landscape heterogeneity scales are less than imagery resolution. However, where landscape scales are close to imagery resolution, spatial energy flux variance can increase as resolution decreases. This effect, caused by a transition from un-mixed to mixed pixel imagery, is most readily seen over the Oklahoma grasslands where heterogeneity scales are on the order of 200-400 m. At Jornada the change in spatial variance is not seen due to landscape heterogeneity scales typically less than 10 m.

H41B-03 0840h

Comparison of Evaporative Fractions Estimated with AVHRR and MODIS Sensors over South Florida.

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We have developed an evapotranspiration estimation algorithm using primarily remote sensing observations. This algorithm is simple, input-data adaptive and scalable. It derives spatially distributed evaporative fraction by using a contextual interpretation of the Pristley-Taylor equation and a relationship between remotely sensed radiometric temperature and vegetation index. This model has been shown to work well with remotely sensed data from Advanced Very High Resolution Radiometer (AVHRR). To further investigate the applicability of the model to different sensors, we compare and contrast estimates of evaporative fraction from AVHRR and Moderate Resolution Imaging Spectroradiometer (MODIS) over South Florida. Our preliminary results suggest that evaporative fraction obtained from AVHRR and MODIS are comparable for a number of clear and partially cloudy days. In particular, evaporative fraction for two clear days show very good agreement between the sensors in terms of high correlation and low root mean square difference and bias.

H41B-04 0855h

Evaporation-based Estimates of Water Use in the Euphrates River Basin (Turkey, Syria, and Iraq) Derived from MODIS Imagery and the MM5 Mesoscale Climate Model

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Almost 98% of the water available to the Euphrates River falls in the headwaters regions of central and southern Turkey. The river then flows 2,000 km through semi-arid and arid conditions on its way to the Persian Gulf, providing an essential agricultural and ecological resource for water deficit regions of Syria and Iraq. Both Turkey and the lower riparian nations have developed massive impoundment and diversion schemes over the past decades, boosting agricultural production from the region but causing tension over water extraction rights within the shared watershed. Indeed, the combined water use proposals of Turkey, Syria, and Iraq currently sum to twice the natural discharge of the river taken on an annual basis. Uncertainties associated with the measurement of water consumption make it difficult to quantify the impact of any particular irrigation scheme or cropping system on the hydrologic balance of the basin. Operational estimates are often derived from water withdrawal surveys or, more recently, from remotely sensed figures for total cropped area. Such estimates lack a physical link to water consumption. In this study, moderate resolution, high frequency images of the MODIS sensor were used to quantify water consumption in large irrigation schemes within the Euphrates basin. MODIS-based estimates of latent heat flux compared reasonably well with ground measurements, but the values differed considerably from latent heat fluxes predicted for the same period using the MM5 climate model with the NOAH LSM. The use of satellite imagery as an input to MM5 may rectify this discrepancy and improve understanding of land-use/climate interactions on the mesoscale.

H41B-05 0910h

ANALYSIS OF LAND SURFACE PARAMTERS AND FLOOD DATA IN THE RED RIVER OF THE NORTH BASIN

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The movement and distribution of water in the hydrologic cycle is affected by the level and type of land surface parameters. Thus accurate representation of the physical and biological features of the landscape within a watershed is required. A strong link exists between climate variability and the resulting changes in such land surface parameters as energy fluxes, land-cover and surface microclimates. Imagery from Landsat and other satellites provide land-cover and surface microclimate information with high temporal and spatial accuracy. This paper utilizes the land surface temperature (LST) derived from the thermal band of Landsat images and Normalized Difference Vegetation Index (NDVI) derived from its red and near-infrared bands to further improve land-cover and surface microclimate mapping. Remotely-sensed spatially distributed surface latent and sensible heat fluxes were also estimated. The study was conducted on the Red River of the North basin, North Dakota/Minnesota. Over the period of 1974-2002, seven images from Landsat Multispectral Scanner, Thematic Mapper and Enhanced Thematic Mapper plus sensors were used. Landsat images were processed using an unsupervised classification. Corrected LST and NDVI, which indicate a strong relationship with the land-cover data, were identified using scattergrams. Surface microclimate parameters (fractional vegetation cover, FVC and fractional impervious surface, FIS area) were estimated and their spatial and temporal distributions determined. Surface energy fluxes (latent and sensible heat) were assessed over space and time. The results indicate that vegetation cover (FVC >0.5) increased from 7% in 1974 to 48% in 1998 due to cropland farming in the Red River Valley and an increase in impervious areas (FIS >0.5) (by 79% from 1974 to 2001) attributed to the growing cities in the valley for the period of study. The study also indicated an increase in sensible and latent heat fluxes from 1998 to 2002 for areas classified as developed and cropland, respectively. Hydrograph analysis of the flow at Grand Forks gauging station also indicated runoff response of the basin has increased between 1993 and 2002 with all years having percent runoff greater than 10

