CODOS – Colorado Dust-on-Snow – WY 2010
Update #1, Monday, March 1, 2010

Greetings from the Colorado Dust-on-Snow (CODOS) program team as we begin our series of Water Year 2010 Updates. Our team, comprised of Chris Landry at the Center for Snow and Avalanche Studies in Silverton, Dr. Tom Painter and his graduate students Annie Bryant and McKenzie Skiles at the University of Utah's Snow Optics Lab, and Dr. Jeff Deems at Western Water Assessment and the National Snow and Ice Data Center at the University of Colorado in Boulder, look forward to sustaining and enhancing these Update products during the coming several months. To that end, we will be conducting more intensive field monitoring at (now) eleven sites around the state this season, evaluating regional MODIS satellite imagery for radiative forcing by dust in snow throughout the spring, and initiating watershed-scale snowmelt modeling for the Uncompahgre River that incorporates the effects of dust.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	*tbd*	*tbd*	*tbd*	*tbd*	*tbd*

Water Year 2010 has already distinguished itself from Water Year 2009 by the absence of dust-on-snow events, to-date. By March 1, 2009 we had received three dust-on-snow events here in the western San Juan Mountains, at our Senator Beck Basin Study Area at Red Mountain Pass, but so far this season we have observed only one dust-on-snow event, labeled D1-WY10, on October 27, 2009 (see table above). That October 27th layer, although it deposited a significant amount of dust on the then-shallow snowpack, did not initiate a significant snowmelt surge at that time and will not play a major role in Spring 2010 snowmelt (except at the lowest snow-covered elevations), given its location at the bottom of the snowpack. The October 27 dust did, however, induce very large temperatures gradients within the snowcover and result in the formation of a structurally weak layer near the base of the snowpack which came into play during a major avalanche cycle in early December. While we have not been able to confirm them, we did receive reports of D1-WY10 as far to the northeast as Summit County – we will look for it later this month (see below).

The absence of dust-on-snow this far this season may be the result of persistent snowcover in the dust source regions. The same two storms that delivered our first significant winter storms in December also blanketed much of the Colorado Plateau. A second, week-long series of three major storms tracking through northern Arizona in January again blanketed the source area with heavy snow, mixed with rain in some locales, and resulted in snowcover extending well to the south (even to northern Alabama as the storm continued to the east!). Although that widespread snowcover has persisted, and been occasionally refreshed, throughout much of the Colorado Plateau, increasing

portions of the lower elevation terrain are now routinely losing snowcover between storms. Figure 1 below presents a map of continental US (CONUS) snow-covered area generated by NOAA on February 25, 2010, two days after a significant winter storm – note the extensive coverage in northeastern Arizona and the Four Corners. Figure 2, from March 1st, reveals how quickly portions of that desert snowcover can melt, exposing the ground. Spring snows can quickly restore widespread snowcover in the Plateau but rain-on-snow, and/or warm air temperatures, and/or local dust-on-snow can also quickly melt that snowcover. Currently, NOAA's Climate Prediction Center anticipates warmer and wetter than normal conditions for the March/April/May period in this region of the US.

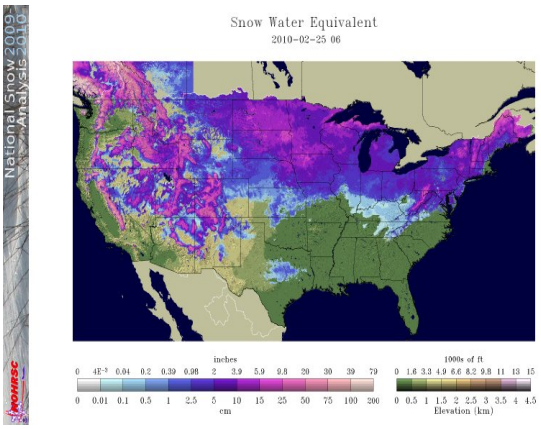

Figure 1 – CONUS snow water equivalent as of February 25, 2010.

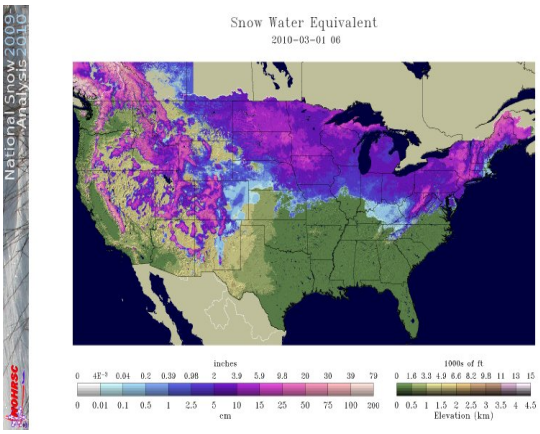

Figure 2 – CONUS snow water equivalent as of March 1, 2010.

In order to verify the presence or absence of the D1-WY10 layer, and to determine the "baseline" snowpack conditions at our CODOS monitoring locations throughout the Colorado mountains, we will conduct our first field monitoring campaign of the season beginning at our own Senator Beck Basin Study Area on March 21st and returning to Silverton on March 25th. That 1,000+ mile tour will, once again, include digging snow pits at our Park Cone, Spring Creek Pass, Wolf Creek Pass, Hoosier Pass, Loveland Pass, Berthoud Pass, Willow Creek Pass, Rabbit Ears Pass, and McClure Pass locations. In those snowpits we will note the presence (or absence) of any dust layers, their location within the snowpack, the snowpack temperature profile, and other notable features. On some of our CODOS site tours, Painter and his graduate students will also collect snow samples for spectroscopic and other analyses of the dust properties, and measure snow albedo.

In addition to those sites, CODOS is now benefitting from continuous monitoring of snowpack albedo and other snow and weather variables at the new Grand Mesa Study Plot (GMSP), a collaborative effort between the USGS Southwest Biological Sciences Center at the Canyonlands Research Station in Moab, Tom Painter and the Snow Optics Lab at the University of Utah, and the Center for Snow and Avalanche Studies. CSAS installed the new 10-meter tower and instrumentation at the site last fall (Figure 3), located at 10,600' within the Skyway Nordic Ski Trail System. This GMSP infrastructure was fully funded by USGS through the Snow Optics Laboratory – no CODOS funds were used for this installation. The GMSP site includes the same albedo

monitoring sensors employed in the Senator Beck Basin Study area. Given its location on the Grand Mesa, those sensors could document previously unmeasured changes in snow albedo resulting from dust-on-snow events that enter the Colorado mountains on more northerly or westerly storm tracks, along the I-70 corridor, and that do not produce dust-on-snow farther south in the San Juan Mountains. CODOS will also visit GMSP and conduct snowpack profiles there during our state-wide field campaigns, and GMSP data are downloaded daily, via cellular communications.

Figure 3 – the new Grand Mesa Study Plot snow albedo monitoring instrumentation array just after startup, on October 18, 2009.

That concludes this CODOS Update. As and when we receive new dust events, and/or after we complete our first CODOS site tour, we will provide further Updates.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #2, Monday, March 29, 2010

Between March 21st and March 26th Chris Landry and Andrew Temple, from the Center for Snow and Avalanche Studies, completed the first WY 2010 Colorado Dust-on-Snow tour of the State, performing snowpack profiles at all eleven of the sites being monitored by CODOS (see Figure 1). We were joined at the Grizzly Peak (Loveland Pass) and Berthoud Summit sites by CODOS collaborator Dr. Jeff Deems, from Western Water Assessment and the National Snow and Ice Date Center at the University of Colorado.

No discernible dust layers were observed in the snowpack at any of these sites during this field campaign (aside from the October 27, 2009 (D1) layer found at or near the ground in the Swamp Angel and Grand Mesa plots). Table 1 (next page) presents the depth of the snowpack and snowpack temperatures observed at the CODOS pit locations, all of which are in open meadows, and data from their respective adjacent Snotel sites.

Figure 1: *CSAS and CODOS field assistant Andrew Temple identifying snow crystal types during the McClure Pass snowpack profile performed early on March 25th. A profile of snow temperatures taken every 10 cm is underway in the shaded corner of the pit.*

Aside from the absence of dust layers, other notable observations from our snowpack profiles included the presence of multiple melt-freeze crusts and/or thick, clear ice layers in the upper portion of the snowpack at most sites. These layers were generated in relatively clean snow by solar absorption and warmer air temperatures; additional absorption of solar energy by dust did not play a role in forming those layers. Further, we found evidence of snowpack wetting in the middle and lower snowpack at Wolf Creek, Berthoud, Rabbit Ears and McClure Passes, probably from free water percolation during the warm weather (and/or rain?) that generated the ice layers and melt-freeze crusts in the upper snowpack at those sites.

Table 1: *CODOS March 2010 Tour Snowpit Data*

CODOS Monitoring Site	Most Recent CODOS Snow Pit	Most Recent CODOS Snow Pit Depth (HS)	Mean Snowpack Temperature Deg C	SWE at Adjacent SNOTEL Same Day
Swamp Angel Study Plot *(1)*	3/21/10	79"	-3.7	20.3" (23.9")
Park Cone	3/21/10	38"	-2.1	9.2"
Spring Creek Corrals *(2)*	3/22/10	38"	-5.5	*na*
Wolf Creek Summit	3/22/10	82"	-0.9	33.3"
Hoosier Pass	3/23/10	52"	-4.2	12.9"
Grizzly Peak	3/23/10	37"	-4.9	11.0"
Berthoud Summit	3/23/10	56"	-3.1	16.8"
Willow Creek Pass	3/23/10	31"	-2.6	6.2"
Rabbit Ears (West Summit)	3/24/09	61"	-3.2	14.3"
McClure Pass	3/25/09	43"	-1.6	16.6"
Grand Mesa Study Plot *(3)*	3/25/10	67"	-2.2	14.6"

(1) Red Mountain Pass Snotel SWE shown; SWE in parentheses is actual measured SWE at Swamp Angel Study Plot
(2) No Snotel station near our Spring Creek (Pass) Corrals CODOS monitoring site
(3) Nearest Snotel to Grand Mesa Study Plot is Mesa Lakes, 2 miles to the west and 600 feet below GMSP

Last, some sites did contain moist snow in the lower snowpack – Wolf Creek Pass, McClure Pass, and Grand Mesa – and the pits at Wolf Creek Pass and McClure Pass were approaching isothermal snow temperatures throughout all but the near-surface layers.

Of course, it was also striking how thin and patchy the snow cover was in the mountains of Summit County, the Front Range, and the Middle Park valley, as we drove through. Conversely, we were struck by the substantial valley floor snowcover in the Rio Grande River valley above Creede. Although the up-slope storm that was in progress as we passed through Berthoud Pass and Willow Creek Pass on March 23rd did produce additional SWE in those locales, a SWE deficit persists in most watersheds along and north of I-70.

In the meantime, since Update #1, the intermittent pattern of drying, followed by re-wetting, followed by re-drying in the Colorado Plateau has continued over the past month. We have logged five winter storms at our Senator Beck Basin Study Area in March, all of which tracked through the Plateau. First hand accounts from locales like Moab, Bluff, and Kayenta report that soils have remained moist and/or briefly snow-covered over very large portions of the dust source area. Snowcover tracking maps generated by the National Operational Hydrologic Remote Sensing Center (such as the examples shown in Update #1) document that on/off pattern of drying/wetting and continue to show heavy snowcover over the highest terrain in the Plateau, the residual of record storms in mid-winter.

Notwithstanding this slow drying of soils in the dust source area, should drier weather dominate the balance of the spring, those soils will still have the opportunity to become available for wind transport, and could still generate significant dust-on-snow deposition here in Colorado during snowmelt season, given sufficiently energetic winds. As Table 2 below shows, since we began rigorously monitoring dust-on-snow, the months of April and May have produced the majority of events observed here in the western San Juan Mountains.

Table 2: *Dust-on-Snow Events 2002/2003 through 2009/2010, to-date*

Dust-on-Snow Events Documented per Month, by Winter **Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains**										
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	*tbd*	*tbd*	*tbd*	*tbd*	*tbd*

The impact of multiple, major dust layers was well demonstrated during the spring of 2009. However, the potential impact of a single significant dust layer was also demonstrated during the Colorado snowmelt season of 2006 when the February 15, 2006 dust layer emerged and stayed at the snowpack surface during a prolonged period of dry and sunny weather that spring, advancing snowmelt and "snow all gone" (SAG) by as much as 30 days.

Given current snowpack conditions, late-season dust-on-snow accompanied by a prolonged period of dry and sunny weather could result in two worrisome scenarios. Those areas with already diminished snowpacks could experience rapid snowmelt and reach SAG at very early dates. Conversely, other areas with heavy low-elevation snowpacks like the Rio Grande River valley and southern slopes of the San Juan Mountains could experience rapid acceleration of snowmelt at both high and low elevations concurrently, generating flooding potential. If and when we receive new dust events, we will issue Alerts.

Our next CODOS tour around the state is scheduled for the week of April 12-16 and will revisit the 11 monitoring sites with an expanded team including Dr. Tom Painter and his graduate students Annie Bryant and McKenzie Skiles. That will be preceded, during the week of April 5th-9th, by a very intensive, very high-tech field campaign here in Senator Beck Basin. Several teams will converge that week from throughout the country to deploy radar, lidar, field spectrometry, and other technologies to ground truth SWE and snowpack data collected by satellites passing over Senator Beck Basin several times that week. There may be no new dust in the snowpack by that time but, weather permitting, this campaign could nonetheless represent a significant new dataset for the field of snow hydrology and advance the interpretation of remote sensing data of SWE and other snowpack properties. Our next Update will be issued no later than just after our April tour. In the interim, please feel free to contact us if you have any observations or questions for us.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #3, Friday, April 9, 2010

Figure 1: *Recent dust layers D2, D3, and D4 are seen in profile at the Swamp Angel Study Plot at Red Mountain Pass on April 6, while collecting a 0.5 m^2 "bulk sample" of the merged D3/D4 layer. Chris Landry is pointing to the D2 (March 30/31) layer, and the merged D3/D4 are seen above D2, a couple of inches below the snowpack surface. The layer seen below D2 is an ordinary melt/freeze layer produced by warm air temperatures (only).*

Since Update #2, issued March 29, 2010 a series of three closely spaced dust events has resulted in widespread dust-on-snow deposition throughout the Colorado mountains and beyond to the Great Plains (Figure 1). The first of those – event D2-WY2010 – arrived in the late afternoon of March 30th and continued into the early hours of March 31st here in the western San Juan Mountains and our Senator Beck Basin Study Area, depositing approximately 2 grams of material per square meter, followed by several inches of snow. That D2 event was widely observed throughout the Colorado mountains as the first dust-on-snow event of the season. The next event – D3-WY2010 – followed on April 3rd. D3 was a dry event, without associated precipitation, that fell

onto and remained exposed at the snowpack surface. Then, the most significant event – D4-WY2010 – came closely on the heels of D3, with only a few hours of clear skies between, depositing directly onto and merging with the D3 layer on April 5th. D4 began here in the San Juan Mountains as a dry event mid-day and intensified during the afternoon and evening (Figure 2), running into the night. Fresh snowfall began covering that merged D3/D4 layer later that night and continued into the following day.

