical data was collapsed into two new parameters: the Fluvial Reach Index (FRI) and the Marine Reach Index (MRI). These indices are a quantitative measure for the relative importance of fluvial and marine influence along the river-estuarine transition zone, based on the means of all fluvial and marine petrographical indicators. The FRI and MRI are generic tools that can be used to compare the Dyfi river with estuarine systems that have a different energy balance between tidal, wave and fluvial processes.

CONTEMPORARY AND HISTORICAL SEDIMENT-ASSOCIATED METAL DISPERSAL AND STORAGE IN THE LOWER RIVER DANUBE: AN EXAMPLE OF STUDY WITHIN A MULTI-NATIONAL DRAINAGE BASIN.

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The storage and (re)dispersal of contaminant metal-bearing sediment throughout the lower Danube Basin is of key concern for basin management and the implementation of the EU WFD. This paper reports on the use of Pb isotopes and multi-element geochemical data to track the source of metal-enriched sediments in the Lower Danube and on the use of mixing models to quantify sediment contributions from Serbian, Romanian and Bulgarian tributaries to River Danube channel and floodplains. It is possible to differentiate between metal ore deposits within the Danube Basin based upon $^{208/207}Pb$, $^{207/206}Pb$, $^{208/204}Pb$ and $^{206/204}Pb$ signatures and therefore track sediments in catchments draining differing mineralization types and to quantify of sediment-associated metal dispersal at the catchment scale. In the Lower Danube, enriched Cu concentrations (250-280 mg kg^{-1}) mirror peaks in sediment contribution from two key tributaries, Rivers Timok and Iskar, with multivariate mixing model data indicating sediment delivery from these mining impacted catchments contribute 10-24% of the channel sediment load of the Lower Danube. Sediment cores (3-4 m in length) collected from the lower Danube floodplain display a temporal record of metal dispersal and offer the potential for the reconstruction of temporal patterns in metal provenance.

HOW THE TIDE AFFECTS THE TEMPERATURE OF COASTAL WATERS

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Observations in the coastal waters of north Wales show a springs-neaps cycle of water temperature. In winter, water temperature is about 1 degree higher at spring tides than it is at neaps and in summer the phase reverses and warmest water occurs at neap tides. We examine the hypothesis that this signal can be explained by the tidal advection of an offshore temperature gradient. In winter, offshore waters are warmer and the flood tide brings warm water to the coast. This effect is greatest at spring tides and explains the observed warming at this time. In summer, the gradient is reversed and the flood tide brings cooler offshore water to the coast. A closer examination of this process, however, reveals that it can explain the observed signal qualitatively but not quantitatively. The amplitude of the springs-neaps cycle of water temperature depends on the exchange rate between offshore and coastal waters and on the temperature gradient. As the exchange rate is increased it destroys the temperature gradient: the onshore waters have the same temperature as those offshore. This means that there is an optimum exchange rate which produces the maximum springs-neaps cycle in coastal water temperature. Exchange rates that are both smaller and larger than this optimum create a smaller springs-neaps temperature range. The maximum range that can be produced in this way for the conditions along the north Wales coast is 0.25 degrees - one quarter of the observed value. An alternative hypothesis is that the springs- neaps temperature cycle is produced by produced by local heating and cooling. We show that the interaction between the tide and the day-night cycle of heating and cooling produces a springs-neaps cycle of water temperature which is in the same sense as the observations although not exactly of the same phase. It is possible that the observed temperature variation is produced by a combination of these two processes: local heating and cooling and advection of offshore water.

MORPHODYNAMICS IN TIDALLY-INFLUENCED RIVERS: RE-THINKING CATCHMENT MANAGEMENT, FLOOD RISK & MATERIAL FLUXES

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Studies of channel morphodynamics and overbank sedimentation have a long and well-established history in piedmont/lowland rivers and also in estuarine environments. However, our understanding of process regimes at the critical interface between these two domains, i.e. where rivers are tidally influenced, is poorly understood. There is a pressing need to better understand morphodynamics in tidally influenced rivers because it is these reaches that are likely to be the most sensitive to, and earliest to respond to, predicted increases in sea-level. This paper reports results from an extensive floodplain coring programme in a 12 km long tidally influenced reach of the River Dyfi, west Wales. Seventeen floodplain cores (3 to 5 m long) were recovered from channel proximal and channel distal locations throughout the study reach. Core geochemistry and geochronology were determined using an ITRAX core scanner (0.5-1.0 mm resolution) and by ^{14}C dating, respectively. The core data show that there was a major period of floodplain sedimentation (0.5-4 m) in tidally-influenced Afon Dyfi over the last 400 years, especially during the mining period, but in last 100 years sedimentation rates have significantly reduced, in places by an order of magnitude. This has serious implications for flood risk management in that tidal flood risk would have been reduced during the period of accelerated floodplain sedimentation (early 17th to late 19th century) but may now be increasing due to reduced catchment sediment supply and rising sea level.

