A Community Resource for Research in Hydrologic Science

South Platte River Hydrologic Observatory

Concept

The intersection between: (1) the Rocky Mountains and developments occurring in high altitude fragile environments; (2) the metropolitan areas emerging at the interface of the mountains and the plains; (3) the irrigation occurring along rivers as they break from the mountains and snake across the Great Plains; and (4) the grasslands and the dryland farming that covers the vast amount of the Great Plains, represents a dynamic, complex, highly integrated ecosystem, stretching from Montana and North Dakota to New Mexico and Texas. This swath of land, and the rivers that cross it (headwaters of the Missouri, the Yellowstone, the North Platte, the South Platte, the Arkansas, the Cimarron, the Red and the Pecos Rivers), represent a significant percentage of the landmass of the United States. Within this large area, besides tremendous increases in population in metropolitan areas, there are new energy developments, old hard rock mining concerns, new recreation developments, irrigation farms selling water to meet urban demands, new in-stream flow programs, struggling rural areas, and continued *mining* of ground water. The corresponding impacts are creating endangered and threatened species conflicts which require new knowledge to fully understand the measures needed to mitigate harmful ecosystem conditions.

Within the Rocky Mountain/Great Plains interface, water is limiting and land is plentiful, presenting natural resource managers with a number of unique problems which demand a scale of integrated science not achieved in the past. For example, water is imported into a number of the streams flowing east from the Rocky Mountains, complicating the natural systems, on both sides of the continental divide. Nitrogen is deposited in pristine watersheds that rise up high in the Rocky Mountains. Cities capture spring runoff in reservoirs to use at a steady rate over the entire year, putting water into river systems normally moving low flows in the winter. Irrigation of both urban landscapes and farm fields may be at a scale that impacts climate patterns in the region. Government programs, to help manage natural resources in the region, have fractured jurisdiction over the area, as illustrated by a series of agency maps on the website: http://greatplains.cesu.unl.edu/map_links.htm.

While there is a north/south gradient across the Rocky Mountain/Great Plains interface, there are also many commonalities that should assist transferring scientific findings from one river basin to another.

The purpose of this NSF Hydrologic Observatory proposal is to employ the "hydrologic observatory" concept to make the necessary observations in order to study the South Platte River Basin, as representative of many of the scientific hydrologic issues facing the Rocky Mountain/Great Plains interface watersheds. In particular, the South Platte Hydrologic Observatory will examine the following:

- Linkage of Biogeochemical and Hydrologic Cycles
- Sustainability of Water Resources
- Hydrologic Influence on Ecosystem Functions
- Understanding of Hydrologic Extremes
- Fate and Transport of Chemical and Biological Contaminants

With a detailed integration of data sets, from a wide array of study efforts, the South Platte Hydrologic Observatory will produce sound science findings to assist natural resource decision making in the region. In addition, with careful planning and efforts to correlate the South Platte findings with other rivers in the region, the findings will be able to assist decision making from Canada to Mexico.

- Scaling
- Coupling across interfaces
- Forecasting and Limits to Predictability

The South Platte Hydrologic Observatory will also be incorporated into plans for an upcoming NEON proposal as a means to further enhance the study of scale and coupling across interfaces.

The South Platte Hydrologic Observatory will coordinate its work with the water institutes in Montana, North and South Dakota, Wyoming, Nebraska, Kansas, Oklahoma, New Mexico and Texas, as part of an effort to extend the knowledge of the Rocky Mountain/Great Plains river system hydrology from Canada to Mexico. This water institute coordination will be organized under the auspices of the National Institutes for Water Resources.

Location[1]

The South Platte River Basin has a drainage area of about 24,300 mi^2 and is located in parts of three States: 79% of the basin is in Colorado, 15% is in Nebraska, and 6% is in Wyoming. The South Platte River originates in the mountains of central Colorado at the Continental Divide and flows about 450 mi northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska. Altitude in the basin ranges from 14,286 ft at Mt. Lincoln on the Continental Divide to 2,750 ft. at the confluence of the South Platte and North Platte Rivers.

