Evaluation of Proposed Reservoir Release Guidelines
Dolores River Below McPhee Dam – Emphasis, Big Gypsum Valley Reach

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Many experienced scientists have worked with the Dolores River Dialogue and other groups to summarize and delineate the current and past conditions of Dolores River hydrology and its impacts on geomorphology, native fish, and riparian vegetation. Rather than re-state in detail everything that these researchers have previously compiled, I will give a summary of the most important aspects of both natural and altered flow regimes as they influence riparian vegetation and community dynamics in the semi-arid southwest, with reference to some (but by no means all) of the key citations. From this broader view I will give a more detailed account of the status of both riparian vegetation and patterns of discharge in the Big Gypsum Valley reach of the Dolores River. Then, from this framework, I will address the primary question of this report: How might the specific release guidelines developed to favor native fisheries and recreation, while still supporting irrigation needs, be expected to affect native (and exotic) plant species in different portions of the riparian zone?

1) Summary of Literature & Research

A) *Riparian community response to altered flow regimes in semi-arid environments*

The biggest impacts of highly managed flow regimes on western rivers stem from the loss of peak spring flows, as snowmelt is captured in reservoirs for later agricultural use (e.g. Nilsson & Berggren 2000, Merritt & Poff 2010). This single modification of a river's "natural flow regime" (Poff et al. 1997) has led to the following changes in floodplain systems:

- Loss of bank-scouring floods (Scott et al. 1996; Nilsson & Berggren 2000)
    - Which leads to changes in sediment erosion and deposition
- Loss of floodplain-inundating floods
    - Leading to resultant loss of groundwater recharge (Stromberg et al. 1996, Mahoney & Rood 1998, Rood et al. 2003)
    - And loss of shallow soil water availability (Mahoney & Rood 1998, Williams & Cooper 2005)
    - Both of these factors have been implicated in the long-term loss of mature cottonwood canopy (Shafroth et al. 2000, Rood et al. 2003, Williams & Cooper 2005, Merritt & Poff 2010), as well as the establishment of new cottonwood and willow seedlings (Mahoney & Rood 1998, Johnson 2000, Sher & Marshall 2003, Douhovnikoff et al. 2005, Rood et al. 2005).

The other common flow alteration in managed rivers is an increase in summer baseflows (due to flow stabilization), for a variety of reasons associated with irrigation water delivery (Rood et al. 2005) and often with maintenance of fish habitat (Rood et al. 2005, Wilcox & Merritt 2005).

- Increased baseflow can result in an increase in wetland-type habitat along stream banks and sand bars (Stromberg et al. 1996, Merritt & Cooper 2000, Williams & Cooper 2005).
- Higher baseflows in concert with the lack of scouring floods have also led to increased vegetation density on streambanks (Kriegshauser & Somers 2004, Douhovnikoff et al. 2005, Merritt 2005, Williams & Cooper 2005). This combination of factors sets up a positive feedback between vegetation density and resultant bank armoring, which leads to decreased erosion potential on river banks, which supports increased vegetation density of both native and non-native species (e.g. Douhovnikoff et al. 2005).

Native Species:

<u>Cottonwoods</u>

- Two species are abundant on the Dolores River: *Populus angustifolia* (narrowleaf) at higher elevations, and *Populus deltoides* subsp. *wislizenii* (= *P. fremontii,* Fremont) at lower elevations.
- These species have declined significantly in both recruitment and abundance on regulated rivers across the west (Merritt & Poff 2010).
    - The decline is at least partly due to dropping water tables in riparian floodplains due to lack of spring floods for recharge (Scott et al. 1999, Amlin & Rood 2002, Rood et al. 2003).
    - But decline is also linked to lack of available soil water in upper soil layers resulting from lack of spring floods that inundate the floodplain (Williams & Cooper 2005).
        - This leads to loss of upper soil root density and subsequent loss of leaf area and branches due to drought stress (Scott et al. 1999, Williams & Cooper 2005, Dott *personal observation*).
        - Thus cottonwoods growing on regulated rivers exist in permanent drought conditions, which makes them even more prone to stress when actual drought occurs (Dott et al. 2011).
        - When the floodplain water table is > 3m deep, up to 50% of roots are found in the upper 1m of soil, and groundwater declines of $\geq$ 1m cause severe stress and canopy dieback (Scott et al. 1999, Williams & Cooper 2005).
- Cottonwood seedling establishment and survival depends on timing of peak flows and draw-down rates (the "Recruitment Box" model of Mahoney & Rood 1998; see Figure 10).
    - First year seedlings survive best where groundwater depth $\leq$ 1m (Mahoney & Rood 1992, Segelquist et al. 1993, Stromberg et al. 1996).
    - The ideal drawdown rate for cottonwood establishment is 2.5 cm (1") per day (Mahoney & Rood 1998, Amlin & Rood 2002, Rood et al. 2005).
    - On the Dolores River, a stage decline of 1"/day has been estimated as roughly equivalent to a discharge drop of ~100 cfs/day (Wilcox & Merritt 2005).

Willow species

- The dominant willow in all reaches of the Dolores River is *Salix exigua* - sandbar or coyote willow.
- *S. exigua* establishes from seed under conditions very similar to those required by cottonwoods (Johnson 2000, Amlin & Rood 2002, Douhovnikoff et al. 2005), though it does best with slower drawdown rates closer to 1 cm/day (Amlin & Rood 2002).
- Sandbar willow also tolerates shallower groundwater conditions, and its roots are able to grow into the water table, implying that they can tolerate anaerobic conditions much more readily than cottonwood (Amlin & Rood 2002). This fact helps to set up the classic zonation observed along southwestern rivers, with a band of willows along the river bank and subsequent bands of different aged cottonwoods growing behind the willows (Mahoney & Rood 1998).
- Like many of the shrubby willows, *S. exigua* can spread vegetatively to form large clones along river banks. Douhovnikoff et al. (2005) found that reduced flooding due to dam control reduced the availability of seedbeds for both cottonwood and willow seedling establishment, but nonetheless led to an increase in overall canopy cover, height and productivity of *Salix exigua.* This is because the importance of clonal growth increases in the absence of regular disturbance to scour and clear the banks, and the size of individual clones increases, with some as large as 325 m^2 (Douhovnikoff et al. 2005).

Box Elder

- Box elder *(Acer negundo)* is most abundant in more constrained canyon reaches along western rivers (DeWine & Cooper 2007).
- Unlike cottonwood and willow, it produces large seeds in the fall that don't germinate until the following spring (DeWine & Cooper 2007). Box elder is also capable of growing in shaded conditions, unlike the other dominant woody plants of western riparian habitats – cottonwoods and willows - which are sun-loving early successional species (e.g. Rood et al. 2003).
- Nonetheless, box elder establishment has been linked to high flow events (DeWine & Cooper 2007, Coble 2010), showing that this species too is adapted to the variable flow conditions present on unregulated western rivers (Arthington et al. 2006).

Other Native Woody Species

- Several other woody species are found along the Dolores River in various habitats and river reach types (Kittel & Lederer 1993):
    - Obligate Riparian shrubs – specialists that are restricted to streamside zones - include red-osier dogwood *(Swida sericea),* river birch *(Betula occidentalis),* and strapleaf willow *(Salix ligulifolia)* (Rood et al. 2010, USDA 2012), in addition to the dominant tree and shrub species described earlier.
    - Facultative Riparian species – generalists that are abundant in riparian zones, but may also occur less abundantly on adjacent uplands - include hawthorne *(Crataegus spp.),* three-leaf (skunkbrush) sumac *(Rhus aromatica),* silver

    buffaloberry *(Shepherdia argentea),* and New Mexico privet *(Forestiera pubescens)* (Rood et al. 2010, USDA 2012).

- Much less is known about the flow regime requirements or tolerances of most of these species, or how river regulation affects their survival and establishment. However, the Facultative Riparian species that occur in floodplains tend to be moderately flood tolerant, and thus are likely to occur in areas that are transitional between the lower, more frequently flooded portion of the floodplain that is colonized by sandbar willow and the uplands which are dominated by big sagebrush or pinyon-juniper communities (Merritt 2005, Oliver et al. 2011). Some of these species are also considered later successional and may occur in the understory of cottonwood-willow stands (Kittel & Lederer 1993).

Exotic Invasive Species

<u>Tamarisk</u>

- Tamarisk has a similar range of flow requirements and tolerances as cottonwood, except broader (Sher et al. 2002, Merritt & Poff 2010, Chew 2011).
- Flow conditions that favor cottonwood will also favor tamarisk, indicating that tamarisk would have invaded western riparian habitats in any case, regardless of flow regulation (Merritt & Poff 2010, Mortenson & Weisberg 2010, Mortenson et al. 2011)
    - This means that managing flows in such a way as to support recruitment and growth of native species like cottonwood are also likely to encourage growth of successful invaders like tamarisk which have both a longer period of seed production and wider environmental tolerances (Merritt & Poff 2010, Mortenson et al. 2011)
    - BUT both cottonwood and willow seedlings, under ideal conditions, are superior competitors to tamarisk (Sher et al. 2002, Sher & Marshall 2003).

