AN EVALUATION OF RIPARIAN REVEGETATION EFFORTS IN ARIZONA

by

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ABSTRACT

Twenty-five riparian revegetation projects and two alternative mitigations were evaluated in Arizona. Sites were visited and agency personnel were interviewed to detail riparian revegetation methodologies and categorize revegetation projects based on how well they achieved their objectives.

Riparian revegetation is limited in its ability to improve degraded riparian ecosystems and is most effective when the causes of site degradation are addressed. Of the selected successful revegetation projects, 73% incorporated other forms of mitigation (e.g., improved land management strategies, bank stabilization structures, irrigation) that either indirectly or directly addressed the causes of site degradation. Over 33% of the successful revegetation projects experienced prolific natural regeneration, demonstrating the potential for natural regenerative processes to accomplish revegetation objectives. Of the unsuccessful revegetation projects, 85% did not achieve objectives due to low water availability or flooding.

The appropriateness of using riparian revegetation should be determined on a site by site basis using two check-lists developed from the results of this study. The first check-list describes the potential effectiveness of artificial revegetation, the second check-list describes the potential that prolific natural regeneration will occur.
INTRODUCTION

Recent investigations have demonstrated that riparian ecosystems of the southwest are some of the most productive ecosystems in North America (Johnson and Jones 1977; Johnson and McCormick 1978). Riparian ecosystems include drainages, streams, rivers, lakes, and other landscape settings where the availability of water is much greater than in surrounding uplands. The more mesic nature of these areas permits establishment and growth of many plant species not found on adjacent, more xeric uplands (Warren and Anderson 1985).

Riparian areas provide a multitude of beneficial environmental functions that indirectly affect the stability and quality of the entire ecosystem. These functions include: floodpeak reduction, sediment and nutrient sinks, water temperature control, and groundwater recharge (Schmidt 1987).

Riparian ecosystems are characterized by high diversity in both plant species and wildlife. Youngblood et al. (1985) found over 600 plant species located within 469 50-square meter sample plots in eastern Idaho and western Wyoming. Spear and Mullins (1987) observed that bird populations such as waterfowl, wintering bald eagles (Haleaeetus leucocephalus), peregrine falcons (Falco peregrinus), whooping cranes (Grus americana) are constant visitors to the riparian ecosystem along the Rio Grande River. In addition, this riparian system is home to over 30 species of amphibians and reptiles. Mammals such as the desert shrew (Notiosorex crawfordi), hoary bat (Lasiurus cinerus),
mice (*Peromyscus* spp.), bobcat (*Felis rufus*), and mule deer (*Odocoileus hemionus*) also are very much a part of these ecosystems. Hubbard (1977) described riparian areas, in general, as having a fairly high endemism including a relatively large number of endangered species.

The rapid growth of the human population in the southwest has negatively impacted riparian ecosystems in both direct and indirect ways. As a result, many of these valuable ecosystems have been damaged or destroyed. The disappearance of a large percentage of native southwestern riparian ecosystems has been noted by several authors (Lowe 1964; Phillips et. al. 1964; Carothers et al. 1974; Ohmart et. al 1977, Anderson and Ohmart 1985). Hall and Bammon (1987) noted that 22 of Arizona’s 27 native fish are federally classified as being in danger of extinction; this is probably as good an indicator as any of the health of Arizona’s riparian areas.

Concern over the plight of riparian ecosystems in the southwest has resulted in the development of different conservation strategies specifically designed for riparian ecosystems. One such strategy, coined "riparian revegetation", involves planting trees, shrubs, forbs, and grasses in degraded riparian ecosystems. Once established, such plantings can help to replace lost riparian vegetation and stabilize deteriorating conditions, initiating recovery of the riparian area. Such riparian revegetation schemes have been used for years in Arizona with varying degrees of success.

The objective of this study was to evaluate the effectiveness of riparian revegetation in restoring degraded riparian ecosystems in the southwest. This was
accomplished by evaluating the results of 27 riparian revegetation projects completed years ago by an array of different organizations. Although all of these projects are located in Arizona, they encompass a wide variety of ecosystem types. Some of these projects are located in arid, low-elevation, ephemeral washes; others are along reaches of larger drainage systems such as the Gila, Verde, and Colorado Rivers; and still other sites are located in small, relatively high elevation, mesic stream systems. The lessons learned from the results of each project will be brought together so that educated statements can be made as to the feasibility and limitations of using riparian revegetation to rehabilitate damaged riparian ecosystems.
LITERATURE REVIEW

The causes behind the decline of native southwestern riparian ecosystems are not well understood. More than likely, no one factor can be singled out as the root cause of their demise. Rather, a combination of several factors intricately intertwined is responsible. Many authors have commented that the direct and indirect consequences of man's influences have probably had much to do with the recent and quite rapid disappearance of many southwestern riparian ecosystems (Hastings and Turner 1965; Ohmart et al. 1977; and others).

Riparian areas have been destroyed directly by gold mining, exploitation of timber resources, caustic fumes from smelters, and overgrazing (Szaro and DeBano 1985; Schmidt 1987). Diversion of water from upland streams has also had a profound impact on riparian ecosystems. Water shortages become more acute as more water is diverted from streams and rivers. Indeed, many major southwestern floodplains are no longer capable of supporting viable riparian stands as a consequence of agricultural drainage, channelization, flood control, irrigation diversions, and phreatophyte control (Swenson and Mullins 1985).

Phreatophyte control programs implemented in the late 1960's encouraged clear-cutting of vast areas of river-side vegetation. Such efforts were performed by state and government organizations in the belief that clear cutting riparian vegetation would lead to increased base flows, thereby providing more water for downstream consumers. The
Bureau of Reclamation, for example, began a phreatophyte clearing and control program in the bottom land of the Acme-Artesia reach of the Pecos River in March 1967. By the time the project was completed in May 1969, over 7,695 ha of riparian vegetation had been cleared. The long-term impact of this and other so-called "phreatophyte control - water salvage" programs on river flow was usually negligible, while the impact on riparian ecology, stream channel stability, and overall survival of riparian habitat was usually quite profound (Welder 1988).

Of man's influences on riparian ecosystems, livestock grazing has probably been the best documented. Riparian areas have characteristics that make them ideal for supporting livestock. This is especially true during the dry months in the southwest when the higher water availability of riparian systems makes them attractive to livestock. According to Soil Conservation Service records, over 27,000 cattle were brought into the southwest from Texas in 1885. The resulting over-grazing undoubtedly contributed to erosion and arroyo development (Behnke and Raleigh 1977; Davis 1986; Platts 1981).

Herbivores can alter the composition of plant communities by selecting for or against specific plant taxa (Szaro 1989; Valentine 1989; Platts 1981; and others). Such selection pressure can reduce or even eliminate certain species of vegetation, which can indirectly impact other species of vegetation as well as wildlife and fish. When a riparian area is located within a grazing allotment, the stream side vegetation is usually grazed and impacted more heavily than surrounding upland vegetation (Holscher and
Woolfold 1953; Armour 1977). Gunderson (1968) found large differences in stream side vegetation cover between grazed and ungrazed areas.

Cattle also contribute to the decline of riparian vegetation and increase bank instability through trampling (Marlow and Pogacnik 1985). Unstable banks are characterized by accelerated erosion and contribute greatly to instream sediment loads (Winger 1977; Duff 1979). Overgrazing of streambanks reduces vegetation cover, which may lead to increased water temperatures (Van Velson 1979), which in turn can have negative consequences for aquatic vertebrate and invertebrate populations (Marlow and Pogacnik 1985).

Riparian ecosystems are very complex and dynamic. The characteristics of a particular riparian ecosystem - the diversity and density of vegetation, and the size of the riparian ecosystem - are the products of the simultaneous interaction of several environmental factors, including: topography, hydrology, geology, elevation, and climate. Due to this complexity, it is very difficult, if not impossible, to predict how a riparian ecosystem will react to a specific disturbance. In many cases the affects of a disturbance to a riparian ecosystem will be subtle, possibly taking years to be noticed. The construction of impoundment structures across rivers and streams exemplifies the type of disturbance whose impacts on riparian ecosystems may not be fully apparent for years following their completion.

Impoundment structures affect riparian ecosystems in ways that are, as yet, not well understood. The changes that take place in stream dynamics and the subsequent
impacts on stream vegetation that a dam structure can have are much more complex than previously thought (Nilsson 1982). Reservoirs create changes in natural patterns of flooding, sedimentation, and groundwater fluctuations, and these changes, in turn, affect vegetation composition (Buma and Days 1975) both upstream and downstream from the impoundment structure (Gill 1973; Hagen and Roberts 1972; Kerr 1973; Schumm 1969; Wolman 1967).

**Geomorphology and Stream Dynamics**

A stream channel can be viewed as an energy regime where a delicate balance exists between the geometric form and the inflow and outflow of energy (Bradford and Priest 1980). The energy level of a stream channel is determined by factors such as discharge, channel morphology, sediment load, and controlling hydraulic variables (Heede 1985).

