STATE OF COLORADO

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TO: Colorado Water Conservation Board Members

FROM: Joe Busto, Watershed & Flood Protection Section

DATE: July 2, 2012

SUBJECT: **Agenda Item 13, July 17-18, 2012 Board Meeting**
State of the Science for Basin Forecasting

Background

Accuracy of basin water forecasts is critical for effective water management around the state. For example, when forecasts change during the runoff period in the Rio Grande watershed, the DWR often must curtail senior water rights holders during the irrigation season to make up for the changed volume. The CWCB has partnered to add SNOTEL sites around the state to partially address forecast errors, but more is needed to fully address the problem. An April meeting between NOAA, NWS-Office of Hydrologic Development, DWR, and the CWCB examined potential partnerships to develop a more comprehensive observation and hydrologic accounting approach to further improve this process.

The current radar coverage in mountainous areas of Colorado is often too poor for use in water management, flash flood prediction, aviation, avalanche forecasting, snow removal, and cloud seeding, among other uses. Complete basin radar coverage would benefit the economics and safety of Colorado. Radar coverage projects have been recently cosponsored by CWCB in the Gunnison and Durango areas, and both projects were well-received by local officials.

As a demonstration of the effectiveness of this technology, the CWCB recently cosponsored an effort with the Urban Drainage and Flood Control District to improve flash flood forecasting in the Denver area. This project used radar calibrated to rain gauge data to feed streamflow simulations to set debris flow and flooding thresholds for the Fourmile Creek fire area following the large fire in 2010. It has been effective in managing the elevated flash flood threat in this watershed, and this methodology could be utilized statewide with complete radar coverage, including recent burn scars.

Over the last eight years, several CWCB projects were performed to develop new observations and utilize new modeling for greater certainty of snowpack and water. Staff will provide an overview of previous work by the agency and then discuss potential projects developed through a multi-agency collaboration to address water supply forecast issues in the Rio Grande watershed with future applications in other areas of the state.

Staff Recommendation

This is an information item with no formal board action requested.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Office of Hydrologic Development, R/PSD
325 Broadway – David Skaggs Research Center
Boulder, Colorado 80305-3328

July 03, 2012

Joe Busto
Colorado Water Conservation Board
1313 Sherman Street, Suite 721
Denver, Colorado 80203

Dear Joe,

I am writing to offer you my endorsement of your collection of proposed forecast projects that you recently shared with us, and my encouragement to continue to pursue them. It is my belief that the five projects you outlined in your email today, if funded, could help advance our collective capabilities to monitor and forecast our precious and oftentimes scarce water resources in Colorado.

Furthermore, as you are aware, we are currently working on the development of new and enhanced national capabilities for high resolution, integrated modeling and data services at the National Water Center, which is slated to open next year. If successful, the results of your proposed projects would be of interest to us (e.g. improved methodologies to monitor and predict snowpack), leading to potentially broader (i.e. national) impacts of these projects.

Please keep us apprised of your efforts and any developments along these lines.

Sincerely,

Timothy Schneider

IWRSS/ National Water Center Program Office
NOAA/NWS/Office of Hydrologic Development
Phone: 303-497-5160
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Cc: Andy Rost

State of the Science for Basin Forecasting
Background

How has the CWCB helped with Forecasts?

- **SNODAS (2004-09) -** The CWCB, in partnership with Riverside Technologies Inc. (RTi), used a newer snowpack model (SNODAS) and tailored the data for use in Colorado. Three basins were calibrated and new tools were developed for the Colorado Basin River Forecast Center (CBRFC). The Rio Grande basin, which makes use of SNODAS to track runoff and issue basin forecasts, was also examined. The final report recommended better input data to SNODAS.
- **Snow Covered Area Archive (2011) -** The CWCB completed a Snow Covered Area Archive Project in 2011 that provided ten years of SNODAS and Moderate Resolution Spectrodiameter (MODIS) satellite imagery to all the RFCs that cover Colorado. Methods to use this data operationally are under development.
- **SNOTELs (2004-11) -** The CWCB partnered with other agencies to install twenty SNOTEL sites for a statewide total of 110, an 18% increase**.** The Natural Resources Conservation Service (NRCS) is at maximum capability making the ability to operate and maintain any future SNOTEL sites uncertain.
- **Mobile Dual Polarization Radar (2009-ongoing)** – Summer 2009 in Gunnison, summer 2010 in Durango, in February 2011 in Durango, NOAA-NSSL deployed mobile radar to collect data in beam blocked areas of NWS network. The results were published in an abstract for the 2011 Western Snow Conference.
- **Rainfall Runoff Models for the Fourmile Burn area (2011**) – CWCB partnered with the Urban Drainage and Flood Control District (UDFCD) to develop methodologies to use radar data in real-time operational models to reflect the post-fire conditions. This increases the capabilities of the local response agencies during flood season.
- **Dust on Snow Research Program (2009-ongoing) –** CWCB funds partners with the Center for Snow and Avalanche Studies (CSAS) to collect data on dust layers in snowpack. CSAS is also working with the National Center for Atmospheric Research to develop this dataset as inputs to models for forecasts.