<u>Russian Olive</u>

- While Russian olive *(Eleagnus angustifolia)* is not currently known from the Dolores River (at least above Bedrock), it is an invasive tree that is likely to become important on this river. It has become very abundant along other rivers in the region such as the Animas and the San Juan (Dott, *personal observation),* and could easily invade sites along the Dolores.
- Unlike tamarisk and cottonwood, Russian olive is shade tolerant (Katz & Shaftroth 2003), which enables it to establish in the understory of other riparian trees and shrubs until it can grow up through the canopy and ultimately shade out the other, less shade-tolerant species.
- It is also a nitrogen-fixer, has longer-lived seeds that are bird-, not wind-dispersed, appears to thrive under conditions of flow regulation, and may be somewhat more drought tolerant than other riparian species (Katz & Shafroth 2003), all of which combine to make it a strong competitor even to the non-native invasive tamarisk.

B) Dolores River – Big Gypsum Valley Study Reach, Summary of Current Conditions

i) Shifts in Species Dominance

According to surveys done in the 1970s, extensive groves of Fremont cottonwoods *(Populus deltoides* subsp*. wislizenii)* were found in the Big Gypsum valley (Merritt 2005), but most of these groves are thin to non-existent today, with many cottonwoods succumbing to old age. Little to no cottonwood regeneration is evident in this or other reaches of the Dolores River, with the exception of some vegetative reproduction in Reach 1 between McPhee Dam and Bradfield Bridge (Dott, *pers. obs.*). The woody dominant vegetation had shifted to tamarisk *(Tamarix spp.)* in most parts of the valley, but the combination of the arrival of the tamarisk leaf beetle *(Diorhabda carinulata)* biocontrol agent in the summer of 2009 (Tamarisk Coalition 2011) and the removal work of the Dolores River Restoration Partnership (DRRP 2011) has greatly reduced tamarisk abundance in the area. Woody vegetation in the riparian zone is thus dominated by dense stands of coyote willow (*Salix exigua)* along the river banks and patchy stands of New Mexico privet *(Forestiera pubescens)* in the upper floodplain, with occasional individuals of three-leaf sumac *(Rhus aromatica)*. Most areas of the upper floodplain, however, are dominated by a mix of big sagebrush and rabbitbrush *(Seriphidium (*formerly *Artemisia) tridentata & Chrysothamnus nauseousus),* indicating a shift in vegetation to more upland species (= "terrestrialization" of the floodplain) (Wilcox & Merritt 2005, R Anderson 2011, Korb et al. 2011).

We can begin to understand when and how these shifts in species dominance have occurred thanks to a handful of recent dendrochronology (and other) studies in the region. Coble (2010) used dendrochronology to reconstruct the periods and conditions of cottonwood establishment throughout the Dolores River watershed. In the lower Dolores where Fremont cottonwood is found, he documented few establishment events. In the reach above Big Gypsum Valley there was no difference in establishment events before vs. after McPhee Dam construction (Figure 1). In the reach below Big Gypsum, there were significantly more establishment events after the dam was constructed, leading Coble to conclude that summer minimum flows were the most important variable constraining successful recruitment (Figure 1; Coble 2010). This is likely a reflection of the conditions prior to McPhee Dam construction, when most to all summer flow was diverted – just upstream of the current dam site - for irrigation purposes, leaving a dry channel downstream in some years (Wilcox & Merritt 2005). As summarized above, soil moisture draw-down in excess of 2.5 cm/day through the growing season will lead to cottonwood seedling mortality (Mahoney & Rood 1998), which was almost certainly the case during this period in the lower Dolores River. After the dam was completed, while peak spring flows were reduced, summer baseflows were increased (Richard & Wilcox 2005, Wilcox & Merritt 2005, Richard & Anderson 2007), apparently providing enough soil moisture in some years to support successful seedling recruitment.

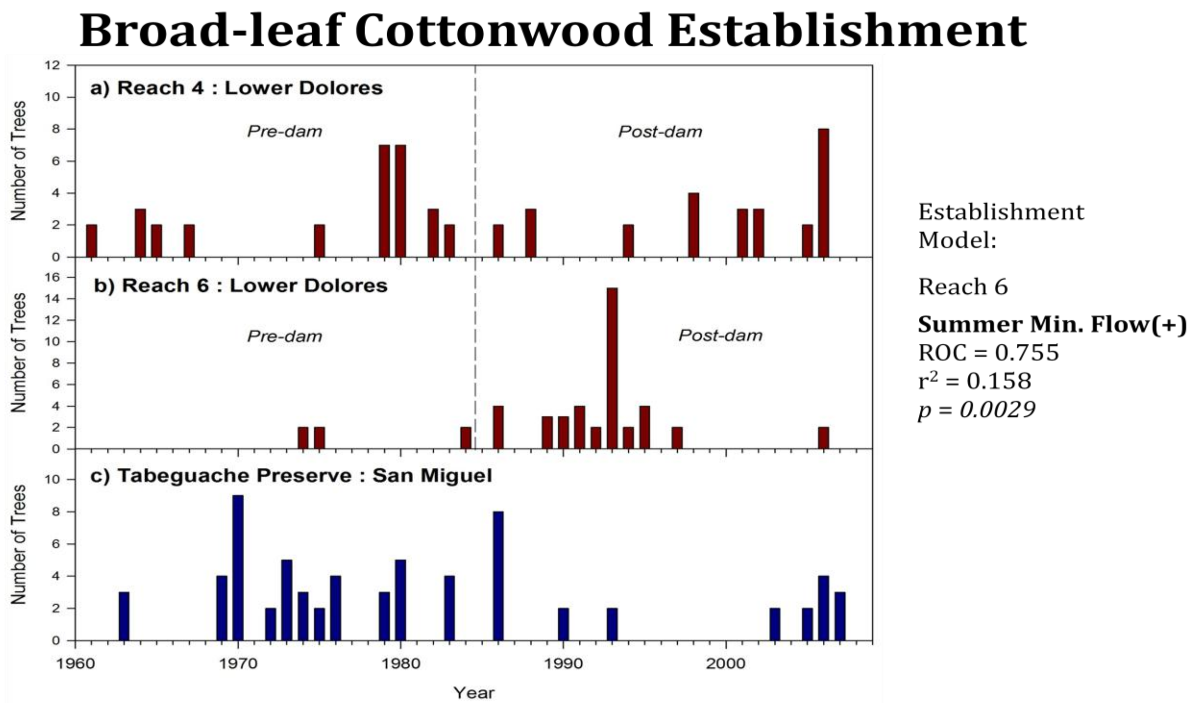

Figure 1. From Coble 2010. Fremont cottonwood establishment events in two dammed reaches of the Dolores River (Reach 4, above Big Gypsum Valley and Reach 6, below Big Gypsum) and a reach of the undammed San Miguel River for comparison. Few establishment events occurred in Reach 4, with no difference pre- and post-dam. Significantly more successful establishment events occurred in Reach 6 after dam construction, in contrast to the pattern observed on the San Miguel. The only variable to show a significant relationship with establishment events on the Dolores River was summer minimum flow.

Bombaci et al. (2011) used dendrochronology to understand the timing and conditions of tamarisk establishment in the Big Gypsum Valley. Their results were exactly the opposite of Coble's (2010): almost without exception, tamarisk recruitment in this reach occurred before McPhee Dam completion, during the period when peak spring flows were allowed to come downstream but summer flows were low to non-existent (Figure 2; Bombaci et al. 2011). Of all the flow and climatic variables tested, the only one with a significant relationship to tamarisk establishment was total June precipitation (r=.440, p=.008) (Bombaci et al. 2011). Given the low summer flows during this time period, it makes sense that rain during the usually dry month of June would be a strong precursor to seedling survival. Usually, cottonwood seedlings can outcompete tamarisk (Sher et al. 2002), but the superior drought tolerance of tamarisk (Merritt & Poff 2010) must have allowed it to survive during a time when cottonwood could not. The lack of tamarisk recruitment after dam completion is initially counter-intuitive, but does fit with the conclusions of Merritt & Poff (2010) that tamarisk recruitment is lower on rivers with flow alteration.

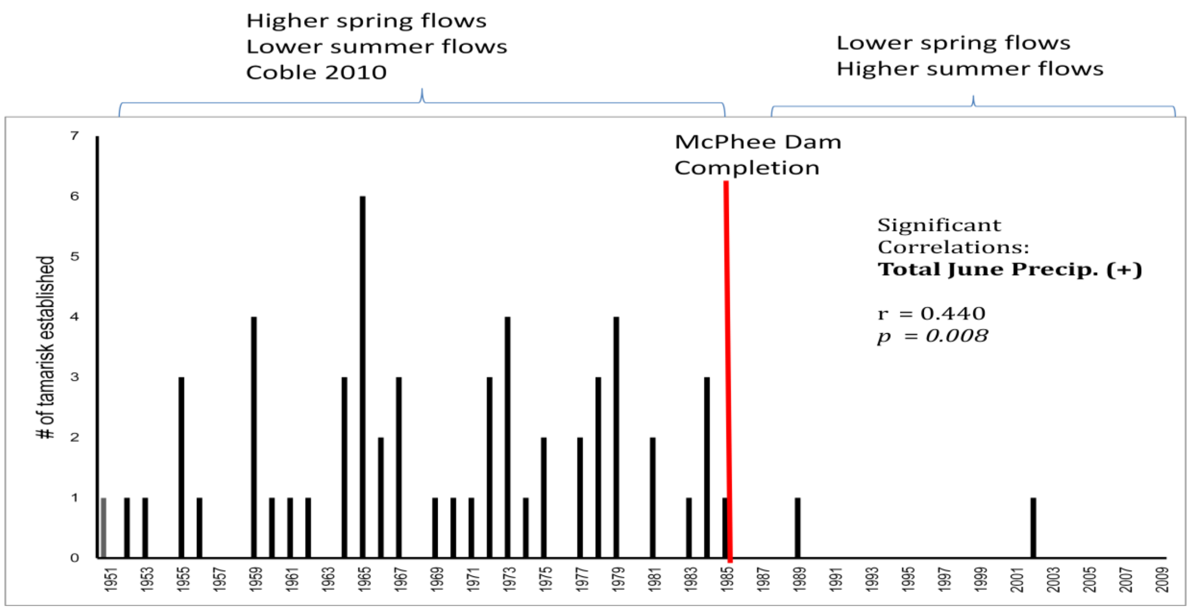

Figure 2. From Bombaci et al. 2011. Tamarisk establishment events in the Big Gypsum Valley reach (Reach 5) of the Dolores River. Almost all successful establishments occurred before the completion of McPhee Dam, during the period of unaltered spring snowmelt flows but extremely low to non-existent summer flows. Of the many flow and climatic variables tested, only total June precipitation was significantly correlated with tamarisk establishment.