Climate

The basin has a continental-type climate modified by topography, in which there are large temperature ranges and irregular seasonal and annual precipitation. Mean temperatures increase from west to east and on the plains from north to south. Areas along the Continental Divide average 30 in or more of precipitation annually, which includes snowfall in excess of 300 in. In contrast, the annual precipitation on the plains east of Denver, Colorado, and in the southwest

[1] Information in the sections: Location, Climate, and Land Use were adapted from information posted on the USGS NAWQA webpage at: http://co.water.usgs.gov/nawqa/splt/

part of the basin, ranges from 7 to 15 in. Most of the precipitation on the plains occurs as rain, which typically falls between April and September, whereas most of the precipitation in the mountains occurs as snow, which typically falls between October and March.

Land Use

The three-State area of the South Platte River Basin has about 2.8 million people, over 95 percent of whom live in Colorado. The basin contains the most concentrated population density in the Rocky Mountain region, located along the Front Range urban corridor in Colorado where the mountains meet the plains. Population densities outside the urban corridor are small and centered in small towns located along the main streams. The principal economy in the mountainous headwaters is based on tourism and recreation; the economy in the urbanized south-central region mostly is related to manufacturing, service and trade industries, and government services; and the economy of the basin downstream from Denver is based on agriculture and livestock production.

Land use and land cover in the South Platte River Basin during 1975-80 is divided into: 41% rangeland, 37% agricultural land, 16% forest land, 3% urban or built-up land, and 3% other land. Rangeland is present across all areas of the basin except over the high mountain forests. Agricultural land is more restricted to the plains. Forest land occurs in a north-south band in the mountains. Urban or built-up land is present primarily in the Front Range urban corridor. The 'other land' category includes: water (110 mi^2), barren lands (160 mi^2), tundra (400 mi^2), and perennial snow and ice (1 mi^2). Barren lands primarily are areas under construction or are areas of strip mining, quarries, or gravel pits.

Science Questions

Biogeochemical and Hydrological Cycles

- *Hypothesis*: Basin-scale transport of *N* is regulated by coupled hydrologic and biogeochemical processes occurring in terrestrial, riparian and aquatic ecosystems, involving atmospheric processes and surface water and groundwater flowpaths and interactions.

- *Hypothesis*: Atmospheric transport driven by evapotranspiration on the plains is a dominant process responsible for basin scale dispersal of anthropogenic *N* to pristine headwaters.

- *Hypothesis*: The importance of coupled hydrologic and biogeochemical processes in regulating *N* transport is greatest in the headwater catchments and decreases downstream as the anthropogenic inputs and degree of ecosystem *N* saturation increase.

- *Question:* How are field-scale and regional-scale evaporation and transpiration patterns affected by soil salinization?

Sustainability of Water Resources

- *Question:* Sixty to eighty percent of sustainable water yield in the western US is from snowmelt runoff. Climate change scenarios suggest a decrease in annual snowfall and a forward shift in the start date of snowmelt runoff, even if annual precipitation does not change. How will changes in the amount, timing and duration of snowfall and snowmelt affect water availability?

- *Hypothesis*: The water resource impacts of predicted climate variability and land use change will be exacerbated by increased impairment of water quality by excess *N*.

- *Question:* How do the spatial and temporal patterns of recharge, both from precipitation and irrigation, affect the spatial and temporal patterns of return flow from the alluvial aquifer to the stream?

- *Question:* To what extent is it practical, from a fundamental science perspective, to employ groundwater aquifers to store water during times of plenty and use it during times of water shortages?

- *Question:* Can groundwater storage play a larger role in the sustainability of water resources than it has in the past - is there large capacity of unused groundwater storage available in western aquifers?

- *Question:* Can we mine current evaporative-seepage losses from surface storage via subsurface storage?

- *Question:* How are large-scale infiltration and surface runoff patterns affected by salinization (through changes in hydraulic conductivity and macrostructure associated with EC and SAR, etc.)?

