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# TECHNICAL MEMORANDUM

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| Date: | February 11, 2008 |
| To: | Beth Bardwell<br>World Wildlife Fund<br>100 E. Hadley Ave.<br>Las Cruces, NM 88001 |
| From: | Todd Caplan<br>Parametrix<br>6739 Academy Rd.; Ste 350<br>Albuquerque, New NM 87109 |
| Subject: | Canalization Reach - Environmental Flows |
| Project Number: | 573-5659-001 |

## Project Background

In the 1940's, the International Boundary and Water Commission (IBWC) constructed the Canalization Project along a 105-mile river reach of the Rio Grande from Percha Dam, New Mexico to American Dam, Texas. The project consisted of the construction of a 95-mile pilot channel, the clearing and leveling of 3400 acres of floodplain, construction of 131 miles of levees, and removal of 10-miles of meanders. The purpose of the project was to provide flood control for agricultural and municipal lands, and regulate water deliveries to Mexico, New Mexico and Texas irrigators. The Canalization Project significantly reduced the quality of riverine habitat and freshwater biodiversity in the Canalization Project.

World Wildlife Fund (WWF), the IBWC and the Elephant Butte Irrigation District (EBID) are working collaboratively to identify future operations and management of the Canalization Project that will integrate flood control, conveyance functions, and habitat restoration. Under the collaboration, the US Army Corps of Engineers (USACE) will be undertaking biologic and hydrologic analyses to inform the selection of future operations and management. If agreement is reached among the collaborative partners, the preferred alternative will be formalized in a Record of Decision for the Canalization Project Environmental Impact Statement.

In September 2007, the IBWC requested a comparison of restoration plans at 5 sites under three different flow regimes (irrigation operational flows, 3500 cfs, and 5000 cfs). In response, the USACE issued a report in January 2008 titled, ***"Restoration Habitat Prescriptions at Five Sites and Three Flow Regimes within the Rio Grande Canalization Project Area"*** **(USACE 2008).** The purpose of the analysis was to inform the collaborative partners about the relative costs and benefits of restoration activities including the extent of restored acreage, the type of habitat, evapotranspiration rates, and water budget under each of the flow regimes. This information was provided to project partners, to assist them in selecting a restoration design flow for development of a larger conceptual restoration plan. Once a restoration design flow is selected, the USACE will prepare a conceptual restoration plan for up to 30 sites along the 105-mile river reach at design flows.

## Biological Basis for Environmental Flow

The World Wildlife Fund is specifically interested in purchasing water rights and applying those rights to supplement irrigations flows for environmental (biological) benefits. However, the biological justification for the environmental flows discussed in the USACE (2008) report is not clearly defined. The report indicates that the primary objective of supplementing environmental flows is to facilitate maintenance of native riparian vegetation. The report suggests periodic inundation (every 3-5 years) was required for this purpose, and to minimize the cost of supplemental water required for this activity, the analysis of inundation timing emphasized providing supplemental flows during late June (see Figure 1).

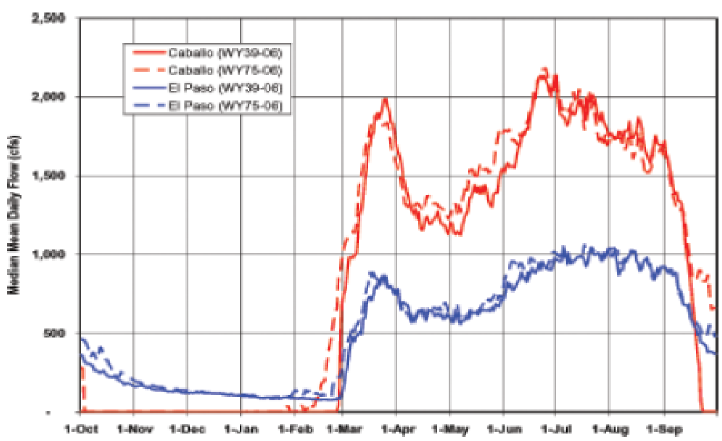



**Figure 1. Median mean-daily flow for two periods-of-record below Caballo Dam and below American Dam (from USACE 2008).**