No specific data exist for the Big Gypsum Valley on changes in recruitment and cover of willows, but Kriegshauser & Somers (2004) documented changes in willow *(Salix exigua)* cover in the reach below McPhee Dam (Figures 3 & 4; Kriegshauser & Somers 2004, Dott 2009). *S. exigua* is known to spread vegetatively and form large clones, especially under conditions of infrequent flooding (Douhovnikoff et al. 2005). Based on the data and repeat photography (Figure 4) available from upstream, it appears likely that a rapid increase in willow cover along river banks has occurred throughout the Dolores River watershed since the completion of McPhee Dam and the loss of large, scouring spring floods in combination with raised baseflow which supports willow growth (Amlin & Rood 2002, Douhobnikoff 2005). While *Salix exigua* is a valuable native species, its dense encroachment on the banks and channel margins has several negative side effects including bank stabilization, channel narrowing, and a reduction in the scouring potential of high flow events (Douhovnikoff 2005, Merritt 2005, Korb et al. 2011). All of these factors combine to lead to a loss of potential open germination sites for other native species like cottonwood.

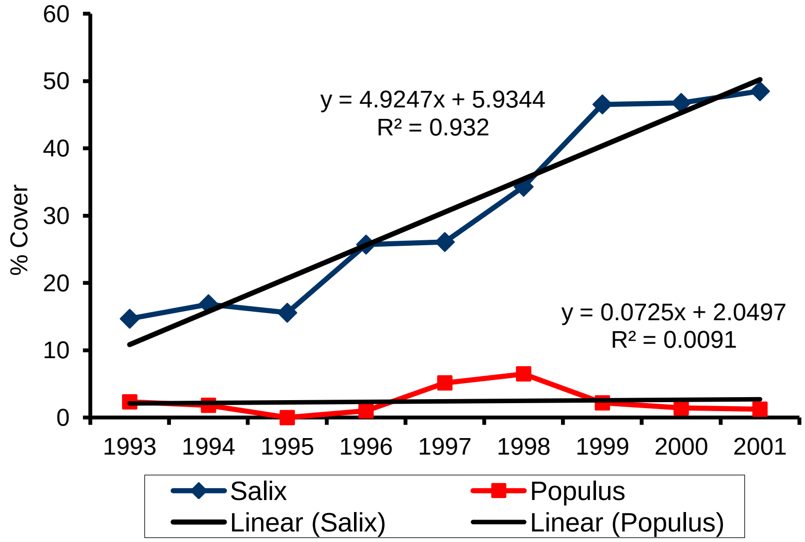

Figure 3. Modified from Kriegshauser & Somers 2004. Changes in willow and narrowleaf cottonwood cover on the river bank ("beach" area) between 1993 and 2001 – the post-dam period - at a long-term study site in Reach 1 of the Dolores River (below McPhee Dam). While cottonwood cover remained essentially constant during this time period, willow cover increased dramatically.

1988 2007

Figure 4. Repeat photo pair of the Lone Dome long-term study site (6 miles below McPhee Dam) showing a dramatic increase in vegetation cover, mainly by willow species, along the river bank/point bar (or "beach"). As a result, much less open sediment is available for seedling establishment. 1988 photo (left) by P. Somers, 2007 photo (right) by C. Dott.

ii) River Hydrographs & Riparian Vegetation

In trying to establish plans for managing flow regulation via "environmental flows" (sensu Arthington et al. 2006, Shafroth et al. 2010), there are several parameters that must be taken into consideration, in order to mimic the natural range of variation present in unregulated rivers (Poff et al. 1997, Arthington et al. 2006). These variables include: magnitude, frequency, timing, duration, rate of change, and predictability of flow events (Poff et al. 1997). Some of these are easier to address than others in a managed system where there are many demands on the water resource, but the fact that rivers in their natural state exhibit high year-to-year variation gives managers some flexibility in their efforts to generate environmentally sound flows.

Magnitude

Flow magnitude on regulated rivers will almost never be as great as it was prior to dam and diversion construction, since capturing spring snowmelt and storing it for later use is at the core of irrigation management. In addition, the structural limitations of dams often mean that the maximum discharge volume is limited: on the Dolores River, peak releases are limited to 5,000 cfs. What this means is that the river is "resized" (Rood et al. 2005, Richard & Anderson 2007) based on these lower flows, and floodplains will naturally be forced to narrow as a result of the lower volumes of water that come downstream. Still, the key point here is that higher magnitude "flood" events are necessary to maintain even a narrowed floodplain, and to scour the channel and banks to maintain and create habitat for both aquatic and riparian species. High flows of varying magnitudes are essential to the health of river ecosystems.

Work in Big Gypsum Valley by Richard & Wilcox (2005) and Richard & Anderson (2007) indicates that flows of at least 2,600 cfs are required to inundate 50% of the floodplain surface, and 3,400 cfs are needed to inundate 95% of the floodplain. However, flows of these magnitudes are greater, respectively, than the 1.5-year and 2-year recurrence interval flows post-dam (Table 1; Richard & Anderson 2007). So-called bankfull flows are required to inundate the floodplain and recharge the water table, which in turn supports floodplain vegetation. These targets (2,600 and 3,400 cfs) are minimum flows for floodplain maintenance, and will not achieve the channel scouring and streambank clearing that true flood flows accomplish. In fact, for significant movement of sediment and cobble in the river channel, and for substantial sediment erosion and deposition on the floodplain, much higher magnitude flows on the order of 10,000 cfs are needed (Table 1, Richard & Anderson 2007). Given the 5,000 cfs limitation on dam releases, flows of these magnitudes will not happen from dam releases alone. However, the Dolores River does offer a unique opportunity for generating rare large magnitude flood events, in years when there is a significant snowpack at low elevations (D. Graf *pers. comm,* C. Dott *pers. obs.)*, such as occurred in 2010 (Figure 5). In 2010, early snowmelt generated a discharge peak in April that was as large or larger than the dam release peak. If dam discharge had occurred at the same time, the peak flow that might have been achieved would only be ~2500 cfs (Figure 5); however, there may be years when a much larger spill is possible, and on-site snowmelt could be added to the equation to generate larger magnitude flood-type flows. This should not become a frequent occurrence, however, due to other ecosystem needs (see section on Timing, below).

Table 1. Modified from Richard & Anderson 2007. Comparison of channel-forming discharge estimates for the Dolores River from pre- and post-dam periods. Recurrence intervals were derived from flood frequency curves developed from the Dolores River at Bedrock gage (Wilcox & Merritt 2005 developed by D. Graf 2005; Richard & Anderson 2007).

Channel-Forming Discharge Estimate (Current Study)	Discharge (cfs)	Post-dam Recurrence Interval (years)	Pre-dam Recurrence Interval (years)
Bankfull Discharge			
Big Gypsum Reach (50% floodplain inundation)	2,600	1.8	1.36
Big Gypsum Reach (95% floodplain inundation)	3,400	2.5	1.44
1.5-yr Recurrence Interval			
Pre-dam - Bedrock Gage (1918-22, 1970-84)	3 ,712	2.8	1.5
Post-dam - Bedrock Gage (1985-2005)	1 ,010	1.5	<1.0
2-yr Recurrence Interval			
Pre-dam - Bedrock Gage (1918-22, 1970-84)	4 ,280	3.7	2.0
Post-dam - Bedrock Gage (1985-2005)	3 ,140	2.0	1.4
Critical Shear Stress			
Marginal transport - Big Gypsum Reach	3 ,200	2.1	1.4
Significant Motion - Big Gypsum Reach	10,000	>35	>30