- *Question:* What are the magnitude and extent of evaporation from fallow fields or native ground fed by upflux from shallow water tables that are sustained by recharge on adjacent irrigated fields?

- *Question:* If measures are taken to lower saline shallow water tables to reduce soil salinization and to increase crop production, to what extent will increases in evapotranspiration on irrigated land [due to increases in osmotic potential (i.e. less negative)] be offset by reductions in evaporative upflux from shallow groundwater under adjacent fallow ground?

- *Question:* How are the long-term geomorphology and ecology of snow-melt dominated streams in semi-arid climates affected by off-season return flows generated by intensive irrigation of alluvial lands?

- *Question:* Can tributary return flows and groundwater return flows be predicted with an acceptable degree of uncertainty as a function of regional-scale properties and processes that are relatively easy to measure (through remote sensing, satellite, ground-based radar, etc. - e.g. CHILL and NEXRAD precipitation, vegetation, DEMs)?

Fate and Transport of Chemical and Biological Contaminants

- *Question:* What are the transport mechanisms associated with the movement of S_e from soils to waterways and how is it impacted by long-term irrigation of lands *vs.* the irrigation of new lands (particularly on small acreage developments that are exploding across the western U.S.)?

- *Question:* What are the comparative nature and magnitude of non point-source pollutant loading in the form of overland flow versus subsurface flow?

- *Question:* What properties and processes affect the rate and magnitude of dissolution of salts and metals (e.g. S_e and F_e) from marine-derived shale formations and their mobilization toward the river?

Hydrologic Influence on Ecosystem Functions

- *Question:* What are the ecological consequences of dewatering secondary and tertiary streams in the South Platte watershed and how are these manifested in short term changes in ecosystem structure and longer-term effects on ecosystem function?

- *Question:* What are the relative sensitivities of South Platte ecosystems (tundra, riparian, grassland, forests) to short- and long-term manipulations of winter and summer precipitation (increases and decreases) and what suite of organismic and ecosystem processes exhibit the same consistency of response, regardless of vegetation type?

Regional Scale Evapotranspiration

- *Question*: How do storm characteristics (e.g. seasonality, duration, intensity, and spatial extent) affect soil moisture fluxes beneath different geomorphic surfaces in arid and semi-arid catchments?

- *Question*: How do dominant plant species on different geomorphic surfaces respond to seasonal storm events and subsequent soil moisture availability, and how do evapotranspiration rates differ within and between these geomorphic surfaces and vegetation types?

- *Question*: Can we examine and quantify sources and pathways of evaporated water in a semi-arid environment; can we distinguish between groundwater and soil water as sources, and between transpiration from vegetation and evaporation from bare ground as moisture flux pathways?

- *Question*: Do direct measurements of potential evaporation rates by pans and actual evapotranspiration by eddy covariance techniques relate to estimates of actual evapotranspiration made by a state-of-the-art, physically based ET_a model operating in an semi-arid environment?

- *Question*: Can a physically based ET_a estimation procedure that distinguishes between transpiration and evaporation at the local scale be scaled up to quantify the total evaporative response on the basin and regional scales and then be regionalized such that it is transferable to other hydrologic systems in arid and semi-arid lands? What are the scaling characteristics of ET processes in space and in time?

- *Question*: How do storm characteristics affect runoff in the channel network (e.g. basin lag-time, magnitude of flow, sediment concentrations and transport mechanisms, and the rate of transmission loss with distance downstream)?

Surface Water/Groundwater Interactions

Hydrologic studies of mountainous terrain have traditionally focused on surface water and typically assume that groundwater storage and flow in the bedrock underlying mountain catchments is negligible. Surface water modeling studies and baseflow recession analyses often treat groundwater as a residual term, or as a black box, on the basis that it is a negligible component of the water budget. However, recent studies suggest that bedrock groundwater may be an important component of mountain hydrologic systems. Mountain groundwater may deliver significant dissolved mass and anthropogenic contaminant loads to streams, and in some cases may escape the mountain catchment through deep circulation to become a major source of recharge to adjacent basin aquifers. Because of rapid development in many mountain areas, greater utilization of mountain water resources, and increasing pressures on basin aquifers potentially recharged by mountain groundwater, there is a growing need to improve our understanding of the occurrence, storage and flow of groundwater in mountainous terrain. Major unanswered questions include:

- *Question:* What are the significant geologic controls on the infiltration, storage, and flow of groundwater in these systems?