Rio Grande Projects/Background:

A team of the West Gulf River Basin Forecast Center (WGRFC), National Center for Atmospheric Research (NCAR), Riverside Technologies Inc. (RTi), the National Oceanic Atmospheric Administration National Severe Storms Lab (NOAA-NSSL), Colorado Division of Water Resources (DWR), and Portland Natural Resources Conservation Services (NRCS) and CWCB staff is working together to develop approaches to address forecast improvements. A need exists to continue to develop methods to analyze and display the existing data, develop new data, and develop new approaches. CWCB staff's role includes serving as a liaison between these agencies and water users in the Rio Grande. These ideas were presented to the September 13, 2011 Rio Grande BRT. An explanation of five proposed projects developed by this team is provided in this narrative.

Science Team Agency	Areas of Expertise
Colorado Division of Water Resources	Water administration in the Rio Grande Basin
Colorado Water Conservation Board	Water management in Colorado
National Center for Atmospheric Research	Data networks, atmospheric research and modeling
National Operational Hydrologic Remote Sensing Center	SNODAS, remote sensing
Natural Resources Conservation Services	Forecasting with regression models, SNOTEL stations
NOAA-National Severe Storms Laboratory	Radar technology, research to operations
Riverside Technology, inc	Forecast models, operational systems, DSS tools
NWS-West Gulf River Forecast Center	Forecasting with regression and hydrologic models

What is a water supply forecast?

A water supply forecast is a prediction of seasonal volumetric runoff. The forecast presents a range of possible runoff volumes with probabilities of occurrence. This range in forecast volumes reflects uncertainty with future weather conditions, errors in data, and uncertainty in the forecasting procedure.

RIO GRANDE BASIN

Streamflow Forecasts - April 1, 2011

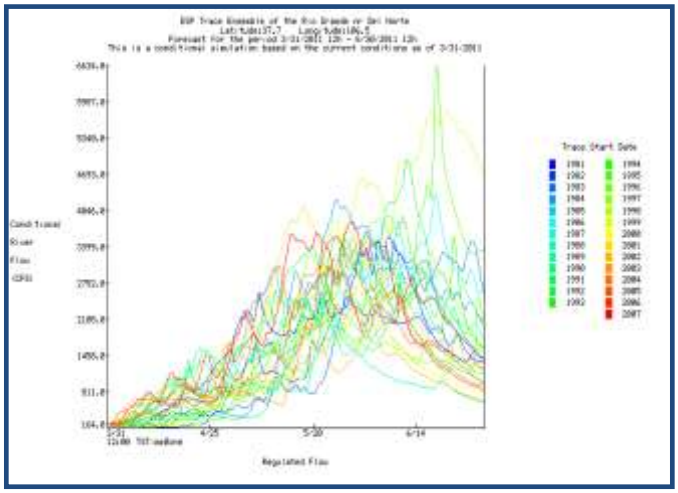
Forecast Pt	<==== Drier === Future Conditions === Wetter ====>						
	========== Chance of Exceeding * ==========						
Forecast Period	90% (1000AF)	70% (1000AF)	50% (Most Prob) (1000AF)	30% (% AVG.)	10% (1000AF)	30 Yr Avg (1000AF)	
Rio Grande nr Del Norte (2)							
APR-SEP	280	340	390	73	440	525	531

Who is responsible for issuing the water supply forecasts in the Rio Grande Basin?

The Natural Resources Conservation Service (NRCS) and the National Weather Service West Gulf River Forecast Center (WGRFC) in the Rio Grande are responsible for issuing forecasts.

What are the two water supply forecasts techniques?

The first technique is multivariate regression analysis, which predicts seasonal water supply as a function of snow water equivalent at SNOTEL stations. Other variables, such as year-to-date precipitation, may also be included. Regression methods have historically been the sole technique in the Rio Grande Basin.



The second technique uses hydrologic models to track snow accumulation and ablation and to perform soil moisture accounting. To generate a water supply forecast, the Ensemble Streamflow Prediction (ESP) program uses the snowpack and soil moisture conditions and historical weather

data to generate a series of possible runoff scenarios. The runoff traces produce the probabilistic information.

How accurate have the historical water supply forecasts?

The forecasts have been accurate in some years. In other years, the forecast error has been as large as 24%. Typically, the forecast models tend to perform best in average years, with dry and wet years being more difficult to predict.

The Issue

Rio Grande at Del Norte	June Forecast Water Supply [ac-ft]	Actual Water Supply [ac-ft]	Forecast Error June Forecast – Actual [ac-ft]
WY 2005	795,000	683,000	+112,000 (16%)
WY 2006	350,000	412,000	-62,000 (-15%)
WY 2007	450,000	593,000	-143,000 (-24%)
WY 2008	655,000	623,000	+32,000 (5%)
WY 2009	490,000	513,000	-23,000 (-4%)
WY 2010	485,000	455,000	+30,000 (+7%)

As a rule of thumb in U.S. water management, 1 ac-ft is the planned water usage of a suburban family household annually.

1 ac-ft = 326,000 gallons of water 2007 error = 46,618,000,000 gallons

How do forecast errors affect water users in the Rio Grande Basin?

The water supply forecasts are used by the DWR to determine Colorado's delivery obligations under the Rio Grande Compact, as well as the water available for San Luis Valley water users. Forecast errors may result in too much or too little water being delivered to New Mexico. Correspondingly, too much or too little water is made available to local water users, depending on the direction of the forecast error.

Basin underrepresentation by SNOTEL, sun, wind, dust, temperature, terrain, soil moisture, groundwater recharge, and spring weather complicate the timing and volume of runoff.