H41B-06 0925h

Relations Between Albedos and Emissivities From MODIS and ASTER Data Over North African Desert

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This paper analyzes relations among MODIS surface albedos, ASTER broadband (3-14 μm) emissivities, and a soil taxonomy map over the arid areas of Algeria, Libya, and Tunisia in North Africa at 30 second (about 1 km) and 2 minute (about 4 km) spatial resolutions. The MODIS albedo data are from 7 spectral bands and 3 broadbands during dust-free seasons and the emissivity data are derived from a linear combination of the waveband emissivities of the ASTER five thermal infrared channels. Both albedo and emissivity data in the study region show similar considerable spatial variability, larger than assumed by most climate models, and such variability is related to the surface types (sands, rock, and soil orders). Emissivity over bare soils exhibits statistically significant correlations with albedos at both broadbands and most of spectral bands and decreases linearly with albedos. Albedo and emissivity are more strongly correlated with each other than either is to the surface types, apparently because of their higher resolution either spatially or in surface mineralogy. This paper provides guidance for the possible inclusion of such correlation to specify albedo and emissivity in climate models.

H41B-07 0940h

A Comparison of Surface Flux Maps from Remote Sensing-based Models

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A number of energy balance models using remotely sensed boundary conditions for producing spatially distributed maps of surface fluxes have been proposed. Validation typically involves comparing model output to flux tower observations at a handful of sites, and hence there is no way of evaluating the reliability of model output for the remaining pixels comprising a scene. Moreover, there is also the issue of a mismatch between the spatial scale of model output defined by the satellite pixel resolution and the size and location of the flux footprint or source area contributing to the tower-based flux measurements. To gain some insight as to the uncertainty in flux estimation from various models over a remote sensing scene requires one to conduct pixel-by-pixel comparisons of the output. Two models, which have potential for operationally monitoring ET with satellite data will be described. Some preliminary comparisons of the spatially distributed flux maps from the two models with remotely sensed imagery collected over a semiarid rangeland site in Arizona and subhumid grassland site in Oklahoma will be presented and discussed. A framework for conducting future model comparisons will also be discussed.

H41C MCC: Level 2 Thursday 0830h

Environmental Impacts of Coal-Bed Methane Development II Posters

(joint with B, GC)

Presiding: **R W Healy,** U.S. Geological Survey**; R L Smith,** U.S. Geological Survey

H41C-1017 0830h POSTER

Coalbed Methane Co-Produced Water Budget at a Storage Impoundment Site, Beaver Creek Drainage, Powder River Basin, Wyoming

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Rapid coalbed methane (CBM) development in the Powder River Basin, Wyoming, has resulted in a dramatic increase in the number of producing wells, from less than 300 in 1997 to more than 10,000 in 2002, with as many as 40,000 new wells projected to be drilled during the next decade. CBM development involves the co-production of large volumes of coalbed water, which is most commonly discharged to impoundments. Little is known about the potentially significant effects that this co-produced water may have on shallow aquifers and water budgets. A small study site (1600 meters in length) was chosen in the Beaver Creek drainage (a tributary to the Powder River) to quantify the fate of CBM water. Discharge into two in-channel infiltration impoundments (areas of 4000 m^2 and 10,500 m^2) began in November, 2002. We installed monitoring wells at three locationsupstream, between, and downstream of the ponds. We emplaced a series of v-notch weirs between and dowstream of the ponds to quantify conveyance losses, and constructed a floating pan in one impoundment to measure evaporation. Over the study period from July 23 to August 21, 2003, we established a water budget from daily coalbed water production,

flow measurements, and evaporation data. Water production from five wells into the two ponds averaged 647 L/min, or about 4500 bbl/day. Mean evaporation from the ponds and stream channel was 102 L/min. Infiltration determined by differences in water production and streamflow plus evaporation loss indicate an average infiltration of 240 L/min in the ponds, and 97 L/min within 1100 meters of investigated stream channel. Approximately 52% of the CBM co-produced water infiltrated, 16% was lost to evaporation, and 32% left the study area as surface water. Mean infiltration rates within the ponds ranged from 0.07 cm/hr in the smaller upstream pond to 0.1 cm/hr in the larger pond. In the middle sections of the stream channel, infiltration rates were about 0.7 cm/hr. Directly below the downstream pond, the infiltration rate was 0.3 cm/hr, slightly less than that determined for other streambed sections. In the most dowstream section of stream channel, the infiltration rate was 1.1 cm/hr. Well water levels in a control area unaffected by CBM water dropped by 18.3 cm over the study duration, while levels dropped only 6.1 cm between the ponds, and 12.2 cm below both ponds. Preliminary results suggest potentially significant variations in infiltration rates between the pond and stream settings. The response of the shallow aquifer water table also appears to vary within the study area.

