techniques have allowed an appreciation of the aerodynamic nature of sand dunes, particular problems with field research are evident in the measurement of aeolian processes on dune surfaces. Specifically, it is shown that attempts to ascertain shear stresses on dune windward slopes in the field and relate changes in stress to sand transport rate and erosion/deposition measurements have generally failed. Significant advances have been achieved in wind tunnel modelling where high frequency hot-wire anemometer measurements have enabled shear stress and turbulence characteristics to be determined, although problems have been encountered in choosing appropriate scaling parameters. Empirical field and wind tunnel data have allowed the calibration of mathematical models which are now at a stage where the flow field around dunes can be calculated and recent experiments concerning computational fluid dynamics of airflow over dune surfaces are described.

H31F-03 0910h

Aspects of Turbulent Flow over 2D and 3D Bedforms

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Sediment transport in sand bedded alluvial channels is strongly conditioned by bedforms. Understanding the turbulent flow field over bedforms is crucial to understanding flow resistance in rivers. Most of the research on flow over bedforms has focused on straight crested, two-dimensional bedforms, and the characteristics of the turbulent flow field are fairly well understood. In contrast, few studies have examined flow over 3D bedforms, which typically have irregular heights, lengths, and crestlines. This paper reports on experiments undertaken to examine how 3D dune morphology affects the turbulent flow field and, ultimately, flow resistance. An experiment was designed to examine flow over fixed bedforms 0.45 m long and 25 mm high in a 0.5 m wide and 17 m long flume. In each experimental run, discharge and dune size were held constant, but the crest shape was varied. Flow over six bedform crest shapes was examined, including a 2D crest, a saddle shaped crest, a lobe shaped crest, a regular 3D crest alignment, an irregular 3D crest alignment and a sinuous crest. Measurements of velocity were made at a sampling rate of 50 Hz using an acoustic Doppler velocimeter at 350-500 points over a dune in each morphology. Three-dimensional bedforms significantly modify the flow field over a dune. Lobe shaped configurations cause lateral and vertical divergence of momentum and turbulent energy, thereby enhancing the level of turbulence compared to a 2D bedform. Saddle shaped crestlines cause lateral and vertical convergence of momentum and turbulent energy towards a small area in the lee, thereby reducing the level of turbulence. Other bedform morphologies (regular, irregular and sinuous crests) exhibited characteristics of both lobes and saddles, but the net effect was to reduce levels of turbulence. Total drag, calculated from spatially averaged Reynolds stress profiles, can be enhanced or reduced by as much as 50 %. These results suggest that current conceptions of bedforms that link the bedform size to flow resistance directly may be greatly oversimplified.

H31F-04 0925h INVITED

Entrainment From Mixed-Load Beds

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Most fluvial, and many aeolian, beds have grain size distributions that are sufficiently broad to allow for simultaneous motion of grains in suspension and by saltation. Yet, previous mechanistic attempts at describing the process of fluvial entrainment have assumed all particles in the bed go into one or the other modes of transport. Furthermore, most models of entrainment either assume a uniform grain-size distribution or account for the relative immobility of smaller grains by an empirical hiding factor or an increased particle friction angle. Larger, bedload-size grains radically alter the turbulent velocity that flows around individual smaller suspended-size grains that rest on the bed, because the small grains are fully below the tops of the large grains. Realistic models of entrainment from mixed load beds must consider this as the primary factor for relative immobility of smaller grains. In this presentation, a set of experiments and a discrete particle model are used to investigate how grains are simultaneously entrained into suspension and saltation. A series of experiments were conducted in a laboratory water flume having an erodible bed, which was a mixture of two well-sorted sands having median diameters of 0.1 and 1mm. A vertical laser light sheet illuminated a narrow strip of the sediment in the flow and at the top of the bed. Entrainment and transport of individual grains in the light sheet were captured by high-speed video. These experiments showed that, similar to flows with only bedload transport, bedload particles are entrained primarily during sweeps and outward interactions when the near-bed downstream velocity is greater than average. However, the mechanism of suspended particle entrainment is very different than for uniform grain size beds; suspended-size grains are entrained simultaneous to the entrainment of bedload grains rather than during ejections of slow moving fluid away from the bed. A highly concentrated layer of suspended grains is apparent from the bed to about four bedload grain diameters above the bed during entrainment events, which is about twice the thickness of the bedload layer. A three-dimensional discrete particle model that directly calculates the equations of motion for each bedload-size grain was modified to allow suspended-size grains to be disentrained and entrained in the interstices of much larger bedload grains. Suspended grains are entrained when the bedload particles forming the interstitial pockets begin motion. The suspended grains are accelerated to the fluid velocity more rapidly than the bedload grains which leads to collision with the slower bedload grains, thus pushing many suspended load grains to the top of the bedload layer. The model does not predict, however, a highly concentrated suspended load layer well above the bedload layer. This most probably occurs because the vertical velocity in, and near the top of, the bedload layer is inadequately modeled. A key question remains as to how suspended particles entrained during sweep and outward interaction events are entrained further into the flow. Because mixed load fluvial beds are generally hydraulically rough, the well-know turbulence structures (e.g. low speed streaks and horseshoe vortices) over smooth beds are not likely to occur. Furthermore, the near-bed turbulence structures are highly modified by flow separation and acceleration when dunes and ripples are present. Future research on the vertical velocity structure over mixed loads beds is needed.