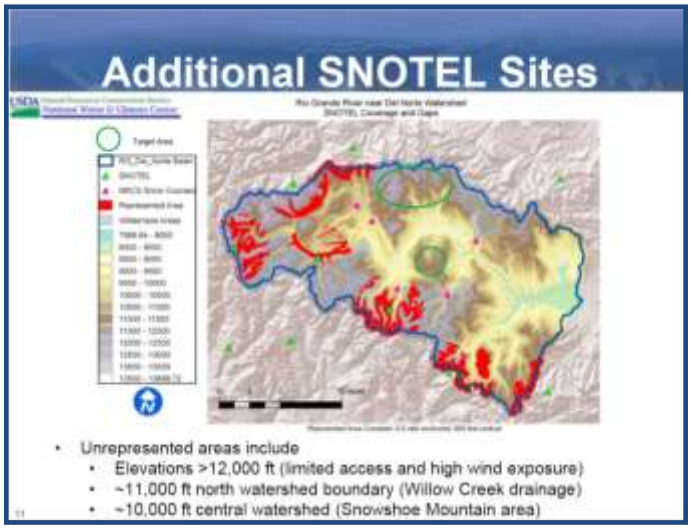
What is the economic impact of forecast errors?

It is difficult to assign an exact cost, but assuming a lease rate for water in the Rio Grande is $135/ac-ft, then the potential cost of the forecast error in 2007 of 143,000 ac-ft is estimated to be $19,305,000.

Will more SNOTEL sites help?

Starting in 2004, the CWCB developed a popular program to cost share with the NRCS and local agencies in the development of more SNOTEL sites.

More SNOTEL sites will help as inputs to models, but they are not the sole answer to more accurate forecasts. By nature, they are in snow catchment basins and will always

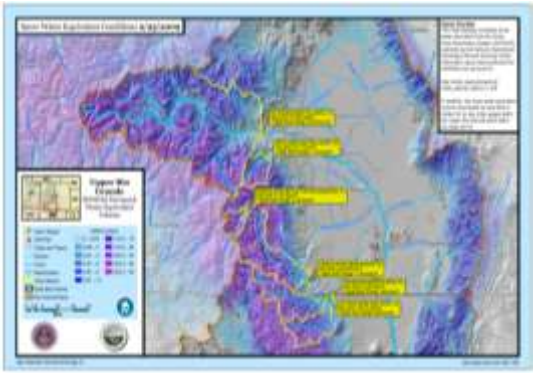


have values that do not fully represent the basin-wide snow hydrology.

The red areas in the above figure show regions where NRCS has the highest confidence in hydrology for the Rio Grande watershed. The Rio Grande has significant wilderness lands where no SNOTELs can be deployed. The green circles show areas where additional SNOTEL sites, if they could be installed, would be most valuable.

What is SNODAS?

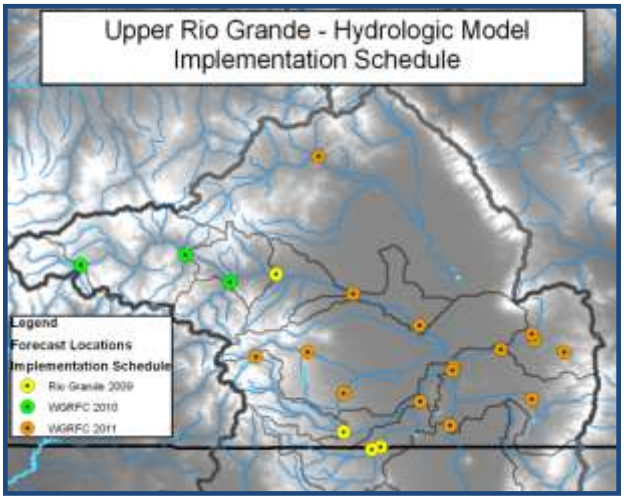
In recent years, remotely sensed data and land surface models have been used to estimate snowpack characteristics for the conterminous U.S. The CWCB partnered with the USBR and Riverside Technology, inc (Riverside) to develop products for the Rio Grande Basin using the Snow Data Assimilation System (SNODAS). These products were distributed to the CWCB, CDWR, WGRFC, NRCS, and San Luis Valley Irrigation District (SLVID) throughout the last four snow seasons.



David McClow of the USGS published a 2012 paper titled "Evaluation of SNODAS Depth and SWE for the Colorado Rocky Mountains, USA". McClow states that SNODAS products have the potential to substantially improve the calibration and performance of spatially distributed hydrologic models in snow-dominated catchments of the western U.S. It is the only nationwide, moderate resolution, gridded snow water equivalent (SWE) product available at a daily time step. The objective of this study was to evaluate the accuracy of SNODAS snow depth and snow water equivalent in the Colorado Rocky Mountains using two independent methods, including (1) ground-based snow surveys, and (2) water-balance calculations on headwater basins. Results from this study indicate that SNODAS can provide reliable data for input to moderate- to large-scale hydrologic models, which are essential for creating accurate runoff forecasts. Refinement of SNODAS SWE estimates for alpine areas to account for wind redistribution of snow could further improve model performance.

What recent projects have led to the current state of basin forecasting for the Rio Grande watershed?

In 2009, the CWCB and the Rio Grande Water Conservation District (RGWCD) partnered to redevelop the NWS hydrologic models for the four index gages specified (yellow circles). The NWS is now able to produce water supply forecasts using hydrologic models coupled with Ensemble Streamflow Prediction, in addition to the traditional regression-based methods.