The energy level of a stream is at dynamic equilibrium when sediment loads entering a stream reach equal those leaving it (Heede 1985). A stream reach at dynamic equilibrium will tend to maintain its form and local gradient over a period of years (Leopold, 1964, p.267; Van Haveren and Jackson 1986). Energy level changes cause stream reaches to make incremental or periodic adjustments in their channel geometry (including incremental bank cutting, cycles of streambed scour and fill). These responses
are due to continual (though not necessarily constant) changes in independent\(^1\) variables, mainly sediment load and discharge (Leopold 1964, p.267; Hendrickson and Minckley 1983; Van Haveren and Jackson 1986). Riparian ecosystems are adapted to such incremental changes and can also be said to be in dynamic equilibrium with local fluctuations canceling out over the whole (White 1979).

The length of time a flood plain remains relatively unchanged depend largely on the regimen of the stream flowing within it. Periods of channel stability are often broken up by abrupt, comparatively instable periods of erosional and depositional changes (Schumm et al. 1984; Wallace and Lane 1976).

Land use changes, such as overgrazing, plowing, wagon and cattle trails (Elliott 1979; Schumm et al. 1984) or any of a number of upland watershed activities and overt up and downstream channel alterations, including channelization, dams, bank training work (Heede 1981), or even changes in climatic factors (Leopold 1951) can produce changes in watershed runoff and erosion characteristics. Such changes can initiate periods of episodic erosion in several ways (Heede, 1981; Wallace and Lane 1976).

An intrinsic threshold (dependent variable) is an alteration in the landform itself, and, as far as the channel system is concerned, the gradient and width of the channel are of particular importance. An extrinsic factor (independent variable) is external to the landform. Discharge pattern an the size and quantity of soil supplied by slope erosion

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\(^1\) An independent variable, such as time, initial relief, geology, and climate, determine or constrain the variation of a dependent variable, such as vegetation type and density.
are important extrinsic factors that, when altered, can produce profound impacts on a river channel's orientation and geometry (Schumm et al. 1984; Howard 1980).

**Channel Instability and Adjustment**

Once a stream enters into a period of relative instability, it will seek a new dynamic equilibrium by altering its geometric form (Schumm et al. 1984). The magnitude of this alteration and the manner in which it occurs depend largely upon the degree to which an intrinsic or extrinsic variable has been altered, the composition of the channel (e.g. bedrock, fine grained alluvium, or coarse gravel), and the ease with which equilibrium can be reached (Howard 1980; Schumm et al. 1984; Heede 1986).

During this period of instability, the stream channel may begin to incise into valley alluvium (Wolman and Leopold 1957; Harvey and Watson 1986; Burkham 1976). Bed degradation usually precedes and predisposes channel widening which occurs as a result of mass failure of banks (Harvey and Watson 1986; Schumm et al. 1984), after a critical bank height has been exceeded (Thorne 1981; Little et al. 1982). The critical bank height and the type of failure that takes place depend on the nature of the materials that compose the banks, and the rate of bank retreat is primarily determined by the rate at which failed material is removed (Harvey and Watson 1986).

Schumm's (1961) study of ephemeral stream sediment characteristics found a large difference in mass-bank failure between areas of cohesive and non-cohesive sediment. Banks composed of poorly-cohesive sediment tend to widen rapidly by bank
caving after initial incision. In contrast, banks composed of cohesive sediment erode more slowly, and can actually prevent further channel widening when point sources for deposition are created by blocks of failed cohesive bank material that has fallen into the stream channel (Schumm 1961).

Bed degradation produces nickpoints\(^2\) that migrate upstream, incising into the channel beds of increasing numbers of tributaries (Schumm et al. 1984). As this occurs, ever greater quantities of sediment are produced, resulting in downstream aggradation that continues until instability due to oversteepening becomes too great and a threshold is exceeded (Schumm et al. 1984; Elliott 1979). The streams in the valley are once again degraded as stored sediment is flushed out (Elliott 1979). Therefore, various parts of the drainage system can be out of phase, with gullying and channel incision taking place at one location, and deposition and subsequent channel filling occurring elsewhere. The entire process can then repeat itself with lateral erosion followed by renewed incision (Schumm et al. 1984). Such cyclic erosion and deposition patterns appear to be common in the fluvial histories of many drainage systems (Elliott 1979).

Incision into valley alluvium leads to the formation of terraces (an abandoned alluvial flood plain no longer affected by annual floods) changing the morphology of the flood plain from broad and shallow (when excess sediment is stored) to narrow and deep, and more sinuous as the head water portion of the drainage basin evolves (Burkham 1976; Wolman and Leopold 1957; Harvey and Watson 1986; Schumm et al. 1984). As

\(^2\) Location on the stream profile where there is an abrupt change in elevation and slope.
channel flow becomes confined to the narrow dimensions of the incised channel, the stream becomes ever more efficient at scouring channel beds and banks (Van Haveren and Jackson 1986; Elliot 1979). As channel incision proceeds, there is less probability of floods inundating the entire valley floor as they become confined to an ever more restricting main channel (Elliott 1979). In addition, precipitation falling on the watershed will spend less time in the fluvial system due to the lack of lateral dispersion onto adjacent flood plains (Glinski 1977). Increase in travel time may also influence aquifer recharge rates. Degradation of the channel bed also produces a drop in the level of the local water table roughly equal to the depth of incision in the main channel (Van Haveren and Jackson 1986).

**Affects of Channel Instability on Riparian Vegetation**

Degradation of riparian vegetation due to increased flood plain instability has been documented along the Carmel River, California (Kandolf and Curry 1984); Dry Creek, California (McBride and Strahan 1981); Gila River, Arizona (Minckly and Clark 1984); Lower San Lorenzo River, California (Griggs 1984); Rio Puerco, New Mexico (Elliot 1979); San Pedro River (Zimmerman 1969); and Sonoita Creek, Arizona (Glinski 1977).

These studies reveal that channel incision degrades associated riparian ecosystems in two general ways. First, by destroying riparian vegetation directly via bank erosion and subsequent loss of channel bank and flood plain integrity; and, second, via the subsequent dewatering of the riparian zone, which may leave surviving riparian
vegetation solely dependent upon precipitation for moisture. Loss of local riparian vegetation can decrease resistance to flow, resulting in higher flow velocities during floods (Van Haveren and Jackson 1986), aggravating the deterioration of the flood plain even further.

Not only does channel incision reduce existing riparian vegetation, but it may also prevent or retard the natural establishment of succeeding generations. Glinski (1977) noted that the increased xeric conditions associated with abandoned flood plains not only may be responsible for inhibiting natural regeneration of riparian species like cottonwoods (*Populus fremontii*) that reproduce mainly by seed dispersal, but also may inhibit species like Arizona Sycamores (*Platanus wrightii*) that reproduce mainly by sprouting. Minckley and Clark (1984), noted that dry conditions and the subsequent lack of riparian regeneration on abandoned terraces are probably responsible for the replacement of broadleaf riparian trees by mesquite bosques along the Gila River.

The return of a new dynamic equilibrium occurs within a fairly short time period after the channel has widened to the point where eroded stream bank material is not removed (Harvey and Watson 1986; Schumm et al. 1984). This seems to be the point where channel geometry has changed enough to accommodate the changes in discharge and sediment load that brought on the period of instability initially. In their study on the formation of arroyos, for example, Cooke and Reeves (1976) found that an arroyo will continue to be unstable until the geometric form of the channel can accommodate floods that no longer degrade the banks.
Riparian Vegetation Dynamics

Reichenbacher (1984) described the extent of the riparian community in terms of a continuum. The continuum is most unstable closest to the stream channel where flood occurrences are common, and most stable in areas further removed from the stream channel (e.g., flood plain terraces) where flood disturbances are relatively infrequent.

The characteristics of an established riparian woodland often reflect this continuum. Everitt (1968) and McBride and Strahan (1981) observed that woody riparian vegetation exhibited a well defined age diversity, ranging from young seedlings found mainly along the stream side of typical point bars to well established woodlands on the higher elevations.

Dynamics of the Flood Plain

Germination and growth of riparian vegetation are intricately related to the discharge of the river, movement of the channel, and development of the flood plain (Everitt 1968; Hendrickson and Minckley 1985). Rice (1949) defines a flood plain as "a strip of relatively smooth land bordering a stream.......and is called a living flood plain if it is overflowed in times of high water." Wolman and Leopold's (1957) review of literature relating to river morphology and analysis of hydrologic data compiled from rivers of eastern and western United States, and India, found that flood plains are generally composed of two types of deposits: 1) over bank deposits, formed by vertical accretion when a river overflows its banks and material is deposited from water flowing
or standing outside the channel, and 2) point bar deposits, which form by lateral accretion on the inside of a river bend.

Both flood plains and point bars serve as temporary sites for storing much of the material eroded from a watershed (Wolman and Leopold 1957). Erosion of banks and flood plain removes this material from temporary storage, increasing the river's sediment load until deposition occurs downstream during point-bar construction or when the water overflows its banks.

The frequency of over bank flow of many rivers is similar even though they occur in quite different climatic and physiographic regions (Wolman and Leopold 1957). The channel, in most cases, is adjusted to carry the larger over-bank flows and, therefore, the frequency with which the river overflows onto its flood plain may be identical in areas of diverse runoff. Point bar development, however, seems to have the most dominant impact on the development of the flood plain. Wolman and Leopold (1957) found that 80% to 90% of the flood plain is composed of deposits of lateral accretion, with the remaining 10% to 20% percent consisting of over-bank deposits.