H31F-05 0945h

Roughness Length Representation in Fluvial and Aeolian Environments: Measurement Estimates and Model Representation

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This paper is concerned with a specific problem that is common to both fluvial and aeolian environments: the meaning of the roughness length in relation to the growing application of 2D and 3D computational fluid dynamics. Conventional approaches to roughness length measurement have been based upon experimental and field observation of velocity variation with elevation above the bed. By fitting a range of different curves to this variation (e.g. semi-logarithmic), it is possible to determine the height above the bed at which the velocity becomes zero. In both fluvial and aeolian environments, this elevation has been weakly rated to surface properties: for instance, in the case of rivers, it is found to be a function of a characteristic grain-size, but has to be multiplied upwards in order to represent the effects of grain organisation. In the last 5 years, there has been the progressive application of computational flow dynamics to understand both time-averaged and turbulent components of flow over fluvial (e.g. gravel- river beds) and aeolian (e.g. sand dune) surfaces. These applications require some form of wall treatment, involving a roughness height, and so there has been the direct transfer of field and laboratory estimates of roughness height to these models. In this paper, we present results from a porosity based model of flow over a gravel-bed river surface that shows that field and laboratory estimates of roughness height cannot be transferred in this way. The model development is important as it allows explicit representation of the full 3D complexity of a gravel-bed or sand-bed surface. Two issues emerge. First, we show that the conceptual underpinning of wall treatments in CFD leads to the theoretical basis of field and laboratory estimation of roughness heights. However, field and laboratory measurements are made over much longer vertical length scales and thus the associated velocity profiles yield roughness heights that are influenced by much larger lateral length scales. Wall treatments apply only to the bottom cell in the model, with shear higher in the flow resolved explicitly by the model. Second, the research demonstrates fundamental problems in using roughness height perturbation to represent sub grid scale effects (e.g. grain organisation, sand surface roughness) as compared with explicit representation of the geometry of the associated surface. This suggests that explicit representation of surface morphology in model geometry is required rather than parameterisation using upscaling of bed roughness heights.

H31G CC: 520 F Wednesday 0830h

Focus on Student Contributions to Hydrology

Presiding: **T Bullen,** U.S. Geological Survey**; R D Beckie,** University of British Columbia

H31G-01 0830h

Spectral Analysis As A Tool To Investigate Phosphorus Transport

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The transport of phosphorus (P), a major source of pollution in freshwater ecosystems, is directly linked to the flow paths and travel time of water through a catchment. The objective of this research is to understand P movement for improved management of drinking water resources. Here we used spectral analysis to show the differences in long-term P transport trends between an active agricultural watershed (160 ha) and an abandoned agricultural forested watershed (85 ha) in the Catskills Mountains, NY, specifically, in Delaware County. The watersheds were close to each other, 6.4 km apart, so that hydro-meteorological differences were small. The results suggest interesting shifts in P transport behavior when historically fertilized land is abandoned and allowed to revert to forest. Spectral analysis, a long-term frequency domain time series analysis method, has been successfully used to analyze long-term time series data, quantify travel time distributions, and measure the watershed scale retardation factor for reactive solutes (Kirchner et al. 2000, Nature 43:524-527; Kirchner et al., 2001J. Hydrol. 254:82-101). We found that spectral analysis is a useful tool for analyzing long-term time series of water and chemical fluxes record for understanding ecosystem responses to disturbance and provide a in depth view of long-term effects of changing agricultural and natural resource management practices.