THE TRAPPING OF FLUVIAL-TIDAL SEDIMENT IN THE RHINE DELTA THROUGH THE HOLOCENE

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Compared to the typical British estuary, the Dutch delta plain is flatter, bigger, peatier, lower-shouldered and denser populated. The tidal reaches of rivers in the delta plain are nowadays strongly managed, as are the rivers upstream and the beach barrier coast and tidal inlets that make the coast line. In tidal reaches I include: inland tidal rivers and their upper estuarine mouths, down to brackish central estuarine environments. Geological mapping has very completely resolved the build up of the Rhine delta in space and time. Thanks to efforts in the last decade, this now holds also for the Early and Middle Holocene transgressive basal sediments, below high stand deposits from the youngest 6 ka. I will first briefly sketch the tidal situation in historic and present times, and how this situation relates to sea level rise and the North Sea bathymetry. I will play some attention to terminology and concepts of tidal propagation inland of the coast line, in the water levels of brackish estuaries and fresh open water in tidal river channels, and on the shallow groundwater table in drowning floodbasins. I will then present a series of paleogeographical maps showing the tidal reaches of the Rhine delta during its transgressive stage, with focus on sediment trapping in that environment, as estimated from cross-sections spanning the entire delta. Next I will highlight difference in sedimentation between the separate Rhine and Meuse outlets into the North Sea during the high stand stage, leading up to the Medieval situation, at which stage the tidal river network became locked between dykes. Lastly, I will present a historical case of a failing freshwater-tidal avulsion, triggered by a 1421 AD storm surge, causing dramatic loss of early reclaimed land. Here we studied the sediment budgets involved in deltaic-splay formation following dike failure and inundation in the 16th and 17th century. I will conclude quoting some numbers of tidal river sediments as are dredged from the Rotterdam harbour in the modern situation. The talk intends to give insight in the differences in functioning of tidal reaches as fluvial sediment traps during transgressive and high stand natural situations, and under subsequent human control in larger flat delta plains. The talk is based on cooperative work with Marc Hijma (valley transgression, sea-level rise), Gilles Erkens (Holocene sediment budgeting), Esther Stouthamer (avulsions), Janrik van den Berg (Sedimentology), Maarten Kleinhans (river geomorphology and physical modelling), Hans Middelkoop (managed rivers) and Henk Weerts (sedimentology and archeology), published in 2009-2011, under the umbrella of the Delta Evolution programme at Utrecht University, with Deltares and TNO Geological Survey of the Netherlands as partners.

Selected references:

Hijma, M.P., K.M. Cohen (2011), Holocene transgression of the Rhine river-mouth area, The Netherlands / Southern North Sea: palaeogeography and sequence stratigraphy. Sedimentology 58, 1453-1485.

Kleinhans, M.G., H.J.T Weerts., K.M. Cohen (2010) Avulsion in action: reconstruction and modeling sedimentation pace and upstream flood water levels following a Medieval tidal-river diversion catastrophe (Biesbosch, The Netherlands, 1421–1750 AD). Geomorphology 118, 65-79.

EFFECT OF URBAN DEVELOPMENT ON RIVER DISCHARGE USING DETERMINISTIC AND STOCHASTIC MODELS

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Estimation of river discharge is a key step in many engineering and scientific projects. Design of flood protection structures such as dikes and estimation of long/short term sediment transport in river outlets and estuaries are highly dependent on reliable and accurate prediction of river discharge.

Statistical analysis of historical flow data, collected from gauging stations, has been traditionally used to predict river discharge. Nevertheless, river catchments (due to urban development) and precipitation pattern (due to climate change) are subjected to dynamic changes in the future. Since statistical study of historical flow data cannot detect these changes, deterministic and/or stochastic rainfall-runoff models have been widely used as a more effective tool for prediction of river flow data. Some studies show that urban development and climate change may result in 34% of increase in river discharges (Hejazi and Markuz, 2009).

In the present research, HEC-GeoHMS rainfall-runoff model along with HEC-RAS river hydraulic model have been employed to study the effect of urban development on Shiraz River peak discharge. Shiraz River is located in Shiraz City. The total Catchment area of the river is about 1041.5 Km2and the average height of the catchment is 1540m above MSL. The estimated discharge of the river with 100yr return period is 520m3/s. The Catchment is equipped with several flow and rainfall gauging stations.

DEM of the catchment was used to provide a detail analysis of the catchment geometry and terrain processing in GIS environment. Then, satellite images of 11 subcatchments were analysed to examine land use changes from 2004 until 2009. Consequently, the runoff coefficient map (CN) for those years were provided and employed in the rainfall-runoff model. The rainfall-runoff model was also calibrated and verified by several observed events in 2005 and 2007.

Results show that land use change affects the magnitude, volume and time to peak of the river discharge. For instance, in Nahreazam flow gauge location, considering the same rainfall, the volume of flood and peak discharge increased 15.8% and 33.7% respectively for low flows during the study period. In contrast, the increase of flow in high flows (e.g., 100yr return period discharge) was not that significant and was reported less than 5%. This can be associated with the infiltration rate mechanism. In other words, in high intensity rainfall, there is no enough time for infiltration of the rainfall and therefore the land use changes have minor effect. The sensitivity analysis showed that rainfall intensity temporal variation should not be overlooked in this analysis.

As an alternative approach, the time series of rainfall and discharges in several hydrometric stations were analysed with Mann-Kendall test in order to find any trend in observed data. No significant trend was observed in rainfall data while 13.3% increase in low flows and 17.5 in high flows are expected.