While sensitivity to cost is extremely important, it is equally important to the WWF to understand the potential biological advantages (and disadvantages) of various environmental flow alternatives. Following conversations with WWF it is clear that there is strong desire to achieve multiple biological benefits in order to justify the costs associated with acquiring water rights and modifying water operations. WWF has specifically emphasized the desire to use environmental flows to improve and expand habitat for the federally endangered Southwestern willow flycatcher, and to increase the potential for recruitment and establishment of native riparian vegetation. Biological benefits for native fish or other aquatic species have not been discussed, primarily because most native fish have been extirpated from this reach (J. Obrien, personal communication).

To assist the WWF in reaching an informed decision for selecting a preferred environmental flow alternative, the remainder of this technical memo focuses on the timing, frequency, duration and volume of water needed to achieve the following three biologically-based environmental flow objectives:

1. Enhance and expand native riparian habitat to benefit the Southwestern willow flycatcher;

2. Increase the probability of natural recruitment, establishment and survival of native riparian vegetation, and;

3. Maintain native riparian vegetation through periodic flooding to facilitate nutrient cycling and leaching of sodium salts from floodplain soils.

## Ecological Attributes of Southwestern Willow Flycatcher Habitat

The Southwestern willow flycatcher (flycatcher) is listed under both Federal and State of New Mexico regulations as Endangered and is viewed as an important indicator of the health of southwestern riparian ecosystems. The flycatcher is generally characterized as an obligate riparian species, meaning it requires riparian habitats having proximity to water as essential for the survival of the species. While the specific benefits to the flycatcher have not been identified, certain characteristics of riparian habitats do appear to provide essential habitat needs that benefit the success of flycatcher populations during nesting.

Flycatchers wintering in Mexico and Central America begin to arrive on New Mexico breeding sites in early May. While there are exceptions, these birds tend to return to the same general breeding area each year, but not necessarily to the same exact nesting site or territory (FWS, 2002). Males usually arrive a week or so ahead of females and yearlings and begin to establish territories. In New Mexico, flycatchers build nests and lay eggs in late May and early June, with young being fledged by early July; however, these characteristics are locally affected by altitude, latitude, and re-nesting attempts. Second broods or nesting attempts can occur into August. The adults and juveniles begin their southern migration in July through August, 3 to 4 weeks after completion of nesting.

Most breeding territories for flycatchers along the Rio Grande occur in young and mid-aged riparian vegetation dominated by dense growths of willow at least 10 feet high, or with other riparian woody species (Ahlers et al., 2002). Within these willow patches, nests have been commonly found in individual saltcedar plants, especially in older willow patches, where an understory of saltcedar provides more suitable nesting substrate. Ahlers et al. (2002) suggested for the MRG that flycatchers may "key-in" on areas dominated by native vegetation, but often select exotic vegetation, particularly saltcedar, as their nest substrate. While breeding flycatchers have been found nesting in the saltcedar dominated patches on the Sevilleta NWR (Ahlers et al., 2002), the vast majority of flycatcher's in New Mexico nest in native dominated riparian habitat (Moore and Ahlers, 2006).

Regardless of the plant species composition or height, occupied sites usually consist of dense vegetation in the patch interior, or an aggregate of dense patches interspersed with openings. In most cases, this dense vegetation occurs within the first 10 to 13 feet aboveground (FWS, 2002). These dense patches are often interspersed with small openings, open water, or shorter/sparser vegetation, creating a mosaic that is not uniformly dense. In almost all cases, slow-moving or still surface water and/or saturated soil are present at or near breeding sites during most years.

The relationship between flycatcher nesting and hydrologic parameters is an important focal point for biologists and restoration planning agencies. This is due, in part, to the fact that many areas along the Rio Grande support the vegetation structure apparently preferred by the flycatcher, but the vast majority of these areas remain "unoccupied" by the birds. Many attribute this to the absence of key hydrologic attributes (e.g., standing water, saturated soils) along most of the Rio Grande (citations in Tetra Tech, 2004). This may be why such a disproportionately high percentage of flycatcher territories along the Rio Grande are concentrated in the Elephant Butte delta, where soils remain inundated or saturated for long periods (Ahlers, personal communication).