- *Question:* How deeply does mountain groundwater actively circulate?

- *Question:* Does groundwater commonly escape local catchments (failing to discharge into the local stream), and, if so, under what conditions?

- *Question:* What are the geochemical processes controlling solute transport?

- *Question:* What is the range and distribution of hydraulic heads, recharge rates, residence times, porosities, and permeabilities, and can these be linked to specific lithologic or geological structural features?

Connectivity and scaling of systems along the mountain-plains front

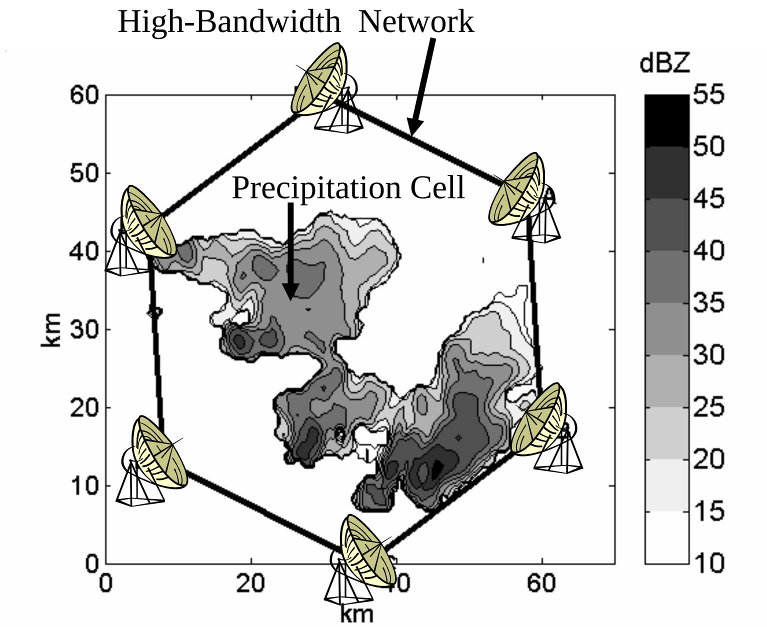
- *Global connections:* how does the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) influence hydrologic variability in the South Platte basin, in particular, how do AMO and PDO influence hydrologic extremes?

- *Connectivity between land use change and atmospheric processes:* - how does agriculture and urbanization affect land-atmosphere water flux?

- *Connectivity between mountains and plains:* how are water and chemicals redistributed throughout the basin, and how are water vapor and pollutants (*e.g., N*) transported against wind patterns from plains back up into mountains?

Precipitation Measurement Network for the South Platte Basin

One of the most important components of the South Platte Observatory that is proposed is a precipitation measurement network. Continuous monitoring of precipitation is an important aspect of this observatory. However the precipitation monitoring in the South Platte environment, including the urban setting and mountains brings some unique challenges. In order to address the specific hydrologic challenges we propose to develop a "network of small radar systems" that can be continuously reconfigured and redeployed to address specific science questions. For example, these radars can be configured to monitor snow at higher elevations or rainfall in mountain valleys as well as the South Platte Basin. Recent national level studies have shown that conventional long range radars such as NEXRADs will not serve this purpose and an alternative strategy is required (National Academy of Sciences Report, Weather Radar Technology beyond NEXRAD, National Academy Press, Washington DC, 2002). As part of this observatory we propose to develop “reconfigurable” and Networked Radar systems to serve the needs of Hydrologic community.