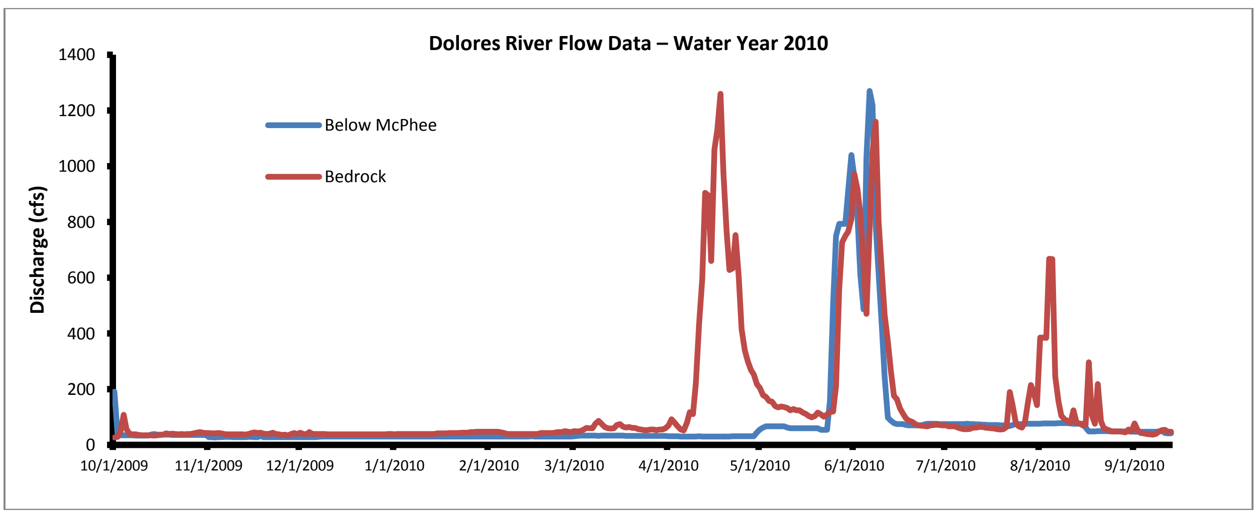

Figure 5. Dolores River stream gage data from water year 2010. Dolores Below McPhee gage shows dam release of almost 1300 cfs in early June. But the Bedrock gage shows an early peak of over 1200 cfs, driven entirely by low-elevation snowmelt, in April when dam discharges were still at baseflow. If the dam release were timed to coincide with the early snowmelt, a much larger peak discharge could be achieved.

Frequency & Predictability of Flow Events

As has been outlined above, annual peak flows in the spring are critical to obligate riparian species as well as to aquatic organisms (e.g. Rood et al. 2005, Arthington et al. 2006, Merritt & Poff 2010). Most of these species have reproductive strategies that are linked to annual bankfull or greater flows, and when frequent high flows are removed from the system native species are lost (Merritt & Poff 2010). Again, variability is the rule however, making a goal of nearly-annual higher spring flows reasonable, as long as multiple back-to-back years with no spill are avoided. On the Dolores River during the major drought that extended from 1999 or 2000 through 2004, there were four years with no spill from the dam (2001-2004) which led to measurable die-back in cottonwood canopy cover below the dam (Figure 6; Dott et al. 2011). Whenever possible, this scenario of sequential no-spill years should be avoided.

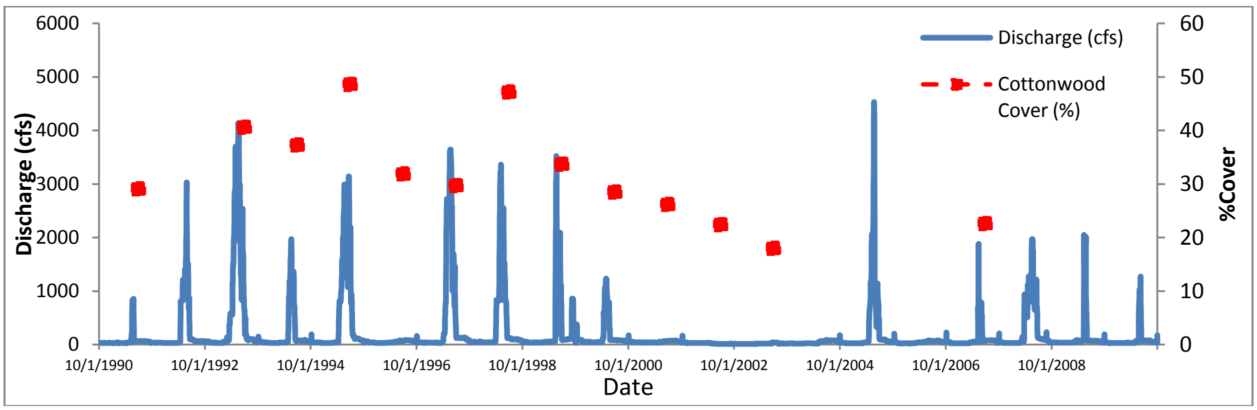

Figure 6. From Dott et al. 2011. Dolores River below McPhee discharge data from 1990 to 2010, with cottonwood canopy cover data superimposed (note that there are some years with missing data). Cottonwood canopy data are from the long-term study site (Lone Dome Recreation Area) described in Kriegshauser & Somers 2004, and documented in Dott et al. 2011. Between 2001-2004, during the drought of record for this region, there were no spills from McPhee Dam, which led to significant declines in cottonwood canopy cover.

On unregulated rivers, bankfull flows that leave the channel and inundate portions of the floodplain have an average recurrence interval of 1.5 years. On the Dolores River since the construction of McPhee Dam, such flows have had a recurrence interval of greater than 2 years (Table 1). As discussed in the previous section, the frequency of floodplain-inundating flows would, ideally, be greater than they have been. Unfortunately, given the limited availability of water in the Dolores River drainage basin and the predictions of a warmer climate bringing lower snowpacks to the southwest (Clow 2010), demand for that water will become even greater. Flood or high flow frequency will not, however, become any less important for the maintenance of floodplain forests.

Timing

Timing of peak flow events is essential for many biological processes in river systems, as described previously. On the Dolores River, management of spills from McPhee Dam has been timed to coincide fairly well with the peak of the historic hydrograph (Figure 7). However, as noted earlier, flow variation is a hallmark of unregulated rivers, and variation in the timing of peak flows has been essentially absent in this system. Recreational river users have come to rely on a Memorial Day weekend spill for whitewater rafting, but there may be unintended consequences for the ecosystem in linking peak timing to the calendar so tightly. Because riparian and aquatic species exhibit variability in the timing of reproductive processes like flowering, seed dispersal, spawning, and hatching, lack of variability in the hydrograph is likely to favor some species and disadvantage others. If possible, given the wide range of other constraints on this system, it would be good to allow the peak discharge to move a little bit – even just by one week earlier or later in some years. Since we can never know everything about all of the species occupying an ecosystem and how they will respond to changes in physical conditions, the most conservative approach is to mimic natural processes as much as possible (Arthington et al. 2006). Linking dam release timing to snowmelt input above the dam is one way to insure variability in timing to the hydrograph.

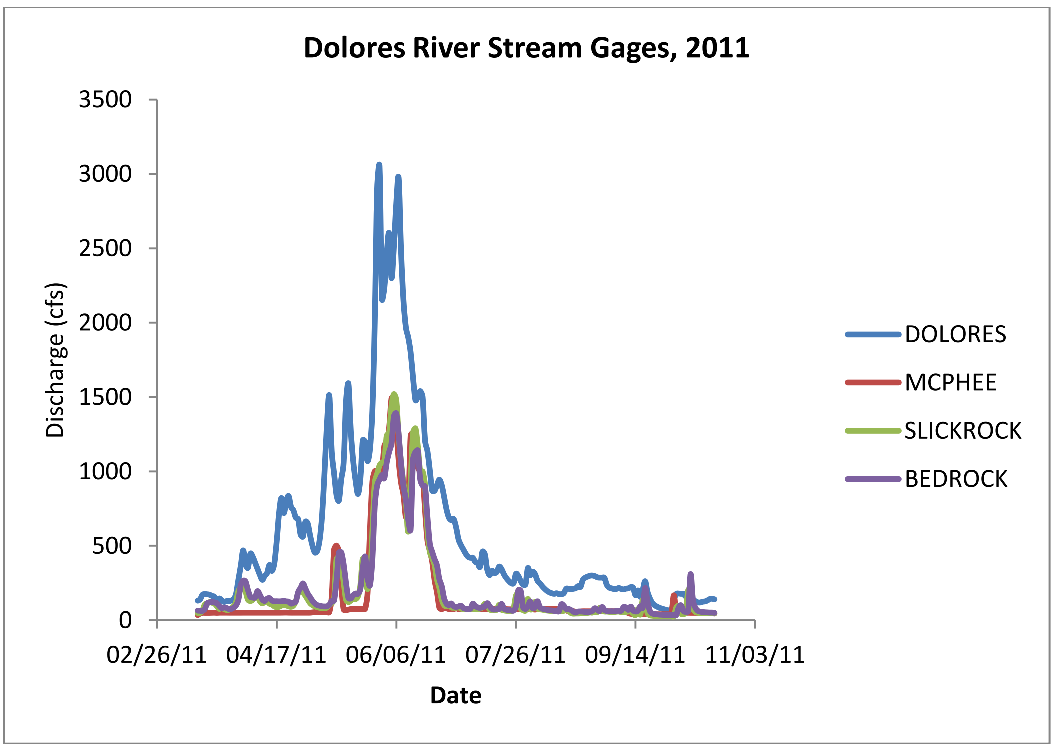

Figure 7. Dolores River hydrographs for water year 2011, with discharge data from four gauging stations superimposed to show matching of peak discharge above and below McPhee Dam. Gages are listed, from top to bottom, in upstream to downstream order: Dolores at Dolores (above dam, unregulated), Dolores below McPhee Dam, Slickrock gage (upstream of Big Gypsum Valley) and Bedrock gage (downstream of Big Gypsum).

On the subject of peak flow timing, I would refer back to a topic addressed under magnitude: the idea of occasionally (rarely) linking the dam spill with early low-elevation snowmelt (Figure 5). This recommendation would seem to go counter to the theory of matching the timing of flow events to the historical hydrograph, which, indeed, it does. However, the benefits derived from generating a rare, larger flood would be so great in terms of re-activating physical processes and creating habitat that they would almost certainly outweigh the costs of the change in timing. I emphasize that this should be a very low frequency event as it falls outside of the range of historic flow peaks. This would also be a way of reintroducing some variation into the discharge dynamics of the river.