Data from recent flycatcher studies is providing strong support for the important relationship between nest site-selection and hydrology. For example, data from nesting flycatcher's at the Pueblo of Isleta (Smith and Johnson, 2007) demonstrates that flycatcher's appear to prefer dense cottonwood-willow habitat with saturated soil at least through the nest establishment period (May-June). Willows associated with soils saturated for extended periods at their study sites tended to have more vigorous plant growth, denser foliage, and more suitable branch structure for nest placement.

Similar results have been reported by Moore and Ahlers (2006). They analyzed the relationship of flycatcher nest placement with hydrologic attributes for all nesting sites (excluding Pueblo lands) along the MRG. Results indicated that most flycatcher nests (nearly 90 percent) were constructed less than 50 m from water, and the greatest proportion of flycatchers (42 percent) appeared to favor nest site locations in habitats saturated all season. Flycatcher nests were equally distributed (28 percent each) between locations either flooded all season or dry all season. Few nests (2 percent) were in habitats that were dry after being flooded or saturated early in the season.

Applying these data to restoration in the Canalization Reach, we derive the following conclusions with regard to using environmental flows to benefit the Southwestern willow flycatcher:

1. Inundation of existing nest sites and proposed flycatcher restoration sites should coincide with the beginning of the breeding season (May).

2. Flycatcher restoration/enhancement sites should be managed to maintain saturated soil conditions for at least the duration of the nest establishment period (approximately 45-60 days; early May through mid-June) on an annual basis.

3. Supplementing flows to achieve site inundation timed with normal peak irrigation releases would provide no (in March) or few (in late June) biological benefits to breeding flycatchers.

## Ecological Attributes of Cottonwood-Willow Recruitment and Establishment

Historically, gallery forests of cottonwood and Goodding's willow were one of the most abundant riparian ecosystems along low-elevation rivers of the southwestern United States and Mexico (Stromberg, 1993). Today this ecosystem is considered one of the most threatened forest types in the United States (Swift, 1984 as cited in Stromberg, 1993). Its decline is attributed to a variety of factors associated with river channelization, flood control, alterations to peak flow timing, duration and magnitude, groundwater pumping, and agricultural drainage (Howe and Knopf, 1991; Parametrix, 2008). These extreme hydrologic changes reduce the potential for successful seedling recruitment and establishment, and allow exotic invasive species, like saltcedar, to occupy sites and out-compete existing native riparian species for water and other important resources (Stromberg et al, 2005). Restoration of cottonwood-willow vegetation, therefore, requires an understanding of the key hydrologic attributes associated with recruitment, establishment and survival of these species.

### *Seedling Recruitment & Establishment*

Cottonwood and willow colonize new sites primarily from seed rather than asexually. Plain's cottonwood (*Populus deltoides)* has been found to produce more than 25 million seeds per tree (Braatne et al., 1996, as cited in Karrenberg et al., 2002). The seeds of both cottonwood and willow retain their germination viability for only a few days, and under optimal conditions, germination occurs quickly and usually within 24 hours (Karrenberg et al., 2002; Stella, 2006).

Seed dispersal of cottonwood and Goodding's willow typically occurs in late spring or early summer. Hink and Ohmart (1984) documented seed dispersal of both species between late May and early July along the MRG. Stella (2006) and Stromberg (1993) report that seed dispersal of Goodding's willow is slightly later than for Fremont cottonwood (*Populus fremontii*). However, timing of peak seed production and dispersal has been correlated closely with air temperature (Stella, 2006), so it is likely that annual differences (1 to 3 weeks) in timing of peak seed dispersal occur.