H41C-1018 0830h POSTER

Study of Ground-Water Recharge Rates in the Northern Powder River Basin

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Coal-bed methane (CBM) production in the Powder River Basin is growing rapidly. The Bureau of Land Management estimates that by the year 2010 there may be as many as 50,000 producing wells in the Wyoming part of the Basin alone. Development of CBM requires the pumping of water from coal seams. As water pressure in the seam is lowered, methane is released from storage. The pumped water is usually discharged into streams, channels, or impoundments. With a typical well producing about 48 cubic meters of water per day, the rate of discharge for the Basin could exceed 2.4 million cubic meters per day by 2010. The fate of that water and its impact on the environment are topics of some concern. Relevant issues include the rate at which water infiltrates and percolates to the water table, the eventual discharge of infiltrated water to surface water, and chemical changes that occur as water moves through the system. An adequate understanding of these issues requires knowledge of local and regional hydrology. This study is investigating rates of ground-water recharge under natural conditions and as impacted be CBM development. Natural recharge within the Powder River Basin occurs by both diffuse mechanisms (infiltration of precipitation and subsequent travel of water through the unsaturated zone to the water table) and focused mechanisms (infiltration from line and point sources, such as streams and ponds). Under natural conditions, the relative importance of each is difficult to assess. Discharged CBM water should substantially enhance the rate of focused recharge, with less effect expected on diffuse recharge. Objectives of this study are to estimate rates of diffuse recharge, naturally occurring focused recharge, and enhanced focused recharge due to the discharge of CBM water. Multiple approaches are being employed: chloride mass balance; tracer methods based on tritium, stable isotopes, and other compounds; Darcy/unit hydraulic gradient; water budget; water-table fluctuation, and channel loss methods. Preliminary results indicate that natural rates of recharge vary spatially as a function of soil texture and land surface slope and range from less than 1 to more than 200 mm per year.

H41C-1019 0830h POSTER

Assessing Cumulative Impacts of Coal Bed Methane Development on Surface Water Quality and its Suitability for Irrigation in the Powder River Basin

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This paper presents a mass balance approach to assessing the cumulative impacts of discharge from Coal Bed Methane (CBM) wells on surface water quality and its suitability for irrigation in the Powder River Basin. Key water quality parameters for predicting potential effects of CBM development on irrigated agriculture are sodicity, expressed as sodium adsorption ratio (SAR) and salinity, expressed as electrical conductivity (EC). The assessment was performed with the aid of a spreadsheet model, which was designed to estimate steady-state SAR and EC at gauged stream locations after mixing with CBM produced water. Model input included ambient stream water quality and flow, CBM produced water quality and discharge rates, conveyance loss (quantity of water loss that may occur between the discharge point and the receiving streams), beneficial uses, regulatory thresholds, and discharge allocation at state-line boundaries. Historical USGS data were used to establish ambient stream water quality and flow conditions. The resultant water quality predicted for each stream station included the cumulative discharge of CBM produced water in all reaches upstream of the station. Model output was presented in both tabular and graphical formats, and indicated the suitability of pre- and post-mixing water quality for irrigation. Advantages and disadvantages of the spreadsheet model are discussed. This approach was used by federal agencies to support the development of the January 2003 Environmental Impact Statements (EIS) for the Wyoming and Montana portions of the Powder River Basin.

H41C-1020 0830h POSTER

Assessing the Erosion Potential of Coal Bed Methane Surface Water Discharges in the Powder River Basin, WY

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The mining of coal bed methane (CBM) in the Powder River (structural) basin (PRB) in northeast Wyoming has been an economic windfall for Wyoming. However, a critical issue in the production of CBM is the removal and disposition of the associated product water. The process of extracting coal bed methane involves drilling a well into a coal seam and then pumping water out of the well. Among other things, the pressure gradient created by pumping water out the well causes the methane to flow towards the well where it is retrieved. As a result of CBM development, many ephemeral streams in the Powder River (structural) basin (PRB) in northeast Wyoming are seeing a significant increase in water discharges. A potential consequence of the increased discharges is accelerated channel erosion. The Wyoming Department of Environmental Quality (WDEQ) issues permits that legally allow CBM developers to discharge CBM water into channels and therefore they must be able to anticipate how much water can be discharged into a channel before there is a significant risk of accelerated erosion. Erosion Potential (EP) Modeler is a GIS based program that was developed to facilitate the calculation of an index that can be used to assess the potential for accelerated channel erosion in response to increased discharges in a channel. In general, EP Modeler was developed to help those responsible for or concerned about watersheds affected by CBM development in the PRB. In particular, EP Modeler was developed to assist WDEQ personnel formulate appropriate management decisions associated with the National Pollution Discharge Elimination System permitting process. EP Modeler estimates pre- and post-CBM development equilibrium channel widths and reports the percent change in width as an index of the potential for channel erosion. Pre- and post-CBM development channel widths are computed as a function of the bankfull discharge and the sum of bankfull discharge and anticipated CBM product water discharge, respectively. Data from field surveys was used to calibrate EP Modeler and data obtained in the future will be used to verify predictions from EP Modeler. Results from EP Modeler indicate that the potential for accelerated erosion because of CBM development is proportional to basin size and that changes in channel width on the order of one to ten percent could occur in the PRB.