Hejazi , M. I. and Markus, M. (2009), Impacts of Urbanization and Climate Variability on Floods in Northeastern Illinois, J. Hydrol. Eng. 14, 606-616

CHARACTERISING SUSPENDED PARTICULATE MATTER IN THE DYFI RIVER ESTUARINE TRANSITION ZONE

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Changing suspended particle loading, organic carbon concentrations and carbon stable isotope composition were quantified for material exchanging between the Dyfi river catchment and the coast. Bulk suspended particulate matter (SPM) and SPM from settling tubes were collected seasonally 1] in the rivers entering the Dyfi, 2] within the river-estuarine transition zone (RETZ) during spring and neap tidal cycles and 3] at the mouth of the estuary. Surface bulk samples were also collected along the axis of the estuary.

In general, spring tidal cycles maintained higher average SPM (7.2±1.5 to 65.8±21.6 mg/L), a lower fraction of which was represented by organic carbon (3.3±1.1 to 12.7±5.1 wt% OC), compared to neap tidal cycles (SPM 2.3±0.7 to 17.9±5.9 mg/l and 8.7±2.2 to 16.9±6.6 wt% OC respectively). SPM concentrations during neap tides in the RETZ, were highest in March 2011 (17.9±6.9 and 17±7 mg/L) and were lower, but similar, during the remaining sampling times (2.3±0.7 to 6.3±1.7 mg/L). During spring tides, was highest during July (31.3±17 and 65.8 ±21.6 mg/L). The carbon stable isotope composition ($\delta^{13}C$) of the organic matter can be used to differentiate between terrestrial and marine organic matter pools. Average end member value for terrestrially derived carbon ($\delta^{13}C$=-28.7±1.3 ‰) was similar to organic matter filtered from the rivers ($\delta^{13}C$=-27.8±0.4 ‰), both of which were different from samples collected in a fully marine setting ($\delta^{13}C$=-24.1±3.9 ‰). Stable isotopic analysis of the particles collected along the axis of the estuary showed that in April 2010 and July 2011, there was simple mixing between marine and terrestrial organic matter along the whole length of the estuary. In March 2011 and particularly in September 2010, however, terrestrial organic matter dominated the particle loading throughout the estuary. Our data indicate that autochthonous organic matter does not contributes significantly to the total suspended matter and that the suspended organic matter composition can often be explained in terms of conservative mixing of riverine and terrestrial sources on the one hand and marine sources on the other hand.

SUSPENDED PARTICULATE MATTER CHARACTERISTICS IN THE RIVER ESTUARY TRANSITION ZONE

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The majority of terrestrially derived suspended particulate matter (SPM) is transported to the open ocean by rivers, therefore the river estuary transition zone (RETZ) represents a globally significant boundary separating the riverine and coastal regimes. Much of SPM is in the form of flocs – loose aggregates of inorganic and organic matter – whose properties vary on short temporal and spatial scales in response to the turbulence regime. The transfer flux of SPM in the RETZ has important social implications due to the role of flocs in hydrophobic biogeochemical transport. The aim of this study is to interrogate the relationship between floc properties and the turbulence regime in the RETZ of the Aberdyfi macrotidal estuary (mid Wales) over a seasonal time frame.

Observations of floc development require high resolution; therefore *in situ* optical instruments (LISST, transmissometer and OBS) were deployed in the RETZ to obtain volume and mass concentrations of SPM. The turbulence parameters were determined via acoustic methods: ADCPs and ADVs were deployed to give vertical and horizontal turbulence gradients. Data have been collected over one spring to neap cycle for 4 periods during the year, thereby supplying a large range of tidal and river discharge conditions in addition to seasonally variable biological conditions. The seasonal dimension is important because we hypothesise that the composition, properties, and behaviour of flocs will vary due to the seasonally variable nature of source material from the catchment.

Preliminary analysis of a large dataset shows that the median particle size (D_{50}) of SPM in the RETZ is related to a combination of aggregation, resuspension, and tidal advection of a lateral gradient. During low river discharge conditions, the tidally averaged D_{50} is significantly related to tidal range with the largest D_{50} coinciding with spring tides (greatest marine influence), smallest D_{50} with neap tides (greatest fluvial influence). Concentration and particle size are related to the turbulence regime but there is a phase lag of 24-72 minutes between the Kolmogorov microscale and median particle size. Net SPM flux is landwards during spring tides and seawards during neaps. Net flux of larger flocs is landwards on all tides while net flux of smaller microflocs is seawards on neaps. This suggests that large flocs are trapped in the RETZ and are not exported to the estuary during low river discharge conditions.

During an exceptional river flood event over several tides, SSC and D_{50} in the river upstream of the RETZ increased 6x and 4x, respectively. The net SPM flux, and net flux of large flocs and microflocs, in the RETZ was seawards. The RETZ was therefore a net exporter of large flocs during this event. However, further analysis of the entire dataset (including data from the upper estuary downstream of the RETZ) is required before the properties and flux of SPM during normal and exceptional river flows can be properly assessed.