To successfully germinate, seeds from cottonwood and riparian willows need to be deposited on moist alluvial sediments that are relatively void of other vegetation (Johnson 2000; Karrenberg et al., 2002; Mahoney and Rood, 1998; Shafroth et al., 1998; Stromberg, 1993). Before 20th century flood control and irrigation infrastructure, the Rio Grande created these conditions by flooding new sites as it periodically shifted back and forth across the valley, or by periodically producing forceful floods that scoured and washed away existing vegetation. Both scenarios created favorable seedbed conditions for germination. Lateral channel constriction (via levees) and flood control (via dams) prevents the river from naturally creating suitable germination sites on the floodplain. Under contemporary water management, therefore, these processes need to be mimicked through artificial (e.g. mechanical) means.

Compared to cottonwood, Goodding's willow tend to establish on floodplain sites that are slightly closer to the stream and closer to the water table (Horton and Clark, 2001; Stromberg, 1993; Stella, 2006). Seedling mortality of both riparian cottonwoods and willows is extremely high, with reported values ranging from 77 percent to 100 percent over the first year (Karrenberg et al., 2002). While first year seedlings are highly vulnerable to both high-flows (from scouring) and low-flows (from desiccation), Karrenberg et al. (2002) reports that most studies they reviewed attributed mortality to desiccation. Thus, seedling recruitment and survival of riparian cottonwood and willow is closely linked to interactions between seed dispersal timing, flood inundation timing, and surface-water/groundwater interactions (Amlin and Rood, 2002; Hupp and Osterkamp, 1996; Scott et al., 1996; Shafroth et al., 1998)

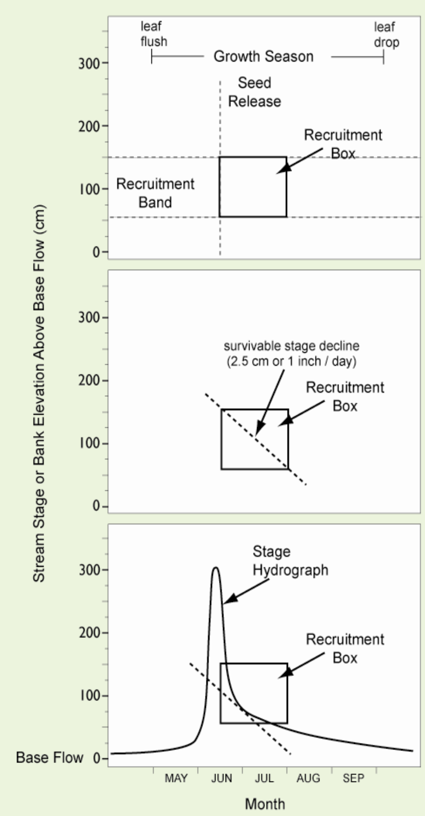
Contemplating these relationships, Mahoney and Rood (1998) developed a conceptual model (the "Recruitment-Box" model) to illustrate the interrelationships between these key ecological factors to better understand conditions required for maximizing seedling recruitment (Figure 2). While this conceptual model was originally developed for cottonwood, it is similarly applicable to seedling recruitment of Goodding's willow (Stella, 2006). The conceptual model in Figure 2 illustrates several important concepts:

- The top graph in Figure 2 highlights the relatively narrow timeframe when cottonwoods release their seed. The box in the center of this graph identifies the time period between early June and late July as the general "window of opportunity" for seed dispersal. In lower-elevation riparian systems of the Southwestern U.S., this time frame is generally a month earlier (May-June).

- The middle illustration conveys the concept that after the seed lands on moist sediments, the receding river stage decline should not exceed more than approximately 2.5 cm (1 inch) per day or else the elongating seedling root may not be able to keep up with the receding water table. This declining water table rate has been validated by several greenhouse and field studies (Amlin and Rood, 2002; Horton and Clark 2001; Rood et al., 2003; Stella, 2006). The seedling root growth rate and the capillary fringe ultimately determine the rate and maximum depth of groundwater to avoid seedling desiccation. Mahoney and Rood (1998) used existing data for both to determine the elevations above base-flow shown along the Y-axis.