URL: http://wwweng.uwyo.edu/civil/research/water/epmodeler.html

H41C-1021 0830h POSTER

A Test of a Major-ion Toxicity Model to Predict the Toxicity of Coal Bed Methane Product Waters to Aquatic Biota

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Coal bed methane (CBM) accounts for about 7.5% of the total natural gas production in the United States, and the Powder River Basin (PRB) in Montana and Wyoming has recently become a major production area. During CBM extraction, a coal seam is partially dewatered to relieve hydraulic pressure, thus causing methane gas to desorb. Some of this water (called product water) is discharged on the land surface and allowed to run into local drainages in the PRB. Due to the massive amounts of product water being discharged (rates up to 64,000 L/day per well), studies are needed to examine the potential effects on aquatic organisms. Additionally, models to predict such effects would be useful regulatory screening tools. To that end, we tested the ability of a multivariate logistic regression model of the toxicity of major inorganic ions (i.e., Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}) to predict the acute toxicity of CBM-related waters to two aquatic invertebrates (*Ceriodaphnia dubia* and *Daphnia magna*) and fathead minnows (*Pimephales promelas*). First, we entered water chemistry data for several CBM product and receiving waters from the PRB into the major-ion model. Then we compared the model's predicted survival to the survival of the three species in toxicity tests we had previously conducted with those waters. For the majority of CBM product water and stream water samples in which CBM product water constituted the entire flow of the stream, the major-ion model consistently under-predicted survival by $>$50%. Therefore, from a regulatory standpoint, this model is conservative for detecting toxicity of CBM product waters (i.e., it over-predicts toxicity). Although the model appeared to be an excellent predictor of survival for receiving waters that contained no inputs from CBM processing (i.e., the difference between predicted and observed survival was $\leq$10%), the majority of those cases were inconclusive tests of the model because the predicted and observed survival were either both $>$90% or both $<$10%. In such cases, it was not possible to test the accuracy of the regression coefficients in the major-ion model.

H41C-1022 0830h POSTER

Hydrologic Reconnaissance of Wetland-Bird Habitat in Areas With Potential to be Influenced by Water Produced During Coalbed Methane Production in the Northern Powder River Basin, MT

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The removal and disposal of ground water during production of coalbed methane has the potential to influence wetland-bird habitat in the Powder River Basin. Office analysis of wetland areas was conducted on National Wetland Inventory maps and Digital Orthophoto Quadrangles along the Tongue and Powder rivers in the northern Powder River Basin, Montana. Selected sites were palustrine emergent, large enough to be important to waterbirds, part of a wetland complex, not dependent on artificial water regimes, in an area with high potential for coalbed methane production, and judged to be accessible in the field. Several promising wetland areas were selected for field examination. Field investigation suggests that the most promising wetlands in oxbow cutoffs would not be productive sites. Only facultative not obligate wetland plants were observed, the topographic position of the wetlands suggested that flooding would be infrequent, and the stream flow would likely dilute the effect of produced water adjacent to these rivers. Fortuitously wetland-bird habitat not recognized on the National Wetland Inventory maps and Digital Orthophoto Quadrangles was observed along Rosebud Creek during the field reconnaissance. This habitat is not continuous. The lack of continuity is reflected in the soil surveys as well as in the reconnaissance field nvestigation. The Alluvial Land soil series corresponds to observed wetland areas but the extent of the wetland-bird habitat varies substantially within the soil unit. When the Korchea series is present, extensive wetland-bird habitat is not observed. Field and aerial photo analysis suggests that the presence of the habitat may be controlled by beaver, and/or by stratigraphic and structural elements that influence stream erosion. Human modification of the stream for irrigation purposes may impact habitat continuity in some areas. The "Rosebud" type wetland-bird habitat may have the potential to be influenced by coalbed methane water production and warrants further more detailed investigation to determine the areal extent of the habitat, to determine the factors that control the distribution of intermittent wetland-bird-habitat areas, and to better model whether and how water produced during coalbed methane development might influence wetland-bird habitat.

URL: http://www.nrmsc.usgs.gov/products/wetlands_cbm.pdf

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