Figure 2: *Event D4-WY2010 in progress during the late afternoon of April 5, 2010 as seen from Silverton. The evident reduction in visibility continued into the evening almost entirely obscuring the timbered slope in the distance. This dust storm was considered comparable to, or even more intense than, the notorious event of April 3, 2009 in Silverton and other mountain locales.*

While not always tied to the precise sequence of events observed here, numerous reports of significant and fresh dust layers in the snowpack have been received during the past week from most of the locales that CODOS monitors and offer very good evidence that some or all three of these events – D2, D3, and D4 – have impacted most or all Colorado mountains. Some reports suggest that the D4 event was particularly intense along the I-70 corridor. Table 1 below updates our Water Year 2010 tally of dust-on-snow events, showing at least two events to-date in April. The dust deposition (in g/m^2) for D3 and D4 will be analyzed by the Snow Optics Laboratory during the coming week.

Here in the western San Juans, where the new snow above the merged D3/D4 layer was either thin (generally less than 6 " deep), or non-existent (due to wind scouring), dirty snow now dominates the snowpack surface at the lowest snow covered elevations and is rapidly emerging on

east, south, and west aspects at treeline and above. Scattered reports from other locales to the north and east indicate a similar, rapid emergence of (most likely) the D4 layer over the past 48 hours.

Table 1: *Dust-on-Snow Events 2002/2003 through 2009/2010, to-date*

Dust-on-Snow Events Documented per Month, by Winter **Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains**										
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2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	1	*≥2 tbd*	*tbd*	*tbd*	*tbd*

As of this writing, the National Weather Service's Grand Junction office anticipates that sunny skies will dominate all but the more northern mountains for the coming weekend (April 10th and 11th), perhaps only interrupted by occasional showers in the Flattops, Elkhead, Zirkel, and North Park areas. Somewhat more unsettled weather is expected during the week of April 12th although some areas will have periods of sunny weather during the early week.

Given the proximity of the D2-D4 dust layers to the snowpack surface, or that they have already emerged at the surface, radiative forcing by dust will increase snowpack temperatures today and this weekend. Where snowpack temperatures were either close to or already isothermal (at 0° C) radiative forcing will also enhance snowmelt runoff rates. Our most recent snowpack profile at the Senator Beck Study Plot revealed that considerable cold content (mean temperature of -4.1° C) is still present in the snowpack at that 12,200' elevation. Radiative forcing by dust at alpine elevations will accelerate the reduction of that cold content but, over the course of the coming week, is unlikely to initiate any significant snowmelt runoff surge; we will monitor the Senator Beck Basin Stream Gauge. However, at the lowest snow covered elevations in the Rio Grande, San Juan, Animas, Dolores, San Miguel, and Uncompahgre watersheds, and particularly where lower elevation snowcover has been unusually heavy this season, a dust-driven snowmelt surge may be underway and could accelerate over the coming several days, aided by higher air temperatures. Until the higher elevation snowpack in those watersheds loses more cold content, and approaches isothermal temperatures, that low elevation surge does not seem likely coincide with a surge from the higher elevation snowpacks.

The CODOS team will conduct another field campaign traveling to all eleven of our monitoring sites during the week of April 12-16, documenting the presence (or absence) of the D2/D3/D4 layers, their position within the snowpack, and snowpack temperatures. Snowpack samples will also be collected by the Snow Optics Laboratory and 'spot' albedo measurements made, along with other spectral measurements, for comparison with remote sensing (MODIS) imagery, quantifying the increase in net solar radiation. We will issue Update #4 following that tour of our sites, and issue a new Dust Alert should any new dust-on-snow events occur in the interim. Update #4 will also include the Snow Optics Laboratory's new product, MODIS Dust Radiative Forcing in

Snow (MOD-DRFS). This analysis will provide maps over the Upper Colorado River Basin of how much additional radiation is being absorbed by dust and will include site specific data for the eleven CODOS monitoring locations.

We greatly appreciate the observations of dust-on-snow we've been receiving from you as you visit your watersheds and welcome the opportunity to discuss your local conditions – feel free to call or email us at any time.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #4, Tuesday, April 20, 2010

The clean and cool snowpacks observed during the March 21st-25th Colorado Dust-on-Snow (CODOS) tour of our eleven monitoring locations are a thing of the past and dust-enhanced radiative acceleration of Colorado snowmelt has commenced. Field observations at our eleven CODOS monitoring locations from Monday, April 12th through Friday, April 16th found all or most of the previously reported dust layers D2, D3, and D4 merged and exposed at or just below the snowpack surface (Figure 1). Based on the observed color of the D4 event in the San Juan Mountains, it appeared that all eleven sites had, at a minimum, received D4 dust and that D4 was the dominant layer reducing snowpack albedo. Further, most or all of the snowpack cold content measured during our first CODOS tour in March had been removed and all snow temperature profiles collected during this trip were either at or very close to isothermal, at 0° C. Except on Tuesday, April 13th (during a snowstorm), we observed active melt at the snowpack surface at all sites, enhanced by radiative forcing by dust at or just below the snowpack surface, with wet or moist snow throughout the eleven snowpack profiles we performed.

Figure 1: *Early on Monday, April 12th at the Swamp Angel Study Plot, collecting "gravimetric samples" of dust concentration within the top 30 cm of the snowpack in ten separate 3 cm thick samples of a column 0.05 m^2 in area. Dust layers D2, D3, and D4 are all merged at the snowpack surface in this photo, prior to deposition of D5 dust later that day.*

Those merged D2/D3/D4 layers were supplemented at most or all locations by a fifth dust-on-snow event (D5-WY2010) on Monday evening and Tuesday, April 12th and early on the 13th, falling directly onto that dirty snow surface. A generally thin layer of wind-drifted new snow then partially buried that dirty surface on Tuesday, the 13th, but by Wednesday the dirty surface, heated by

radiation penetrating that thin layer of new snow, was rapidly melting the overlying new snow and re-emerging (Figure 2).

Figure 2: *McKenzie Skiles of the Snow Optics Laboratory photographing the snowpit face and the merged dust layers at the Grizzly Peak site on Loveland Pass Wednesday, April 14th. Even in this un-altered photo, the tinge of the thinly buried dust layer can be seen through the new snow and the reduced snow albedo is apparent.*

A surge in snowmelt rates is seen in hydrographs from most of the watersheds being monitored by CODOS. Rivers emanating from the San Juan Mountains (Figures 3 and 4) show a discharge surge during the past ten days, following and assisted by the deposition and widespread emergence of D4. Stormy weather on April 13th briefly reversed the increase, delivering colder temperatures and some fresh snow, but the surge quickly resumed in the following days.

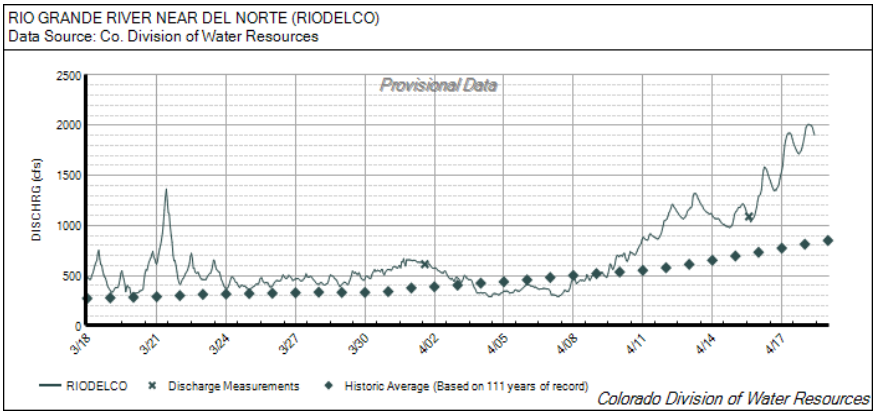
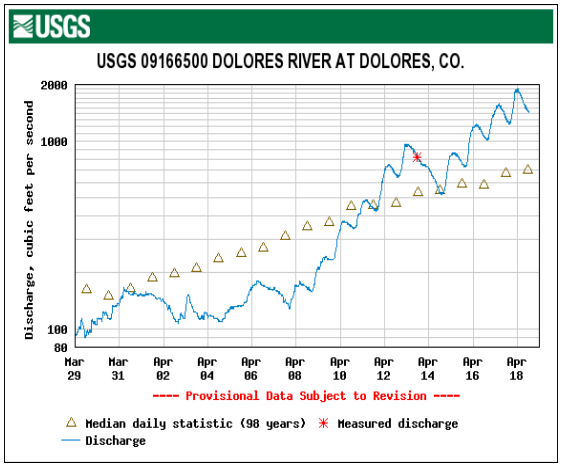
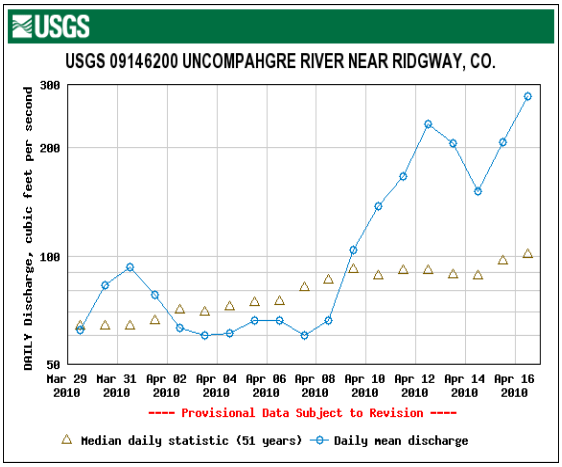
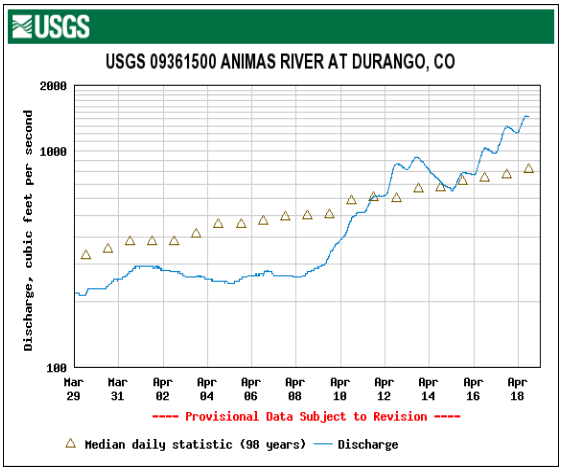


Figure 3: *The Rio Grande River hydrograph includes a controlled release in late March.*







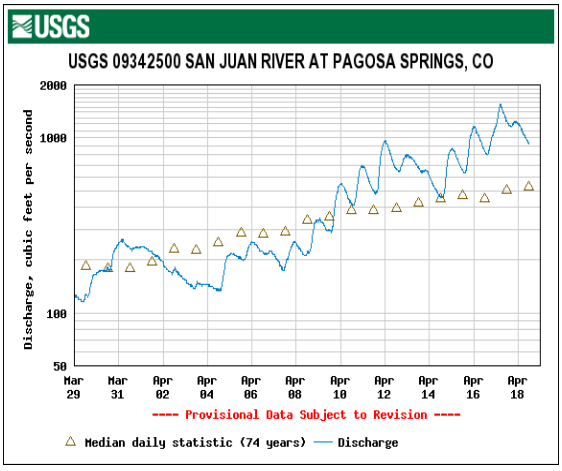
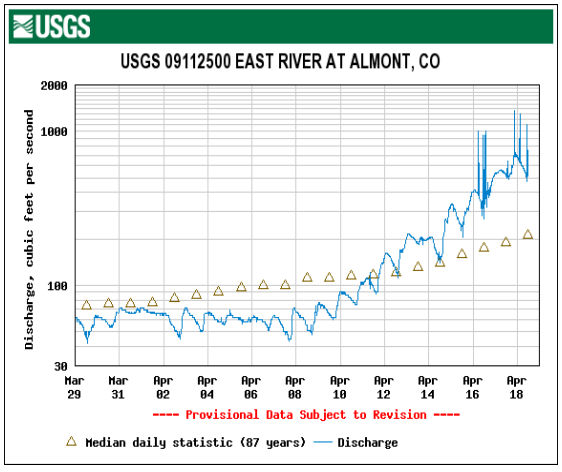


Figure 4: *March 29 through April 18 for watersheds flowing south, west, and north from the San Juan Mountains.*



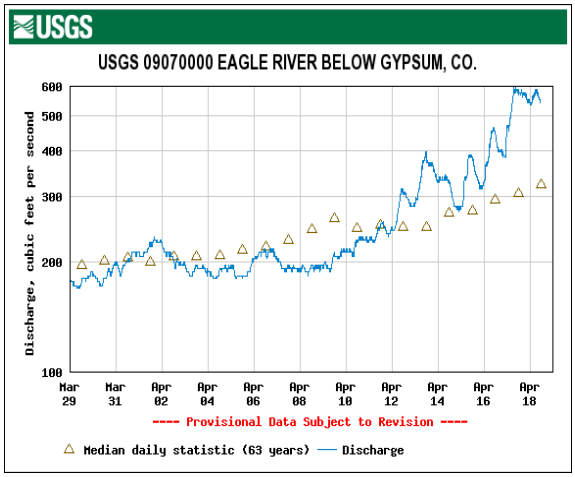


Figure 5: *the East River and Eagle River hydrographs for March 29 through April 18.*

Watersheds farther north and east of the San Juans also displayed the pattern seen in the San Juan drainages, with daily increases in discharge (Figure 5).

Data from the Snotel stations adjacent to our CODOS monitoring sites have also begun to show declining SWE, with rapid rates at some locations. Many sites along or north of the I-70 corridor have begun that decline with peak SWE values in the lower quartile of the site's period of record, whereas sites in the San Juan Mountains recorded peak SWE values at or near the mean or median for their period or record. Figures 6 and 7 present SWE data that bracket that regional difference, from the southwestern Lizard Head Pass Snotel site to the northeastern-most site that CODOS monitors, at Willow Creek Pass. Given the dust already present, and the potential for additional dust deposition, some northern Snotel sites such as Willow Creek Pass may experience complete loss of snowpack (snow all gone) at record or near-record early dates, given a sustained period of clear skies and prolonged emergence of the dust early in May.