Duration

The duration of high (and low) flows is as important – and as problematic – as the magnitude. Because total spill volume is limited on the Dolores River, the magnitude of peak discharge directly impacts the duration of those high flows. And yet both are necessary for ecosystem maintenance. A key aspect of the duration of peak flows is related to groundwater and floodplain soil recharge (Williams & Cooper 2005). Floodplain groundwater levels have been monitored by Gianniny and Dott (and students) during the 2010, 2011 and 2012 growing seasons, at locations in Big Gypsum Valley (Figure 8), Lone Dome Recreation Area (below McPhee Dam), and above the town of Dolores.

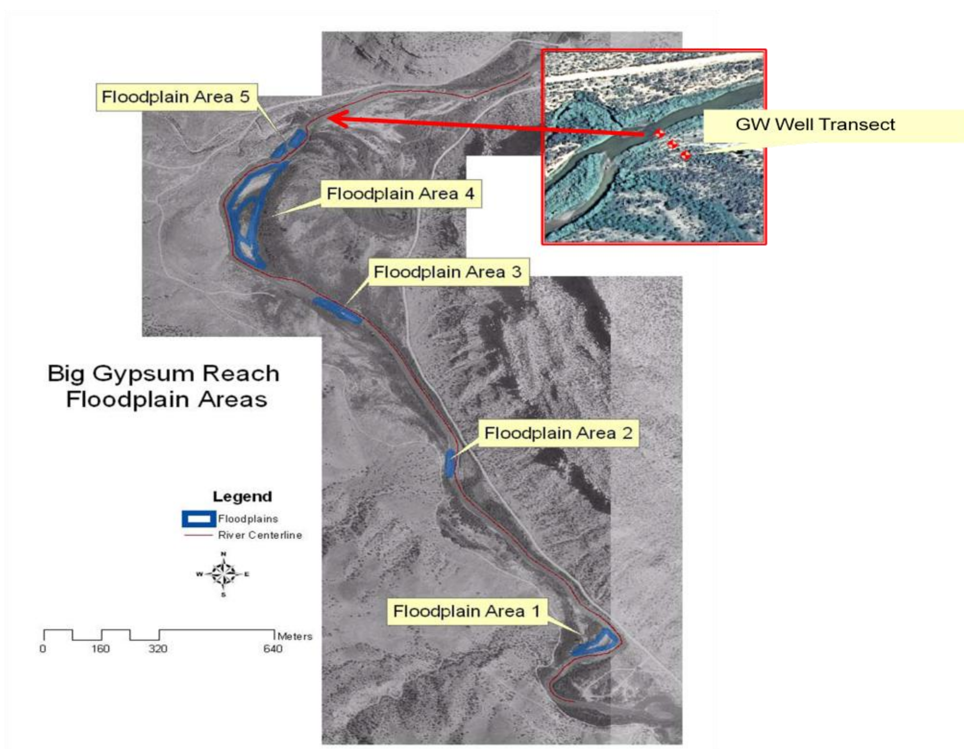

Figure 8. Combined from Richard & Anderson 2007 and Clutter et al. 2011. Aerial image of the downstream end of the Big Gypsum Valley reach, Dolores River, showing locations of floodplain sites where Richard & Anderson (2007) measured stream cross-sections for their discharge analysis. Just downstream of their Floodplain Area 5, near the location of the BG-19 and BG-20 cross-sections of Richard & Wilcox (2005), and on cross-section 3 of R Anderson (2011), is the location of the groundwater well transect (inset image) (Clutter et al. 2011).

Using these data, Clutter et al. (2011) found that duration, more than magnitude of high flows alone, had a strong influence on the amount of groundwater recharge in the floodplain (Figure 9a & b). Spring dam release flows with a maximum magnitude of ~1300 cfs and a duration of about 19 days generated recharge that lasted up to 60 days (Figure 9a; Clutter et al. 2011). In contrast, high flows during monsoon season reached 1650 cfs that lasted only one day, and elevated groundwater levels for only 11 days (Figure 9b; Clutter et al. 2011). This suggests that higher than average flows need to last several days (or 2+ weeks based on our 2010 data) in order to achieve effective, lasting groundwater recharge. This duration, in combination with the shape of the declining limb of the hydrograph (see below) is critical for recharging floodplain moisture, which in turn is critical for the establishment and survival of obligate riparian species like cottonwoods (Rood et al. 2003, Williams & Cooper 2005).

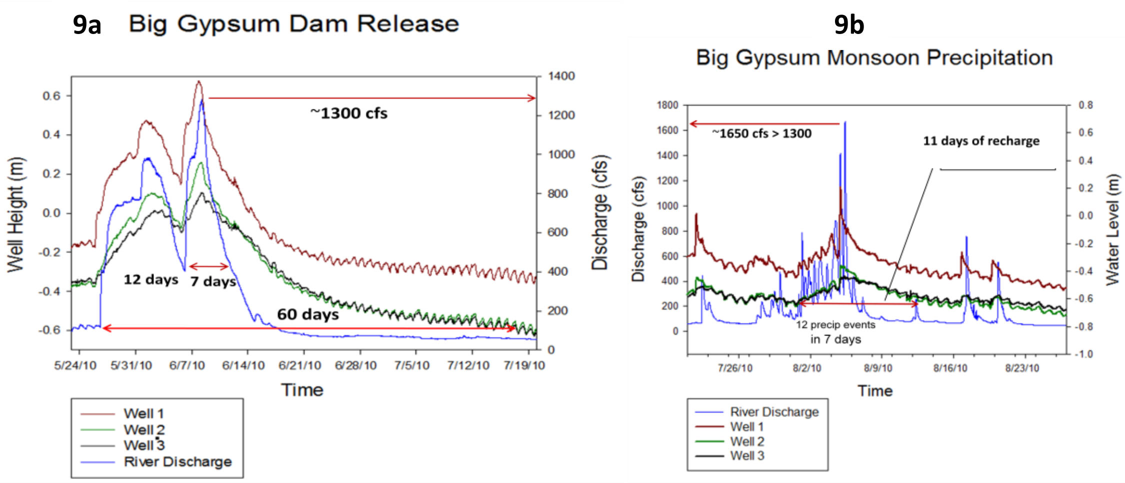

Figure 9a & 9b. Adapted from Clutter et al. 2011. Comparison between river discharge (Bedrock gage) and groundwater levels in three wells in the Big Gypsum valley; well 1 is closest to river, well 3 farthest (Figure 8). **9a –** Water height in wells (relative to river baseflow datum) declines back to base level over a period of 60 days following 19 near-continuous days of dam release discharge greater than 1000 cfs. **9b–** Water height in wells (relative to river baseflow datum) declines over a period of only 11 days following 7 days of individual monsoon-driven discharge events ranging from 600 to over 1600 cfs.

Rate of Change

As stated above, drawdown rates of 2.5 cm/day are ideal for cottonwood seedling establishment (Mahoney & Rood 1998), and average groundwater depths of ~3m are most likely to support stands of mature Fremont cottonwoods (Stromberg et al. 1996). Changes in the shape of the hydrograph – the increasing slope (rates) of the ascending and (especially) the descending limbs – are important drivers of groundwater drawdown. Wilcox & Merritt (2005), based on a previous BLM study, estimated that discharge reductions of 100 cfs/day will result in stage reductions of about 1 inch (2.5 cm)/day on the Dolores River, although stage height for given discharges is very site specific as it is linked to channel geometry and gradient (Mahoney & Rood 1998, Richard & Anderson 2007).

In many years it does appear that the groundwater drawdown rate in Big Gypsum has been too rapid to support cottonwood seedling establishment. Anderson (2011) found that the soil moisture drawdown rate at during part of the 2010 growing season (dates unspecified) was 5.0 cm/day in a site directly adjacent to the river bank on his cross-section 3. Further back from the river's edge (60 ft from baseflow bank) the rate was a much slower 1.4 cm/day (R Anderson 2011), which could be conducive to *Populus* seedling growth if other vegetation cover is not too high (e.g. Mahoney & Rood 1998, Rood et al. 2003). A key point here, though, is the timing of these drawdown rates. The "recruitment box" model of Mahoney & Rood (1998, Amlin & Rood 2002, Rood et al. 2005) specifically prescribes a 2.5 cm/day drawdown rate during the seed dispersal window for Fremont cottonwood, with peak dispersal extending from ~ early June to early July (Fenner 1985, Mahoney & Rood 1998) (although to my knowledge this dispersal window has not been confirmed for the Big Gypsum Valley). Figure 10 (taken from Amlin & Rood 2002) shows the generalized recruitment box model for cottonwood and sandbar willow, to give an idea of how the seed dispersal "box" for cottonwood would, ideally, overlay on the declining limb of a river hydrograph (here shown as stage decline instead of discharge).