- The bottom graphic illustrates the relationship between seed dispersal timing, hydrograph recession and the floodplain elevation above baseflow groundwater elevations. Ideal conditions for seed germination and establishment typically occur in channel positions low enough to provide adequate moisture but high enough to escape scour from subsequent floods.

**Figure 2.**
**Seedling Recruitment-Box Model (from Mahoney and Rood, 1998)**




This conceptual model illustrates that ecological and environmental elements must be closely aligned to result in successful seedling recruitment. It also highlights why natural formation of extensive cottonwood-Goodding's willow forests occur relatively infrequently. For example, studies of the free-flowing (i.e., unregulated) Hassayampa River system in Arizona indicated that Fremont cottonwood-Goodding's willow stands establish on a large scale only about once a decade (Stromberg et al., 1991). On other rivers it may take several decades before the right conditions occur (Stromberg, 1993). However, regulated rivers offer unique opportunities for managing flows to maximize seedling recruitment, and this Recruitment-Box model provides an important management tool for guiding site selection and design criteria for developing a project-specific seedling recruitment hydrograph (Rood et al., 2003; Stella, 2006).

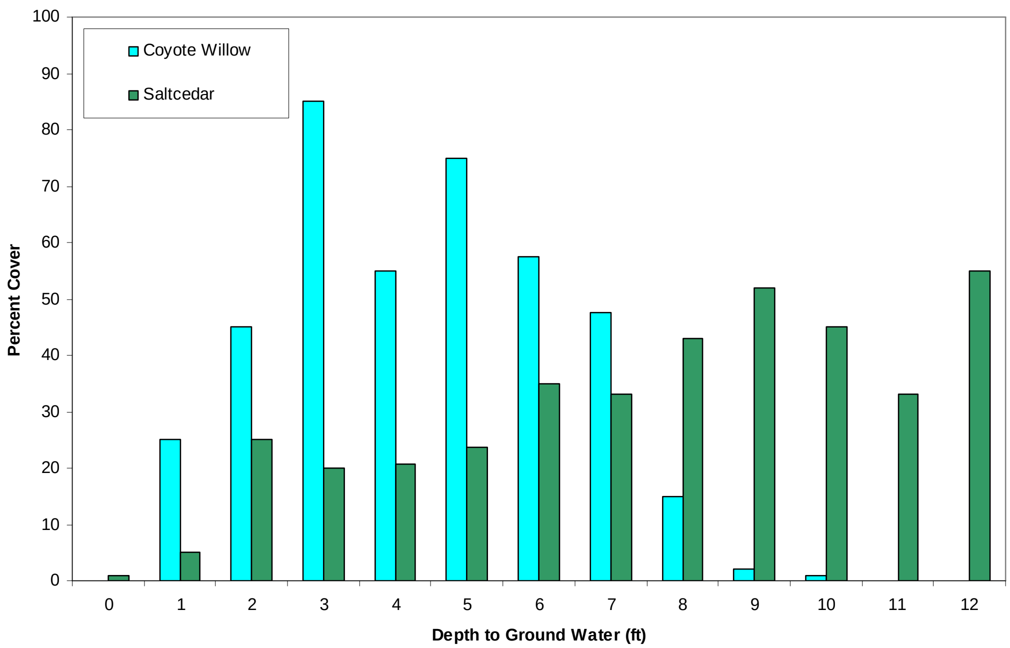
## *Survival*

Once plants have survived the establishment phase, probably the most important environmental factor influencing survival of cottonwood and willow on these sites is root access to available groundwater. While this was discussed previously in relation to seedling establishment, it is also important to emphasize that if the groundwater drops below some maximum depth, even mature plants with well-established root systems can become stressed or die. For example Lite and Stromberg (2005) found that cottonwood and Goodding's willow plants were able to compete successfully with non-native saltcedar plants when the maximum depth to groundwater was less than or equal to 8 feet (2.5 meters). Below 8 feet, cottonwood and willow canopy cover declined and saltcedar cover increased. We have found similar results for coyote willow and saltcedar within the MRG watershed (Figure 3).