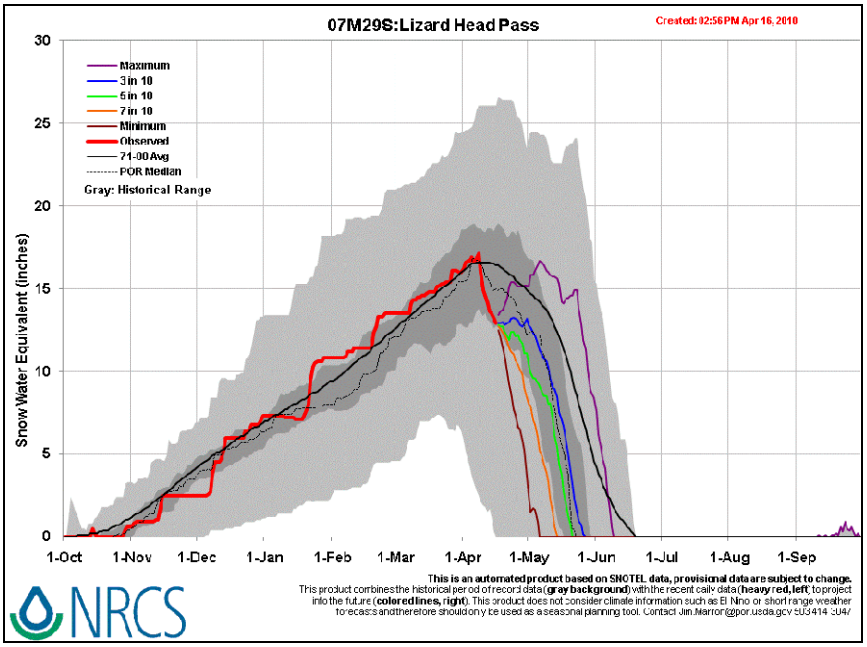


Figure 6: *initial rates of SWE loss at Lizard Head Pass have been rapid but began at near median (and mean) peak values, on nearly the normal date of peak SWE. Note that the snowmelt scenarios represented by the colored traces originating at the end of the red (year-to-date) traces in these plots do not include projected dust-on-snow effects.*

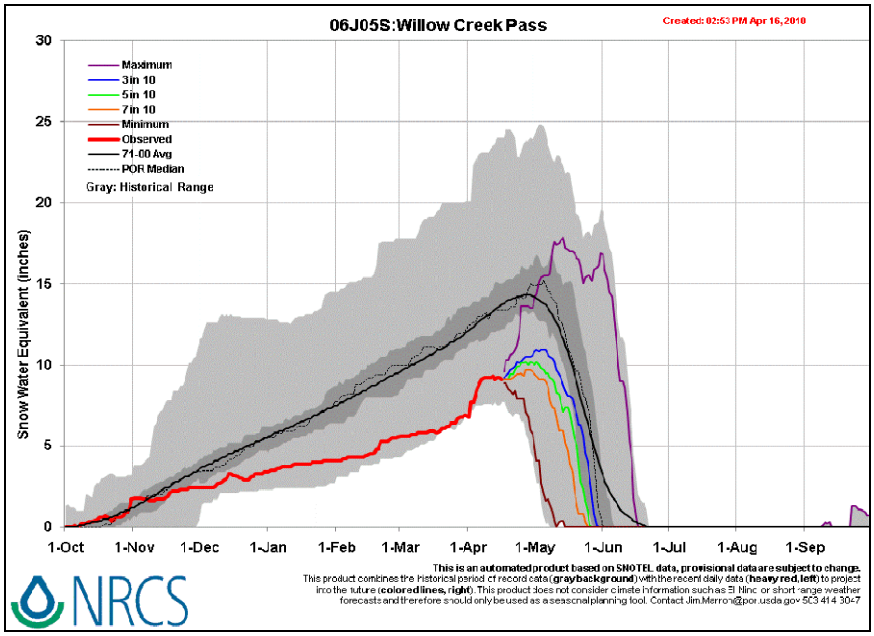


Figure 7: *barring additional significant snowfall, peak SWE has occurred well ahead of the median and mean date at Willow Creek Pass, at a level well within the lowest quartile of peak SWE values in the period of record. Note that the snowmelt scenarios represented by the colored traces originating at the end of the red (year-to-date) traces in these plots do not include projected dust-on-snow effects.*

Our log of dust-on-snow events since the winter of 2002/2003 (Table 1) suggests that additional dust depositions could occur during the remainder of this snowmelt season. Anecdotal reports from travelers in the Colorado Plateau source area indicate that recent storms experienced in Colorado have not substantially wetted and reversed the drying of soils in southeastern and eastern Utah and northeastern Arizona, but detailed, real-time field data quantifying soil moisture conditions in the Plateau remain elusive.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	1	*≥3 tbd*	*tbd*	*tbd*	*≥5 TBD*

Table 1: *Dust-on-Snow Events 2002/2003 through 2009/2010, to-date*

As of this writing, the National Weather Service in Grand Junction anticipates that a cold Pacific closed low pressure system moving on shore today will track through Arizona on Thursday, with strong S'ly winds here on the Western Slope on Wednesday. These conditions are conducive to dust emission from the Colorado Plateau and Great Basin and deposition to the Colorado River Basin. NWS is currently not predicting significant snow amounts that could deeply bury either any new dust, which we may receive on Wednesday, or the merged D5/D4/D3/D2 dust layer(s) already at or near the surface. Sunny skies may return late next weekend but another weather system from the north Pacific is anticipated to enter the West Coast next week.

Given that forecast, it is important to note that, even with the showery weather and extensive cloud cover we've experienced during the afternoons in the past several days here in the San Juans, and the small amount of new snow we received overnight last Friday, our Senator Beck Basin stream gauge has registered increases in flow each day. Further, on recent cloudy days, our radiometers in Senator Beck Basin continue to record 80-85% of the incoming radiation measured during preceding clear days, and the D5/D4/D3/D2 dust that was thinly buried last weekend continues to re-emerge at the snowpack surface on all but the highest northerly terrain. Barring a more significant winter storm than is currently being described by NWS, current snowmelt rates may be only minimally and temporarily reduced and then quickly rebound late this week and next weekend.

A final note – once again, this spring's dust-on-snow has triggered considerable interest in the Colorado and national press, and the principals of the CODOS team, including our colleague Jeff Deems, are doing our best to assist reporters in conveying correct and accurate information to their readers. Please let us know if your local paper would like to contact us, or that we need to contact them with a clarification or correction.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #5, Monday, April 26, 2010

The return of winter weather late last week did, in the end, produce substantial snowfall in most Colorado mountain ranges, adding welcome SWE to the snowpack and burying the widespread D5/D4/D3/D2 merged dust layers reported in Update #4 at depths that have largely curtailed the absorption of solar energy by that dust. Here in the San Juan Mountains at our Senator Beck Basin Study Area the clean new snow overlying the dust is 8" or more thick (Figure 1).

Figure 1: *The D5/D4/D3/D2 merged dust layers at the Swamp Angel Study Plot at Red Mountain Pass are shown buried under 8" of rapidly settling clean new snow on Monday morning, April 26th. The plate in the photo facilitates our "gravimetric sampling" of dust mass from an isolated column of snow 0.05 m2 in area. Ten samples are collected, in 3 cm slices of the column, down to a depth of 30 cm.*

Table 1 (next page) presents a tally of changes in SWE and snowpack depth resulting from that April 22-25 storm period at the Snotel sites adjacent to our CODOS monitoring sites, and at three additional Snotel locations. Much larger snow totals were observed at other locations in the northern mountains, ranging up to 30". Note that ratios of new snow to new SWE at these Snotel sites shown in Table 1 vary considerably, and that Park Cone actually lost SWE and snowpack depth during the period, perhaps indicating that much/most precipitation fell as rain at some sites.

Significant SW'ly winds preceded that large weather system on Wednesday, April 21 and may have entrained dust in the Colorado Plateau source area. However, coinciding precipitation, much of it in the form of rain on Wednesday afternoon, may have quickly scrubbed that dust out of that SW'ly flow before arriving in the Colorado mountains. No new dust was observed in the air here in the Silverton area on Wednesday, before nightfall, but we have heard reports of possible dust in the air in other locales that afternoon. In any event, dust entering the Colorado mountains on Wednesday afternoon and evening would have been deposited onto an already dirty snowpack surface at most elevations and on most aspects. Frontal passage and the surge of colder air on NW'ly flow early Thursday morning (rattling homes at 3:30 AM here in Silverton) delivered the first increment of new snow to cover the pre-existing dirty snow surface, totaling almost 8 inches at the Senator Beck Basin Study Area and somewhat more than that in ranges to the north and east of us. Rapidly clearing skies that morning did result in the partial re-emergence of the dirty snow at lower elevations by later that afternoon, here in the western San Juan Mountains, just as the next wave of new snow began. Substantial amounts of new snow continued to accumulate in most Colorado mountain locations through Saturday, April 24th, and most beneficially in the ranges to the north and along the I-70 corridor where, as was discussed in Update #4, snowpacks have been especially poor.

Table 1: *Changes in SWE and snowpack depth at Snotel sites adjoining CODOS monitoring sites during the period April 21-25, 2010.*

Site	April 21-25 Change in SWE	April 21-25 Max Change in Snowpack Depth
Swamp Angel Study Plot *(1)*	+1.8"	+12"
Park Cone	-0.5"	-3"
Spring Creek Corrals *(2)*	+0.8"	+3"
Wolf Creek Summit	+0.6"	+4"
Hoosier Pass	+1.3"	+9"
Grizzly Peak	+1.2"	+12"
Berthoud Summit	+2.2"	+17"
Willow Creek Pass	+2.7"	+15"
Rabbit Ears (West Summit)	+1.3"	+3"
McClure Pass	+0.4"	+4"
Grand Mesa Study Plot *(3)*	+1.3"	+7"
Beartown	+0.6"	+3"
Lizard Head Pass	+0.8"	+6"
Schofield Pass	+1.8"	+11"

(1) Data is actual measured precipitation and new snow at Swamp Angel Study Plot
(2) Nearest Snotel to Spring Creek monitoring site is Slumgullion, 5 miles NNW and 600 feet above Spring Creek
(3) Nearest Snotel to Grand Mesa Study Plot is Mesa Lakes, 2 miles to the west and 600 feet below GMSP

As would be expected, restoring a high albedo to Senator Beck Basin by burying the D5/D4/D3/D2 dust layer with up to 12" of clean new snow, and cooler, stormy weather has resulted in largely reversing the steadily rising streamflows observed up to April 21st (Figure 2). The same declining trend in runoff can be seen in updates of the hydrographs presented in Update #4, returning many San Juan Mountain watershed discharge levels to near-median values for a particular gauge. It should be noted that those stream gauging stations are located at considerably

lower elevations (than the Senator Beck Basin gauge) and recent rain and low-elevation snowmelt may have partially offset the reductions in high elevation runoff during this period in those watersheds, resulting in a proportionally smaller decrease in flows than is shown for Senator Beck Basin.

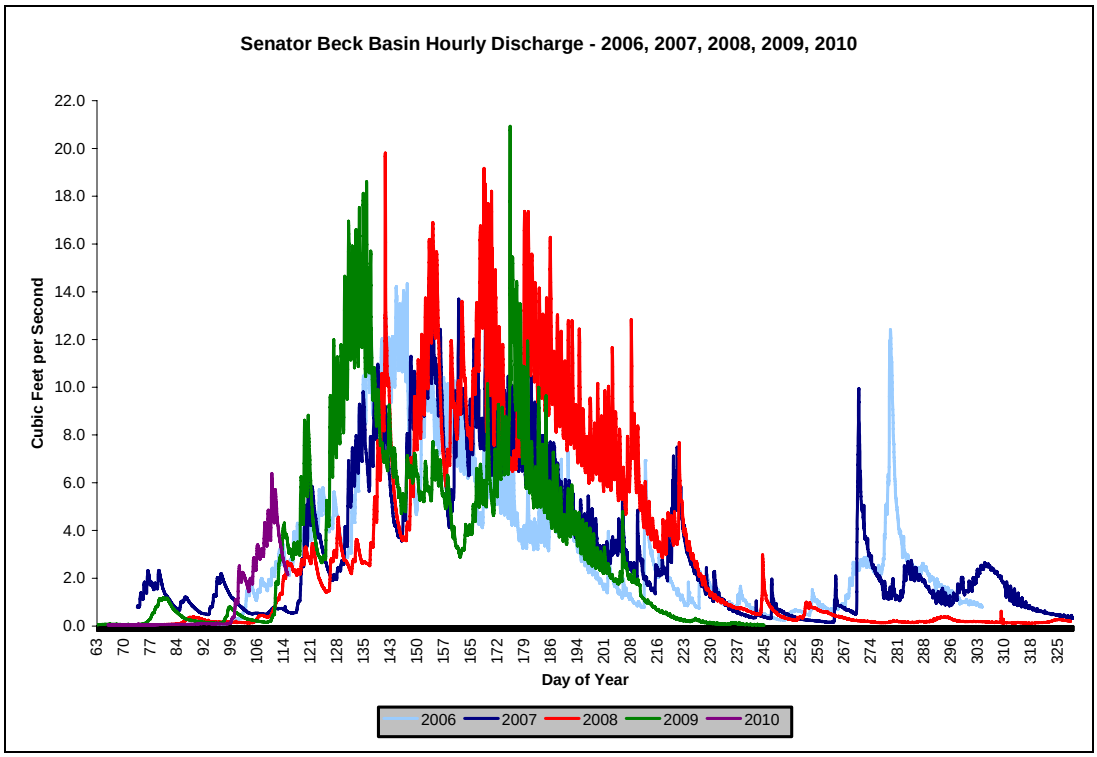

Figure 2: *Senator Beck Basin discharge, showing spring 2010 in purple, and 2009 in green.*

The return of generally sunny and warmer weather throughout the Colorado mountains on Monday and Tuesday, April 26th and 27th, will result in settlement and thinning of the layer of recent new snow now overlying the widespread D5/D4/D3/D2 dust layer and that dirty surface may fully or partially re-emerge in some locales, depending on depth of burial, aspect, and elevation. However, the National Weather Service in Grand Junction anticipates another large low pressure system to dominate Colorado weather later this week, preceded by potentially strong SW'ly winds here on the Western Slope, once again on Wednesday. This approaching weather system may deposit a new dust layer on top of the recent clean snow, or further bury the existing dust layer(s) under additional clean snow, or do both. Although unsettled and cooler weather may dominate the remainder of the week and weekend, weather models have not yet converged on the detailed behavior of this large area of low pressure and NWS is not currently predicting snowfall amounts.

Nonetheless, a prolonged period of high pressure and sunny weather is not anticipated for the remainder of April and longer-term NWS forecasts show better than even chances for continued moist weather in Colorado during the month of May (Figure 3). If that pattern verifies, those conditions may delay and/or moderate the radiative forcing of snowmelt that will eventually result

as the D5/D4/D3/D2 layer re-emerges, or as new dust layers are deposited in advance of additional snowfalls, as was experienced during the spring of 2008. That spring, episodes of emergent dust were interrupted by new snowfalls resulting in alternating high- and low-albedo conditions at the snowpack surface, and snowmelt was prolonged.

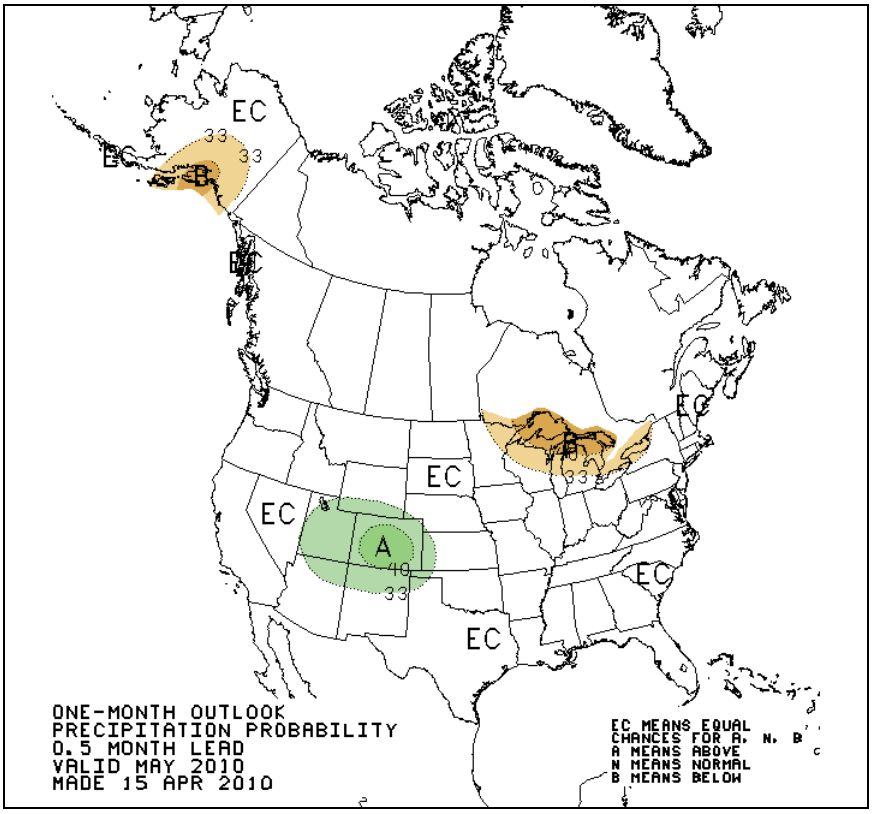

Figure 3: *The National Weather Service Climate Prediction Center precipitation outlook for May 2010.*

Our next tour of all eleven CODOS sites will begin on May 3rd, during which we will observe the extent to which the D5/D4/D3/D2 layers have re-emerged or remain buried, and the presence of any additional subsequent dust layers.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #6, Monday, May 10, 2010

Last week's tour of CODOS's eleven dust-on-snow monitoring sites focused on the April 28th D6-WY2010 dust layer. Reports of the geographic extent and intensity of that event were confirmed – D6 was found as a discrete and very substantial layer (Figure 1) at almost all of our sites that still retained a snowpack, or else already merged with and intensifying earlier dust layers. Table 1 presents recent snowpit data from each of our CODOS monitoring sites including the depth of burial of the D6 (currently the uppermost) dust layer below the snowpack surface.