SAND FLUX AND BUDGET MEASUREMENTS ON TIDAL TO DECADAL TIME SCALES IN A MACROTIDAL ESTUARY

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Quantification of sedimentation rates in estuaries on decadal time scales is important for sustainable coastal management. It is generally considered that errors in sediment flux measurements are too great to make meaningful estimates of sedimentation rates on the required time scales. A comprehensive dataset from the Taf estuary (S W Wales) has been used to test the feasibility of using process measurements to determine sediment budgets.

The estuary is sandy, with a large tidal range (up to 10 m), fast tidal currents (> 2 m s^{-1}), and low river discharge (mean 7 m^3 s^{-1}). The sedimentation rate in the estuary has been determined by (i) annual surveys over a 44 year period to measure the sediment budget and (ii) process measurements over tidal cycles to measure the sediment flux. The long-term surveys show that 4.4 x 10^6 m^3 of sand have accumulated since 1968 at an average rate of 0.017 m yr^{-1}. Mineralogical analysis proves that the quartzose sand of the estuary is derived from offshore and is not supplied by the river which carries mostly lithic sand. The flux of sand through two cross sections of the estuary has been measured over 10 tidal cycles using transmissometers to measure suspended sediment concentration (SSC). Shallow water modification of the tide gives rise to time-velocity asymmetry on spring tides with pronounced flood dominance. The fine sand which characterises most of the estuary bed is readily entrained into suspension by shear velocities that reach 0.14 m s^{-1} and 0.08 m s^{-1} on a spring flood and ebb tide, respectively. Combination of fine sand and large shear velocities means that most sand transport is via suspension. SSC reaches 1000 mg l^{-1} at peak flow, sufficient to cause turbulence damping, and falls to 20 mg l^{-1} at high slack water. Ebb entrainment is significantly less. Net sediment flux is up to 16% of the gross sediment flux, and all measured tidal cycles show a net flood flux. Algorithms have been derived which relate the flood and ebb mass fluxes of suspended sediment to tidal range. These algorithms have been used to estimate the annual net flux of sediment and annual sedimentation rate. This analysis gives a sedimentation rate of 0.015 m yr^{-1}. This is remarkably close to the sedimentation rate from our budget measurements and shows that (i) it is possible to estimate the sedimentation rate from process measurements, and (ii) the net sedimentation rate can be attributed to the tidal regime without consideration of river flow or storm effects. Up-estuary transport of fine sands by tidal pumping produces net sedimentation that has raised the level of the estuary floor above the low water tidal level, which is why the estuary is emptied of seawater for much of the tidal cycle.

CONWY AND SUSFISH

Malham, Shelagh

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The Conwy Project was initiated due to failure of shellfish beds through contamination with E. coli. Through work undertaken by various people, several point sources were identified and their overall contribution to E. coli in the Estuary will be discussed. In particular, one area of concern, the RSPB reserve, was not contributing substantially to E. coli loading in the estuary at the time of sampling. The results from the RSPB reserve will be discussed.

The INTERREG project on sustainable shellfisheries in the Irish Sea (SUSFISH) has started to produce interesting results. Selected examples that will be discussed are:

1. Three-D oceanic particle tracking models have been produced in Bangor and these will be linked to genetic work undertaken in Aberystwyth.

2. Diseases surveys have demonstrated high disease prevalence in crabs (Hematodinium) and could affect the sustainability of the fishery. In bivalves, both Herpes virus and Bonamia ostrea have been found in high abundances and affecting

3. Economically, disease and climate change will affect shellfish productivity These aspects will be discussed in relation to potential climate change.

LONG-TERM MORPHOLOGICAL MODELLING OF TIDAL BASINS

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Complex, processed-based numerical models are frequently used to predict morphological change in the coastal environment. Tidal basins (such as estuaries) are dynamic systems that are composed of a multitude of interacting processes at a variety of spatial and temporal scales. This work outlines some key findings and problems when using a processed-based, finite element model (TELEMAC-2D) to simulate morphological development in a tidally- dominated basin over a period of 100 years.

OBSERVATIONS OF DUNES AND THEIR PREDICTED FEEDBACK EFFECT ON SEDIMENT TRANSPORT IN THE DYFI ESTUARY

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Numerical models of the flow and sediment transport in coastal areas and estuaries commonly represent the bed friction in an oversimplified and/or inconsistent manner. In particular, the spatial and temporal variation of evolving bed forms that occurs at sub-grid-scales in these highly energetic environments is often not included in the modelled bed roughness. Further, the frictional forces due to the presence of dunes in, for example, shallow estuaries create a two-way interaction between the flow and the varying bed form patterns. This feedback process has here been introduced into the TELEMAC Modelling System in order to achieve consistency between its flow module (Telemac2D) and morphodynamic module (Sisyphe) resulting, in principle, in more realistic modelling outcomes. Using an established formulation for the equivalent bed roughness length, ks, Sisyphe has been modified to calculate the total bed roughness (comprising granular roughness and also that of ripples and dunes) which is then passed back to Telemac2D for use during the flow calculation at the next model time step. It is the feedback effect of the dunes on the mean flow that is of principal interest here. Bed form dimensions (height and steepness) extracted from a multibeam sonar survey of the Dyfi Estuary, mid-Wales, have been used as the basis for comparison with these predicted equivalent bed roughness lengths, ks, for a validation exercise involving eight tidal constituents together with the (mean annual) river input to the estuary. The model results show good agreement with the observed ks in the region of the estuary mouth, but poorer agreement within the estuary interior where differences between the actual and (non-contemporaneous) modelled seabed bathymetries become increasingly important. The introduction of bed roughness feedback and also bed form history effects that have been modelled here (albeit tentatively) modify the model outputs significantly. This is especially evident in sediment transport rates which are sensitive to even small changes in local flow strength resulting from the presence of the dune roughness. This paper highlights the modifications made to Telemac2D and Sisyphe, and examines the validation results based on the multibeam survey.