In 2009, the NWS continued redevelopment of the hydrologic models down to the Lobatos gage (green and orange circles) Now the NWS is running the 22 redeveloped hydrologic models and Ensemble Streamflow Prediction.

In 2011, the U.S. Army Corps of Engineers worked to redevelop the hydrologic models for 55 tributary and local inflow points for the Rio Grande in New Mexico. The WGRFC will use these to forecast for the Water Operations Model to support the USACE and USBR in annual operating plans for their reservoirs.

In 2012, RTi continues to work with the WGRFC to develop basin and reservoir models that are used for water supply forecasting/ESP or for forecasting flood flows. In terms of water supply forecasting, RTi was hired to develop hydrologic models for six water supply forecast points in the Pecos River Basin in New Mexico.

What is the current NWS snowpack model?

The current snowpack model used by the National Weather Service is SNOW-17. Water supply forecasting uses SNOTEL to feed a calibrated lumped model called SNOW-17 developed in 1973. Its primary inputs are year-to-date precipitation and air temperature. SNOW-17 is a conceptual model, and most of the important physical processes that take place within a snow cover are explicitly included in the model, but only in a simplified form. There has been a scientific debate about whether calibrated lumped models are better than distributed models, and the answer is still uncertain.

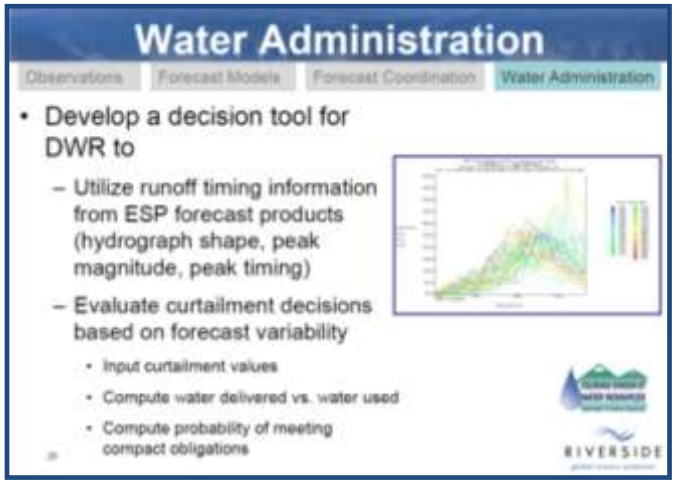
How is SNODAS used in the Rio Grande?

RTi, the CWCB, and the San Luis Valley ID, and RGWCD teamed up to provide SNODAS, above the Lobatos, Del Norte, and Magote compact index stream gauges to assist the Division Engineer in tracking melt out for comparison of forecasted runoff to actual runoff.

Five projects to improve forecasting are proposed by the aforementioned multi-agency team and are described below. These are presented in order of ranking of importance and immediate usefulness, as determined by the National Weather Service. These projects would take place in the Rio Grande watershed as demonstration projects, but the technologies could be eventually expanded statewide.

Project 1 - Rio Grande Compact Decision Support Tool

A DSS tool will be developed for the DWR that will combine the Ensemble Streamflow Prediction traces and planned curtailments to estimate water for delivery to New Mexico, water available to CO water users, and the probability of compact compliance. The tool provides improved scenario for establishing curtailments by using runoff timing information from the ESP to supplement the official seasonal forecast volumes. The tool will help to maximize the likelihood of compact compliance by using probabilistic information to account for the variability in the forecasts. The cost of this project is estimated to be $65,000.

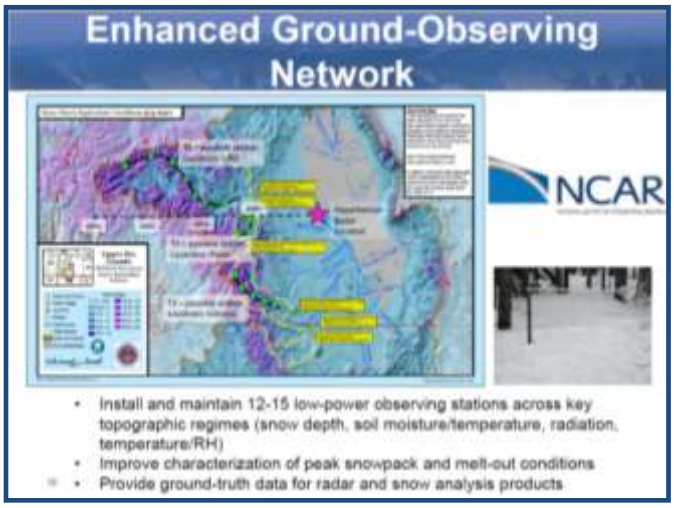


Project 2 - Generate historical forecasts

The redeveloped hydrologic models will be used to generate historical forecasts using Ensemble Streamflow Prediction for the period 1981-2008 at 22 forecast locations in CO to understand which of the hydrologic models perform well for forecasts. The results will support the WGRFC in future forecasts when disparate values are predicted by the regression models and the hydrologic models. The cost of this project is estimated to be $110,000.

Project 3 - Satellite data to improve SNOW-17

The dataset of historical snow-covered area from SNODAS and MODIS will be utilized to investigate whether the inclusion of observed snow-covered area data in the forecast models has the potential to improve the models or to explain historical errors. The cost of this project is estimated to be $35,000.