Figure 1: *The April 28th D6-WY2010 layer is seen here at the Swamp Angel Study Plot, on May 3rd, as the uppermost dust layer buried under 5" of clean new snow that fell afterward, and separated from the dust layers below by about 4" of clean snow. Compare this to Figure 1 of Update #5, April 26, 2010.*

CODOS Site	Date of Most Recent Snowpit	Total Snow Depth	Thickness of Clean Snow Overlying D6 Dust Layer
Swamp Angel Study Plot	5/3/10	59"	**5"**
Park Cone	5/3/10	0"	*0" (SAG)*
Spring Creek Pass	5/4/10	9"	**0"**
Wolf Creek Summit	5/4/10	46"	**0"**
Hoosier Pass	5/5/10	51"	**5"**
Grizzly Peak	5/5/10	34"	**3"**
Berthoud Summit	5/5/10	63"	**6"**
Willow Creek Pass	5/5/10	20"	**0"**
Rabbit Ears *(1)*	5/6/10	67"	**12"**
McClure Pass	5/6/10	0"	*0" (SAG)*
Grand Mesa Study Plot	5/6/10	54"	**3"**

Table 1: *Depth of burial of D6-WY2010 on May 3-6, 2010.*

Our tour began on May 3rd at our **Swamp Angel Study Plot** (SASP) at Red Mountain Pass (Figure 1). That profile provided a "baseline" of WY2010 dust layer accumulation showing separation between the merged D2/D3/D4 events, seen as a single thin and icy layer, and the distinct D5 and D6 layers above, separated from each other and the underlying D2/D3/D4 layer by intervening snowfalls. At SASP, 5" of comparatively clean snow covered the D6 layer (D6 was initially deposited "dry", then "wet" later during the event, entrained in new snow). At higher elevations in the western San Juan Mountains, patches of dirty snow were visible where winds had stripped the D6 storm's new snow and also at other locations where wind had redeposited and concentrated the dust-laden new snow. At lower elevations, the D6 layer had emerged extensively, irrespective of aspect.

Continuing our tour to the Gunnison Basin, our **Park Cone** site had reached "snow all gone" (SAG), even though the adjoining Snotel site was still reporting some SWE. In Taylor Park, the lower edge of significant snowcover on the S'ly and W'ly aspects was approaching treeline and snowcover above treeline retained a high albedo, with clean snow obscuring the underlying dust.

Figure 2: *the CODOS Spring Creek Pass snowpit site fell from 30" total depth on April 13th to just 9" on May 4th. All dust layers have merged at the snow surface in this May 4th photo.*

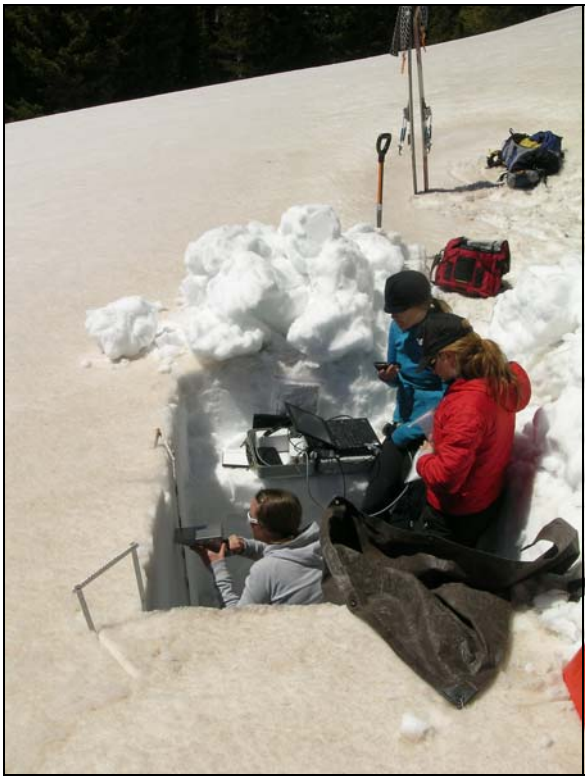

Figure 3: *at Wolf Creek Pass, on May 4th, D6 was merged with the underlying dust layers D5/D4/D3/D2. The Snow Optics Lab student team of Ashley Powell, Annie Bryant, and Mckenzie Skiles are seen collecting snow samples and performing spectrometry in the CODOS snowpit.*

At **Spring Creek Pass**, we found our snowpit site in the final stages of snowmelt, with all dust layers merged at the snowpack surface (Figure 2) and only traces of recent new snow left at the surface. Dust was extensively exposed on the snowpack surface on the adjoining alpine terrain.

At **Wolf Creek Pass** (Figure 3), all dust layers had merged and were extensively exposed at the snowpack surface. Interestingly, dust concentrations here appeared to be somewhat lower than at Spring Creek Pass. Nonetheless, snowpack albedo was very substantially reduced in the Creede and Wolf Creek Pass vicinities as well as on the west slopes of the Sangre de Cristo range. Dust was also readily apparent on the scant snowcover remaining on the east slopes of the Collegiate Range, substantially reducing albedo. In the evening light, the south slopes of the Mosquito and Buffalo Peak ranges appeared comparatively clean and apparently recent loose, blowing snow was observed.

In Summit County, **Hoosier Pass** and the eastern aspect of the 10 Mile Range had only a shallow layer of snow covering the D6 layer, through which the underlying brown dust was clearly visible. Small "wet loose" (sluff) avalanches had scoured down and fully revealed that dust layer in many places.

At the **Grizzly Peak** site, only 3" of snow covered the D6 layer, itself only a few inches above the merged D5/D4/D3/D2 layer(s), and D6 was widely emerged in the nearby terrain on the west side of Loveland Pass (Figure 4) and on Arapahoe Basin's ski runs. That surface snow was extremely wet and rapidly melting despite extensive cloud cover.

Our snowpit at **Berthoud Pass** displayed the largest separation between the D6 layer and the merged D5/4/3/2 layer (Figure 5). Here, again, the snowpack surface was extremely wet and rapidly settling and melting.

Figure 4: *looking south from Loveland Pass on May 5, 2010 at D6-WY2010 emerging.*

Figure 5: *D6 was 6" below the snowpack surface at Berthoud Pass on May 5, 2010 and separated from the underlying merged dust layers by almost 12".*

As is often the case, exposure of dust layers at the snowpack surface in the terrain surrounding and between our CODOS sites was quite variable, governed by elevation, aspect, amount of recent snow (since D6), and exposure to wind stripping and/or wind redeposition and concentration. An example of the variations in the emergence of dust caused by changes in elevation, aspect, and wind exposure was seen in the Berthoud Pass vicinity (Figure 6). We are often asked about the patterns of dust seen in alpine terrain, where "tiger stripes" of alternating dirty and clean snow are often observed. In many, and perhaps most cases, this pattern does not indicate a variable dust deposition pattern, but rather a pattern of new snow drifting over the relatively uniform dust layer. Although wind can cause concentrations of dust on some leeward locations, and entirely strip away a dust layer on other exposed windward locations, eventually the clean snow "stripes" melt and reveal that the layer of dust was also present underneath that clean snow and widely distributed over the terrain at-large.

At **Rabbit Ears Pass** we found a unique, tan-colored dust layer that had been recently deposited at the snowpack surface, most likely arriving during the strong winds of the preceding few days, and perhaps originating from a source area well to the north of the I-70 corridor. We did not observe this layer at sites south of Rabbit Ears Pass but the same event may have been deposited on the already-dirty snow surface at Willow Creek Pass, 35 miles to the east of Rabbit Ears Pass. That comparatively minor layer was separated from the underlying D6 layer, at our site, by almost 8" of clean snow and was also being buried itself by new snow that had fallen overnight and continued falling during our snowpit observations.

Figure 6: *a view from Highway 40 of the north side of Berthoud Pass and the west slope of the Continental Divide showing patches of dust above treeline, the result of wind effects, and emerging D6 dust on a steep slope below treeline revealing the spatial consistency and extent of the D6 layer.*

Heading back to the southwest, the snowpack surface visible on the edges of the Flat Tops, and above treeline in the Elk Range, appeared quite clean, but dust was apparent at the lower edges of snowcover in those locales as well. At **McClure Pass**, our snowpit site had also recently reached bare ground but extremely dirty snow was observed at elevations just a few hundred feet above that 9,500' pass.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	1	4	*≥1*	*tbd*	*≥7*

Table 2: *Log of Dust-on-Snow Events Observed at Senator Beck Basin Study Area*

Figure 7: *our May 6, 2010 snowpit at the Grand Mesa Study Plot.*

Finally, our tour of CODOS sites concluded on the evening of May 6th at our **Grand Mesa Study Plot**. Once again, we observed only a very shallow and rapidly melting layer of wet new snow overlying the D6 layer, and only a small separation between D6 and the underlying merged dust layers (Figure 7). This layer of new snow was thin enough, and wet and transparent enough, that the effect of the underlying D6 layer in reducing snowpack albedo was visually apparent over large areas of the Grand Mesa, and the D6 layer was fully emerged at the lowest snow-covered elevations on the edges of the Mesa.

In summary, the D6-WY2010 dust layer was observed throughout the Colorado mountains at varying stages of emergence and merging with previously reported underlying dust layers, at the lower snow-covered elevations, or of shallow depths of burial under clean snow at higher elevations. Further, since the snowpack at all sites was effectively isothermal, at or very near 0°C, direct absorption of radiative energy by dust at or near the snowpack surface will result in accelerated snowmelt at those elevations. Higher terrain may still retain some cold content in those snowpacks, particularly on north aspects.

Observations during our three CODOS tours this season have been complicated by fresh snowfalls, particularly in and north of the I-70 corridor. Nevertheless, our overall impression is that the extent and intensity of dust deposition in the Colorado mountains during the spring of 2010 may approach that of spring 2009, despite a lower number of dust events this year (Table 2). Weather, and particularly the frequent restoration of higher snowcover albedo by new snow layers, will continue to govern the impact of the dust layers already in the snowpack, but the "engine" for significant radiative forcing of the remaining snowpack is now in place.

Given the generally dry and sunny weather during and since completing our tour, with only minor amounts of new snow deposited on Thursday, May 6th above treeline, D6 has likely continued to emerge in the southern Colorado River tributaries (Eagle, Roaring Fork, and Crystal rivers), and

the Gunnison Basin. Also, at Grand Mesa, D6 was very near the snowpack surface as of Thursday, May 6th. Perhaps since most low elevation snowcover in those watersheds was lost during early April, and recent snow mitigated the effects of the D6 layer at higher elevations, hydrographs have not rebounded from the steep drop experienced following the surge in flows observed in mid April, and flows typically remain below their respective median values at this writing. A prolonged period of sunny weather in those locales will accelerate the emergence of D6 at higher elevations and trigger another surge in higher elevation snowmelt and streamflows.

Farther north, the Yampa River basin is experiencing very low flows at this time. In the Rabbit Ears, Park, Gore, and Front ranges, new snow late last week further delayed snowmelt and dust emergence. Nonetheless, at least two significant dust layers – D6, and a substantial layer of merged dust events below – are present at Rabbit Ears Pass. When D6 does eventually emerge, aided by the minor event lying above it, and then remains exposed at the snowpack surface, D6 will rapidly merge with the underlying merged dust layers and generate a rapid acceleration in snowmelt.

In contrast, in the southwest corner of the state, D6 has been rapidly emerging at high elevations and on all aspects and the Rio Grande and western San Juan Mountains watersheds are already experiencing a snowmelt surge with streamflows returning to and exceeding median values.

Finally, although the spatial extent of the event is not yet known, Sunday, May 9th did produce the seventh dust-on-snow event of the season – D7-WY2010 – in the western San Juan Mountains. This event arrived in the late afternoon, was of moderate intensity, and seemed to dissipate at sunset. In this area, this D7 dust fell on an already dirty snow surface. We will contact other observers around the state to assess the distribution of this event.

However, as of this writing, a weak disturbance is producing scattered snow showers throughout the Colorado Mountains and the National Weather Service in Grand Junction expects a much stronger Pacific storm system to deliver several inches of additional snow to the state north of I-70 beginning Tuesday and into Wednesday. Lesser snow amounts south of I-70 may only very briefly restore higher snowpack albedo in the Central and Southern mountains. In either case, the snowpack will not substantially cool, as new snow provides an effective insulator from cool air and conserves the heat already in the snowpack. Unsettled weather will dominate most of the Colorado mountains for the remainder of the week of May 9th-15th, but NWS currently anticipates a rapid warming and drying trend early the following week that could find dust already at the surface, or not far below. The ensuing sunny skies would initiate a new surge in snowmelt where new snow has temporarily restored a higher snow albedo, as that new snow is melted from above by warm air and below by absorbed solar energy in underlying dust and the dust emerges. Or, where snowcover albedo has remained low during this week's unsettled weather and dust has remained at or near the surface, current rates of snowmelt and runoff will very quickly resume and then accelerate.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #7, Thursday, May 20, 2010

Snotel and stream gauge data throughout the state reflect divergence, from north to south, in snowmelt progress this spring. Many Snotel sites north of I-70 have recently benefited from storms that have maintained or produced gains in SWE in late April and early May (Figures 1 and 2) while simultaneously restoring and sustaining a high snowpack albedo. In contrast, after much less new snow, Snotel sites in the southern mountains have experienced large (or total) losses of SWE (Figures 3 and 4), under more prolonged periods of exposed dust-on-snow and low albedo.