Establishment Patterns

Of the numerous landforms that comprise a typical flood plain, riverside bars (called gravel bars or sand bars depending upon the size of the predominant sediment) that develop in "typical point bar" locations appear to be especially important in the lifecycle of many southwestern woody riparian species. Seedling establishment of Populus
Populus fremontii and willow (*Salix* spp.) was restricted almost entirely to gravel bars along Burro Creek (Hall, pers. comm.), the Gila and San Pedro Rivers (Brady et al. 1985), Little Missouri River (Everitt 1968), the Sacramento River (Strahan 1981), and Sonoita Creek, Arizona (Glinski 1977), despite seed dispersal over a much larger area (McBride and Strahan 1981).

Point bar deposits occur when sediments, picked up on the concave side of a stream meander, where water velocity tends to be the greatest, are deposited on the convex side as water velocity slows (McBride and Strahan 1984). The greatest accumulation occurs on the inside bank just downstream from the position of maximum curvature. The result of these processes is meandering or lateral stream movement (McBride and Strahan 1984).

Following high flow events, open sites are produced that are suitable for riparian seed germination (White 1979), if water availability is sufficient (Fenner et al. 1984; Reichenbacher 1984). Fenner et al. (1984) found that *Populus fremontii* seeds could successfully germinate on sandy-loam alluvial material when soil moisture was as low as 10%, but more than 80% was required for high germination rates.

**Vegetation Adaptations to the Riparian Environment**

High alluvial moisture content decreases rapidly as high flows recede and residual surface water evaporates (Fenner et al. 1984). Depending on the predominant particle size of the alluvium, water availability sufficient for seed germination may only last a
few days to weeks. To establish successfully, riparian species need to disperse seeds during a time when high flows or wind can carry seeds to newly deposited alluvium. Following germination, seedlings need to be adapted for growth in an environment characterized by rapidly declining water availability.

To meet such challenges, most riparian plant species have developed the following adaptations: an early spring bloom, seed dispersal during early summer, no seed dormancy, and short seed viability (White 1979). Early spring bloom and subsequent seed dispersal during late spring to early summer allow the greatest opportunity for seed dispersal to occur concurrently with high flows (which commonly occur during this time period due to winter snow melt and spring rains). The timing of *Populus fremontii* seed dispersal (Fenner et al. 1984) and *Populus deltoides* (Farmer and Bonner 1967) respectively correspond with receding high flows of the Salt River in Arizona and the Mississippi River in the lower Mississippi Valley. This exemplifies the adaptation of riparian vegetation to natural river flow regimes.

Farmer and Bonner (1967) observed that speed of germination, rather than the total number of seeds that germinate, is critical in the rapidly changing environments of riparian ecosystems. They found that the germination energy of cottonwood seed gradually decreased as moisture stress increased from 0.0 to 10.0 atm. (optimum was between 27-32°C and 0 atm. moisture stress).

In a review of literature concerning vegetation adaptations to various disturbance regimes, White (1979) noted seven attributes of major flood plain trees found in the
eastern deciduous forest (Acer saccharinum, Betula nigra, Populus deltoides, and Salix nigra) conducive to successful reproduction in a riparian system: large regular seed crops, light wind and water dispersed seeds, fast growth rates, short life spans, low shade tolerance, ability to sprout, and high tolerance to floods. Everitt (1968) found that Populus sargentii is well suited for colonizing fresh alluvial deposits that commonly have the following characteristics: denuded or disturbed sand or coarse soil with high moisture availability, initial absence of competition from other species, and exposure to full sunlight.

Rapid root growth allows newly germinated seedlings to chase rapidly receding water vertically down to the water table, spreading laterally only after consistent water is reached. Fenner et al. (1984), found that Populus fremontii root growth rates, immediately following germination, averaged 6 mm per day. This means that cottonwood seedlings have the potential to reach groundwater 162 cm below the soil surface following the first summer of growth (Fenner et al. 1984). Furthermore, rapid above-ground growth rates (2-3 m/year) enable seedlings to establish and become less vulnerable to spring floods of the following year (White 1979).

Although most obligate riparian species depend upon high flows to provide newly deposited alluvium for germination, they are very vulnerable to prolonged periods of inundation and scouring during the seedling stage (Reichenbacher 1984; Harvey and Watson 1986; Glinski 1977; McBride and Strahan 1984). Therefore, riparian vegetation will have a much greater chance of reaching maturity when the migration of the stream
channel leaves the newly established trees in a location that does not experience frequent flooding.

Consequently, flood disturbances not only play an important role in the initial establishment of riparian vegetation, but also in determining riparian vegetation patterns (Hupp and Osterkamp 1985; Reichenbacher 1984; Campbell and Green 1986; Everitt 1968). The pulse behavior of stream flows often forms a mosaic composed of vegetation of different ages, varying colonizing abilities, and tolerance to flooding and shade (White 1979). As seedlings continue to grow, further stabilization of the riverside bar is promoted as the root systems of the seedlings become stronger and alluvium accumulates, progressively elevating the surface above the water level (Minckley and Clark 1984). This creates a landform that becomes progressively less vulnerable to high flows. However, an elevated surface means greater distances to the water table. Therefore, following the first year or two of floods, whether or not seedlings reach maturity depends largely on depth to the water table during the growing season, and the overall stability of the landform (McBride and Strahan 1984).

The relationship between riparian ecosystems and the flood plain is complex. Flood plains form and change in response to environmental changes that have occurred along up and downstream portions of the river system, as well as, to land use changes on the upper parts of the watershed. Understanding the interrelationship between the riparian ecosystem and the flood plain environment is important for comprehending the limitations of using riparian revegetation to improve degraded riparian ecosystems. Land
managers who understand these relationships will be better prepared to determine when and where riparian revegetation can be most effectively used.

**Riparian Conservation Strategies**

The loss of many riparian ecosystems in the southwest has lead to the development and implementation of conservation strategies specifically designed to preserve these ecosystems. Conservation strategies have been developed utilizing a variety of techniques, including improved grazing management and installation of physical stabilization structures. These conservation strategies have been implemented either alone or in combination with one another with varying degrees of success. In addition, legislation designed to protect riparian values by maintaining minimum streamflows has been developed during recent years and may play a major role in preserving riparian ecosystems in the years to come.

**Improved Grazing Management**

Riparian ecosystems often differ from one another considerably. Differences in lithology, morphology, hydrology, and soil characteristics can produce large differences in the ability of different riparian ecosystems to tolerate grazing. Nevertheless, lessons learned from the implementation of various grazing strategies can and probably should be applied to future grazing strategies that include riparian areas.
Platts et al. (1989) discussed the results of implementing a "stuttered deferred rotation" grazing scheme on riparian vegetation and stream bank stability on Henry's Fork of the Snake River. In another paper of the same year, Platts et al. (1989) evaluated the type, design, and application of fencing employed to control livestock within the stream corridor. Svejcar (1989) evaluated the impact of different grazing patterns, especially early-season versus late-season effects on riparian vegetation growth. Elmore and Beschta (1987) discussed the need to experiment with "nontraditional" grazing strategies that would entail various seasons of use, levels of utilization and exclusion, and classes of livestock, to ascertain how these strategies can be used to improve both vegetation density and structure and physical channel hydrologic characteristics. Rinne (1988) discussed the results of 4 years of livestock exclusion on a northern New Mexico montane stream.

Although no single conclusion stands out among the authors cited above, all noted that livestock grazing and healthy\(^3\) riparian ecosystems can coexist. This appears to be true even during periods of recovery, as long as the season and intensity of use are controlled carefully (Elmore and Beschta 1987; GAO 1988; Meyers 1989; Marlow et al. 1989; Platts et al. 1989; Debano and Schmidt 1989).

\(^3\) A "healthy" riparian ecosystem is one where the natural regenerative processes of obligate riparian species have not degenerated to any significant extent.
Physical Stabilization Structures

The use of streambank stabilization techniques such as gabions, rip-rap, and check dams to slow erosion and promote restoration of riparian vegetation has also been fairly well documented. Heede (1981) noted that active gulling in a stream system can be stabilized by placing physical structures only in the main stream gully, in the larger tributary gullies, and in the head cuts of discontinuous gullies. Patterson et al. (1981) summarized the effectiveness of various streambank protection techniques currently used by the Soil Conservation Service. Both of these studies expressed a certain degree of optimism in using physical control structures to bring back degraded riparian ecosystems. In slight contrast, Elmore and Beschta (1987) expressed some caution when they noted that building expensive instream structures without solving the problems associated with management of riparian ecosystems or uplands may not bring about the intended results. Schultze and Wilcox (1985) discussed the results of 29 riparian restoration projects in California's Central Coast area. All of these projects combined revegetation with four types of structural mitigation: bank shaping only, pipe and wire revetment, gabions, and rock rip-rap.