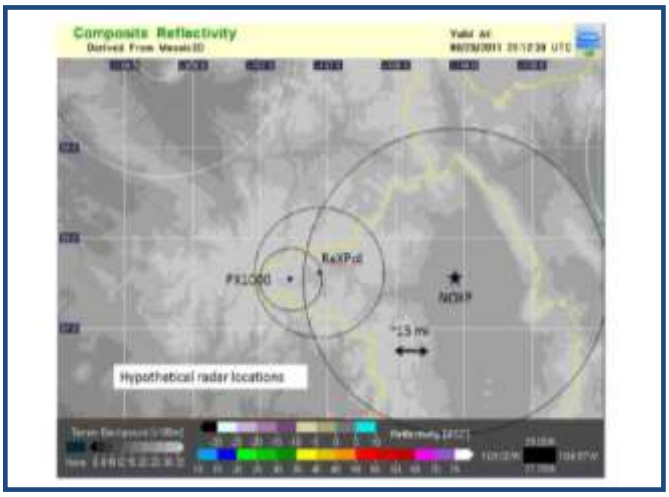


Project 4 – Enhanced Ground Observing Network

A network of 15 snow hydrometeorology stations will be installed and maintained for two snow seasons. These additional observations will enhance the precipitation and SNODAS SWE products. These observations will be used to validate basin average estimates of SWE and snow-covered area. Additional funding will be needed for O&M low cost sensors were intentionally selected to minimize future costs. The cost of this project is estimated to be $125,000.

Project 5 – Radar coupled to SNODAS coupled to the National Weather Service's Research Distributed Hydro Model

Radar will be deployed in the Rio Grande Basin from October 2013-May 2014. Radars will produce an enhanced gridded precipitation product (see http://nmq.ou.edu) as well as an enhanced SNODAS SWE product. The cost of this project is estimated to be $300,000. A more thorough description of this project is provided on the following pages.



NWS Priority Ranking of the Five Proposals:

Project Title (1)	Lead Agencies	Explanation	Cost Est.
Compact Compliance Tool	DWR, WGRFC, RTi	Ensemble Streamflow Prediction (ESP) forecasts to evaluate curtailment scenarios and estimate the probability of Compact compliance	$65,000
Strengths: Increase DWR understanding and use of forecasts to administer water and meet obligations.			
Limitations: None, but is short term need			
Project Title (2)	Lead Agencies	Explanation	Cost Est.
Generate Historic Forecasts	WGRFC, RTi	Use the 22 new hydrologic models to generate historic ESP forecasts for 1981-2008.	$110,000
Strengths: Builds historic data set for newly developed 22 hydrologic models to strengthen forecasts			
Weaknesses: None, but is short term need			
Project Title (3)	Lead Agencies	Explanation	Cost Est.
Snow Covered(4) Area data to improve snow modeling	WGRFC, RTi	Select four forecast locations and compared estimated from MODIS, SNODAS, and SNOW-17	$35,000
Strengths: Three sources of data for comparison. MODIS data was developed for the RFC and NRCS use			
Weaknesses: None, but may take time for CBRFC to develop methodology for use			
Project Title (4)	Lead Agencies	Explanation	Cost Est.
More Ground Observations	NCAR & CWCB	8 SNOTEL stations that will fill gaps in elevation bands not represented by existing SNOTELs	$65,000
Strengths: All models will benefit from different elevation band info. Designed to be low maintenance and calibrated to local SNOTEL SWE. Creates a legacy for better observations in the Rio Grande.			
Limitations: Will require to be maintained locally, probably by DWR.			
Project Title (5)	Lead Agencies	Explanation	Cost Est.
Radar + SNODAS + Distributed Hydro model	NOAA & CWCB	Radar coupled to SNODAS. Data provided to RFC operational system.	$300,000
Strengths: Radar creates continuous coverage and more detailed precipitation estimates. This will provide a rich source of data to models that can accept more detailed detailed.			
Limitations: New data sets from radar, new snow model, and new hydro model. Radar coverage issues remain after project. Project is only to demonstrate the feasibility.			

Summary: Staff believes all five projects have merit, and the Compact Compliance DSS tool may immediately benefit the DWR. Staff believes the Radar+SNODAS+Distributed Hydro (Project 5, outlined in more detail in the following pages) will benefit the state by building integrated systems through state of the art technology. This project will also help build the business case for gap filling radars. Filling the gaps will create complete Basin precipitation coverage and the resulting benefits are numerous.

State of the Science Basin Forecasting

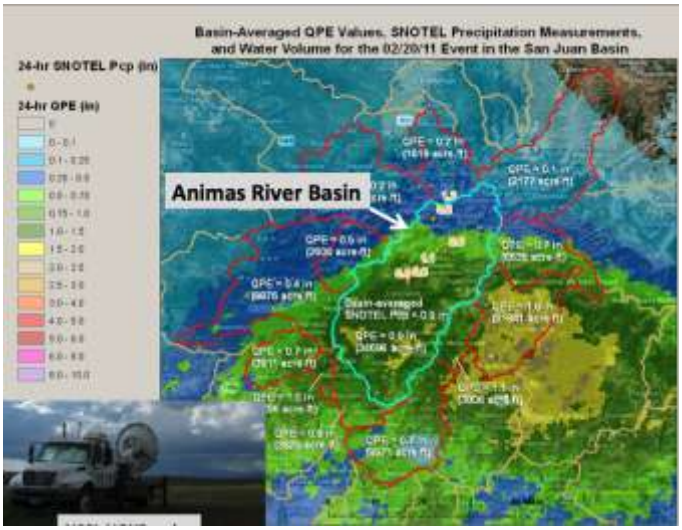
Forecasting Development Demonstration Project for the Upper Rio Grande (Project 5)

Introduction: In order to determine sources of and improve upon errors in water supply forecasts, a multi-faceted multi-agency approach is needed. The goal is to improve forecasting through demonstration of existing observing technology and modeling concepts through a pilot project in the Upper Rio Grande.