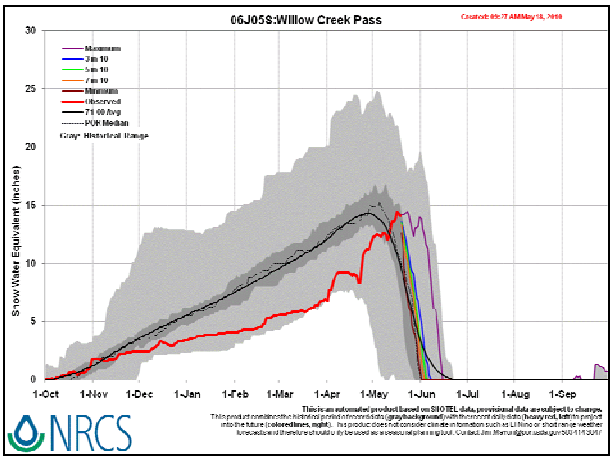

Figure 1: *Willow Creek Pass Snotel, at 9,540', WY2010 graph showing brief episodes of dust-enhanced snowmelt during late April and May followed by significant increases in SWE.*

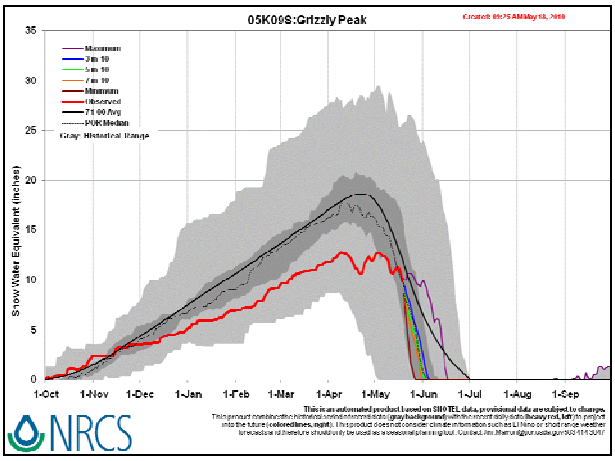

Figure 2: *Grizzly Peak Snotel, on Loveland Pass at 11,100', WY2010 graph showing rebounds in SWE produced by storms after episodes of dust-enhanced snowmelt in late April and early May.*

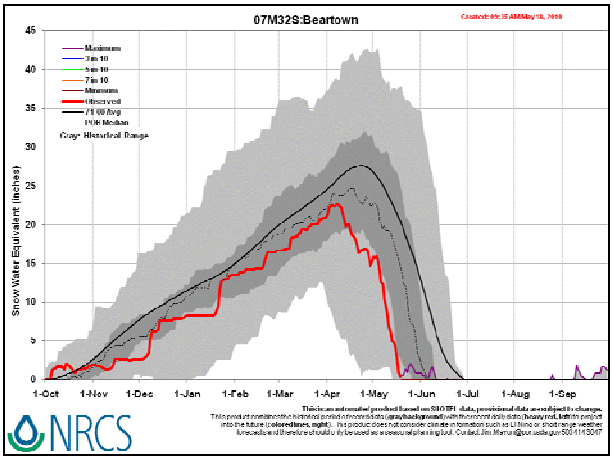

Figure 3: *Beartown Snotel WY2010 graph, at 11,600' near the headwater of the Rio Grande River, approaching "snow all gone" (SAG) as of May 18.*

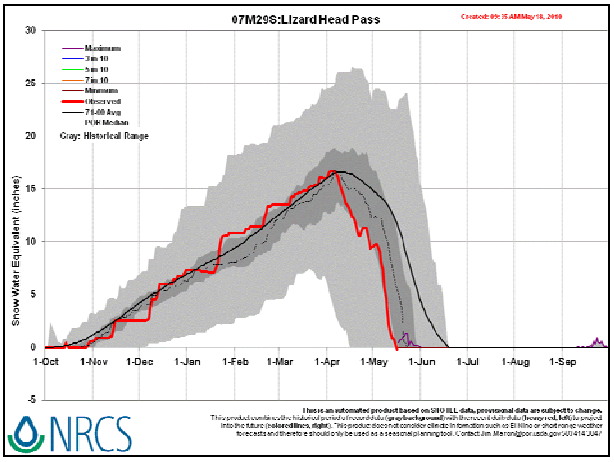

Figure 4: *Lizard Head Pass Snotel, at 10,200', WY2010 graph showing "snow all gone" (SAG) as of May 18.*

Following a surge in runoff throughout most mountain watersheds during mid-April, a north/south divergence appears in stream gauge data as well. Since that mid-April surge, most northern, Front Range, and central mountain watersheds have fallen and remained below median flows, as managers in those locales well know (Figures 5 and 6).

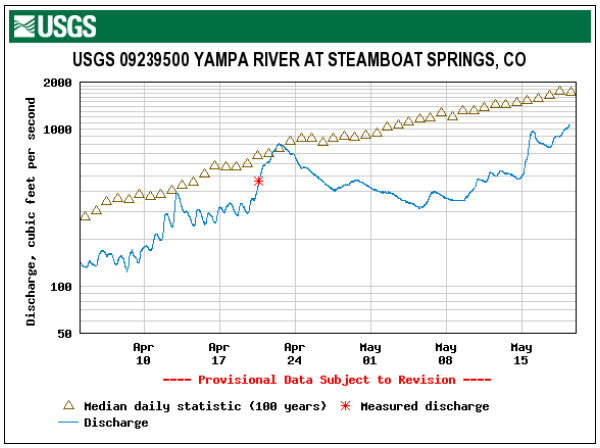

Figure 5: *Yampa River hydrograph showing the mid-April surge and subsequent below-median flows.*

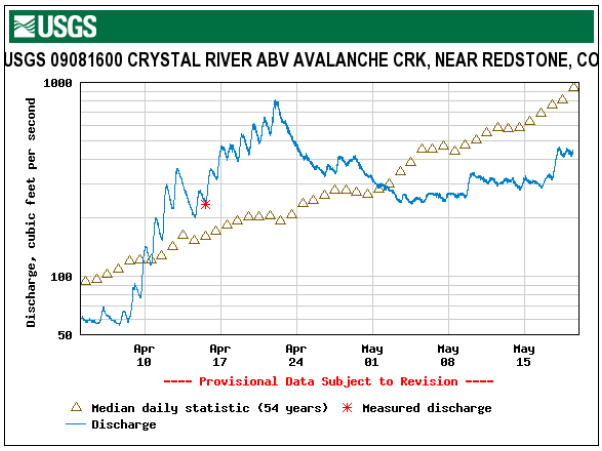

Figure 6: *Eagle River hydrograph showing the mid-April surge and subsequent below-median flows.*

Farther south, following the mid-April surge streamflows have shown more frequent response to periodic exposure of dust, reduced albedos, and warmer air temperatures, as the storms that affected the northern portion of the state produced less new snow and less sustained cloudcover farther south. In the Rio Grande watershed, flows have exceeded median rates at Del Norte several times this season (Figure 7) and other San Juan Mountains watersheds show a similar pattern (Figures 8 and 9).

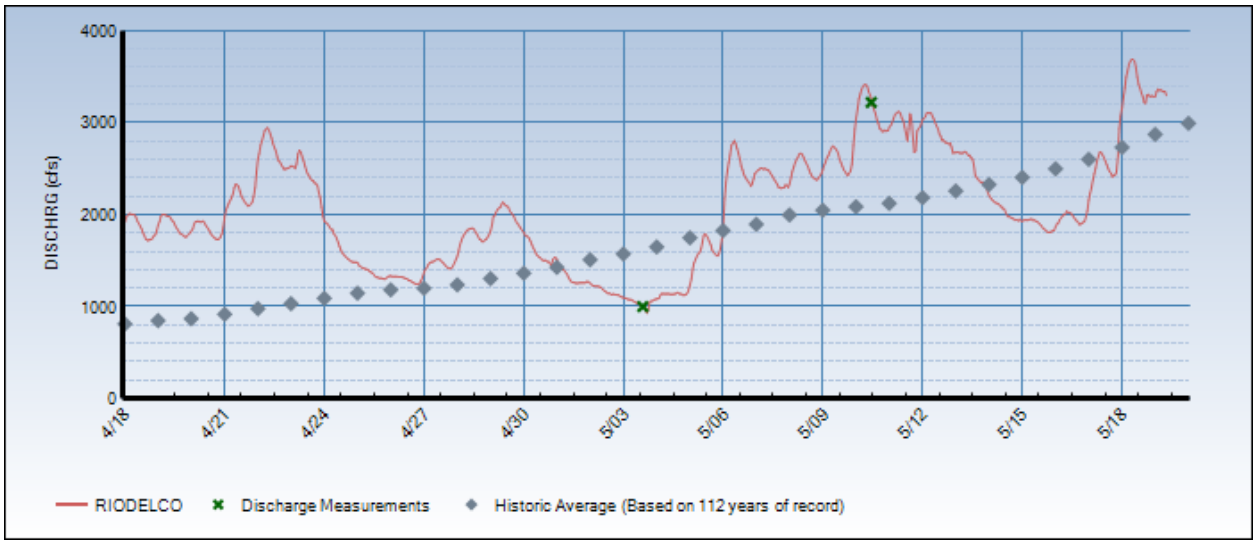

Figure 7: *Rio Grande gauge at Del Norte, showing multiple episodes of surging flows followed by storm-related decreases temporarily restoring a higher snowcover albedo and cooler air temperatures.*

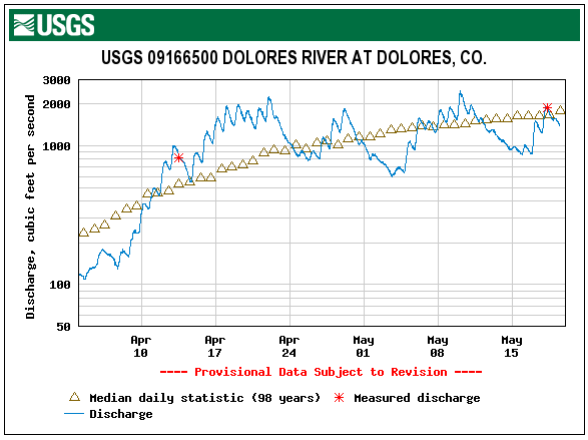

Figure 8: *Dolores River hydrograph showing the mid-April surge and subsequent snowmelt pulses.*

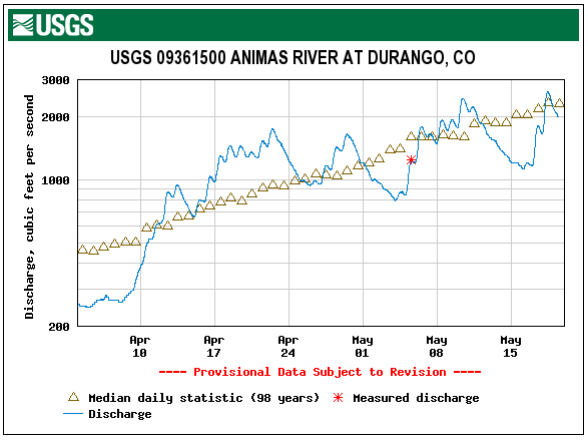

Figure 9: *Animas River hydrograph closely mirroring the Dolores River behavior, at larger volume.*

Comparing our Senator Beck Basin hydrographs for 2008 and 2009 shows two distinct runoff patterns (Figure 10). In 2008, after a prolonged period of dry and sunny weather in late April, several significant winter storms in May resulted in an on/off runoff season, preserving that above-average snowpack and extending and sustaining substantial flows later into the summer. In 2009, an early

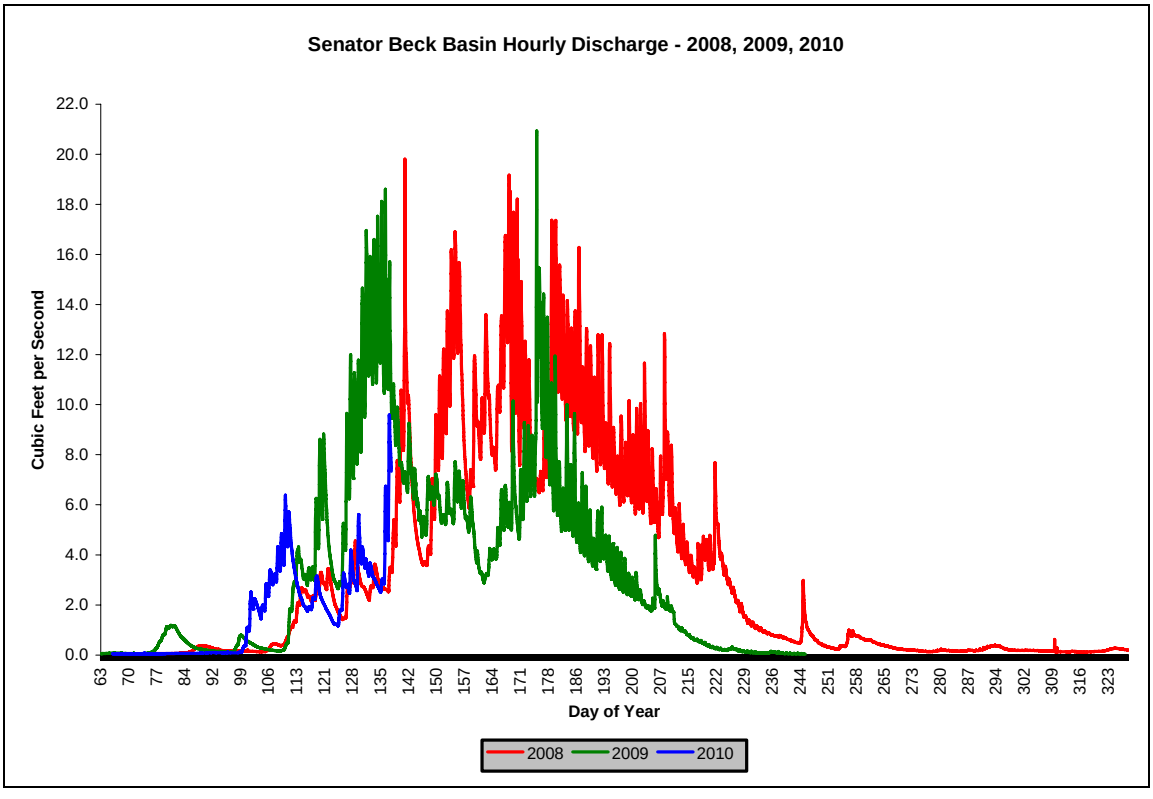

Figure 10: *Senator Beck Basin hydrographs for snowmelt seasons 2008 ,2009, and 2010 to-date.*

and generally sustained surge during the last half of April and the first half of May was disrupted by several weeks of stormy weather in late May and early June, followed by a resumption of high flows in mid-June, consuming the remaining residual snowpack in the Basin.

Spring 2010 runoff in Senator Beck Basin has more closely resembled spring 2008 than spring 2009, to-date, but the potential for a large dust-enhanced surge comparable to the April/May surge of 2009 certainly exists, given a prolonged period of sunny weather, as the most recent major dust-on-snow event (D8 - May 11th) emerges and rapidly merges with the underlying merged D2-7 layers in our alpine terrain. As of this writing, although many Snotel plots in the San Juan Mountains show substantially reduced or no remaining snowpack, we retain substantially more snowpack and SWE at our alpine Senator Beck Study Plot (at 12,200') than was present on this date in 2008 or 2009. Alpine snowpacks elsewhere in the San Juan Mountains, at altitudes above the Snotel network, may mirror our conditions in Senator Beck Basin. Our Grand Mesa Study Plot has also recorded only minor losses of snowpack in the past ten days, since our last visit.