Instream Flow Litigation

The persistence of stream corridor values, such as riparian vegetation, is either directly or indirectly dependent upon maintaining minimum streamflows (Stalnaker and Arnette 1976). Methods for identifying "channel maintenance" flows have been
developed for various stream corridor values, including stream flows needed for preserving riparian vegetation (Jackson et al. 1989). Jackson et al. (1988) analyzed relationships between streamflow and riparian water table elevations and evaluated water table and flood flow requirements for maintaining riparian vegetation along the San Pedro River in Arizona.

It is only recently that legal strategies have focused on protecting these minimum streamflows for instream and related stream corridor values (Garn 1986). For example, an interdisciplinary approach has been developed for determining and protecting instream flow needs. This approach is based upon relationships between flows and flow-dependent resource values and use of legal and other means to protect these minimum instream flows (Jackson et al. 1989). Such interdisciplinary approaches should play an integral part in the preservation of riparian ecosystems in the years to come.

Upstream Vegetation Control

Improving the density and diversity of riparian vegetation by controlling upstream vegetation (thereby decreasing evapotranspiration and increasing down stream flows) has received recent publicity. DeBano et al. (1984) determined that upstream shrub control positively affected the establishment of riparian vegetation downstream by increasing the quantity and duration of stream flow.
Riparian Revegetation Techniques

The remainder of this study focuses on evaluating revegetation techniques as a means of restoring degraded riparian ecosystems. Planting vegetation along stream banks can expedite recovery of degraded riparian ecosystems by slowing or preventing stream bank erosion (Porter and Silberberger 1961; Miller and Borland 1963; Maddock 1976).

Mills and Tress' (1988) review of literature identified five mechanisms by which vegetation increases the resistance of stream banks to erosional forces: 1) root systems bind soil particles together; 2) above ground growth (e.g. stalks, stems, branches, and foliage) increase the stream bank's hydraulic resistance; 3) above ground growth shields stream banks from the abrasive forces of suspended solids; 4) vegetation increases evapotranspiration rates, which can increase bank shear strength, decreasing the possibility of a mass bank failure; and 5) vegetation increases infiltration rates and intercepts precipitation which, in turn, helps to decrease surface erosion rates.

Riparian revegetation has been used for years and existing literature describes planting techniques specifically designed for use in riparian ecosystems (Fry 1938; Herion 1939; Morehead 1939; York 1985; and Swenson and Mullins 1985). Carothers et al. (1989) evaluated the results of 17 riparian revegetation projects in Arizona. Their study is one of the few that specifically evaluates riparian revegetation to develop lessons learned from past projects for the benefit of future riparian revegetation projects. They noted several factors that are important in determining the outcome of riparian
revegetation projects: timing of the project, depth to water table, irrigation timing and amount, soil condition and texture, and type of planting material.

The remaining riparian revegetation literature, especially as far as Arizona is concerned, can be placed into two general categories: (1) literature describing revegetation projects completed along the Colorado River and, (2) literature describing riparian revegetation projects completed in the interior of Arizona. Of the two, the Colorado River revegetation projects, especially those along the lower Colorado River, are better documented.

Anderson and Miller (1988) discussed the results of a revegetation project completed by the Revegetation and Wildlife Management Center at Goose Flats, along the Colorado River near Blythe, California. They concluded that revegetation techniques can be useful in reestablishing valuable habitat for wildlife. They stressed four factors as being important to the success of riparian revegetation projects: (1) fencing around the revegetation site (especially important if the site has the potential of being damaged by beaver, livestock, and/or recreationists); (2) determining electrical conductivity (EC) of the soil prior to planting (they noted that vegetation planted in soils with ECs below $1 \mu S/cm$ ($1\mu S/cm = 1\mu mho/cm$) and above $2\mu S/cm$ did not grow as well as vegetation planted in soils having intermediate EC values); (3) using time-release fertilizer during the initial growing season; (4) augering holes to the water table prior to planting to promote root development to the water table.
Anderson and Ohmart (1982) discussed how revegetation methodologies, in general, can be used to enhance wildlife habitat along the lower Colorado River. Careful pre-planting preparation and post-planting monitoring allowed them to make quantifiable observations of site characteristics conducive to the establishment and growth of *Populus fremontii*, *Salix gooddingii*, *Prosopis* spp., and *Cercidium floridum*. They found that deep tilling prior to planting produced statistically beneficial results with regard to survival and growth rates of all four tree species mentioned above. They cautioned, however, that the short monitoring period (only five growing seasons) made it very difficult to draw definitive conclusions concerning long term tree survival.

In a study sponsored by the California Department of Fish and Game, Anderson (1987) concluded that soil type, EC, and depth to water table are the most important factors influencing the establishment and growth rates of cottonwood/willow (*Populus fremontii/Salix gooddingii*) plantings. Anderson stated that cottonwoods and willows thrive in sandy, well drained soils where the depth to water table is less than 3 m and EC levels do not exceed 2μS/cm.

The Bureau of Reclamation and the Bureau of Land Management have been involved in numerous revegetation projects along the Lower Colorado River. Murphy (1988) developed a "revegetation considerations checklist" from lessons learned from 18 Bureau of Reclamation projects. The checklist contained recommendations on 12 aspects of riparian revegetation, including: irrigation techniques, fencing strategies, control of competitor plant species, augering methodologies, and use of mycorrhiza fungi.
In addition, numerous reports discuss and evaluate riparian revegetation projects in locations other than the Colorado River. Anderson and Ohmart (1986), for example, discussed revegetation work completed at Cecil’s Pond. In Anderson’s (1987) analysis of revegetation efforts along the Kern River, EC levels were noted as possibly being important indicators of *P. fremontii* and *S. gooddingii* establishment rates and vigor. He concluded that pre-planting monitoring of soil EC levels may pay off in the long term.

Goldner (1981) described the results of the Santa Clara Valley Water District’s revegetation of flood control channels. He concluded that a fixed irrigation system and a weed management program are essential to the survival of plantings through the establishment period. Heede (1981), describing revegetation techniques used to rehabilitate a disturbed watershed in the Southern Colorado Rockies, Colorado, concluded that appropriate plant selection, the use of pioneer vegetation to establish quick ground cover, and the use of fertilizer are important aspects in successfully establishing plants in a riparian ecosystem.

The U.S. Forest Service has documented the results of many of their Arizona riparian revegetation projects. Pollock (1984), for example, discussed the results of U.S. Forest Service riparian revegetation projects along the Verde River. He noted that site selection is very important in determining the outcome of riparian revegetation projects. Choosing smaller areas that offer conditions more suitable to the survival of planted vegetation is much more efficient than planting larger areas with large quantities of plants.
Hall and Bammon (1987) summarized techniques used by the Bureau of Land Management to improve riparian ecosystems on Arizona's public lands. They concluded that while riparian revegetation techniques have produced some positive results, long-term improvement of riparian ecosystems can only be accomplished through projects that focus on the health of the entire watershed. Though not complete, this list does bring out three general characteristics of riparian revegetation literature. First, the majority of riparian revegetation literature can be categorized as "close of project reports". Such reports usually do not attempt to apply lessons learned from one project to future projects, nor do they attempt to specifically evaluate revegetation methodologies as a tool that can be used to restore degraded riparian ecosystems. Because it draws from a much larger pool of information, a study that collectively evaluates a group of riparian revegetation projects would be much more meaningful to future riparian revegetation projects. Such collective group evaluations of riparian revegetation projects have been completed, yet many focus only on riparian revegetation projects completed in one specific area. Pollock (1984), for example, evaluated U.S. Forest Service riparian revegetation projects along the Verde River, and Murphy (1988) evaluated the results of the Bureau of Reclamation revegetation projects along the Lower Colorado River. These evaluations are invaluable in offering recommendations to future Colorado and Verde River riparian revegetation projects, but may be limited in their ability to offer meaningful recommendations to riparian revegetation projects occurring elsewhere.
Second, little effort has been allotted to describing riparian conditions that are amenable to revegetation efforts. For example, if a land manager is given the responsibility of rehabilitating a riparian ecosystem, what site characteristics are important in deciding whether or not riparian revegetation is a viable option? Anderson and Ohmart (1985) have documented site characteristics important in influencing the establishment and growth rates of vegetation planted in a riparian ecosystem. Their conclusions, however, are mostly drawn from their revegetation experiences along the Lower Colorado River. Such experiences are invaluable, yet may not be directly applicable when riparian ecosystems much different from the Colorado River (e.g., ephemeral rivers, streams, and washes) are considered as sites for future riparian revegetation projects.

Third, much of the literature evaluating riparian revegetation projects was written only 2 or 3 years following project completion. Such short-term evaluations cannot answer questions concerning long-term survival of planted trees. Only now, after riparian revegetation projects have reached the 10-year mark following completion, can reasonable observations be made concerning long-term tree survival.

The lessons drawn from the evaluation of the 27 riparian revegetation projects included in this study will be discussed in two parts. First, riparian conditions conducive and not conducive to riparian revegetation will be described. Such information should assist land managers to determine when, where, and under what circumstances riparian revegetation can be a viable option in rehabilitating damaged riparian ecosystems.
The second part of this study describes factors that should be considered when developing a riparian revegetation plan. These factors include planting methodologies, choice of species, type of propagule, pre-planting preparation and post-planting management.
RESEARCH METHODS

Data were collected from August 1989 through August 1991. Three data collection techniques were used: a mail questionnaire, a telephone questionnaire, and site surveys.