The fundamental driver of these measurements is to monitor the fine scale spatial and temporal variation of precipitation and the microphysical structure in order to provide feedback into the appropriate scientific understanding. These radars are expected to be dual-polarization in nature, at different frequencies, which have the ability to observe the full matrix of measurements (Bringi and Chandrasekar, 2001). In addition to the networked radar systems, a full suite of special *in situ* measurement systems such as disdrometers will be maintained.

The paradigm of operation for this measurement facility is multifold. These Networked Reconfigurable Radar Systems (NRADS) will provide continuous observations at the South Platte Basin. In addition, these systems, or a subset, as a “mobile” facility will be available for specialized experiments elsewhere in the country. This paradigm ensures nurturing state of the art measurement capability at the South Platte, while leveraging its application nationwide for special projects. Since these are networked systems, the part of infrastructure that is being used for networking can also be used for quick data dissemination to users around the country.

Isotopes in the hydrological cycle

One of the most important facets of hydrological process studies is the measurement and monitoring of the stable isotopes ($\delta^{18}O$ & δD) of precipitation, surface water, ground water, soil and plant water (Dansgaard 1964, Gat et al. 1994, Harvey and Welker 2000, Welker 2000, Harvey 2001, Bowling et al. 2003, Dutton et al. 2004). Isotopes of water in the hydrological cycle provide a natural tracer of a suite of physical and biological processes that characterize condensation, evaporation, recycling of water and plant water use of differential water sources (Alstad et al. 1999) and provide measures that integrate across temporal and spatial scales that can document past and current changes.

Today, the isotopes of water are proving critical to unraveling the watershed recharge properties, ground water-surface water interactions, paleohydrogeologic interactions and articulating the linkages between the water and carbon cycle (Flanagan and Ehleringer 1998, Harvey 2001, Bowling et al. 2003, Pataki et al. 2003). These insights are made possible in part by the emergence of spatial and temporal networks that are collecting precipitation (Welker 2000) and surface water (Kendall and Coplan 2001, Dutton et al. 2004) on a regular basis.

As part of the HO, we propose to use existing sampling networks in the Platte River watershed (USNIP - http://www.nrel.colostate.edu/projects/usnip) (Welker 2000, Welker et al. 2004) and the USGS surface water network (http://water.usgs.gov/nrp/proj.bib/coplen.html) (Kendall and Coplen 2001), in conjunction with site specific process studies. Our sampling and analysis will be designed to address two central themes: First, to what degree do drought conditions, changes in climate phases of the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) affect regional precipitation amounts, timing and isotope geochemistry? Second, how are changes in the isotopes of water manifested in ground and surface water interactions, biosphere-atmosphere interactions, records of climate in proxies records (tree rings) and the use of divergent water sources by native plants and crops in the Platte River watershed.

Existing Infrastructure, Observation and Measurement Capabilities

LTERS

Niwot Ridge LTER

An overarching theme of current research is the impact of climate change on Colorado tundra ecosystems, with a particular focus on the effects of altered snowpack and rainfall regimes. New facilities (e.g., the tundra laboratory), new research initiatives (e.g., the 100-year snow fence, the subnivean laboratory), and centralization of data management activities will assist us in meeting our research objectives.

Routine Measurements

Routine monitoring/measurements include (but are not limited to):

Meteorological/Climatological	**Hydrological**	**Biogeochemical**
▪ air temperature	▪ stream discharge	▪ atmospheric deposition
▪ precipitation	▪ snowpack ablation	▪ snowpack chemistry
▪ relative humidity	▪ snow water equivalent	▪ surface water quality
▪ Wind speed and direction	▪ soil moisture	
▪ solar radiation		

Other Research

Meteorological/Climatological	**Biogeochemical**	**Biological**
▪ lake-ice clearance and freeze-up	▪ atmospheric *N* loading	▪ aboveground phytomass
▪ soil temperatures	▪ soil physical and chemical properties	▪ plant phenology
	▪ wood, litter, and root decomposition	▪ fossil insect assemblages
	▪ soil and microbial *N* transformations	▪ plant species composition
	▪ microbial respiration	▪ small mammal herbivore surveys
	▪ methane and nitrous oxide fluxes	▪ soil microarthropod densities

	▪ plant biomass *N* & storage	

Associated metadata and data for the majority of these research projects are available in Niwot Ridge LTER Data.