Research indicates that physiological processes required for cottonwood and willow growth and survival suffer from water stress when groundwater declines below these thresholds (Amlin and Rood, 2002; Glenn and Nagler, 2005; Horton et al., 2001). These conditions favor the more drought tolerant saltcedar, which is why this species is so widespread along regulated rivers in the southwestern United States (Glenn and Nagler 2005). Thus, the importance of maintaining relatively shallow groundwater conditions for establishment and maintenance of willow dominated habitats cannot be over emphasized.

**Figure 3**

## Groundwater Threshold for Coyote Willow to Compete with Saltcedar




*This graph displays monitoring data from an area along the MRG watershed. The data show that coyote willow cover declined and saltcedar cover increased as the maximum depth to groundwater exceeded approximately 7 feet (2 meters).*

Applying these data to restoration in the Canalization Reach, we derive the following conclusions with regard to using environmental flows to improve potential for recruitment and survival of native cottonwood-willow vegetation:

1. Cottonwood-willow seed production and dispersal has evolved with peak snow-melt runoff (May-June). Flow modifications to achieve seedling recruitment, therefore, must be timed accordingly.

2. Even if flood inundation is timed appropriately with cottonwood-willow seed dispersal, establishment and survival is strongly influenced by the ability of seedlings to maintain root-contact with moist soil through the entire growing season. If a site is flooded, but the groundwater table drops too quickly, the seedling will desiccate and die. Once established, long-term survival of these plants requires that the groundwater table not exceed some maximum threshold. Existing data indicates this maximum threshold is approximately 8 feet, but the ideal depth appears to be closer to 3-5 feet, depending on the species and soil conditions at the site.

3. Candidate restoration sites (those with appropriate soil and water table characteristics that can be flooded in May) will need to be mechanically cleared of vegetation to prepare the seed-bed in advance of carefully managed site inundation.

4. On unregulated rivers, large-scale successful cottonwood-willow seedling recruitment occurs infrequently because all of the hydro-ecological attributes have to align. However, there are case studies on the Middle Rio Grande (Bhattacharjee et al., 2006) and elsewhere (McBain and Trush, 1997; Rood et al, 2003; Stella, 2006) that demonstrate successful seedling recruitment if these attributes are carefully managed at a restoration site.

## Maintenance of Native Riparian Vegetation

Little is know about the potential importance of flooding for maintaining established riparian forests. However, scientific investigations indicate that flooding is a critical process required to facilitate rates of primary biological production and the associated cycling of essential nutrients for plant growth (e.g., nitrogen, sulfur, phosphorous…). For example, Molles et al. (1998) investigated how the absence of a flood pulse on the Middle Rio Grande has affected the structure of microbial and animal populations on the forest floor. Their research found that microbial populations and activity were generally increased through managed flooding. This included increased abundance of soil bacteria, fungi, and cellulose decomposers, as well as considerable shifts in composition of forest floor insect species. Molles et al. (1998) also found a striking increase in forest floor respiration at flooded sites. During the third managed flood, forest-floor respiration was nearly 600 times higher in the flooded sites compared to non-flooded experimental sites. These high respiration rates were attributed to increased activity of soil micro-organisms responsible for breakdown of organic material and facilitation of nutrient cycling processes. However, their study did not find significant differences in rates of forest litter decomposition between flooded and non-flooded sites, which they conclude indicates the time required to achieve these benefits may take several years or even decades (Molles et al., 1998).

In addition to facilitating nutrient cycling, periodic flooding is thought to be important for preventing sodium salts from accumulating to levels that prohibit plant growth. Soil salinity inhibits plant growth primarily because it increases the osmotic pressure in the soil – meaning it affects a plants ability to extract water from the soil. Obligate riparian plant species, like cottonwood and willows, have particularly low tolerances to soil salinity, and published literature indicates they become stressed when soil salinity exceeds 2-3 dS/m (USDA PLANTS Database: www.plants.usda.gov). By comparison, saltcedar can tolerate soil salinities in excess of 16 dS/m (which is considered "highly" saline).