Project overview: A mobile Doppler radar will be deployed by the National Severe Storms Laboratory (NSSL) near Creede, CO during the 2013 water year with high confidence in observations over at least 75% of the basin above Del Norte. The NOAA/National Severe Storms Lab's (NSSL) Multi-Radar, Multi-Sensor system (MRMS; http://www.nssl.noaa.gov/projects/q2/) will be the platform for data integration and display. Calibrated radar data, along with MODIS satellite Snow Covered Area Gridded data (MODSCAG), will be used to adjust Snow Data Assimilation System (SNODAS; http://www.nohrsc.noaa.gov/) grids, recalling that SNODAS is based largely on a 3-hr forecast and limited SNOTEL data. In companion, the hydrologic modeling system operated by the West Gulf River Forecast Center (WGRFC) will run in parallel with the latest distributed hydrologic model. Each system will use different versions of a snow analysis to demonstrate the impacts of each component on the water supply forecast. In addition, enhanced intermediate products will be made available to the end user through the Colorado Decision Support System and other user-friendly interfaces to elicit feedback and recommend improvements to operations.

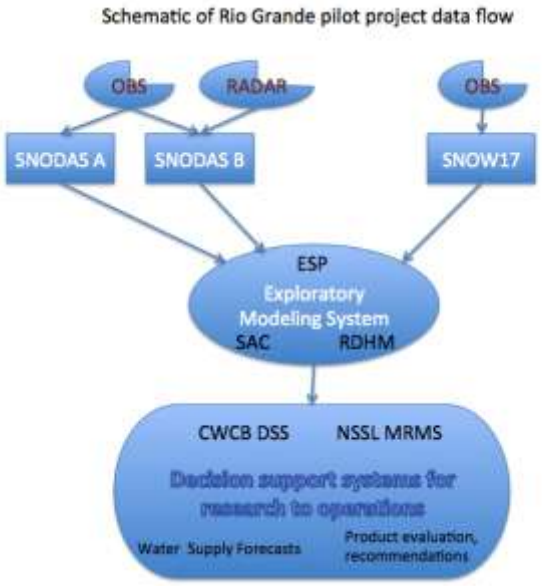
Upper Rio Grande Pilot Project

Objective: Improve snowpack observations and assess hydrologic model performance for improved situation awareness and water supply forecasts through sensitivity studies.



Observations: Radar has proven to provide spatial estimates of snowfall water equivalent (SWE). The image to the right shows basin-mapped SWE over the San Juan Mountains using an NSSL mobile gap-filling radar. For example, the Animas River Basin-average SWE from radar was equivalent to SNOTEL. Radar can provide spatial SWE estimates at up to 100 m resolution. In the Upper Rio Grande (3500 sq km), this conservatively equates to a data point every 1 km or 3500 SNOTELs for hourly/daily SWE precipitation observations.

Hydrologic Models: Historically, water supply forecasts used a multivariate regression analysis, which predicts seasonal water supply as a function of SWE observations at SNOTEL stations and snow courses. The CWCB has recently funded the development of hydrologic models for the West Gulf River Forecast Center (WGRFC). Hydrologic models are able to incorporate many more variables and new methods. There are two essential hydrologic modeling paradigms. The RFC SAC model requires calibration with at least a 30 year record of SNOTEL data. The SAC model is furthermore calibrated for a limited number of streamflow locations. Finally, this model uses large areas to compute mean areal precipitation; often these areas contain guesses for input data based on nearby data. New distributed models are more physically-based and use grid cells that can be aggregated to any scale. Thus streamflows can be extracted at many more points without the need for additional calibration.



The standard input to the SAC model for SWE is SNOTEL data through the SNOW17 model. This model uses limited physical processes to provide snowmelt to the model. The advanced SNODAS is a grid-based product at 1 km resolution with multiple inputs and a sophisticated physics package to drive SWE accumulation and depletion.

Project outline (see schematic):

1. Create new radar-derived SWE products by elevation band for decision support systems and model input
2. Using NSSL's MRMS system, nudge SNODAS with radar and MODSCAG data
3. Set up Research Distributed Hydro Model (Model A)
4. Set up the operational SAC model to mirror WGRFC configuration (Model B)
5. Integrate results within the Exploratory Modeling System
6. For a total of six scenarios, each model with run:
    a. With only SNOTEL
    b. With only SNODAS (already nudged with SNOTEL)
    c. With SNODAS nudged by radar

Partner roles:

1. CWCB – 1 August 2012 application to the state for $150K to set up hydrologic models and data infrastructure
2. NOAA Testbed – October 2012 application to NOAA for $150K to collect radar data in the Upper Rio Grande near Creede, CO for 7 months (1 Oct 2013-31 April 2014)
3. NOHRSC – advise on best practices for nudging SNODAS
4. WGRFC – advise on hydrologic model configuration and calibration; coordinate on use of NSSL-derived products