Mail Questionnaire

A one-page questionnaire (see Appendix) and cover letter was mailed to approximately 35 organizations thought to have experience with riparian revegetation. The organizations targeted were: Arizona Department of Transportation, Arizona Department of Game and Fish, Arizona State University (Center of Environmental Studies), Bureau of Land Management, Bureau of Reclamation, Revegetation and Wildlife Management Center (Blythe, AZ), Soil Conservation Service, U.S. Fish and Wildlife Service, U.S. Forest Service. An overall response rate of 85% was achieved.

The questionnaire requested information concerning name(s) of personnel directly involved with riparian revegetation, the respondent's riparian revegetation experience, and the names of others involved with riparian revegetation work. Over half of the responses contained information on personnel involved with riparian revegetation work that were not originally targeted. In this manner, a list of personnel involved with riparian conservation work was developed.
Telephone Questionnaire

The telephone questionnaire targeted individuals identified by the mail questionnaire as having had riparian revegetation experience. The questionnaire focused on five general areas:

1) General background information: number of projects in which the respondent was involved, location of sites, size of each site (in area or length of mitigated stream reach), respondent’s responsibilities, date of project initiation and completion, and project objective.

2) Site environmental information: primary causes of degradation, description of site at time of mitigation (including stream channel, erosion, vegetation, land use, and upland characteristics), distance to water table, flood frequencies, precipitation patterns and quantities, and predominant soil type.

3) Project methodology: type of vegetation planted, type of propagule used (seed, root cuttings, shoot cuttings, seedlings, poles), amount of vegetation planted, how vegetation was planted, planting treatments (root hormones, tree paint, roughing the butts of poles), secondary mitigation (bank stabilizing structures, irrigation, clearing competing vegetation, fence construction).
4) Post-mitigation work: monitoring, maintenance, vegetation control.

5) Results: survival of planted vegetation, primary reason for success or failure, and outstanding changes in the site environment since project completion.

Site Visits

Site visits were necessary because the majority of sites had not been seen by the respondent since the project was completed (close to 10 years in some instances). The primary purpose of the site visit was to ascertain the present condition of the site. This was accomplished by going to the site with the respondent who had been directly involved with planning and implementing the mitigation. The following information was recorded during the site visitation:

1) Survival percentage (where appropriate) of planted vegetation. This was easily accomplished in some cases, as at Babocomari (site #8), where tree plantings stand-out in a stark landscape, but almost impossible at other sites, like Sugar Dike (site #26), where planted vegetation is surrounded by dense stands of Tamarix chinensis. Obtaining accurate survival data was even more difficult in cases where respondents could not remember (or never knew) the exact amount of vegetation originally planted. The reliability of the percent survival figure was also greatly dependent on the species planted. Determining the survival rate of grass species, for example, is far more difficult
than determining the survival rate of trees. The respondent’s estimate of percent survival was used in situations where the percent survival could not be determined directly.

2) Size of planted vegetation. Height of trees were estimated. At sites where the height of planted trees varied considerably, the average height was estimated. Diameter of tree and shrub trunks was measured at breast height with a tape measure. Percent of ground covered by planted grasses was estimated by the respondent because he/she could best discern between natural and artificial regeneration.

3) Predominant overstory, midstory, and understory species were determined to give a better impression of the overall ecological condition of the site and how the site’s vegetation had changed since the project was completed. In most cases, this information was determined by pace transect. In cases where site rejuvenation was monitored, respondents could provide information concerning vegetation changes since the project completion (such was the case at the Hassayampa Preserve, site #22).

4) Changes in upland erosion rates were noted by the respondent in very general terms. Alluvial deposition was measured by comparing differences between site conditions at the time of mitigation and site visit. At sites (like Tubac) where bank stabilization structures were installed at the toe of incised banks, the extent to which these structures were buried was a good indicator of the amount of deposition that has occurred.
5) Depth to water table - the distance to water during the height of the dry season was unknown for the majority of sites. Measuring this distance was deemed important because it provided a good indication of water availability. Sites were visited (in many cases revisited) during June and July of 1990 and holes were dug during the afternoon (when the level of the water table would probably be at its lowest) to the level of the water table. Depth to water was measured using a tape measure.

6) Effectiveness of secondary mitigation - as defined for this study, secondary mitigation includes techniques that went beyond simply placing vegetation propagules in the ground. A list of secondary mitigation techniques used is given in Table 1.

Table 1. Secondary mitigation techniques on riparian sites in Arizona.

<table>
<thead>
<tr>
<th>Secondary Mitigation</th>
<th>Sites where Secondary Mitigation was Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land use changes (e.g., changes in livestock management and wildlife and recreation use)</td>
<td>Saw Mill Spring, Coleman Lake, Canyon Creek, Gentry Creek, Sheephead Spring, Francis Creek, Burro Creek, Box Bar, McEuen Seep, Hassayampa Preserve, Goose Flats.</td>
</tr>
<tr>
<td>2. Installation of stream bank or channel stabilization structures; installing beaver cages around plantings.</td>
<td>Canyon Creek, Tubac, North Tubac, Nogales Wash, Babocomari River, Sheephead Spring, Horseshoe Lake, Bartlett.</td>
</tr>
<tr>
<td>3. Irrigation</td>
<td>Babocomari River, Burro Creek, Box Bar, Goose Flats, Arlington Ponds</td>
</tr>
<tr>
<td>4. Land forming (e.g., major soil excavation, augering to water table)</td>
<td>Coleman Lake, Canyon Creek, Highway 70, Goose Flats, Rt. 85, 85th Ave.</td>
</tr>
<tr>
<td>5. Removing competing vegetation</td>
<td>Hassayampa Preserve, Goose Flats, Arlington Ponds, Sugar Dike.</td>
</tr>
<tr>
<td>6. Upland reclamation work</td>
<td>Sheephead Spring, Francis Creek, Burro Creek, Aravaipa Creek.</td>
</tr>
</tbody>
</table>
How effective secondary mitigations were in accomplishing their objectives is based primarily on the respondent's judgement. This is especially true for determining the effectiveness of land manipulation, removal of competing vegetation, and upland reclamation work in contributing to the overall success of the project.

The condition of perimeter fences and bank and channel stabilization devices was determined during the site visit. Their present condition is not only a good indication of their current effectiveness, but also a good indication of how much their implementation contributed to the overall success of the project. Overall condition of the perimeter fence was determined by walking along the fence line checking for damage, paying special attention to gates and stop-gaps.

The effectiveness of channel and stream bank stabilization structures was determined by comparing channel and stream bank conditions at the time of the site visit to conditions at the time of mitigation. Amount of deposition along the toe of the stream bank, vertical distance from main channel to abandoned flood plain, and obvious signs of renewed bank incision were recorded along the mitigated reach and up- and downstream from the site. The accuracy of this comparison depended primarily upon the respondent's recollection of environmental conditions at the time of project initiation.
Analysis of Results

The results of the 27 projects were classified into 1 of 5 categories based on how well they achieved their objectives. These 5 categories are as follows:

1) Projects that achieved objectives;
2) Projects that have not achieved objectives, but present conditions suggest that the objectives will ultimately be met;
3) Projects that have not achieved objectives and present conditions suggest that the objectives will never be met;
4) Projects that did not achieve objectives;
5) Too soon to classify into any of the above categories.

Sites included in categories 2 and 3 experienced intermediate results (between the extremes of revegetation projects that achieved their objectives (Category 1) and those that did not achieve their objectives (Category 4)) at the time the site evaluation took place. In category 2, the condition of the artificially-planted vegetation and the ecological trend of the site seem to indicate that the objectives would be realized at some point in the future. Conversely, the condition of the artificially-planted vegetation and the ecological trend of those sites in category 3 indicated that the objectives would not be realized.

Projects classified in the first and second categories are defined as "successful" because they either fulfilled or were deemed capable of fulfilling project objectives. Conversely, projects classified in both categories 3 and 4 are considered unsuccessful because they either did not or were deemed incapable of fulfilling project objectives.

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4 "Artificially-planted" specifically refers to vegetation that was planted during a revegetation project. The term is used to differentiate vegetation planted by humans from vegetation that has reproduced naturally.
Comparing and contrasting mitigation techniques and design, site environmental characteristics, and land use patterns between successful and unsuccessful projects provided clues in understanding what factors are influential in producing successful, as well as unsuccessful, riparian revegetation projects.
RESULTS

Variability Among Sites

The 27 sites studied are highly variable in elevation, average annual precipitation, water availability, major riparian vegetation species, and surrounding vegetation (Table 2, also see Appendix). Sites are scattered among five different southwestern biotic communities, range in elevation from 67.1 m to 2,243.2 m, and range in precipitation from 102 to 579 mm/year. Even those sites located within the same biotic subdivision differ from one another in many respects. Of the 13 sites in the Sonoran Desertscrub of the Arizona Upland Division, eight are on relatively major southwestern drainage systems (Gila River, Verde River, Salt River, and Hassayampa River), three are along smaller drainage systems (Burro Creek, Francis Creek, and Aravaipa Creek), and the remaining two are just downstream from small perennial springs (McEuen Seep and Clay Mines Spring).