PHOSPHOROUS TRANSFORMATIONS AT THE WYRE ESTUARY (LANCASHIRE, UK) DURING TIDAL CYCLES

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A common problem in fresh, estuarine and coastal waters is currently eutrophication, playing phosphorus a key role in this process. For the success of the management in estuaries it is essential not only to identify what arrives from upstream and downstream but to determine what happens in the estuary itself. In order to acquire a deeper knowledge of the short time effects of a tidal cycle on the phosphorus concentrations in the particulate and dissolved forms of estuarine waters, some research has been done in the Wyre Estuary. Variability is very high in this estuary because of the contour conditions: the freshwater discharge from the River Wyre fluctuates between 5 and 100 m3/s while the tide in the Irish Sea is semidiurnal with a range between 4 and up to 9 m. When the tide propagates along the estuary, asymmetry is noticeable. Flood tide usually lasts for 2-3 hours while ebb tide lasts for 9-10 hours. Due to this, field work was designed to survey the upper water column of the estuary at irregular intervals in one station. Water samples and CTD measurements were collected during a tidal cycle and also at both ends of the estuary for two different scenarios: spring tide and low river discharge and medium tide and high river discharge. Regarding salinity and pH, the maximum and minimum values of these variables in autumn mainly depended on river discharge and tidal range. However, pH was mostly related to chlorophyll-a concentrations in spring. Moving to phosphorus forms, ranges for dissolved inorganic phosphorus (DIP) were 1.5-3.6 uM and 2.1-3.1 uM in spring and autumn, respectively. The largest and most rapid variations took place at salinities lower than 2 psu. DIP values were above the theoretical dilution line for almost all salinities in the estuary. This showed a non-conservative behaviour of this form, and probably an estuarine source of DIP, independently of fresh and marine water volumes. Tropical pristine estuaries revealed values between 0.04 and 2.64 uM for DIP (Eyre and Balls, 1999; Kress et al., 2002). Particulate inorganic phosphorus and particulate phosphorus concentrations showed a linear relationship with suspended particulate matter concentration. The particulate P concentrations of the estuarine suspended matter were not constant over the salinity gradient as has been observed in the Gironde Estuary (Deborde et al., 2007). Further explanation on tendencies and comparisons with some other estuaries will be provided in the forthcoming presentation.

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MANAGED REALIGNMENT AS A TOOL TO REDUCE TIDAL PROPAGATION IN ESTUARIES

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In the UK managed realignment has mainly been promoted as a conservation management tool, even though there have been sound engineering reasons for many projects (Brampton, 1992; Empson et al., 1997; Muller, et al 1999). Policy makers and the wider public have therefore tended to regard it as an environmental tool rather than one that should be deployed to address the problem of sea level rise and climate change. Consequently, realignment projects are often opposed and are possibly even located in the wrong places. For example, realignment sites are often chosen to limit impact on estuarine dynamics; whereas perhaps they should be chosen specifically for their impact on estuarine dynamics? Conversely, in two German estuaries, the Ems and the Elbe, major realignments have been proposed in which the objectives are rather different. In the case of the Ems, realignments have been proposed as 'sedimentation basins' to absorb the high suspended sediment concentrations generated by increased tidal propagation arising from channel deepening. Meanwhile, on the Elbe, certain realignments have been suggested as part of an integrated approach to reducing tidal propagation arising from successive channel deepening and shortening combined with loss of accommodation space. The German approach, which focuses on the influence of accommodation space on tidal propagation, has occasionally been used in the UK to improve flood risk management. The best UK example is the managed realignment at Alkborough, which is frequently highlighted as a major wildlife gain. In this example, the business case for the £10m investment was heavily influenced by its potential to reduce storm surge heights and improve flood defences upstream. Both the German and UK examples highlight the potential for managed realignment to be designed as a contribution to climate change adaptation but if they are to gain support the emphasis must change. This presentation explores the potential for realignment to be used as an engineering tool and discusses aspects of realignment geometry that may be relevant to improving its overall performance in both engineering and wildlife management contexts. The popular literature and research focuses primarily on the environmental benefits of realignment whereas the engineering benefits have been largely ignored. This presentation argues that the case for realignment needs to be re- evaluated and future research needs to focus on the potential of realignments to improve engineering resilience rather than wildlife benefits.