Floodplain deposits are generally non-saline at the time of deposition. However, given a relatively short period of time and favorable conditions, soil salinization may occur. Soil salinity may be somewhat dynamic and may vary at specific locations through time as changes occur in the pattern of deposition and overflow. For example, it is not uncommon to find moderate levels of salinity in the soils beneath mature cottonwood stands. It is probable that the soil was non-saline when the conditions were favorable for cottonwood seedling establishment, since cottonwood establishment usually involves flooding. However, given the modifications of the floodplain with channels and dikes, flood inundation no longer occurs on some sites. The dynamics of the movement of soil moisture in these areas is therefore altered, and the leaching of salts that once occurred through occasional overflow events no longer occurs. If the upper soil profile has medium to fine soil texture and the water table is within 3 to 4 feet of the surface, soil moisture tends to move upward through capillary pull. Whatever salt is dissolved in this moisture also moves upward. When the moisture reaches the soil surface and evaporates, the salts are left behind. Over time, soil salinity can become elevated to a level that restricts the growth of certain plants.

Periodic leaching of salts through flooding, therefore, is an important function of overbank inundation and maintenance of riparian vegetation. We find nothing in the scientific literature that discussed the frequency or timing of flood inundation required to prevent accumulation of salts in the plant root zone. However, on free-flowing rivers overbank flooding occurs on average, every 3-5 years (Gordon et al., 2006). We would propose, therefore, that managing flows for the purposes of leaching salts should occur at a similar frequency.

We suspect that the timing could be flexible to inundate a project site for the purposes of leaching salts, although in our opinion, if one were to deviate from the timing of average snow-melt runoff (May/June), it would make more sense to inundate the site earlier in the season when air temperatures and corresponding evaporation rates are lower (than July or August, for example). However, we suggest that intentionally flooding sites earlier in the season (in late March, for example) may have unintended, detrimental consequences for both flora and fauna whose life-cycles have evolved with the May/June flood cycle associated with the natural flow regime. For example, the balance between river ecosystems and the wildlife they support is the result of tens of thousands of years of evolution and adaptation. When humans permanently alter river flows from their established patterns, species-habitat dynamics can be disrupted, creating conditions or landscapes to which native species are poorly adapted. Most researchers agree that managed ecological systems that adhere as closely as possible to a hydrograph that simulates historical timing of flows provide greater biological diversity of wildlife and maintain higher ecosystem integrity (Poff et al. 1997).

Applying these ecological data and concepts to restoration in the Canalization Reach, we derive the following conclusions with regard to using environmental flows to maintain native riparian vegetation:

1. Period flooding is important for biological productivity, nutrient cycling and for leaching salts from floodplain soils.

2. Managed flood inundation frequency and timing should mimic, as closely as possible, the flow regime associated with the natural snow-melt hydrograph. This means ideally inundating a site for these purposes every 3-5 years and coinciding with normal peak snow-melt runoff (May/June).

3. Managing flows to increase floodplain inundation during the average peak irrigation schedule (March or late June) may have unintended detrimental impacts on the life-cycle of species that evolved with a May/June flood pulse.

## Summary and Recommendations

Flood Timing, Frequency, Duration and Volume

To maximize the biological benefits that flood inundation may have in the Canalization Reach, the existing data strongly supports that prescribed flooding should coincide with average peak snow-melt runoff (May/June). The data supporting this timing is especially strong regarding benefits for the Southwestern willow flycatcher and for recruitment of native cottonwood-willow vegetation. Quantitative benefits of flood timing on maintenance of riparian vegetation is poorly understood, although there is wide agreement among ecologists that managed flooding that mimics timing of the natural flow regime would probably provide greater biological diversity of wildlife and maintain higher ecosystem integrity (Poff et al. 1997).