In addition to the differences mentioned above, many of the sites also differ from one another in regard to project objectives and techniques used (Table 3). Project objectives ranged from general ecological improvement (e.g., Hassayampa River Preserve), to stabilizing dikes and stream banks (e.g., Tubac, Babocomari River, Sugar Dike), to habitat improvement for specific wildlife (pole plantings at Bartlett for bald eagles, plantings along Canyon Creek to improve the aquatic environment for game fish, and mitigation at Coleman Lake for waterfowl).
Table 2. Selected riparian sites described by elevation, water availability, major changes in riparian vegetation since mitigation, and surrounding biotic community.

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Water Availability</th>
<th>Major Riparian Vegetation Prior to Mitigation</th>
<th>Major Riparian Vegetation at Time of Site Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Annual Precip. (mm)</td>
<td></td>
<td>Forest Formation</td>
<td>Petran Montane Conifer Forests</td>
</tr>
<tr>
<td>1. Saw Mill Spring</td>
<td>2243</td>
<td>Very High</td>
<td>Overstory: <em>Quercus gambeli</em> and <em>Pinus ponderosa</em>. Canopy was over 50% closed. Midstory: <em>Salix bebbiana</em> and <em>Rosa arizonica</em>. Understory: <em>Bromus spp.</em>, <em>Fus pratensis</em>, <em>Carex spp.</em></td>
<td>No major changes</td>
</tr>
<tr>
<td>2. Coleman Lake</td>
<td>2182</td>
<td>Very High</td>
<td>Overstory: None. Understory: annual grasses, perennial grass and forb species present, but greatly reduced.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>533</td>
<td></td>
<td>Overstory: No major change. Understory: Dramatic increase in <em>Bromus spp.</em> on stream banks and <em>Aquilegia spp.</em>, and <em>shasta daisy</em> on active flood plain.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Site</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Annual Precip. (mm)</td>
<td></td>
<td>Forest Formation</td>
<td>Great Basin Conifer Woodland</td>
</tr>
</tbody>
</table>

Table 2. (continued)

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
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<tr>
<td></td>
<td>Avg. Annual Precip. (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Tubac</td>
<td>976</td>
<td>Medium</td>
<td>Overstory: Islands of old growth Salix gooddingii and Populus fremontii up- and downstream from site. Mesquite bosque (Prosopis velutina) on the upper flood plain. Understory: Scoured reach almost devoid of vegetation.</td>
<td>Overstory: 90% are Salix gooddingii and Populus fremontii, in roughly a 1:2 ratio; Fraxinus cuspidata is also a major component; densities approaching 15 trees (4.5 m or more tall) per 10 meters of mitigated reach. Mid-story: Baccharis glutinosa, Rhus glabra, and many 1- to 2-year old Salix gooddingii and Populus fremontii seedlings. Understory: Elymus canadensis, Carex spp., Phragmites communis, and Bidens spp.</td>
</tr>
<tr>
<td>7. Nogales Wash</td>
<td>1127</td>
<td>High</td>
<td>Similar to Tubac</td>
<td>Overstory: Populus fremontii and Salix gooddingii, in roughly a 1:1 ratio, densities of 320 trees (4.5 m or more tall) per ten meters of mitigated reach. Mid-story: Rhus glabra, Baccharis glutinosa, Fraxinus cuspidata, many 2 to 3 foot high willow and cottonwood seedlings. Understory: Elymus canadensis and Phragmites communis. Ramunculus neomexican on drier slopes.</td>
</tr>
</tbody>
</table>

Grassland Formation Semidesert Grassland
Table 2. (continued)

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Water Availability</th>
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<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grassland Formation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Babocomar River</td>
<td>1310</td>
<td>Very Low</td>
<td>No woody vegetation within stream channel. Mesquite bosque on abandoned flood plains.</td>
<td>112 <em>Salix gooddingii</em> poles have initiated shoots.</td>
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<td></td>
<td>372</td>
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<tr>
<td></td>
<td>310</td>
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</tr>
<tr>
<td><strong>Sonoran Desertscrub</strong></td>
<td></td>
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<tr>
<td>10. Gleason Flats</td>
<td>853.4</td>
<td>Low (abandoned flood plain)</td>
<td>Overstory: Mesquite bosque with arrowweed understory. No woody obligate riparian species; scattered <em>Salix gooddingii</em> and <em>Populus fremontii</em> present up- and downstream of site.</td>
<td>No major change</td>
</tr>
<tr>
<td></td>
<td>102</td>
<td>Medium (live flood plain)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>342</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>342</td>
<td>Medium (active flood plain)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site</td>
<td>Elevation (m)</td>
<td>Water Availability</td>
<td>Major Riparian Vegetation Prior to Mitigation</td>
<td>Major Riparian Vegetation at Time of Site Evaluation</td>
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<td></td>
<td>Avg. Annual Precip. (mm)</td>
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<tr>
<td>14. Horseshoe Lake</td>
<td></td>
<td>Very Low (upper flood plain)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Bartlett Dam</td>
<td></td>
<td>Low to High</td>
<td>Overstory: Thickets of <em>Tamarix pentandra</em> with isolated <em>Salix gooddingii</em>. <em>Prosopis velutina</em> with <em>Coleogyne ramosissima</em> understory surrounding site.</td>
<td>No major changes in diversity or density of vegetation.</td>
</tr>
<tr>
<td>16. Needle Rock</td>
<td></td>
<td>Medium</td>
<td>Overstory: Two mature <em>Populus fremontii</em> Understory: <em>Coleogyne ramosissima</em></td>
<td>Overstory: 48 <em>Populus fremontii</em> trees have been established. Most were 10 to 11 m tall. Understory: no major changes.</td>
</tr>
<tr>
<td>17. McEuen Seep</td>
<td></td>
<td>Medium</td>
<td>Overstory: <em>Mesquite bosque</em> (<em>Prosopis velutina</em>) scattered mature <em>Populus fremontii</em> Understory: <em>Coleogyne ramosissima</em> and <em>Puchoea sessilis</em>.</td>
<td>Overstory: 58 <em>Populus fremontii</em> trees have been established. Most were 10 to 11 m tall. Understory: No major changes.</td>
</tr>
<tr>
<td>18. Clay Mines Spring</td>
<td></td>
<td>Medium</td>
<td>Overstory: <em>Prosopis velutina</em> Understory: <em>cottonwood</em>, <em>Cynodon dactylon</em>, <em>Puchoea sessilis</em>.</td>
<td>Overstory: 8 <em>Juglans major</em>, 3 <em>Populus fremontii</em>, 1 <em>Platanus wrightii</em>, and 2 <em>Salix gooddingii</em> have been established (walnuts and cottonwoods are about 4 meters above mesquite midstory). Understory: no major changes.</td>
</tr>
</tbody>
</table>

*Sonoran Desertscrub* | *Arizona Upland Division* (continued)
<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Water Availability</th>
<th>Major Riparian Vegetation Prior to Mitigation</th>
<th>Major Riparian Vegetation at Time of Site Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Akeelupa</td>
<td>792</td>
<td>High</td>
<td>Flood during October 1983 destroyed large quantities of riparian vegetation, leaving long reaches of the canyon completely bare. Vegetation in side canyons and along protected reaches of creek allowed vegetation diversity to remain high.</td>
<td>Overstory: large numbers of woody obligate and non-obligate riparian species have re-established throughout the canyon. These species include: <em>Populus fremontii</em>, <em>Salix gooddingii</em>, <em>Fraxinus velutina</em>, <em>Plantanus wrightii</em>, <em>Ungnaya major</em>, <em>Tamarix pentandra</em>, <em>Alnus tenuifolia</em>, <em>Quercus emory</em>, <em>Quercus arizonica</em>, and <em>Prospis velutina</em>. Midstory: <em>Baccharis glutinosa</em>, <em>Amphora fruticosa</em> and <em>Baccharis spinillosa</em>. Understory: <em>Cynodon dactylon</em>, <em>Muhlenbergia rigens</em>, and <em>Rhus radicans</em>.</td>
</tr>
<tr>
<td>Creek</td>
<td>360</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Seven-Mile</td>
<td>823</td>
<td>Medium</td>
<td>Overstory: <em>Prosopis velutina</em> and <em>Tamarix pentandra</em>. Midstory: <em>Baccharis glutinosa</em>. Understory: <em>Cynodon dactylon</em>, <em>Phleum sericea</em>.</td>
<td>Overstory: Nine <em>Populus fremontii</em> trees have been established (4 to 5.5 m tall). Understory: No major changes.</td>
</tr>
<tr>
<td>Wash</td>
<td>302</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Highway 70</td>
<td>792</td>
<td>Medium</td>
<td>Overstory: Dense stands of <em>Tamarix chinensis</em>. Understory: No dominate components.</td>
<td>Overstory: Original efforts destroyed by construction. Subsequent revegetation efforts have established <em>Populus fremontii</em> and <em>Salix gooddingii</em> trees (4 to 6.5 m tall) amongst dense <em>Tamarix pentandra</em> growth.</td>
</tr>
<tr>
<td></td>
<td>229</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Haseyampa</td>
<td>886.3</td>
<td>High (adjacent to main channel)</td>
<td>Overstory: Scattered <em>Populus fremontii</em> and <em>Salix gooddingii</em> near river, <em>Prosopis velutina</em> on upper flood plain. Midstory: <em>Baccharis glutinosa</em> Understory: <em>Cynodon dactylon</em> and <em>Phleum sericea</em>.</td>
<td>Overstory: no change Midstory: Dramatic increase in <em>Populus fremontii</em> and <em>Salix gooddingii</em> seedlings, <em>Typha spp.</em>, <em>Baccharis glutinosa</em> and <em>Phleum sericea</em>. Understory: <em>Paspalum distichum</em> along stream banks and major regeneration of native grasses and forbs on upper flood plain.</td>
</tr>
<tr>
<td>River</td>
<td>274</td>
<td>Low (mesquite bosque)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. (continued)