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IMPACT OF TIDAL ENERGY EXTRACTION ON SEDIMENT DYNAMICS

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Large-scale exploitation of the tidal stream resource is likely to alter the regional hydrodynamics, but for practical extraction scenarios this effect is generally considered to be very small. However, since sediment transport is proportional to the cube of velocity, relatively small changes in the tidal currents could translate into large changes in the sediment dynamics. Here, we investigate this effect in relation to two oceanographic processes: tidal asymmetry and headland sand bank maintenance. Both of these processes have major practical significance. Tidal symmetry/asymmetry is responsible for the large-scale long-term distribution of shelf sea sediment. Any tidal energy scheme which has the potential to alter this largescale distribution could affect the supply of sediment feeding into natural coastal defence systems which remove energy from storm waves, such as beaches and offshore sand banks. Headlands are some of the most attractive regions for exploitation of the tidal stream resource. Any tidal energy scheme which could lead to changes in the morphodynamics of the associated headland sand banks could have implications for coastal flooding, due to changes in the wave distribution, including wave refraction and depthinduced wave breaking.

SOUNDING OUT OUR RIVERS AND COASTLINES: SUBSTANTIVE ADVANCES IN UNDERSTANDING MORPHODYNAMICS THROUGH INNOVATIVE APPLICATION OF MULTIBEAM SONAR TECHNOLOGY

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[3] *University of Illinois, USA*

In order to investigate the interactions between turbulence and suspended sediment transport in natural aqueous environments, we ideally require a technique that allows simultaneous measurement of fluid velocity, sediment transport and morphology for the whole flow field. This talk will outline development of a methodology using the water column acoustic backscatter signal from a multibeam echo sounder to simultaneously quantify morphology, flow velocities and sediment concentrations. The application of this new technique will be illustrated with reference to flows in a range of environments, highlighting substantive advances in understanding possible. This includes analysis of the flow field over a swathe of alluvial sand dunes in the Mississippi, which allows, for the first time in a field study, quantitative visualization of large scale, whole flow field, turbulent coherent flow structures associated with the dune leeside that are responsible for suspending bed sediment. Further examples from mixing at large river channel confluences, river deltas and an application to quantify environmental impacts of trawl fishing will also be highlighted. This methodology holds great potential for use in a wide range of aqueous geophysical flows and begins to allow us to holistically explore the linkages between flow, transport and morphology at the field scale for the first time.

APPLICATION OF A COASTAL MODEL TO COMPLEX ESTUARINE REGIONS TO INFORM FUTURE MANAGEMENT DECISIONS

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Complex, high resolution, finite-element TELEMAC 2D grids have been developed to simulate ocean/fluvial interaction in three shallow, intensively managed Welsh estuaries. In each case, important ecosystems and developed areas are exposed to flooding from both tidal and fluvial events. Of particular concern is how the estuaries will be affected by future sea-level rise due to climate change, and how best to manage the estuaries in the future. Each grid has been generated using BlueKenue© and comprises several sub-grids to resolve important aspects of the estuary, such as river channels and flood embankments. Accurate representation of these features is paramount to flood risk modelling. A selection of present-day mean and extreme hydrodynamic/fluvial scenarios has been simulated, as well as future climate change scenarios. These simulations have highlighted the need for local management so that coastal flooding and morphological change are minimised, whilst preserving important ecosystems such as protected salt marshes and peat bogs. Alterations were made to the grids in order to address possible management options such as coastal realignment. In this way, key implications for flood risk, sediment transport and morphological change can be predicted which will aid management decisions.

HYDRODYNAMICS OF THE TIDALLY-INFLUENCED FLUVIAL ZONE, COLUMBIA RIVER ESTUARY, USA

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In this paper we present results obtained from the application of DELFT3D to an 80 km-long and 3-5 km-wide region of the Columbia River Estuary, USA. Bed topography information was derived from a series of bathymetric (Multi- and Single-Beam Echo Soundings) and Lidar surveys conducted during 2009 and 2010 by NOAA, USACE and LCREP, and collated to generate a Digital Elevation Model (DEM). The modelled reach extends between an upriver boundary at the Beaver Army Terminal (BAT) and the Hammond Tide Gauge (HTG) in the lower part of the estuary. This reach is represented in DELFT3D as three sub-domains (computed using domain-decomposition). At these boundary locations, total discharge (BAT) and water surface elevation (HTG) are monitored continuously and provide the model with inlet and outlet boundary conditions. Bed shear stress was estimated using a variety of roughness parameterisation methods including Chezy, Colebrook-White and Manning and turbulence was closed assuming a uniform eddy-viscosity. We present velocity data collected at multiple locations within the study reach obtained using an acoustic Doppler current profiler (aDcp). This data was collected during high ~14,000 m3s-1 (June 20011) and low ~4,000 m3s-1 (October 2011) river discharges as measured at BAT. These results are compared with the DELFT3D model output and these inter-comparisons show that the model reproduces well the spatial distribution of velocity. We are currently running simulations with other roughness parameterisations including van Rijn's (2007) roughness-length predictor and evaluating the influence of model mesh resolution on simulated hydrodynamics.