As of this writing, the National Weather Service in Grand Junction expects the recent winter-like weather that has brought the most new snow to the northern, Front Range and central mountains to exit Colorado to the east by Thursday, as a high pressure ridge moves in from the west and stalls over western Colorado, keeping a large trough of low pressure stalled over the Great Basin during the weekend and allowing only minimal moisture to enter Colorado. This synoptic setup appears likely to generate strong SWly winds over northeastern Arizona on Friday and even stronger winds on Saturday and again on Sunday.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	**1**	**0**	**0**	**0**	**0**	**1**	**4**	***≥2***	***tbd***	***≥8***

Table 1: *Log of Dust-on-Snow Events Observed at Senator Beck Basin Study Area*

According to the Flagstaff National Weather Service office, "…blowing dust will be a likely threat once again for portions of the Little Colorado valley and Chinle Valley during this period [May 21, 22, 23]". Both of those locales were major contributors of dust to the D6 and D8 events earlier this season, as shown in the images described in our May 12th email. If that NWS forecast verifies, a long-duration, "dry" dust-on-snow event in the Colorado mountains would be likely this Friday and/or Saturday and/or Sunday. The effects of another "dry" (without precipitation) statewide dust-on-snow event, which would be the 9th observed event of the season in our locale (Table 1) would be most pronounced in the northern, Front Range, and central mountains, falling on top of a comparatively clean snowpack surface and accelerating merger of that new dust with the underlying D8 layer. A D9 event in the southern mountains would fall on exposed dust at most elevations, or thinly covered dust, further enhancing the existing radiative forcing of snowmelt there.

Further, a ninth event (and any subsequent events this season) would sustain the increase seen since 2002/2003 in the number of dust-on-snow events occurring after March 1st in Senator Beck Basin.

Given the current weather forecasts, beginning on Thursday **in the southern mountains and on the Grand Mesa**, dust that is already widely exposed at the snowpack surface or rapidly emerging from underneath a thin layer of new snow will begin experiencing near maximum solar inputs from generally sunny skies. Since the snowpack is already isothermal, that radiative forcing, aided by much warmer air temperatures, will rapidly accelerate snowmelt in the San Juan Mountains and on Grand Mesa through the weekend and into the following week, with or without any new dust. Additional, new dust will simply enhance that process.

In the central, Front Range, and northern mountains, absent any new dust, the sunny and warmer weather beginning on Thursday will begin to ablate the deeper new snow that has recently accumulated above the D8 (May 11th) dust layer and initiate an increase in streamflows. Underneath that blanket of new snow, the underlying snowpack had become and likely remains effectively isothermal on perhaps all but the highest north-facing terrain. Depending on the duration of this period of sunny and dry weather, melt in the new snow may begin to reveal the underlying D8. As the D8 layer emerges at increasingly higher elevations and over larger amounts of terrain, direct absorption of solar energy by that dust layer (and/or by a new dust layer at the snowpack surface) will then accelerate runoff.

Also of interest, our colleagues at the Colorado Avalanche Information Center have received numerous recent reports of substantial slab avalanches running in the new snow on top of an underlying dust layer, probably the D8 layer, in the Front Range and in Summit County. Rapid warming may result in additional such avalanches.

Our next tour of CODOS sites will begin on Monday, May 24th at Red Mountain Pass and run through Thursday or Friday of that week. We will be performing snowpits, verifying the presence and location of the D8 and other dust layers (and any new dust layer), and collecting snowpack samples. We will report on those observations early the following week.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #8, Tuesday, June 1, 2010

Widespread, dust-enhanced radiative forcing of Spring 2010 Colorado snowmelt escalated over the past 7-10 days, with dust either fully emerged or rapidly emerging at the snowpack surface in all ranges. Our recent tour of CODOS monitoring sites confirmed the presence of the D9-WY2010 (May 22/23/24) layer throughout the Colorado mountains and its rapid merger with the underlying, already merged dust layers, resulting in a large reduction in snowpack albedo on most snow covered terrain. Regional differences in snowcover albedo, as previously described to the north and south of I-70, were reduced during this period due, in part, to the D9 event. As a direct result of reduced snowcover albedo, generally sunny skies, and above normal air temperatures, snowmelt runoff has accelerated throughout the mountain watersheds in a sustained surge producing the highest flows of the season. Some watersheds have experienced record, single-day (natural) flows at their gauges.

Here at the Senator Beck Basin Study Area at Red Mountain Pass, our stream gauge has recently recorded a major surge in flows including the highest single hour average flow in the gauge's brief period of record, at 21.75 cfs on May 28th (Figure 1). As of May 29th, our lower elevation Swamp Angel Study Plot, at 11,080', was snow free (snow all gone, or SAG), down from 28" of

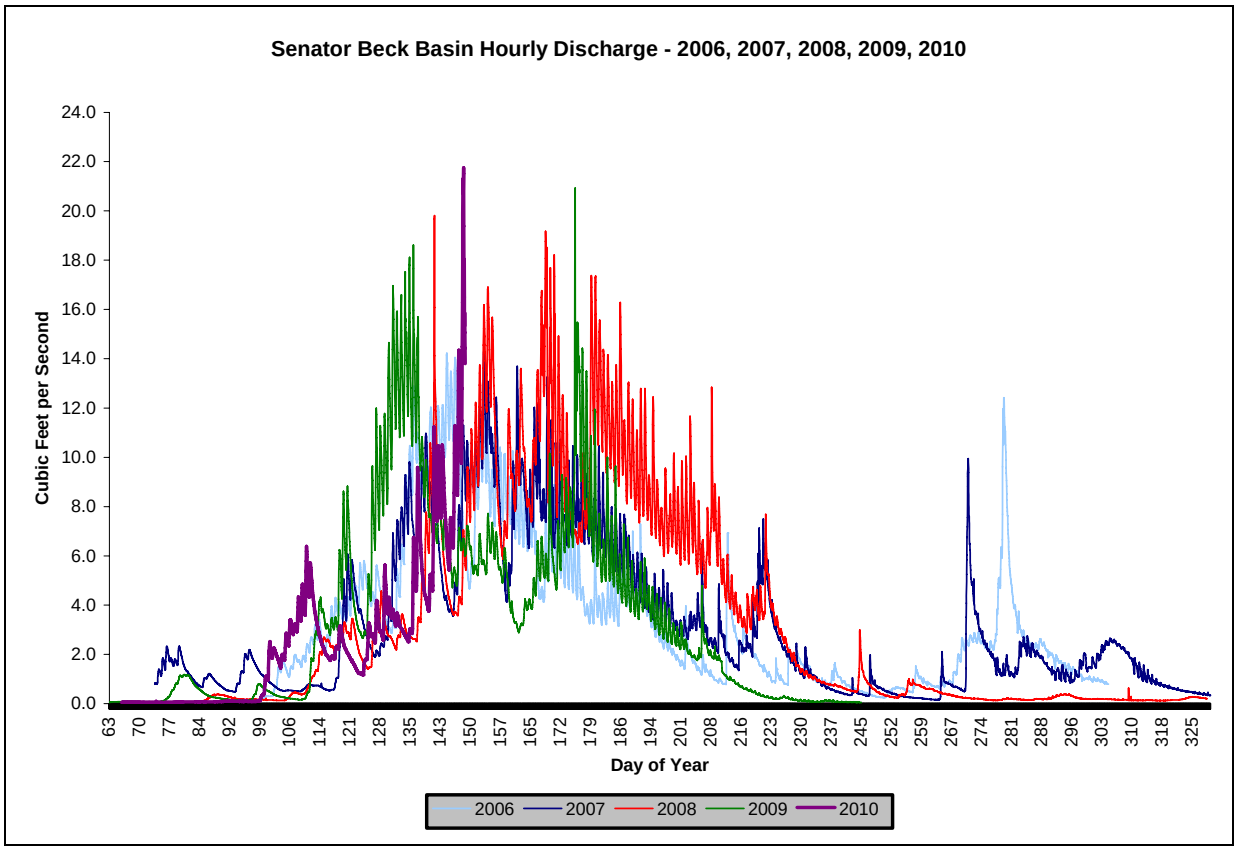

Figure 1: *Senator Beck Basin hydrographs for snowmelt seasons 2006 through 2010 to-date.*

snow containing 11.9" of SWE on May 24th. However, a meter of snow remains at our upper elevation Senator Beck Study Plot, at 12,200', with a density estimated from our last snowpit there of 45% (i.e., approximately 450 mm, or almost 18", of SWE). Similarly, during our May 24th-27th tour of CODOS monitoring sites we found that, while alpine terrain in many ranges did retain significant snowcover, our sub-alpine Park Cone, Spring Creek Pass, Wolf Creek Pass, Hoosier Pass, Loveland Pass (Grizzly Peak), Willow Creek Pass, and McClure Pass sites were either within a day or two of SAG, with a foot or less of snow, or already snow free. We are confident that all of those sites are snow-free as of this writing. Only our Berthoud Pass and Rabbit Ears Pass sites retained over 1 meter of (isothermal) snow, at 45" and 47" respectively, with all dust layers at or within 3-4" of the snowpack surface. Our Grand Mesa Study Plot (GMSP), at 10,630', had 28" of snowpack at 4 PM on May 27th and has dropped to just 14" as of this writing.

It should be noted that, given their location within forest cover, many of the Snotel sites proximal to our snow free CODOS monitoring plots still retain SWE and snowpack. In some cases, this variation in snowpack between the Snotel and our adjacent CODOS snowpit site, from some to none, is occurring within tens of yards of distance, and in other cases the distance is up to 100 or more yards. Our CODOS sites are in more exposed locations than their respective Snotel station and were selected to minimize the contribution of nearby vegetation to the impurities observed in the snowpack, and mingling with dust, as well as the effects of wind redistribution of snowcover and/or human disturbance of the site, while still benefitting from precipitation data logged at the adjoining Snotel.

Counting the long-duration D9 event (May 22/23/24) as just a single event, May 2010 produced more dust-on-snow events than we've previously observed in May at our Senator Beck Basin Study Area (Table 1). In conjunction with those dust events, residents of Colorado's Western Slope have noted that this seems to have been an unusually windy spring. Data from the Senator Beck Basin Study Area Putney Study Plot (PTSP) supports that impression. Table 2 (next page) presents a totalized calculation of "miles of wind" passing that PTSP instrument tower, using wind speeds measured every 5 seconds. In fact, April and May were windier in 2010 than in prior years, and the 2nd and 3rd windiest months in the entire PTSP period of record, among all fall, winter, and spring months.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	**1**	**0**	**0**	**0**	**0**	**1**	**4**	**3**	***tbd***	***≥9***

Table 1: *Log of Dust-on-Snow Events Observed at Senator Beck Basin Study Area*

Monthly Total Miles of Wind - Putney Study Plot							
	0405	0506	0607	0708	0809	0910	*POR Mean*
October	10,578	6,226	7,864	8,222	9,497	9,137	*8,587*
November	9,545	11,785	12,070	9,375	11,152	10,249	*10,696*
December	11,956	12,875	11,490	13,631	14,741	11,879	*12,762*
January	10,581	12,205	11,022	13,133	12,310	9,622	*11,479*
February	8,076	11,991	11,675	11,728	11,970	8,910	*10,725*
March	11,511	14,045	11,484	13,252	13,798	11,264	*12,559*
April	12,846	13,607	11,963	13,841	13,253	**14,646**	*13,359*
May	9,699	9,556	8,620	13,083	10,235	**14,468**	*10,944*
Oct-May Totals	84,792	92,290	86,188	96,266	96,954	90,175	*91,111*

Table 2: *Measured total miles of wind at the CSAS's Putney Study Plot near Red Mountain Pass.*

Since the major surge last week, streamflows have generally stabilized or begun a slight decline under a cooler air mass. The National Weather Service in Grand Junction anticipates a generally dry, sunny, and increasingly warm week ahead, and perhaps also a less windy week, under generally westerly flow. Under those conditions, overall albedo values will continue to decrease on Colorado's remaining snowpack as the dust layers already present continue emerging and merging at the surface, at higher elevations and on northerly aspects. In the central and southern mountains, even with some afternoon cloud buildup, current levels of snowmelt may be sustained, or continue to slowly decline in the coming week, as higher elevation snowcover is rapidly consumed. In some northern mountain ranges, after a slight chance for showers early in the week as a weather system passes to the north, snowmelt rates may continue to ratchet upward on the ascending limb of the Spring 2010 hydrograph as dust continues to emerge at the surface of still-substantial snowcover, particularly in the upper Yampa basin. In other northern watersheds, such as Willow Creek, runoff may already be on the descending limb despite rapid, dust-enhanced melting of the remaining high elevation snowcover. No weather systems capable of generating another large-scale dust-on-snow event are anticipated during the coming week.

Given the advanced state of snowmelt, our May 24th-27th tour of CODOS sites was likely our final tour of the season. As always, we welcome your local observations of conditions, including your photographs of either dust-on-snow conditions or interesting hydrologic activity. Many thanks to those who have helped us keep apprised of their conditions throughout the season.

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CODOS – Colorado Dust-on-Snow – WY 2010
Update #9, Wednesday, June 16, 2010

Early June 2010 witnessed the confluence and optimization, statewide, of all three factors governing snowmelt rate: sunny and dry weather near the summer solstice, abnormally warm (even record) air temperatures, and very low snow albedo, caused by nine significant depositions of dust-on-snow. Although snowmelt had been lagging in the north, and snowpack peak SWE values were generally below or well-below average statewide, the resulting dust-enhanced surging in runoff nonetheless produced many new single-day record flows throughout the Colorado mountains, causing flooding, road and bridge damage, and other public safety hazards.

The timing of this episode, near the maximum annual solar input, exploited the widespread, very large reductions in snow albedo produced by the entire season's dust loading, delivering near-maximum potential solar inputs to the dusty snow over a number of consecutive days. The very substantial increment of energy produced by the direct absorption of radiation in that dust during the long daylight hours, combined with very high air temperatures interacting with the snow surface throughout the day and night, resulted in enormous amounts of total energy available to the Colorado snowpack at-large. Here at the Senator Beck Basin Study Area at Red Mountain Pass, our streamflows accelerated dramatically beginning on June 3rd and our broad-crested weir recorded a new highest single hour average flow in the gauge's brief period of record, at 26.6 cfs between 5-6 PM on June 5th (DOY 156), and a new record 24-hour mean flow rate of 18.0 cfs (Figure 1).