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Water Availability</th>
<th>Major Riparian Vegetation Prior to Mitigation</th>
<th>Major Riparian Vegetation at Time of Site Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonoran Desertscrub</td>
<td>Lower Colorado River Subdivision</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>102</td>
<td></td>
<td>Midstory: Pluchea sericea</td>
<td></td>
</tr>
<tr>
<td>24. Rt. 85</td>
<td>250</td>
<td>Low</td>
<td>Overstory: Dense stands of Tamarix pentandra. Understory: Several annual grass species.</td>
<td>Overstory: 383 S. gooddingii trees (most are 2.5 to 3-m tall, 2-m wide with low foliage density) have been established. Understory: No changes.</td>
</tr>
<tr>
<td></td>
<td>170</td>
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</tr>
<tr>
<td>25. Arlington Ponds</td>
<td>339</td>
<td>Medium</td>
<td>Overstory: Light stands of Tamarix chinensis in the field and surrounding both ponds.</td>
<td>Little change</td>
</tr>
<tr>
<td></td>
<td>170</td>
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<tr>
<td>26. Sugar Dike</td>
<td>259</td>
<td>High</td>
<td>Overstory: Dense stands of Tamarix pentandra. Understory: annual grasses.</td>
<td>Overstory: 250 P. fremontii and S. gooddingii trees (4.5 to 6 m tall) are growing among dense Tamarix chinensis. Understory: No major change.</td>
</tr>
<tr>
<td></td>
<td>170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27. 83d Ave.</td>
<td>365</td>
<td>Low</td>
<td>Overstory: Scattered Prosopis velutina with two Salix gooddingii. Understory: Baccharis glutinosa, Cymodo con decipiens, and Pluchea sericea.</td>
<td>Overstory: 5 S. gooddingii have been established. Understory: prolific increase in density and diversity, species include: Cymodo con decipiens, Muhlenbergia rigens, Elymus canadensis, Carex spp., and Phragmites communis.</td>
</tr>
<tr>
<td></td>
<td>170</td>
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</tr>
</tbody>
</table>

1 Water Availability

Very High - Year-round water table fluctuations rarely drop 0.5 m below the soil surface; High - Year-round water table fluctuations rarely drop 1.0 m below the soil surface;
Medium - Year-round water table fluctuations rarely drop 2.0 m below the soil surface; Low - Year-round water table fluctuations rarely drop 3.0 m below the soil surface;
Very Low - Year-round water table fluctuations frequently drop 3.0 m or more below the soil surface.

Table 3. Mitigation objectives, techniques, and results at selected riparian sites in Arizona.

<table>
<thead>
<tr>
<th>Site - Year Mitigated</th>
<th>Objectives</th>
<th>Techniques Used</th>
<th>Results Note</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Saw Mill Spring,</td>
<td>Re-establish woody riparian communities to provide improved habitat for bird</td>
<td>100 <em>Salix gooddingii</em> cuttings and 25 <em>Alnus pensylvanica</em> containerized seedings were planted along 90 m of the stream. Logging slash was used as mulch.</td>
<td>0% survival of artificially-planted vegetation (4).</td>
<td>Probable causes for high mortality is unknown. Respondents noted that some of the plantings were pulled up by recreationists.</td>
</tr>
<tr>
<td>Coconino National</td>
<td>and fish species.</td>
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<tr>
<td>Forest (1985)</td>
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<tr>
<td>2. Coleman Lake,</td>
<td>Improve habitat for waterfowl and other wildlife.</td>
<td>Perimeter fence was constructed to exclude livestock. <em>Agropyron</em> spp. seed was drilled on the uplands and broadcast on the wetter lowlands. Shallow pools and mounds were created by blasting with dynamite. <em>S. bobbiana</em> planted on mounds.</td>
<td>Erosion rates greatly reduced, deep pools established, and dramatic recovery of many grass and forb species has improved ecological conditions for waterfowl, elk, and other wildlife. None of the artificially-planted trees survived; survival of artificially-planted grasses varied tremendously (1).</td>
<td>Tremendous recovery of vegetation was attributed mostly to high water availability and reduction of grazing pressure.</td>
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<tr>
<td>Kaibab National</td>
<td></td>
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<tr>
<td>Forest (1976)</td>
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<tr>
<td>3. Canyon Creek Tonto</td>
<td>Improve aquatic habitat for game fish</td>
<td>Perimeter fence constructed to exclude livestock. Boulders and large logs were used to protect the stream banks and divert channel flow. 150 <em>Populus</em> spp., 300 <em>Salix</em> spp. poles, and <em>Bouteloua gracilis</em> seed was planted along 4.5 km of stream reach.</td>
<td>325% increase in the fish population since project completion. Only 5% survival of artificially-planted vegetation (1).</td>
<td>Prolific increase in <em>Bromus</em> spp. is deemed very important in protecting stream banks from spring floods and trapping sediment, encouraging bank construction.</td>
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<tr>
<td>National Forest</td>
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<tr>
<td>(1985)</td>
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<tr>
<td>4. Gentry Creek Tonto</td>
<td>Increase density and diversity of riparian vegetation and reduce erosion.</td>
<td>2000 <em>Salix</em> spp. cuttings were planted along 3-km of stream. Perimeter fence constructed to exclude livestock.</td>
<td>Prolific natural regeneration of <em>Bromus inermis</em>, <em>Muhlenbergiarigens</em>, <em>Poa pratensis</em>, <em>Trifolium</em> spp., and western wheat grass is evidence that primary succession is beginning to rebuild the flood plain. About 5% of survival of artificially-planted willows (2).</td>
<td>Maintenance of stop-gaps is deemed important for long-term recovery of ecosystem.</td>
</tr>
<tr>
<td>National Forest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1989)</td>
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<tr>
<td>5. Tubac Santa Cruz</td>
<td>Stabilize stream bank near Tubac Elementary School</td>
<td>50 <em>P. fremontii</em> and 500 <em>S. gooddingii</em> poles were planted in front of and among stabilization jacks installed along the toe of the heavily-incised river bank.</td>
<td>Soil deposition along the toe of the banks (1.5 meters in some places) and prolific regeneration of riparian vegetation indicates improved stability of the stream banks. Natural regeneration obscured artificial planting results (1).</td>
<td>Tree densities and channel characteristics up and downstream are similar to that of the mitigated reach, indicating that natural processes may be largely responsible for renewed stability.</td>
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<tr>
<td>River (1983)</td>
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Table 3 (continued).

<table>
<thead>
<tr>
<th>Site - Year Mitigated</th>
<th>Objectives</th>
<th>Techniques Used</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. North Tubac</td>
<td>Stabilize stream banks to prevent loss of private property.</td>
<td>Over 2000 S. gooddingii poles were planted among stabilization jacks along the toe of incised river banks.</td>
<td>Soil deposition along the toe of the banks (1-m in some places) and prolific regeneration of riparian vegetation indicate improved stability of the stream banks. Natural regeneration not as prolific as at Tubac (1).</td>
<td>Natural regeneration is not as prolific as at Tubac site. Artificially-planted trees can be seen distinctly from natural regrowth. Water availability appears to be less than at Tubac.</td>
</tr>
<tr>
<td>Santa Cruz River</td>
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<tr>
<td>(1984)</td>
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<tr>
<td>7. Nogales Wash</td>
<td>Stabilize river banks to prevent loss of private property.</td>
<td>Over 500 S. gooddingii whips were planted amongst stabilization jacks along the toe of incised river banks.</td>
<td>Dense vegetation has been established along the reach where the vegetation was planted and over 1 meter of soil has been deposited since the completion of the project (1).</td>
<td>Tree densities and characteristics up- and downstream are similar to those along the mitigated reach, indicating natural regeneration may be largely responsible for prolific regeneration of riparian species.</td>
</tr>
<tr>
<td>(1984)</td>
<td></td>
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<tr>
<td>8. Babocomari River</td>
<td>Stabilize stream banks bordering the Huachuca City sewage pond.</td>
<td>180 S. gooddingii poles were planted between the heavily incised stream banks and a rail and wire fence. Poles were irrigated during the first two summers.</td>
<td>It is too soon to determine how well the objective will be achieved (5).</td>
<td>68 willow poles show no shoot initiation and may have died due to inefficiencies in the irrigation system.</td>
</tr>
<tr>
<td>(1990)</td>
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</tr>
<tr>
<td>9. Sheephead Spring</td>
<td>General ecological improvement of riparian conditions.</td>
<td>No vegetation was planted at this site. Check dams were constructed across the channel, livestock exclusion fence was constructed around the site, and improved livestock management plans were implemented on the uplands.</td>
<td>Prolific recovery of riparian vegetation. Hardwood seedlings have established and understory development has been dramatic (1).</td>
<td>Check dams filled with sediment 1 year following construction.</td>
</tr>
<tr>
<td>(1981)</td>
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</tr>
<tr>
<td>10. Gleason Flat</td>
<td>Establish bald eagle nesting sites and provide future sources of seed</td>
<td>600 dormant P. fremontii poles were planted at a density of 4 to 5 poles per hectare. Poles were harvested from the Gila River.</td>
<td>1% of planted vegetation survived. Site conditions may be too unstable for long-term survival (4).</td>
<td>This portion of the Salt River channel shows signs of instability. Narrow and deep channel offered newly-planted vegetation little protection from flooding and desiccation.</td>
</tr>
<tr>
<td>(1980)</td>
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Table 3 (continued).