- Niwot Ridge/Green Lakes Valley: Niwot Ridge LTER

Short Grass Steppe LTER

- Short Grass Steppe LTER: SGS-LTER

CSU-CHILL National Radar Facility

The CSU-CHILL multi-parameter radar system is available for use by the research community. The radar uses a dual transmitter / receiver design mated to a high performance antenna. This system configuration achieves isolation values of ~35 dB between the horizontal and vertical polarization channels; both the co- and cross-polar return signals are digitally processed. The radar has a variety of data collection capabilities which can be adjusted to best serve the individual investigator's interests.

1. General Capabilities of CSU-CHILL Radar:

The CHILL is a transportable 11 cm wavelength, pulsed Doppler weather radar with dual polarization capabilities. An 8.5 m diameter parabolic antenna produces a half-power beamwidth of 1.0 degree. Both the main beam and sidelobe radiation patterns at horizontal and vertical polarization are very well matched. The klystron-based dual transmitter systems each have a maximum output power level of ~1.0 MW. The matched dual receivers have noise power levels of ~-115 dBm. Data are available in real time on an interactively- controlled color display system.

2. Software - Controllable Radar Parameters:

Considerable real time flexibility is available in the operation of the CSU-CHILL system. Transmitter pulse lengths from 0.3 to 1.0 microseconds are available, yielding range resolutions of 45 to 150 meters. Pulse repetition times from 800 to 2000 microseconds may be used to adjust the limits on the radar's unambiguous velocity and range. Both the sequence of transmitter polarizations and the number of received pulses per integration cycle are user controllable.

- CSU-CHILL National Radar Facility

CoAgMet

- COlorado AGricultural Meteorological nETwork -- COAGMET: CoAgMet

CoCoRaHS

CoCoRaHS: an existing network of over 500 volunteers already collecting daily precipitation data in the South Platte Basin. CoCo RaHS has NSF funding through 2005. The large network of automated rain and stream gauges encompassing the Denver metro area (UDFCD) as well as the foothills of Jefferson and Boulder counties, the USBR network above the Olympus Dam, the Fort Collins Flood Warning System and the many SNOTEL sites in the upper reaches of the South Platte – as well as specialized observering networks set up over several of the recent burned areas -- all contribute to an exceptional existing hydrologic monitoring system in the basin.

- Community Collaborative Rain and Hail Study: CoCoRaHS: CoCORaHS

CIRA

- Cooperative Institute for Research in the Atmosphere

Cooperators

- The USGS Great Plains NAWQA: http://co.water.usgs.gov/nawqa/hpgw/HPGW_home.html
- South Platte NAWQA: http://co.water.usgs.gov/nawqa/splt/
- Rocky Mountain Cooperative Ecosystem Study Unit: http://www.forestry.umt.edu/research/cesu/
- Great Plains Cooperative Ecosystem Study Unit: http://greatplains.cesu.unl.edu/
- Short Grass Steppe LTER (located in the South Platte River Basin): http://www.lternet.edu/sites/sgs/
- Niwot Ridge LTER (located in the South Platte River Basin): http://www.lternet.edu/sites/nwt/
- Frasier Experimental Forest (removal of water from the forest for use in the South Platte Basin): http://www.fs.fed.us/rm/fraser/
- Loch Vale Watershed Research Project (located in the South Platte Basin): http://www.nrel.colostate.edu/projects/lvws/pages/homepage.htm
- South Platte Mapping and Analysis Program (models groundwater/surface water exchanges in the lower South Platte basin):
- Colorado State Government development of DSS for South Platte Basin:
- Tree Ring studies in South Platte Basin:
- NRCE snow survey data
- USGS, State Engineer's Office, and Denver Water flow data
- CWRRI reservoir study results
- Wildfire impact data
- Salinity data set from the Arkansas River

- Weighing lysimeter data from Arkansas River

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