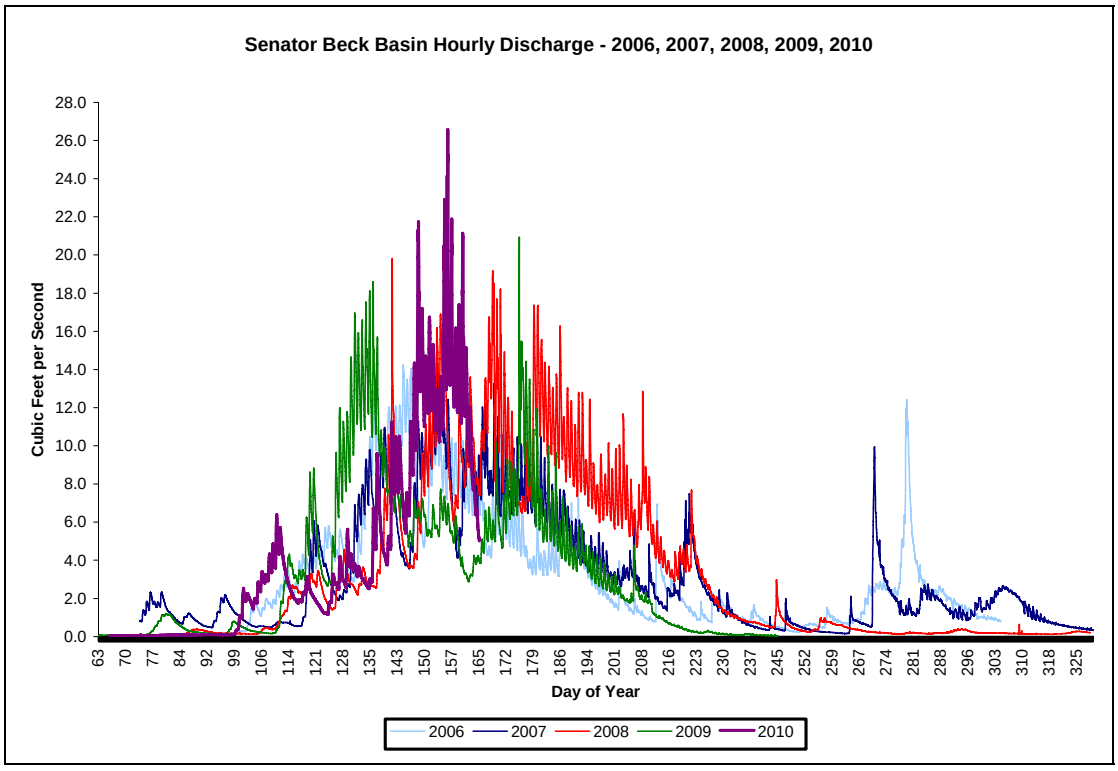

Figure 1: *Senator Beck Basin hydrographs for snowmelt seasons 2006 through 2010 to-date.*

Figure 2: *the Senator Beck Basin broad-crested weir on May 13, 2009, near 2009 peak flow.*

Figure 3: *the Senator Beck Basin broad-crested weir just hours before 2010 peak flow on June 5, 2010.*

This record setting surge in early June 2010 was not only more abrupt and larger than the surge leading to the peak flows in 2009, it also resulted in the most turbidity yet observed in this stream (Figures 2 and 3). However, this June's surge has begun to wane almost as quickly as it began, accentuating the compressed nature of the 2010 runoff to-date, as compared with the 2008 and 2009 seasons (Figure 4). Then, along with the rapid reduction in remaining snowcover in Senator Beck Basin from June 3-10, some 4-6" of high elevation new snow and cold weather over the weekend of June 12th-13th further depressed runoff rates and temporarily restored high albedo values to our remaining snow. In northern and Front Range watersheds that same weather resulted in significant rain and rain-on-snow, sustaining streamflows at higher levels there.

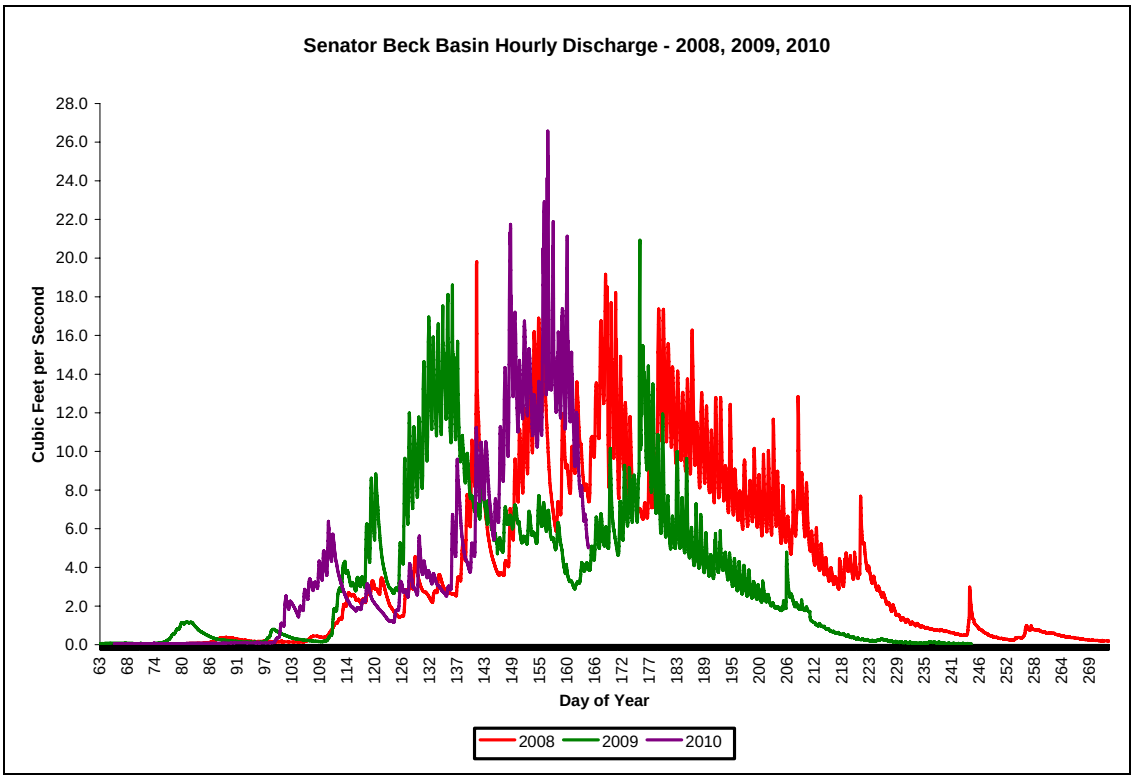

Figure 4: *Senator Beck Basin hydrographs for snowmelt seasons 2008, 2009, and 2010 to-date.*

This recent statewide runoff behavior, with very rapid acceleration to very high levels, once again highlights the importance of the timing, duration, and spatial extent of the interacting factors governing snowmelt. Spring 2010 has demonstrated the hydrologic impact that unusually warm temperatures *in tandem with* unusually low snow albedo values can have in early June, even with below-average snowpacks. In spring 2008, frequent additions of new snow interrupted episodes of sunny weather interacting with reduced snowcover albedo (at ~0.50) throughout the Colorado mountains, fortunately prolonging snowmelt and averting flooding snowmelt surges in what were well-above average snowpacks in many locales, including Senator Beck Basin (Figure 4).

In spring 2009, with virtually average peak SWE, on the average date, here at Red Mountain Pass (per Snotel data), two early spring episodes of sunny weather and then unprecedented amounts of exposed dust (albedo values were as low as 0.33 at meltout in 2009) resulted in the bulk of total

runoff occurring well in advance of normal "center of mass" dates, but that surge was also disrupted by stormy weather lasting well into June, followed by a second peak in flows (enhanced by rain on dirty snow). Spring 2010 also saw two early surges in runoff, depleting lower elevation snowcover, followed by the steep and generally sustained surge of late May and early June seen in the hydrograph. Albedo ranged, at melt out this spring, from ~0.35 at our lower Senator Beck Basin study site to ~0.45 at our upper study site. The steepness of the descending limb on that hydrograph currently suggests that Spring 2010 may result in the "flashiest", most compressed runoff yet observed in our short history of streamflow monitoring at Senator Beck Basin, given the long interruption in the bi-modal 2009 runoff.

These Senator Beck Basin discharge datasets illustrate episodes of dust-enhanced radiative forcing of spring snowmelt interacting with the weather of five late winter and spring seasons. Unfortunately, our guarded March hopes for a "clean" season were dashed on March 30 so there still is no Senator Beck Basin runoff dataset reflecting an entirely dust-free snowmelt season. Nonetheless, these streamflow data do depict dust-enhanced snowmelt runoff behavior in Senator Beck Basin Study Area, where the complex interactions of dust-on-snow, radiation, weather, soil conditions, and snowpack are constantly measured in an integrative effort to understand that snow system's behavior in response to desert dust.

Some non-trivial fraction of the winter snowpack does remain in many watersheds. The National Weather Service anticipates a return to sunny and generally dry weather continuing into the coming week, with seasonably warm temperatures. As and when the underlying very low albedo snow re-emerges from beneath last weekend's new snow, or has remained exposed in the absence of new snow, dust-enhanced radiative forcing of snowmelt will resume. However, almost all watersheds may now be on the descending limb of the runoff hydrograph and actual flow levels will likely continue to decline.

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CODOS – Colorado Dust-on-Snow – WY 2010
Final Update (#10), Wednesday, July 14, 2010

Just as every winter season is different, driven by hemispheric-scale atmospheric dynamics, each Colorado dust-on-snow and snowmelt season also reflects complex interactions between mountain weather, snowpack formation, snowpack albedo, desert weather, soil conditions in the Colorado Plateau, and the solar calendar. This final Update of Water Year 2010 summarizes the past season and reflects on the growing dataset captured by the Colorado Dust-on-Snow (CODOS) program.

Figure 1: *the Arapahoe Basin ski area on May 26, 2010 dramatically illustrated the local reduction in snow albedo caused by dust-on-snow during late Spring 2010. Through heroic grooming efforts, the ski area was able to remove or bury some or most of the season's accumulated dust on the three ski runs seen on the left, creating a skiable surface for their customers and preserving the snowcover on those runs. In vivid contrast, for those who may have tried, the snow to the right of the chairlift no doubt proved essentially unskiable, akin to skiing on mud. Most Colorado ski areas had eked out an almost complete ski season before the Spring 2010 dust storms began, but many areas experienced a "damaged product" before the end of their season in early April.*

Altogether, nine separate dust-on-snow events were documented during the winter of 2009/2010 at the Center for Snow and Avalanche Studies' Senator Beck Basin Study Area at Red Mountain Pass, in the western San Juan Mountains, the second highest total in our 8-year period of record. Spring 2010 produced a notable shift in the overall timing of dust deposition, with 7 of the

9 events occurring in April and May, and another on March 30th (Table 1). This shift in timing resulted, in general, in more of the total dust load being located higher in the snowpack than in prior seasons, with less overlying snow to ablate before those layers were exposed. Further, the intense dust loading from event D9-WY2010 of May 22-24, very late in the spring, was either immediately or very quickly exposed, further reducing measured snowcover albedo to values of 0.35-0.45 (at our Senator Beck Basin and Grand Mesa study sites) and absorbing near-maximum amounts of potential radiation, given the proximity of those very low albedo values to the Summer Solstice.

Dust-on-Snow Events Documented per Month, by Winter
Senator Beck Basin Study Area at Red Mountain Pass – San Juan Mountains

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Total**
2002/2003					2		1			**3**
2003/2004							2	1		**3**
2004/2005	0	0	0	0	0	1	2	1	0	**4**
2005/2006	0	0	1	0	1	1	3	2	0	**8**
2006/2007	0	0	1	0	1	1	3	1	1	**8**
2007/2008	0	0	0	0	0	3	3	1	0	**7**
2008/2009	1	0	1	0	1	4	5	0	0	**12**
2009/2010	1	0	0	0	0	1	4	3	0	***9***

Table 1: *Log of Dust-on-Snow Events Observed at Senator Beck Basin Study Area.*

Most dust storms we've observed have arrived here at CODOS headquarters, in the western San Juans, during mid/late afternoon and then dissipated the following night. While most of the nine events during the winter of 2009/2010 were comparable in duration to those observed in prior seasons, this season produced one particularly long, sustained dust storm from May 22nd through 24th, event D9-WY2010. That D9 dust storm produced discernible dust in the atmosphere for 48 hours or more, depending on location, due to a virtually stationary wind field generating sustained and strong SW'ly flow into Colorado. The dates of onset of the logged dust-on-snow events at Senator Beck Basin, by winter season, were as follows (WY = Water Year):

2002/2003 (WY 2003): Feb 3, Feb 22, Apr 2
2003/2004 (WY 2004): Apr 17, Apr 28, May 11
2004/2005 (WY 2005): Mar 23, Apr 4, Apr 8, May 9
2005/2006 (WY 2006): Dec 23, Feb 15, Mar 26, Apr 5, Apr 15, Apr 17, May 22, May 27
2006/2007 (WY 2007): Dec 17, Feb 27, Mar 27, Apr 15, Apr 18, Apr 24, May 4, Jun 6
2007/2008 (WY 2008): Mar 16, Mar 26-27, Mar 30-31, Apr 15, Apr 21, Apr 30, May 12
2008/2009 (WY 2009): Oct 11, Dec 13, Feb 27, Mar 6, Mar 9, Mar 22, Mar 29, Apr 3, Apr 8, Apr 15, Apr 24, Apr 25
2009/2010 (WY 2010): Oct 27, Mar 30, Apr 3, Apr 5, Apr 12, Apr 28, May 9, May 11, May 22

Our nine previous WY2010 Updates have reported that four CODOS tours of ten sites distributed throughout the Colorado mountains confirmed the presence of dust layers at all those sites that were closely associated with, or identical to, the sequence of Spring 2010 dust events at Senator Beck Basin. However, the magnitude of dust deposition clearly does vary geographically. A subset of six of those ten CODOS monitoring sites (Table 2) shows that somewhat less dust was

deposited at the San Juan Mountains sites in 2010 than in 2009 (at Swamp Angel Study Plot and at Wolf Creek Pass), but larger dust loads were observed at our sites along the I-70 corridor in 2010 than in 2009. It's important to note that this finding is based on comparatively small "point" samples capturing a full-depth column of the snowpack at those selected sites (Figure 2) and the values reported here may not be predictive of regional dust loading. Nonetheless, these samples enable year-to-year comparison of total dust load differences at the respective sites.

CODOS Monitoring Site	Spring 2009 Total Dust Load in Column Sample, (*mg*)	Spring 2010 Total Dust Load in Column Sample, (*mg*)
Swamp Angel Study Plot	584	325
Wolf Creek Summit	393	349
Hoosier Pass	106	172
Grizzly Peak	109	270
Berthoud Summit	110	189
Rabbit Ears Pass	217	111

Table 2: *comparing total dust load in full snowpack column samples (see Figure 2) taken at select CODOS monitoring sites in Spring 2009 to samples collected in Spring 2010. The known effects of spatial variation in dust deposition and concentration by wind redistribution introduce uncertainty in any dust-on-snow sampling method, but these sites were selected to minimize those effects and consistent sampling locations enable year-to-year comparison, at a given site.*

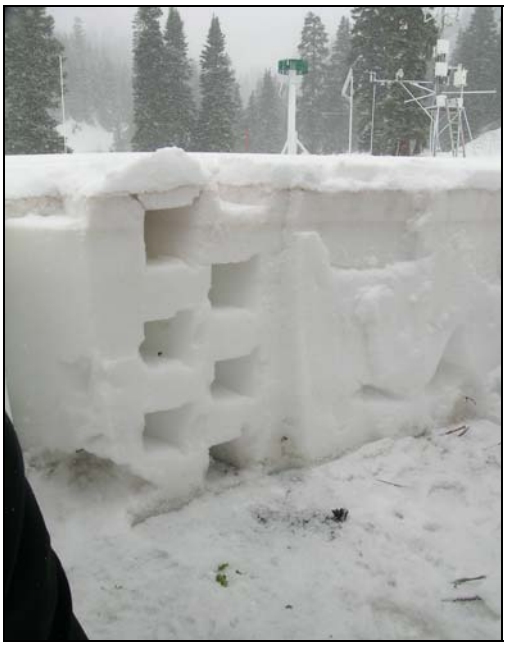

Figure 2: *snowpit face at the Swamp Angel Study Plot on May 24, 2010, as several inches of new snow were accumulating. Staggered, wedge-shaped, one liter samples are collected from the snowpack surface to the ground, capturing a "full column" of the snowpack. At this juncture, dust-on-snow events D2-D9 of WY2010 were present and merged near the snowpack surface, while event D1-WY2010, the October 27, 2009 layer was still visible just above the ground surface.*

In general, a significant, synoptic (regional) scale, pre-frontal wind field, from the S/SW/W quarter, is required to first mobilize, then lift, and finally transport Colorado Plateau dust from the source areas of northwestern New Mexico, northeastern Arizona, southeastern and eastern Utah, and southwestern and western Colorado for deposition as far away as the northern Front Range mountains of Colorado, even to the urban areas and plains east of the mountains. As it happens, several Spring 2010 dust storms were captured, at their origin, in satellite imagery. The US Geologic Survey's Southwest Geographic Science Team, based in Arizona, and their dust monitoring program, is now posting a library of 2010 dust storm imagery at the following website: http://sgst.wr.usgs.gov/dust_monitoring/dust-events/. The long-duration May 22-24 event began under clear skies and was captured in a MODIS Terra image (Figure 3).