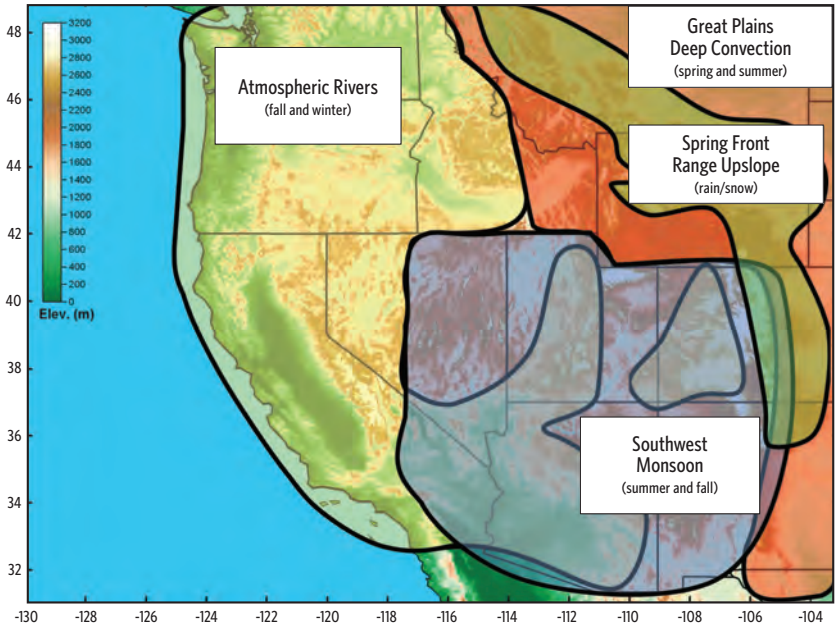
21ST CENTURY

Western Observing System for Extreme Precipitation

The Western States Water Council supports developing an improved observing system for extreme precipitation events in the West (position #332, adopted June 2011). A better ability to forecast the timing and amount of precipitation expected from major storms will benefit state flood management, emergency response, and traffic operations programs, as well as state, federal, and local reservoir managers and coastal resources managers. Recognizing the importance of preparing for climate extremes, the Western Governors' Association and the National Oceanic and Atmospheric Administration (NOAA) signed a memorandum of understanding in 2011 which called for undertaking projects to help reduce disaster risks associated with extreme events.

At the request of the Council and the California Department of Water Resources (CDWR), NOAA's Hydrometeorology Test Bed (HMT) program worked with the research community to develop a vision for a proposed 21st century Western observing

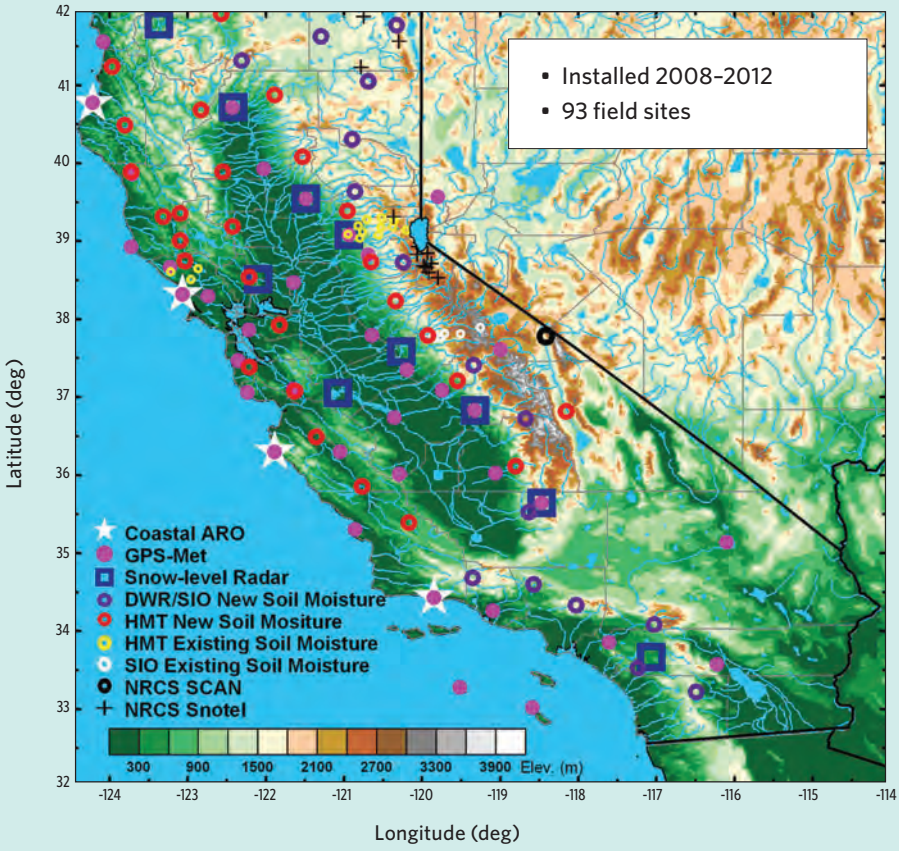
Regional variation in sources of Western extreme precipitation. *NOAA figure*