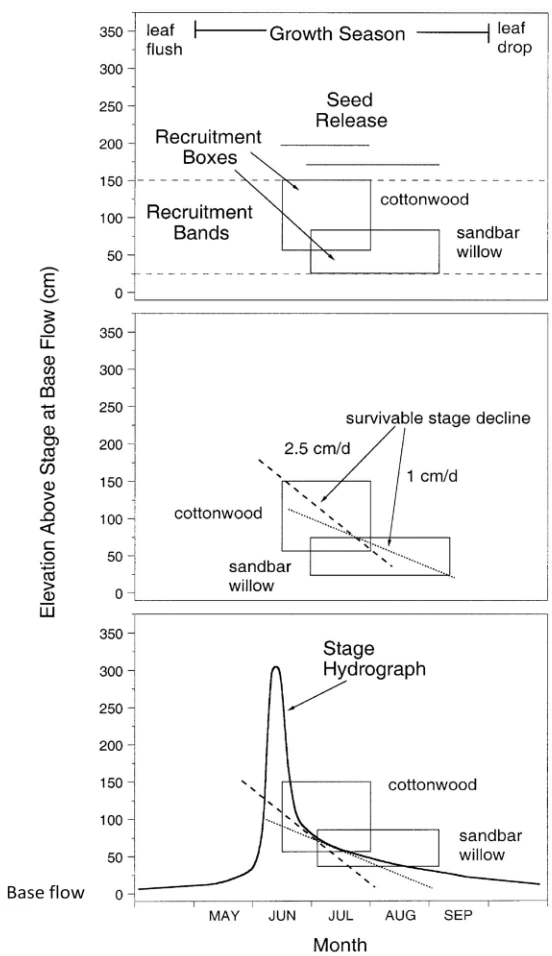

Figure 10. From Amlin & Rood (1998). The "Recruitment Boxes" for riparian cottonwoods and willows defined by the establishment elevation (Recruitment Band) and seed release periods for each genus (top), survivable rates of water-table decline (middle) and stage hydrograph requirements (bottom) for both genera. Note that the vertical axis is not river discharge, but stage height above base flow (in centimeters).

Because of the ongoing groundwater studies of Gianniny & Dott we have additional data to complement the work of Anderson (2011). Groundwater drawdown rates in well #1 (adjacent to river bank) at Big Gypsum between 15-26 June 2011 were similar to those documented by Anderson (Figure 11): 5.01 cm/day. However, from 27 June-9 July the average drawdown rate was 0.92 cm/day (Figure 11), which is a rate that could support cottonwood seedling survival if it continued through the summer. In addition, at this well location groundwater depths never exceeded 1.5 meters below the surface, which falls within the survivable range outlined by Mahoney & Rood (1998). However, this well location is too close to the active channel to support long term seedling survival (Mahoney & Rood 1998), and further from the riverbank the groundwater depth may be too great or the stage decline too rapid to promote recruitment. We know from previous work (L Jamison 2005, *unpublished data)* that seeds of both cottonwood and tamarisk can germinate following high spring flows in the Big Gypsum reach, but no seedlings of that cohort are known to have survived (Dott, *pers. obs.).*

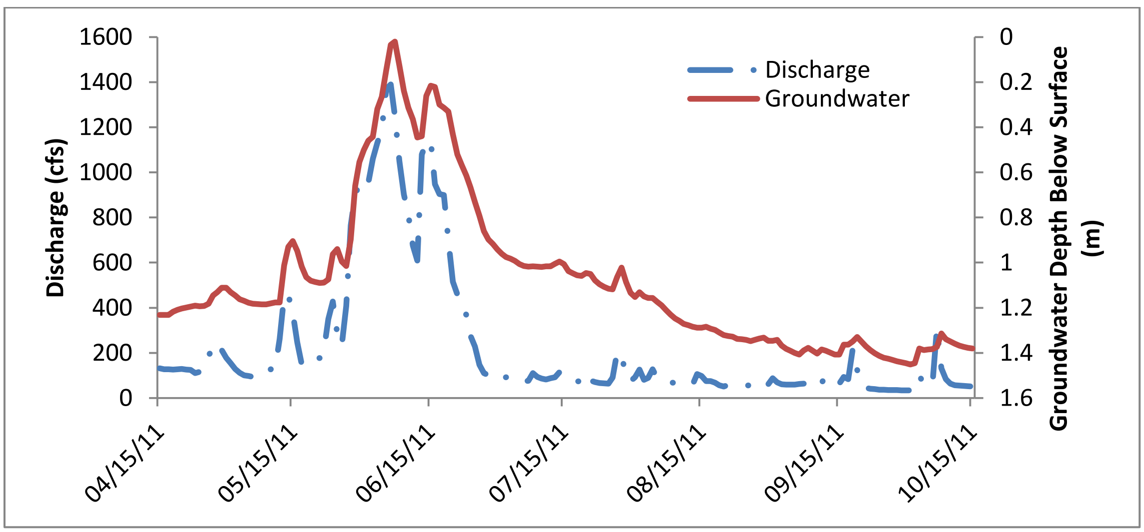

Figure 11. From Gianniny & Dott, unpublished data. Daily average depth to groundwater in well #1, Big Gypsum Valley, during 2011 growing season. Between the period from 15-26 June groundwater declined on average 5.01 cm/day. Between 27 June-9 July average drawdown rate was 0.92 cm/day. Discharge at the Bedrock gage is shown for comparison. Note that discharge decline is more rapid than groundwater drawdown.

2) Evaluation of Reservoir Release Guidelines for Riparian Ecosystem Needs

A) *25,000 Acre Feet Spill*

This spill target (Figure 12), with peak discharges of less than 1,000 cfs, will not inundate the floodplain (based on the work of Richard & Wilcox 2007), and thus will have minimal positive impact on native vegetation on the intermediate or secondary floodplain. To overtop riverbanks that are typically 1.5-2 or more meters high would require flows of at least 2000 cfs in most areas (Richard & Wilcox 2005, Richard & Anderson 2007).

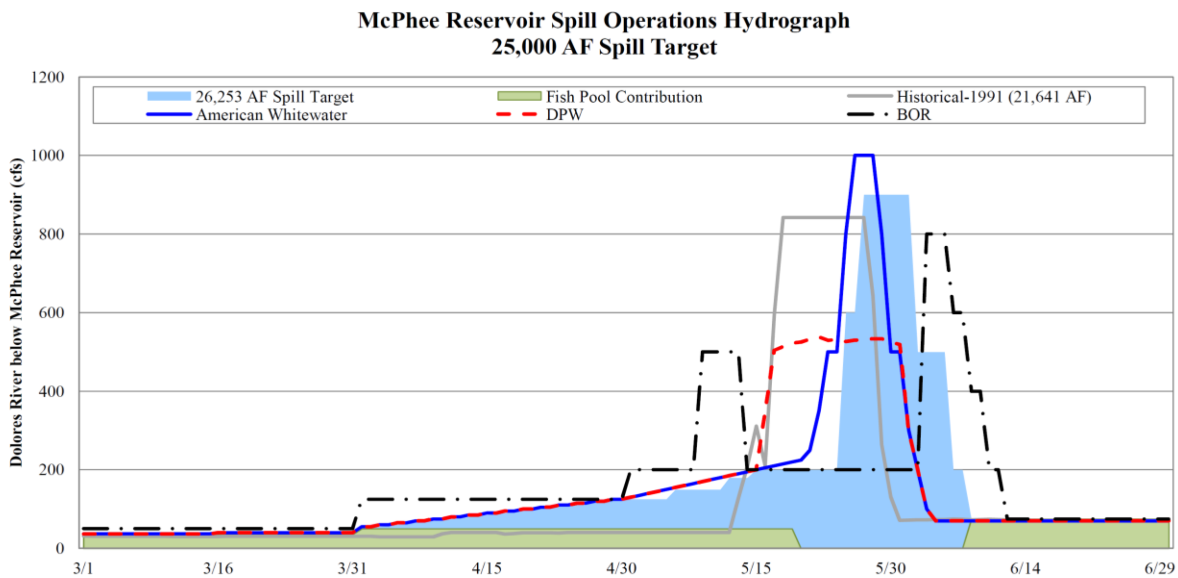

Figure 12. 25,000 AF Spill Target – Dolores River.

Flows generated by a 25,000 AF spill are likely to promote the moisture-loving riverbank vegetation present along alluvial reaches of the Dolores River today, which is characterized by dense stands of sandbar willow and common reedgrass *(Phragmites australis)* (Figure 13; Dott et al. 2011a).

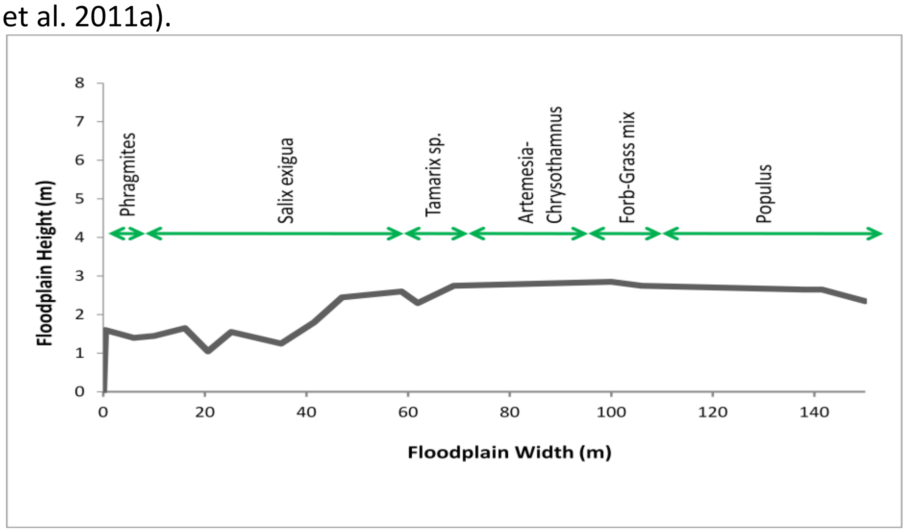

Figure 13. From Dott et al. 2011. Typical floodplain elevation profile and vegetation bands along the lower Dolores River, in the vicinity of Big Gypsum Valley.