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HYDRODYNAMICS AND WATER QUALITY IN THE CLYDE ESTUARY

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Scottish Environment Protection Agency

Scotland’s Clyde Estuary consists of two contrasting sections: the outer estuary, relatively undeveloped and home to wetlands of international importance; and the inner estuary, heavily modified over the centuries, and subject to extensive land-claim and dredging. A key motivation for the morphological changes 200 years ago was to alter the hydrodynamics of the estuary, specifically to increase water levels in central Glasgow and speed-up the propagation of the tidal wave for the benefit of the shipping industry. While these aims were achieved, the artificially deep channel also reduced current speeds, which increased the residence time of the estuary, the quantity of sediment deposited within it, and caused stratification in the water column. Morphological changes also contributed to the estuary being tidally- asymmetric, with stronger currents on the flood cycle than ebb. Together, these hydrodynamic changes have exacerbated water quality problems in the estuary, particularly low levels of Dissolved Oxygen (DO). The estuary receives organic waste from the Greater Glasgow area, and this waste consumes DO as it degrades. The low currents and stratification suppress vertical mixing, thereby inhibiting the downward transfer of replenishing oxygen from the surface. In the 1970s, when regular monitoring of water quality began in the Clyde, the inner estuary was found to be essentially devoid of oxygen. Since then, DO levels have risen due primarily to improvements in sewage treatment and the reduction of industrial inputs. In 1983, salmon reappeared in the inner estuary after an absence of more than a century, and have returned each year since. Nevertheless, depleted DO levels still occur, particularly during dry, warm spells when river flows are low. SEPA is working with Scottish Water and other partners to improve DO levels further, with the aim of achieving Water Framework Directive (WFD) classification targets. As part of this, a 3D numerical model of the estuary is being used to help assess various options for water quality enhancement and to develop a cost-effective and coherent implementation strategy. One option, which has been trialled this year, is the direct injection of pure oxygen into the estuary. While this does increase DO levels, at least locally, it is expensive both financially and in terms of carbon- footprint, and does not address the underlying causes of the water quality issues. Potential changes to the location and timing of discharges from the sewage works are also being considered with the model. Measures to alter the hydrodynamics themselves are also being investigated. One possibility is using the tidal weir to store water upstream of the estuary, then releasing this additional water on the ebb tide to enhance flushing. Further morphological change – to the estuarine width and/or bed profile – is being modelled to establish whether the flood-dominated tidal asymmetry can be reversed. It is likely that achieving ‘good’ status under WFD will require a range of these measures.

TURBULENCE-CONTROLLED FLOCCULATION IN A MACRO-TIDAL ESTUARY

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Suspended particular matter (SPM) determines turbidity, impacting both water quality and primary production. SPM generates benthic fluff on the seabed, modifying biogeochemical exchanges and constraining primary productivity. Further, SPM carries important biogeochemical components (e.g. carbon, nitrogen, contaminants and pollutants), deciding the fates of anthropogenic inputs to the estuarine system. Outside of the non-cohesive fraction (sand), little is known of the properties of SPM (i.e. particle size, density, settling velocity) and how these impact fine particle entrainment and sedimentation. This is due to most SPM being in the form of flocs (aggregates of dead and living organic matter, cohesive inorganic matter, and water) that are dramatically modified by conventional sampling methods (easily ruptured and/or may aggregate during sampling). As such we lack reliable and comprehensive information on key parameters such as pick- up functions and settling velocities, particularly since floc properties change on a range of time scales: tidal (suspension/advection), lunar (spring-neap cycle), and seasonal (storm resuspension and biological production). Turbulence is an important mediator of floc characteristics; promoting particle collision and aggregation at low levels, while high levels result in shear- induced rupture, literally tearing aggregates apart. Because of this, accurate turbulence parameterisation is key to understanding the relationships between turbulence and particle size, as well as accurately modelling flocculation. The results of an extensive field campaign and SPM flux modelling of the Dee estuary (N.W. Britain) are presented, giving insight into the fates of both riverine input and advected SPM from offshore. Using data from a combination of acoustics, optics, moored deployments and CTD stations, a 1-D (GOTM) model shows variation across tidal, spring-neap, and seasonal time-scales. This is extended by use of a recently published flocculation formula to predict D50 particle sizes.

ADAPTATION OF THE RHINE-MEUSE CHANNEL NETWORK TO LARGE-SCALE HUMAN INTERVENTIONS OVER THE PAST 150 YEARS

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The Rhine and Meuse river deltas form to a large extent the western part of The Netherlands. They form an estuarine channel network that is both influenced by river run-off and by tides. Due to high population densities and large economic interests, the channels are subject to large anthropogenic influences since the Middle Ages. Over the past 150 years, two major engineering works have been realized in the estuarine network. First, the Nieuwe Waterweg was dug between the Rotterdam harbor and the North Sea in 1872, thereby creating a new river outlet at the north of the estuary. Secondly, the Haringvliet, the southern outlet of the Rhine-Meuse estuary, was closed off in 1970. The main aim of this study is to analyze and discuss the hydraulic and morphological changes that occurred in the Rhine-Meuse channel network after the interventions. This will improve our understanding of the morphological response of estuarine channel networks to human perturbations. Since 1880, river water discharge carried by the Nieuwe Waterweg in the north gradually increased, at the expense of discharge through the Haringvliet in the south. With the deepening and widening of the Nieuwe Waterweg, necessary for navigation purposes, the tidal range increased and the tidal limit propagated landward. This resulted in changed flood risks in all parts of the estuarine channel network, caused by the changed river-tide interactions. With the increased discharges and tidal flow, river branches in the northern part of the estuary strongly eroded, while erosion was less strong in the south. Since the closing of the Haringvliet estuary in 1970, all river water is diverted to the Nieuwe Waterweg. Furthermore, tides can only enter the system through the Nieuwe Waterweg. This has resulted in a strong decrease of tidal amplitudes and tidal flow velocities in the south of the estuary. Since 1970, the southern part of the estuary shows sedimentation due to decreased discharge and tidal flow, while the center and northern part show erosion due to increased discharge. Apart from the morphological adaptation of the channel network to the closure of the Haringvliet, the depth of several river branches is controlled by dredging to maintain navigation depths. The channel network is not only greatly disturbed by large-scale human projects, but is also kept out of equilibrium by dredging and smaller measures. The system is thus in a continuous state of morphological adaptation.