H31G-02 0845h

Geochemistry of a Tetrachloroethene and Trichloroethene Plume at the Borden Aquifer

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Under favourable redox conditions biodegradation is one of the processes that controls PCE and TCE attenuation at the Borden sand aquifer. This paper presents geochemistry data obtained in a study which main aim is to evaluate the fate of a PCE and TCE plume in the Borden forested area. Selected multilevel piezometers for five transects in a Tetrachloroethene (PCE) and Trichloroethene (TCE) plume were sampled for analysis of VOC concentrations, ^{13}C-VOC and δ^{18}O in dissolved oxygen, as well as DIC, DOC, DO, cations and anions concentrations. Field parameters such as, temperature, pH, conductivity, ORP, and alkalinity were measured as part of the study. The results showed a decrease in DO and an increase in iron concentration along the groundwater flow system indicating a pattern toward anoxic conditions. DIC and DOC increase along the flow. A significant change is observed in PCE concentration in the first 45m down gradient from the source. The increase in TCE concentration and the occurrence of cis-DCE, methane and ethane in the downgradient areas indicated that biodegradation is one the processes controlling PCE concentration along the groundwater flow system. Part of the plume in the downgradient areas is discharging into a creek and it is postulated that a change in sediments in the riparian zone explain the occurrence of methanogenic

conditions that facilitated the biodegradation of PCE. Carbon isotope data in VOC will confirm the role of PCE biodegradation in the plume.

H31G-03 0900h

Groundwater Flow and Salt Transport at a Sand Tailings Dam: Field Observations and Modelling Results.

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Large volumes of sand tailings are produced during the extraction of bitumen from the oil sands of Northeastern Alberta. The long-term groundwater response and subsequent movement of water and solutes within the large permeable sand tailings storage areas is uncertain. At the Southwest Sand Storage (SWSS) Facility, located at Syncrude's Mildred Lake operations near Ft. McMurray, there is concern that salts from the tailings water may discharge to newly placed reclamation material that covers the sand tailings. This saline discharge water could destroy the reclamation soil structure and negatively impact vegetation. The steady-state groundwater flow and transient movement of salts at the local (bench and slope) and intermediate (pile) scales in the SWSS are investigated. Water levels, seepage and groundwater quality (including TDS) have been measured for over a year along two transects of piezometers installed in the SWSS. The field data have been used to complete traditional hydrogeological interpretations of the site, and to develop a conceptual model of flow and transport. The local and intermediate flow systems and salt transport in the dam are being evaluated with numerical models. The models will allow possible future hydrogeological behaviour of the structure to be tested. Preliminary results show differences in flow systems and salinity distribution that depend on the deposition of the SWSS. This research will facilitate better long-term environmental management of this and similar sites.

H31G-04 0915h

Ecohydrological Controls on Natural and Drained Peatland Methane Emissions: Implications for Climate Change

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As natural sources of methane (CH_4), peatlands play an important role in the global carbon cycle. Increased evapotranspiration and lower water tables at many northern peatlands under a 2 x CO_2 scenario are predicted to lead to lower CH_4 emissions. Additionally, changes in water table position may encourage shifts in the vegetation community and the impact of this on CH_4 emissions must also be determined. This study examines the CH_4 emissions, gross ecosystem photosynthesis (GEP) and water table position during 2001-2002 for natural and drained (eight years prior) sites within a poor fen in central Québec. Growing season CH_4 emissions at the drained site were 55% lower than the control site primarily due to significantly reduced flux at topographic highs (up to 97% reduction), while the flux from topographically low areas remained high. The maintenance of high fluxes at these hollow sites was related to hydrological and ecological effects of the water table drawdown. The removal of standing water removed a potential zone of CH_4 oxidation and also enabled plant colonization at these locations leading to an increase in GEP. At the hollow sites, seasonal CH_4 emissions were significantly correlated to seasonal GEP (R^2=0.85). These results suggest that the response of northern peatland CH_4 dynamics to climate change depends on the antecedent moisture conditions of the site. Moreover, ecological succession can play an important role for determining CH_4 emissions, particularly from wetter sites.

H31G-05 0930h

Using Climate Station and Gridded Data for Modelling Daily Streamflow of a Large Mountainous Catchment

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Mountainous catchments consist of a complexities of landscape and the application of macro-hydrological models requires climatic data commensurate with the influence of the rugged terrain. The SLURP model was applied to a mountainous catchment (Liard basin) in northern Canada, using three sets of Canadian data to examine the effects of climatic input on streamflow simulation. Climatic stations in and around the Liard catchment provide in situ temperature and precipitation records for the model runs. Spatially gridded data from a Canadian regional climate model as well as from a weather forecast model of the Canadian Meteorological Centre were also applied to the basin. The use of climate stations and climate models produced similar Nash-Sutcliffe values ranging from a R2 of 0.87 to 0.85. The ability of SLURP to simulate the correct timing and magnitude of hydrograph rises, peaks and summer flows varies depending on the temperature and precipitation fields of the three data sets. This suggests that the climatic input data have notable effects on streamflow simulation for the mountainous environment.