Constant base flows and low peak spring flows provide a steady supply of water directly to the streambank vegetation. This vegetation type undoubtedly creates wildlife habitat, but it is not a plant community that likely existed under the historic flow regime of western rivers (Williams & Cooper 2005). Furthermore, its density limits the ability of higher flows to re-work the banks (Douhovnikoff et al. 2005) and thus the channel, which therefore impinges on the habitat of other aquatic and riparian species. It is a judgement call as to whether this community type is "good" or "bad." It is dominated by native species (there is some disagreement as to whether common reedgrass is an introduced or a native species; it may be an introduced subspecies), and is dense enough to keep most other invasive species at bay, though on other rivers Russian olive has grown up through the understory in similar settings (Dott, *pers. obs.)* and is likely to do so on the Dolores in the absence of active disruption of willow stands. Russian olive thrives and quickly rises to dominance on rivers with minimal flood disturbance (Katz & Shafroth 2003). Thus, the low magnitude flows generated by this spill volume may be considered "minimum flows" (Rood et al. 2005), and perform the essential role of delivering some moisture during hot, dry summers – enough to maintain the riverbanks, but unlikely to provide much groundwater recharge (but we need more site-specific data to really address this issue). Under these flow release guidelines alone, Fremont cottonwood will likely become extinct in this river basin below the dam due to a lack of the scouring flows and aquifer recharge which allow for seedling establishment and survival.

B) *50,000 Acre Feet Spill*

This spill target (Figure 14), with peak discharges just below 2,000 cfs, is likely to inundate the edges of the riverbanks and some low-lying areas on the outer edge of the intermediate floodplain.

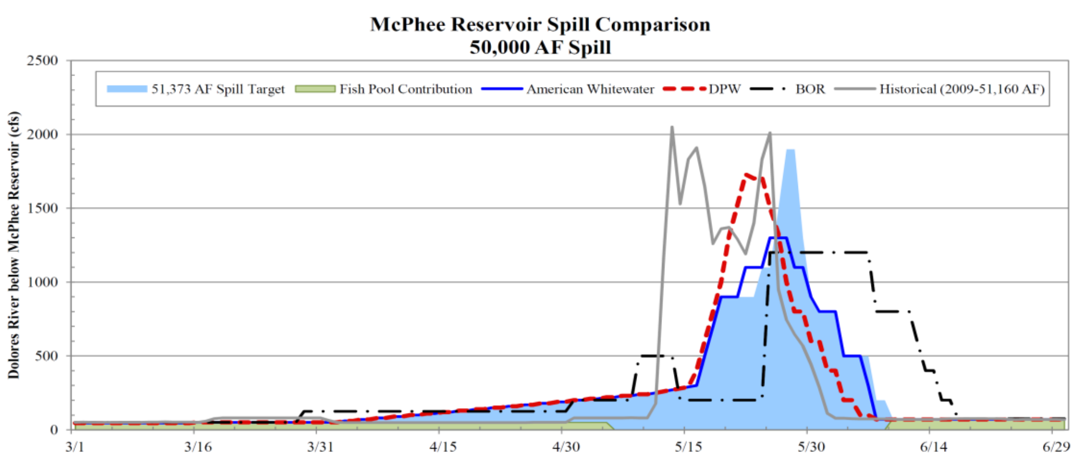

Figure 14. 50,000 AF Spill Target – Dolores River.

Groundwater data from 2010 and 2011 (Gianniny & Dott *unpubl. data)* reflect spill conditions intermediate between this and the 25,000 AF spill (peaks of ~1300 cfs). Floodplain aquifer recharge did occur in these years, though not at high rates and generally not enough to keep

groundwater above base level through the entire growing season (Figure 9a & b; Clutter et al. 2011). An important difference of this hydrograph versus those from 2010-11, however, is that the descending limb of the hydrograph may ramp down more slowly than it has in the past (see Figure 11 for comparison). That fact could allow discharges such as these to maintain (and probably promote) the dense streambank vegetation, and may help maintain obligate riparian species on the outer edge of the intermediate floodplain, but will not halt terrestrialization of the intermediate and secondary floodplain. These water levels may aid in flushing concentrated salts out of the adjacent floodplain soils (R Anderson 2011), which could promote growth of native species and help them outcompete tamarisk.
Flows such as these are important "maintenance flows" (Rood et al. 2005) that should assist native riparian species in their efforts to compete with invasive species. This hydrograph is unlikely to lead to seedling recruitment of native obligate riparian species like cottonwood or willow, which may lead to local extinctions.

C) *100,000 Acre Feet Spill*

This spill target (Figure 15), with peak discharges exceeding 2,000 cfs, will inundate the stream banks and should reach portions of the intermediate, but not the secondary floodplain (Richard & Wilcox 2005, Richard & Anderson 2007). The descending limb of the hydrograph, while dropping steeply initially (~500 cfs/day while flows are above 800 cfs), declines to more moderate drawdown rates below 800 cfs (200 cfs/2 days). This is also better than some of the very steep declines seen in recent years, although the drop to baseflows is much more rapid than it would be in an unregulated river (see Figure 7, Dolores gage hydrograph, for example). Richard & Anderson (2007) predict that very little transport of sediment will occur at this discharge level, and it is equally unlikely that new riparian habitat will be opened/created in the outer zone along the banks. This makes it unlikely that cottonwood seedling establishment will occur. However, longer lasting groundwater recharge should result, which supports riparian species even outside of the zone of inundation. These events represent "growth flows" (Rood et al. 2005), important in the long-term survival of riparian species.

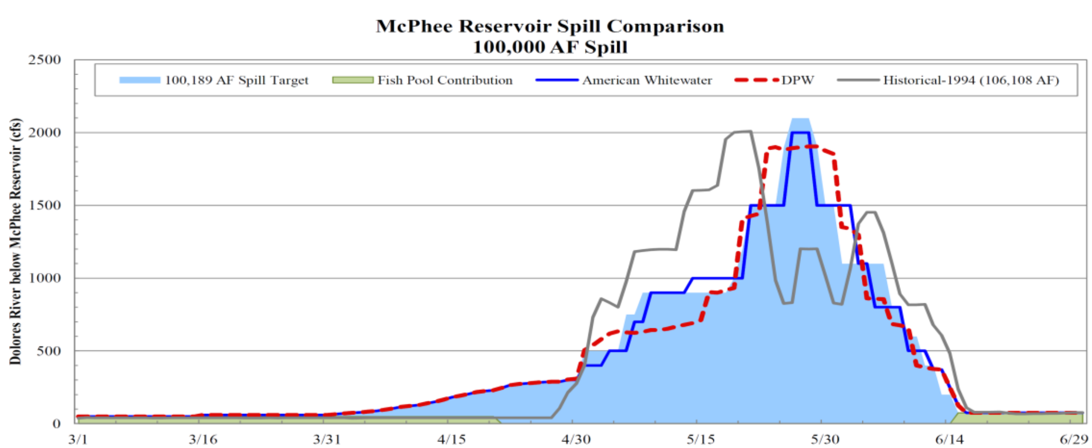

Figure 15. 100,000 AF Spill Target – Dolores River.

Flows of this magnitude will probably flood portions of the mature tamarisk stands present in Big Gypsum floodplains. There are multiple possible effects of such flooding, including the possibility of flushing some salts from the soil (though this is not guaranteed – see R Anderson 2011), and carrying new nutrients into the floodplain. However, several non-native herbaceous invaders like Russian knapweed also inhabit this zone and are abundant under tamarisk stands (Korb et al. 2011). Their tolerance of disturbance in general, including flooding, makes them exceedingly hard to control or eradicate (Jacobs & Denny 2006), and flooding may have the undesired effect of increasing their abundance. Active control of such invasive weeds is the only way to reduce their dominance in the floodplain understory now that they are well-established.

D) ***200,000 Acre Feet Spill***

This is an extremely important spill target (Figure 16), with peak discharges reaching (or exceeding?) 3500 cfs. Flows of this magnitude have occurred only once in the last 12 years (in 2005), and they were able to achieve substantial re-working of channel sediments (D Graf, *pers. comm).* Peak discharges in this range may be able to scour stream banks and redistribute sediment, will fully inundate the intermediate floodplain, and will at least partially inundate the secondary floodplain (Richard & Wilcox 2005, Richard & Anderson 2007). The magnitude and duration of high flows should cause prolonged groundwater recharge, to the benefit of both obligate and facultative riparian species. A flood of this magnitude, while not huge, will be important in maintaining the unique riparian shrub communities of the Dolores River, in particular those dominated by the facultative riparian species three-leaf sumac, silver buffaloberry, and New Mexico privet. These species tolerate periodic flooding, and will otherwise be outcompeted by upland species like rabbitbrush and big sagebrush which do not (Merritt 2005).