THE MIGRATION OF LARGE SCALE BEDFORMS AND THEIR CONTRIBUTION TO THE SEDIMENT BUDGET OF AN ESTUARINE ENVIRONMENT

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The Dee Estuary is macrotidal, with a peak spring tidal range in excess of 10m. The large tidal range and associated strong currents make the estuary a very dynamic system with large fluxes of sediment. Large scale bedforms are visible in the intertidal zones at the mouth of the estuary in aerial photographs. These features can be seen to be migrating into the estuary from X-band radar images. It is therefore important to monitor the movement of these large scale bedforms to determine the stability of the complex area of sand banks and channels. Monitoring the migration patterns of large scale bedforms in the mouth of the estuary will aim to show if they correlate with the transport of sediment into the estuary and how they contribute to the overall estuary sediment budget. The driving forces behind large scale bedform migration are investigated to determine whether it is the action of waves, tidal currents or a combination of the two which are important. ADCP deployments on West Kirby Sands show a strongly flood dominated tide which could be indicative of a flood dominant residual sediment transport into the estuary. Modelling of the estuary using Telemac, validated with ADCP measurements at West Kirby Sands, shows flood dominant sediment transport over a tidal cycle. DGPS survey data over the intertidal area of West Kirby Sands shows sediment transport through 1D and 2D calculations. Wave data covering the DGPS surveys and X-band radar image analysis shows a strong correlation between larger wave heights and higher rates of bedform migration, suggesting that it is the increased shear stress associated with larger waves that is the driving factor for bedform migration into the estuary.

SOURCES AND DELIVERY OF PHOSPHORUS TO RIVERS AND THE COASTAL ZONE

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Phosphorus (P) enters surface waters in a complex array of dissolved and particulate forms from numerous spatially variable sources via a number of different hydrological pathways and at different times of the year. Fluxes to the estuary boundary are heavily flow dependent but also vary according to anthropogenic source pressures such as urbanisation and agricultural intensification. Sources differ with respect to their composition (concentration and bioavailability), and mode and timing of delivery and have been grouped according to their ecological relevance into wastewaters (sewage and septic tank discharges), runoff from impervious surfaces (roads, tracks and farmyards) and runoff from pervious surfaces (farmed land), (Edwards and Withers, 2008).

A range of physical, chemical and biological processes further modify P fluxes, forms and bioavailability within the water column as it travels down the river-estuary-coastal zone continuum (Withers and Jarvie, 2008). Interactions between these processes are complex and poorly understood. New techniques such as cross-flow ultra-filtration that differentiate truly dissolved P from colloidal particles are needed to help define the role of colloids in nutrient transport and the nature of P transformations along the continuum (Jarvie et al., 2012). An understanding of the magnitude of P retention and release is also important as it regulates downstream delivery and timing of P to the freshwater-estuary boundary and beyond to the coastal zone.

Recently a novel empirical method of interpolating routinely-measured concentration and flow data (Extended Endmember Mixing Analysis (E-EMMA)) has been developed to explore macronutrient retention and release in lotic ecosystems (Jarvie et al., 2011). Application of E-EMMA to the Thames river basin suggests significant retention and release of P can occur. For example, up to 14% of the annual P flux was retained in the main river Thames but during the ecologically critical low-flow periods, in-stream processes resulted in net retention of up to 42% of the P flux. In one tributary of the Thames, net release of stored P resulted in large increases in ambient river P concentrations. This simple and versatile tool has potential to be deployed more widely to quantify spatial and temporal variation in net macronutrient retention and release and inform catchment management.

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NEAR-BED ENERGY DISSIPATION IN A CANALISED RIVER ESTUARINE TRANSITION ZONE

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Starting at Llyn Cefni, the Cefni River is the longest river on the Isle of Anglesey. Running south from the centre of the island past LLangefni, the river alters course to south-west just north of the A55. From here it passes through the Malltraeth Marshes, where the river course was canalised in 1824. The location where the river commences its path through the Malltraeth Marshes marks the upper limit of the tidal influence. The Cefni River flows into the Irish Sea via the Malltraeth Estuary on the south-west of Anglesey Island.

An ultrasonic Doppler velocity profiler (UDVP) was used to measure near-bed velocities at the tidal limit of the Cefni River. Several transducers were aligned into the flow with the uppermost positioned at a height of 29.4 cm. The UDVP system provides high quality velocity data with high temporal and spatial resolution. These data are used to calculate the rate of loss of kinetic energy per unit area, the turbulence intensity and the variation in friction velocity with respect to height above the bed.