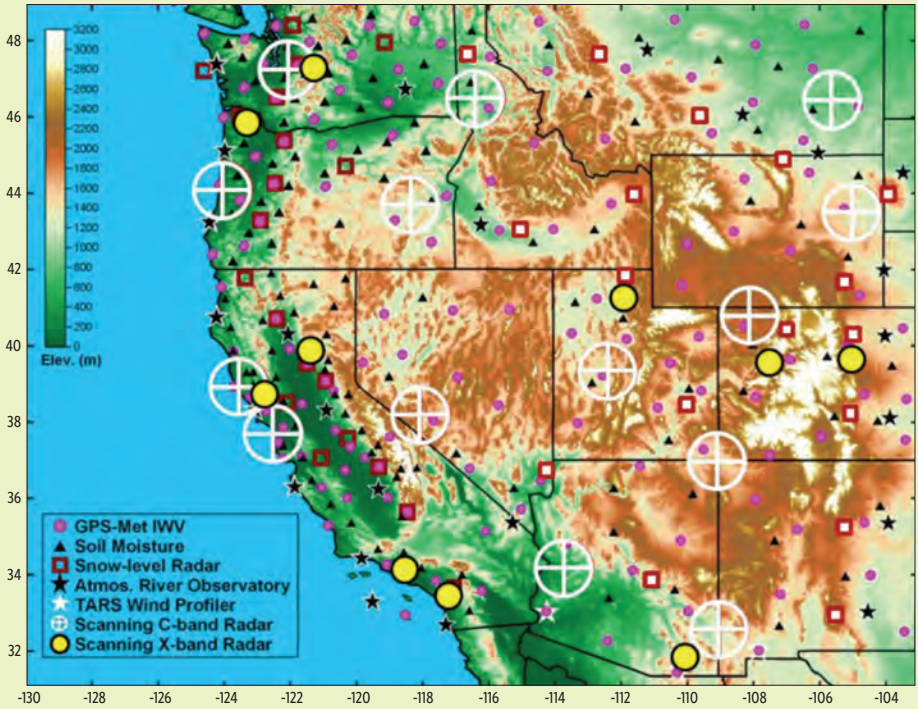
system for extreme precipitation. The observing system is based on experience gained in California, where the HMT program has partnered with other federal agencies, local agencies, and CDWR for almost 10 years to carry out field research and monitoring of winter storms. The HMT project's success in California and recent CDWR/NOAA efforts to permanently install HMT monitoring technologies prompted the Council's interest in expansion of these monitoring capabilities more broadly in the West.

The **HMT project's success in California** and recent CDWR/NOAA efforts to permanently install HMT monitoring technologies prompted the Council's interest in **expansion of these monitoring capabilities** more broadly in the West.

Examples of Existing and Potential Instrumentation



An AR-focused long-term observing network is being installed in California as part of a 5-year project between CDWR, NOAA and Scripps Inst. of Oceanography.
NOAA figure

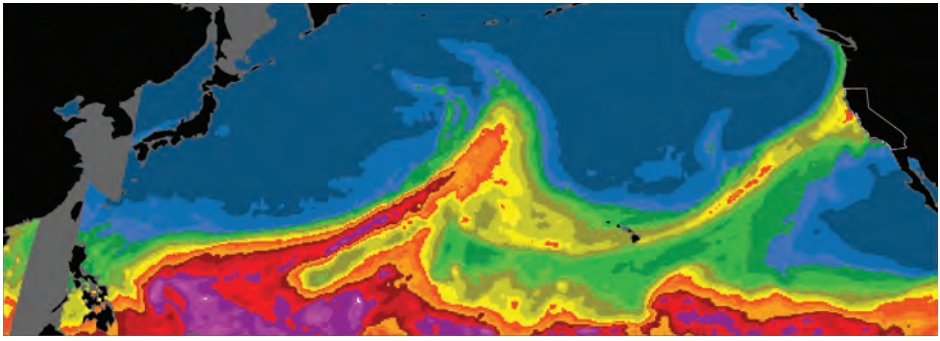


Schematic network of new land-based sensors to improve monitoring, prediction and climate trend detection for hydrometeorological conditions that create extreme precipitation and flooding. Offshore coastal sensors not shown.

NOAA figure.

The HMT project in California identified a major gap in existing hydrometeorological monitoring and precipitation forecasting — our limited ability to track and quantify water vapor transport from the Pacific Ocean across the West's mountainous terrain. Existing meteorological observations do not measure winds and water vapor far up enough into the atmosphere. Using new methodologies and technologies that have largely only become available in the past decade, the envisioned 21st century observing system would fill this gap and augment or complement existing monitoring networks already in place.

The HMT project in California identified a **major gap in existing hydrometeorological monitoring and precipitation forecasting** — our limited ability to track and quantify water vapor transport from the Pacific Ocean across the West's mountainous terrain.



Satellite image of atmospheric river reaching West Coast. Atmospheric river storms — storms fueled by concentrated streams of water vapor from the Pacific Ocean — are responsible for most episodes of major West Coast flooding. The HMT's efforts in California were responsible for identifying this storm type and its importance for flood management and water supplies.
NOAA figure

The envisioned Western observing system will require research and the development and installation of instrumentation to improve real-time tracking of hydrometeorological conditions, forecast lead times, and quantitative precipitation estimates for major storms in the West. Examples of needed instrumentation include atmospheric river observatories with specialized radars and other meteorological instrumentation such as wind profilers and water vapor monitors, together with precipitation, streamgage, and soil moisture networks and new types of snow instrumentation. Examples of needed research include developing offshore monitoring systems (e.g., buoy-mounted systems) to provide early warning and forecasting capabilities for major storms hitting the West Coast. The network design and combinations of instrumentation would vary from place to place as needed for observing specific storm types responsible for causing extreme precipitation in different areas of the West. West-wide installation of the observing system is estimated to cost in the range of $200 million over six years.

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western states
water council