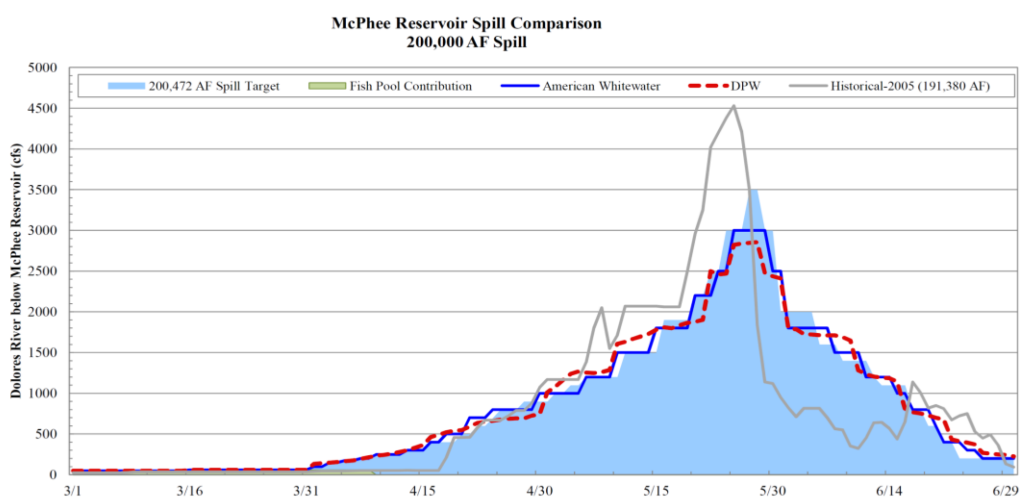

Figure 16. 200,000 AF Spill Target – Dolores River.

Flows greater than 3500 cfs have stimulated both cottonwood and tamarisk seedling establishment in the past (L Jamison, *unpubl. data)*, though not successful recruitment. For recruitment to succeed, major changes would need to occur in the streambank and lower floodplain willow zones, probably involving active vegetation removal and soil exposure prior to the spring spill. Both tamarisk and cottonwood, if a seed source were available, would be likely to take advantage of such openings, and some authors actually recommend avoiding simulated floods during the recruitment window for these species in order to avoid generating a new cohort of tamarisk (Mortenson et al. 2012). However, on the Dolores River – at least in the Big Gypsum Valley reach – the combination of active tamarisk removal (via the efforts of the DRRP) and ongoing defoliation by the tamarisk leaf beetle (and, importantly, the associated lack of flowering) seem likely to give cottonwoods a chance to colonize more sites and gain a competitive edge over tamarisk, especially if flood flows could happen soon to take advantage of recent tamarisk removal work (cf. Drus & Brooks 2011).

3) Suggestions for Additional Management Actions to Benefit Native Species
The proposed spill guidelines will be a great improvement in the management of the aquatic and riparian ecosystems of the lower Dolores River, provided that prolonged drought does not preclude spills for too many years running. Multiple years of base flows only with no spills will lead to conversion of the floodplain habitat to upland vegetation, extreme narrowing of riparian vegetation (mainly willow and common reed) to the river's banks, and narrowing of the channel. Given all of the constraints on water in the Dolores system, and the recognition that water is likely to become even more limiting under future climate scenarios, wise and careful management of the available water is of paramount importance. Following is a summary of suggestions for creative ways to address the flow regime limitations discussed earlier.

A) Magnitude
High magnitude flood discharges that duplicate >10 year recurrence interval floods (Wilcox & Merritt 2005) are much-needed, but cannot be achieved through dam spills alone. Occasionally linking the spill with early low elevation snowmelt events is one possible way to increase flow magnitudes. Summer monsoons can also generate short duration peak flows (rarely), which might do some channel- and bank-scouring work. These events fall outside our ability to manage, but it may be possible to take advantage of them after the fact by augmenting any sediment movement such flows accomplish.

B) Frequency
The frequency of peak flows is driven by water availability, and so there is not much leeway in how it is managed, other than the suggestion to avoid multiple no-spill years in a row if at all possible. The proposed spill guidelines address this parameter as well as possible given the constraints.

C) Timing

Dolores River peak flow timing is one variable that has been well managed since the completion of McPhee Dam, so that spring spills generally match snowmelt timing. That said, variability is a crucial element of river flows (Merritt 2005). Varying the timing of the peak spill slightly is highly recommended (as opposed to always linking it to calendar dates), in order to benefit the largest number of species possible and thereby maximize species richness (Merritt 2005).

D) Duration

The proposed spill guidelines have created hydrographs that more closely resemble a naturally shaped hydrograph, and include ramping rates that allow for longer duration peak flows than are often seen below dams. Since we know that the duration of high flows is important to driving groundwater recharge in the floodplain, I suggest continued monitoring of groundwater under several different spill volumes in order to develop a clearer understanding of how these variables are related. Then, I urge flexibility in spill management if the evidence suggests that occasional lower peak but longer duration flows might benefit floodplain vegetation.

E) Rate of Change

Drawdown rates of groundwater on the declining limb of the hydrograph are critical. I suggest continued monitoring of this variable under the different spill guidelines proposed, and using a variety of methods including soil moisture measurements (as per R Anderson 2011), groundwater monitoring (continuing work of Gianniny & Dott), and site-specific stream stage measurements which are more meaningful to riparian processes than discharge data (Mahoney & Rood 1998). Fort Lewis College student Colin Aanes (under the direction of Gianniny & Dott) began documenting stage height data at the Big Gypsum groundwater well transect (R Anderson's cross-section #3) in spring 2012. Ultimately this should allow us to generate a rating curve for that portion of the channel which can then be used to relate changes in discharge to groundwater drawdown rates.

Again, I urge flexibility where possible in managing ramping rates (especially the declining limb of the hydrograph) to match known ideal rates of drawdown from the literature (e.g. Mahoney & Rood 1998).

Several of these flow variables are involved in driving the ability of obligate riparian species – like cottonwood – to recruit seedlings. However, without available open seed beds all of the changes in hydrographs will not lead to increased recruitment of the dominant cottonwood, and may lead to more and more channel narrowing due to willow encroachment. For this reason, I suggest active removal of patches of dense streambank vegetation on sites that have high seedbed potential, to encourage recruitment of additional riparian species and to increase community diversity where it is currently dominated by willow and reed. Such removals should be limited in scope, and would be best if timed before the initiation of a large spill year. Ideally, a small-scale experimental removal study would be used to guide larger removal treatments (see below under Recommendations for Further Study). Another option for reintroducing variable age structure to the cottonwood population is to plant poles in areas with known shallow groundwater and to protect them with beaver fences (Anderson 2011).

Finally, less strongly related to hydrograph management, the issue of invasive herbaceous vegetation encroaching on the floodplain must be addressed. Korb et al. (2011) found that the understory vegetation of tamarisk stands was dominated by weedy exotic species, in contrast to the understory of cottonwood or willow stands. In Big Gypsum, Russian knapweed is now the dominant plant in areas that were formerly tamarisk stands. The DRRP does have plans to address and treat invasive weeds, but unfortunately in many former tamarisk stands aggressive treatment and re-seeding with native grasses will be the only way to reduce exotic species cover and support native biodiversity (Sher et al. 2009). On the lower Dolores, it appears unlikely that removal of tamarisk alone will lead to passive restoration of native riparian vegetation (Dott et al. 2011a).

4) Recommendations for Further Study

Every change we make in natural systems leads to new ecosystem and river hydrology interactions which we need to understand to best manage this resource. There are many possible avenues for further study in the Dolores River watershed that will add to our knowledge of how best to manage flows to support riparian ecosystem health and diversity. Below are a few ideas that seem especially relevant to the preceding discussion.

- **Seed rain.** What is the timing, abundance, and composition of wind-borne seed onto potential seedbed sites along the river? Is the proposed timing of hydrograph peaks and declines in sync with seed dispersal of desirable species? Is there cottonwood seed availability at sites where seedbed preparation is proposed? Is there tamarisk seed production in the area, and if so how abundant is it? If cottonwood seedlings would be overwhelmed by tamarisk seed input, then it might be necessary to re-evaluate the idea of opening up streambank habitat for native seedlings.
- **Seedling establishment.** What are the rates of seedling establishment on moist seedbeds after spills of varying magnitudes? What species (cottonwood, tamarisk, willow, other?) are colonizing those sites? What are the survival rates of seedlings under different conditions of discharge magnitude and drawdown rates? Studies like these could be strictly observational, or they could involve experimental manipulation of the site or of some set of physical variables. A lot of general work has been done on this subject, but site-specific responses would provide valuable information.
- **Seedbed preparation/vegetation removal.** Small-scale experimental manipulation of potential seedbed sites would be a useful way to pilot the idea of larger scale creation of open sites in the dense willow-reed community. Is this a practical approach? It would be good to test on a small scale before embarking on a very large scale intervention such as the tamarisk removal project of the DRRP.
- **Groundwater monitoring.** On-going study of how groundwater recharge and drawdown responds to different flow prescriptions and different spill volumes.
- **Frequency of early, low-elevation snowmelt.** Study historic hydrographs to assess how frequently such events occur and how practical it would be to time spill so that it overlaps with snowmelt. What would the magnitudes of such potential floods be?

- **Biology and hydrological needs of other native riparian species.** Much of the research in riparian ecology has focused on the dominant, obligate riparian species. Much less is known about the requirements of native shrubs living in floodplain habitats. Species that are somewhat unique to the Dolores River include silver buffaloberry, New Mexico privet, and three-leaf sumac.
- **Other alluvial reaches.** Long-term vegetation data exist for the Lone Dome area, 6 miles below McPhee Dam (Kriegshauser & Somers 2004, Dott 2009), as well as additional groundwater data (Gianniny & Dott on-going data collection). There may be ways to use some of these data to help inform the long-term management of spills and hydrograph shapes in another, very different alluvial reach of the Dolores River.

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