While the May/June timing of flood inundation is recommended for all biological benefits addressed in this paper, the inundation frequency is quite variable. For example, the literature indicates that to maximize the biological benefits to flycatchers, their territories should be flooded regularly (1-2 years). For maintenance of riparian vegetation, less frequent inundation on the order of 3-5 years is probably sufficient. Flood inundation to achieve riparian seedling recruitment can occur even less frequently (on the order of 7-10 years).

The duration of inundation also varies by management objective (Table 1). As described previously, the literature indicates that flycatcher's may prefer sites that are inundated, or that maintain saturated soil conditions for <u>at least 45 days</u> corresponding to the nest-establishment period. The ideal inundation duration for maintaining riparian vegetation is not well understood, so we suggest providing whatever the minimum flood period required to ensure soil saturation at a given site would probably be sufficient.

For riparian seedling recruitment the duration of site inundation is probably less important than ensuring that the seedling root can maintain contact with moist soil. This means that management would need to flood a site <u>at least</u> long-enough to saturate the alluvium, but then pay special management attention to achieving a gradual hydrograph recession as a means of managing the level of the groundwater table through the first growing season. The precise hydrograph recession rate would need to be calibrated based upon site-specific data (e.g., alluvium stratigraphy, floodplain elevation, maximum groundwater depth), but generally the literature indicates a hydrograph recession rate corresponding to a drop in surface water/groundwater elevation not to exceed 2-3 cm/day (Mahoney and Rood, 1998; Stella, 2006).

Since all three biological management attributes requires attaining saturate soil conditions, an estimate is needed for the quantity of water for establishing and maintaining saturated soil. The soils of the Rio Grande floodplain, as with most floodplains, are variable and complex. Soil conditions can range from sandy to clayey within short distances. Any estimate of the quantity of water needed to saturate the soil must be an approximation, unless field conditions are examined on-site.

Soil types vary in the amount of water that it takes to saturate the upper four feet. The available water capacity of a soil is defined as the amount of water that the soil can hold between the wilting point of most plants and field capacity. Field capacity is the moisture content at which the soil can hold moisture against the gravitational pull. Therefore, in order to saturate a soil, the soil water "reservoir" must be filled. In other words, the soil must be filled to field capacity, and the available water capacity is a good approximation of the amount of water required to do this.

Sandy soils require less water to achieve field capacity and clayey soils require more water. Generally, the available water capacity of a sandy soil is about 4 inches in the upper four feet. The available water capacity of a clayey soil is approximately 8 inches in the upper four feet. Once the soil is filled to field capacity, an additional increment of water is needed to reach saturation. This quantity of water is more difficult to estimate, and it is assumed for this report that about 50% of the water needed to bring the moisture content to field capacity will need to be applied to establish saturation. It is also assumed for this evaluation that a permanent water table occurs within four feet of the soil surface.

Using these general guidelines, the quantity of water needed to fill the soil profile and saturate the soil is, on average, about 12 inches. Maintaining the saturated conditions (that is, replacing moisture lost to evapo-transportation) may require an additional 6 inches of water applied periodically as the site conditions require. (Note: If the planned plant community uses more than 6 inches of water in a growing season, then that amount of water should be budgeted.) Therefore, the total amount of water for the establishment and maintenance of saturated soil conditions is roughly estimated to be 18 inches (1 ½ feet). Consequently if the size of the project area is, for example, 50 acres the amount of water required for this purpose is 50 acres x 1.5 feet/acre, or 75 acre-feet of water.

A summary of the recommended timing, frequency, duration and water volume requirements for each of the three biological goals are provided in Table 1.

**Table 1. Summary of critical flow elements for maximizing biological benefits in the Canalization Reach.**

| Biological Benefit | Timing | Frequency | Duration | Approx. Volume |
|---|---|---|---|---|
| 1. Flycatcher Habitat | May/June | Every 1-2 years | Minimum 45 days | 1.5 acre ft. per acre |
| 2. Riparian Seedling Recruitment | May/June | Every 7-10 years | Long enough to saturate soils | 1 acre ft per acre |
| 3. Riparian Vegetation Maintenance | May/June | Every 3-5 years | Long enough to saturate soils. | 1 acre ft. per acre |

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