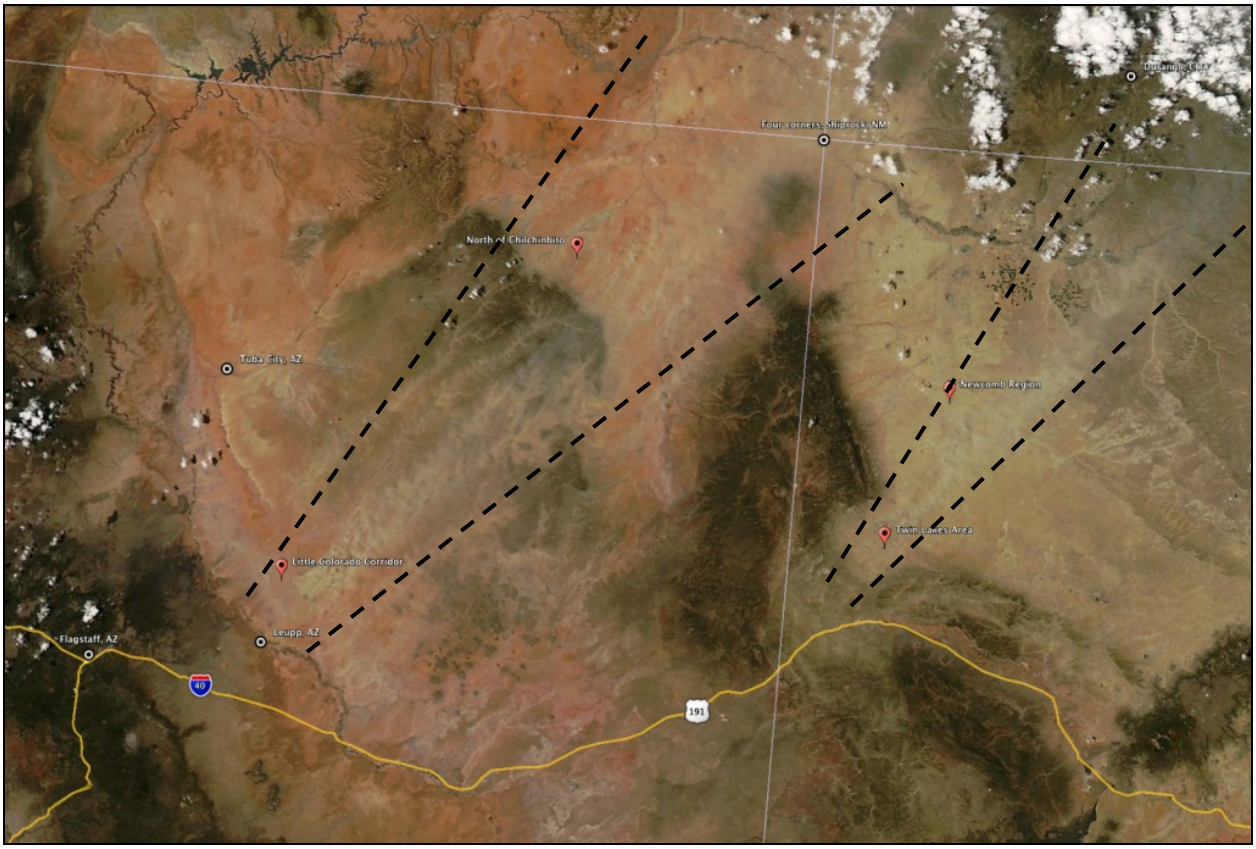

Figure 3: *showing the Four Corners region on May 22, 2010 at 2 PM local time. Interstate 40 is seen traversing the image, leading to Flagstaff, Arizona in the lower left corner. Durango, Colorado, is shown in the upper right corner of the image. The dashed lines approximately contain developing dust plumes just beginning to enter Colorado. Although dust plumes in these images often appear to have a distinct, single origin, substantial additional material may also be entrained from "downstream" locations closer to Colorado that are obscured by the dust already in the atmosphere, or by clouds. Additional plumes may have developed to the north of this image, and the source, intensity, breadth, and direction of plumes originating from the terrain in this image undoubtedly varied over the course of the D9 event, as the synoptic scale weather unfolded and progressed eastward.*

As discussed in previous Updates, Spring 2010 did seem to most Western Slope residents to be unusually windy and, hence, alarmingly dusty. In fact, data from the CSAS's Putney Study Plot, at Red Mountain Pass, support that impression of wind conditions. Not only were April and May 2010 windier than any prior April/May period since 2005 (when our Putney dataset begins), they were the 2nd and 3rd windiest of any winter months during those six winter seasons, following December 2008. However, even when synoptic scale weather patterns favor more and longer duration wind events, vegetation and soil conditions in the Colorado Plateau lowlands clearly do not remain static, over time, and several other factors influence when, where, and how much soil is mobilized and transported to the Colorado mountains. Further, even a single major dust event, such as the February 15, 2006 event, can have significant impacts on Colorado snowmelt timing and rates when spring conditions favor early and persistent exposure of that layer at the snowpack surface.

Monthly Miles of Wind - Putney Study Plot

	Winter Season						
	0405	0506	0607	0708	0809	0910	*Mean*
October 8-31	10,578	6,226	7,864	8,222	9,497	9,137	*8,587*
November	9,545	11,785	12,070	9,375	11,152	10,249	*10,696*
December	11,956	12,875	11,490	13,631	14,741	11,879	*12,762*
January	10,581	12,205	11,022	13,133	12,310	9,622	*11,479*
February	8,076	11,991	11,675	11,728	11,970	8,910	*10,725*
March	11,511	14,045	11,484	13,252	13,798	11,264	*12,559*
April	12,846	13,607	11,963	13,841	13,253	**14,646**	*13,359*
May	9,699	9,556	8,620	13,083	10,235	**14,468**	*10,944*
	84,792	92,290	86,188	96,266	96,954	90,175	*91,111*

Table 3: *a comparison of seasonal "miles of wind", by month, totaling the movement of air past the Putney Study Plot of the Senator Beck Basin Study Area, near Red Mountain Pass in the San Juan Mountains. Wind speed is measured every five seconds, 30 feet above the ground, and those measurements are averaged each day at midnight, producing a 24-hour mean wind speed (in MPH) that is then multiplied by 24 to obtain daily "miles of wind". The ridge-top location of the Putney site reduces the effects of local terrain on wind speed and direction.*

Previous CODOS Updates discussed the likely impacts of the Spring 2010 dust season on Colorado snowmelt timing and rates, addressing regional and watershed-scale differences across the state. While there were substantial differences in early snowmelt runoff patterns, from north to south, the very intense surging and very high flow levels experienced in late May and early June was uniformly enhanced, statewide, by the D9 (May 22-24, 2010) event, as discussed above and in Update #9. A review of our Senator Beck Basin's streamflows may be of some value in reviewing other hydrographs. Senator Beck Basin discharge data now include Water Years 2006-2009, and 2010 to-date (the now familiar Figure 4), all influenced by dust-on-snow. As previously reported, Spring 2010 produced peak flow levels reaching almost 27 cfs on June 5, enhanced by D9 and albedo values of 0.35-0.45. Spring 2010 albedo values were comparable to the albedo values of 2009, which persisted at 0.35 and slightly below for a prolonged period prior to "snow all gone".

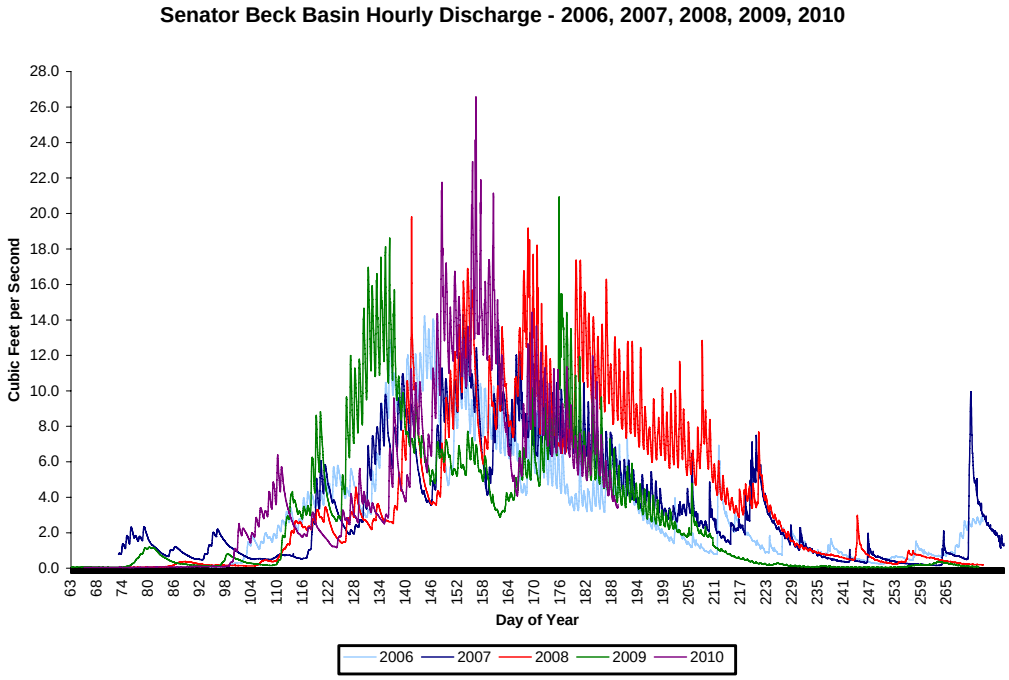

Figure 4: *Senator Beck Basin hydrographs for snowmelt seasons 2006 through 2010 to-date.*

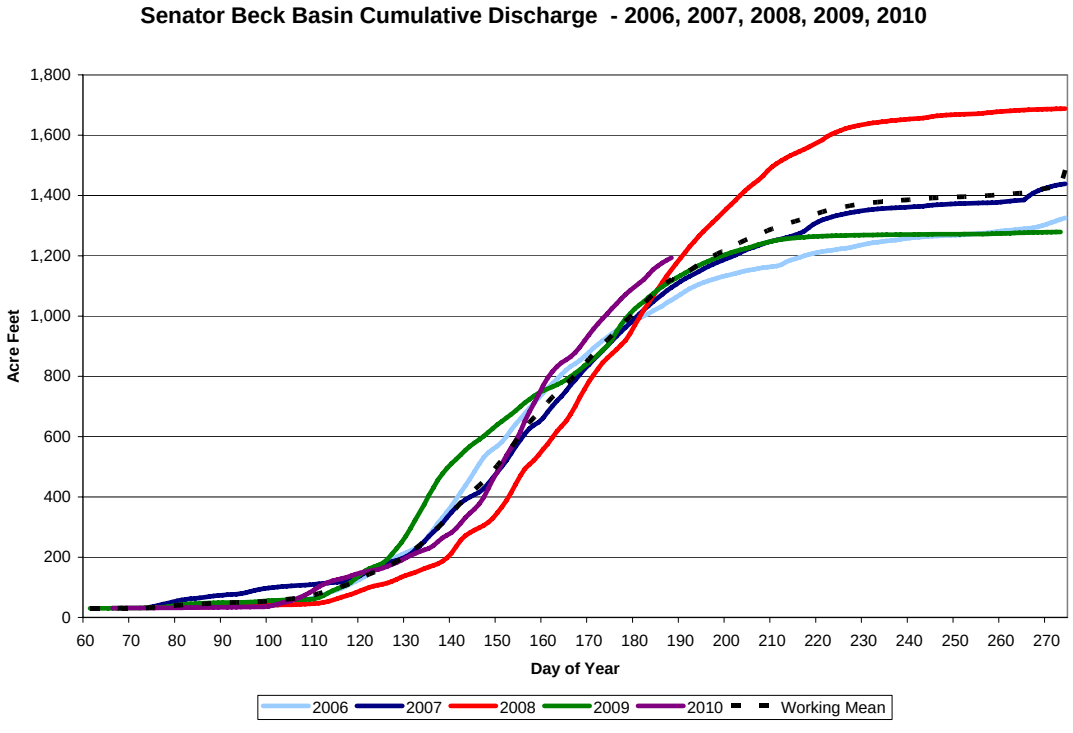

Figure 5: *cumulative Senator Beck Basin discharge for Water Years 2006-2009 and 2010 to-date.*

June is the driest month of the year, climatologically, in the San Juan Mountains, making snowmelt the principal contributor to early summer (June) streamflows. A summer monsoon season, typically beginning in early July and sometimes extending well into fall, supplies much of the remainder of water year discharge. While we do not yet have sufficient knowledge of the total water budget of Senator Beck Basin to fully characterize the hydrology of the basin, particularly of infiltration and transpiration losses and/or groundwater contributions, a graph of cumulative discharge from Senator Beck Basin, measured at the basin pour point, does highlight differences in the progression of snowmelt runoff seasons (Figure 5). Water Year 2008, with its well-above-average snowpack and relatively lower dust loading, produced the largest total discharge in those five years of record, but also the latest spring runoff, with repeated episodes of alternating low and high snowcover albedo as dust intermittently emerged at the snowpack surface, only to be reburied under a prolonged series of late spring snowfalls. In contrast, Water Year 2006 produced a comparatively early runoff, and Water Year 2009, with an average snowpack, produced an even earlier major surge in runoff between Days 126-139, after which rates tapered off and eventually fell behind 2006.

Water Year 2007, despite an early start, conforms most closely to a "working mean" hydrograph, recognizing that this is a very small dataset. Finally, while Water Year 2010 lagged behind other years between Day 130 and Day 158, as of Day 159 the 2010 cumulative runoff total had exceeded all other seasons. Further, the period between Days 146-161 in 2010 shows a prolonged period of high rates of discharge that closely matches the rates and exceeds the duration of the surge between Days 126-139 in 2009. After a brief decline in rates from Day 162-167, caused by a winter storm, 2010 runoff resumed and reached the 800, 900, 1,000 and 1,100 acre feet cumulative total thresholds earlier than in any prior season. Additional years of data will enable us to reliably characterize expected annual snowmelt discharge volumes, and the timing of the center of mass of discharge, but these data do suggest likely ranges of values.

Finally, we must address the oft-asked question, 'do you see a trend' in your observations of dust-on-snow in Colorado? We reply that our eight seasons of rigorous observation simply are an insufficient basis for identifying statistically supported trends in the number of dust-on-snow events or their magnitude. Nonetheless, our data do document and many of you have experienced, first hand, back-to-back spring seasons of intense dust storm activity in 2009 and 2010. While the wind data presented above may partially explain the 2010 season, wind is just one factor enabling these dust storms, with source area soil conditions being likewise a critical component. CODOS's focus is on the deposition of dust but we have been and will continue supporting the research initiatives of other science teams investigating the source area emission of dust by providing them with dust samples collected from the Colorado snowpack for their increasingly sophisticated analyses and potential linkage to particular source locations. It is our hope that this integrative, interdisciplinary research approach, combined with ongoing field monitoring and analyses of dust in the snowpack, will continue to improve understanding of the physical processes producing dust-on-snow and enable water and other resource managers to adapt to and perhaps eventually mitigate the effects of dust-on-snow.

Thank you, again, for your support of CODOS in Water Year 2010.

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