H31G-06 0945h

Differential Atmospheric Controls on Transpiration of Boreal Trees: A Potential Factor in Pre-mature Tree Mortality in Green-Tree Retention Strategies

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Green-tree retention, a harvesting strategy that involves the preservation of isolated and interconnected patches of live trees within the boundaries of harvested areas, is assumed to emulate natural disturbance, while preserving forest canopy continuity for wildlife habitat, maintaining forest biodiversity, and many other landscape level objectives. Unfortunately, many of the retention trees die within a few years after harvesting, thus much of the desired function of these trees is lost. This research focuses on understanding the relationship between changes in microclimate following harvesting and transpiration, potentially leading to drought-induced mortality of aspen, balsam poplar, white spruce, and white birch. Continuous measurements of whole-tree water use (sap flow) and micro-climate were taken before and after harvesting of two adjacent boreal mixedwood stands in west-central Alberta in the summer of 2003. Differences in micro-climate including radiation, air temperature, relative humidity and wind penetration into the canopy produced large differences in atmospheric moisture demand (PET) between partially harvested (green-tree retention) and undisturbed forest canopies. The variability in atmospheric conditions created large differences in sap flow velocity and transpiration rates among these four boreal species. Differential transpiration rates among species will be discussed in context of atmospheric controls on water use and drought tolerance of boreal trees with differing autecology and/or hydraulic architecture.

H32A CC: 520 F Wednesday 1030h

Estimating the Flux of Freshwater From the Pan-Arctic Landmass I

(joint with A, OS)

Presiding: **R Lammers,** University of New Hampshire**; A Shiklomanov,** University of New Hampshire**; T Prowse,** University of Victoria

H32A-01 1035h

Model-based estimation of river flows to the Arctic Ocean

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Land surface models capable of representing the role of vegetation and land cover on the dynamics of the surface water balance and land-atmosphere energy exchanges are now used in most weather prediction and climate models. These models have been used in both off-line and coupled model to evaluate the effects of land cover and climate change at scales ranging from large river basins to global. The effects of climate and land cover change are key concerns in the pan-Arctic region, especially since most climate models predict that the region will be particularly sensitive to global warming. Nonetheless, land surface models have not been as well evaluated as elsewhere globally. Arctic hydrology, for instance, differs from that of more temperate regions, primarily because of the cold temperatures, dominance of snow cover and spring snowmelt floods, the presence of permafrost, and prevalence of lakes and wetlands. We describe a set of simulations with the Variable Infiltration Capacity (VIC) model implemented at 100 km spatial resolution across the pan-arctic domain that is intended to evaluate the model's representation of arctic processes. For a 20-year simulation (1980-99) we diagnose model simulations using observations of key processes simulated by the model, including: 1) comparison of snow cover extent with satellite-based estimates from the NOAA Northern Hemisphere weekly snow cover extent data; 2) summer permafrost maximum active-layer thickness from the Circumpolar Active Layer Monitoring (CALM) network site data; and 3) stream gauge observations of discharge at over 70 locations that constitute the outlets of major river basins and internal confluences. For the 20-year study period, we then produce an estimate of the annual mean freshwater inflow to the Arctic Ocean and its spatial distribution, which we compare with previous estimates.

H32A-02 1050h

Estimates of River Discharge to the Arctic Ocean and Northern Seas

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Several estimates of pan-Arctic freshwater flux to the ocean are made using observed river discharge data, modeled results, and a composite of the two. For observed data we report on an updated version of the R-ArcticNet river discharge database. This database now contains over 5000 gauges from Alaska, Canada, Scandinavia, and Russia. Modeled results use the Permafrost Water Balance Model (P/WBM) to characterize runoff, and other key hydrological variables, throughout the pan-Arctic region. The composite runoff field uses a hybrid of the observed data and modeled results to provide a "best guess" river discharge estimate. All estimates are carried out using the 25 km resolution digital river network based on the NSIDC Northern Hemisphere EASE grid. This river network contains over 3089 drainage basins within 18 Sea Basins throughout the pan-Arctic drainage system. An intercomparison of the different methods of estimating discharge to the ocean provides us with a range in expected outcomes which will yield those regions with increased uncertainty in discharge. The resultant database will be of use to Arctic Ocean modelers and those interested in the flux of freshwater continental shelves in the Arctic Seas.

H32A-03 1105h

On Connections between the Atmosphere, Runoff and Arctic Shelf Marine Environment with Focus on the East-Siberian Region.

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