<table>
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<tr>
<th>Site - Year Mitigated</th>
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<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Francis Creek (1981)</td>
<td>Improve ecological condition along Francis Creek.</td>
<td>Several hundred P. fremontii poles were planted along a 1.5-km reach of Francis Creek. Beaver cages were installed around most poles. Improved livestock management plans were also implemented.</td>
<td>30 to 40% of the poles have survived to trees over 9-m tall. There is also much rejuvenation of natural vegetation. Density of woody vegetation for both sides of the stream channel is roughly 10 to 15 trees per 30-m (1).</td>
<td>Density of cottonwoods from natural regeneration out-number artificially-planted vegetation at least 3:1. Improved riparian condition is largely attributed to improved grazing management.</td>
</tr>
<tr>
<td>12. Burro Creek (1982)</td>
<td>Improve overall ecological condition of riparian ecosystem.</td>
<td>Planted P. fremontii, S. gooddingii, and P. wrightii containerized seedlings in enclosure (plantation). Irrigation was used during the first five summers. Improved grazing management implemented in 1981 impacted whole of Upper Burro Creek.</td>
<td>Channel conditions have stabilized, erosion rates greatly decreased, and prolific natural regeneration of riparian vegetation along Upper Burro Creek. None of vegetation planted inside plantation is alive today (1).</td>
<td>Positive results mainly due to improved grazing system and absence of catastrophic floods. High mortality of artificially-planted vegetation due to low water availability and inefficient irrigation system.</td>
</tr>
<tr>
<td>13. Box Bar Verde River (1979)</td>
<td>General ecological improvement, also to determine the feasibility of revegetating riparian ecosystems.</td>
<td>P. fremontii and S. gooddingii poles, rooted cuttings, and containerized seedlings were planted on abandoned flood plain and in secondary channel. Irrigation was used during the first three summers.</td>
<td>Only 5% survived through the first year (4).</td>
<td>Surviving plantings were in areas of greater moisture availability, e.g., near leaks in irrigation system, or in lower secondary channel.</td>
</tr>
<tr>
<td>14. Horseshoe Lake (1981)</td>
<td>Provide nesting habitat for Bald Eagles.</td>
<td>Over 1000 P. fremontii seedlings and 202 poles were planted at the lake site. Root hormones and beaver cages were also used.</td>
<td>By Nov. 1986 none of the planted vegetation was alive (4).</td>
<td>Large fluctuations in the level of the water table created conditions hostile to establishing vegetation.</td>
</tr>
<tr>
<td>15. Bartlett Project Verde River (1982)</td>
<td>Establish bald eagle nesting sites.</td>
<td>253 P. fremontii poles were planted along a 5 kilometer reach of the Verde River. A variety of treatment combinations were used: root hormones, fertilizer, tree paint, and roughing the butt of the pole.</td>
<td>19% survival of planted vegetation. Trees are over 10-m tall, some showed signs of stress, but most appeared healthy (1).</td>
<td>Low survival rate was due, in part, to high beaver activity and dewatering of Bartlett Dam during the first fall after the planting.</td>
</tr>
</tbody>
</table>
Table 3 (continued).

<table>
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<tr>
<th>Site - Year Mitigated</th>
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<th>Techniques Used</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Needle Rock</td>
<td>Establish bald eagle nesting sites.</td>
<td>297 <em>P. fremontii</em> poles were planted using similar methodology as Bartlett site.</td>
<td>20% survival of planted vegetation. Trees are over 10 m tall, most appear to be in good condition (1).</td>
<td>50% of planted vegetation was destroyed by cattle and vandalism. An additional 16% died up and died due the closure of Bartlett Dam during the fall of 1992.</td>
</tr>
<tr>
<td>Verde River (1982)</td>
<td></td>
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</tr>
<tr>
<td>17. McEwen Seep</td>
<td>Decrease erosion rates and improve wildlife habitat.</td>
<td><em>P. fremontii</em>, <em>Platanus wrightii</em>, and <em>Juglans major</em> seedlings were planted. The area was fenced to exclude livestock.</td>
<td>48% survival of the planted species. <em>Juglans major</em> and <em>Populus fremontii</em> plantings are doing especially well (over 9-m tall) (1).</td>
<td>Many of the sycamores died because they were placed in areas that did not receive adequate sunlight.</td>
</tr>
<tr>
<td>1981</td>
<td></td>
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</tr>
<tr>
<td>18. Clay Mines</td>
<td>Habitat improvement for wildlife and forage improvement for livestock.</td>
<td>5 <em>Populus fremontii</em> and <em>Salix exigua</em> poles were planted.</td>
<td>4 of the 5 planted trees survive today. <em>Populus fremontii</em> are almost 6-m tall, <em>Salix exigua</em> is almost 5-m tall (2).</td>
<td>Large poles are deemed less vulnerable to livestock. Site is considered saline, therefore poles were harvested from saline sites along the Gila River.</td>
</tr>
<tr>
<td>Spring (1987)</td>
<td></td>
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<tr>
<td>19. Aravipa Creek</td>
<td>Expedite recovery of riparian vegetation following 1983 flood.</td>
<td>1853 plantings were put into the ground. Species included: <em>P. fremontii</em>, <em>S. gooddingii</em>, <em>J. major</em>.</td>
<td>5% to 10% survival of planted vegetation (1).</td>
<td>Prolific regeneration of natural vegetation has almost obscured artificial revegetation efforts.</td>
</tr>
<tr>
<td>1984</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>20. Seven Mile</td>
<td>Stabilize river banks and improve aesthetics.</td>
<td>30 <em>Populus fremontii</em> poles were planted along toe of bank, rip rap was installed on the bank.</td>
<td>Increased deposition along the toes of banks has increased bank stability. 40% survival of planted vegetation (1).</td>
<td>Large poles were less vulnerable to livestock than smaller plantings.</td>
</tr>
<tr>
<td>1984</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Highway 70 Bridge</td>
<td>Bank stabilization</td>
<td>35 <em>Populus fremontii</em> and <em>Salix gooddingii</em> poles were planted in trenches dug by a backhoe. Saltcedar was removed prior to planting.</td>
<td>Increased deposition along the toes of banks indicates increased bank stability. 90% survival of artificially-planted vegetation one year after project completion (1).</td>
<td>The use of large poles helped considerably to ensure survival in the face of continued grazing pressure.</td>
</tr>
</tbody>
</table>
Table 3 (continued).

<table>
<thead>
<tr>
<th>Site - Year Mitigated</th>
<th>Objectives</th>
<th>Techniques Used</th>
<th>Results¹</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. Hassayampa</td>
<td>Restoration of the ecological processes, structural integrity, and species</td>
<td>Livestock grazing and recreation pressure greatly curtailed. No artificial</td>
<td>Tremendous recovery of riparian vegetation. Dense riparian vegetation</td>
<td>Results exemplify the resiliency of riparian ecosystems.</td>
</tr>
<tr>
<td>River Preserve</td>
<td>composition of the Preserve.</td>
<td>revegetation work was attempted.</td>
<td>grows along the channel today where 3 years ago there was none (2).</td>
<td></td>
</tr>
<tr>
<td>(1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Goose Flats</td>
<td>Improve wildlife habitat.</td>
<td>Atriplex lentiformis, Symphoricarpos oerophiles, Cercidium floridum, Prunus</td>
<td>A total of 4172 trees and shrubs were established as a result of the</td>
<td>Holes were augered prior to planting. This technique facilitated root</td>
</tr>
<tr>
<td>Colorado River</td>
<td></td>
<td>juliflora, Prunus pubescens, and S.gooddingii were planted. 38 grams of time</td>
<td>revegetation effort. The prognosis for wildlife is good (2).</td>
<td>development to the water table, essential to the survival of species</td>
</tr>
<tr>
<td>(1988)</td>
<td></td>
<td>release fertilizer was used/tree. All trees were irrigated from the day of</td>
<td></td>
<td>such as S.gooddingii and P.fremontii.</td>
</tr>
<tr>
<td>24. Rt. 85 Site</td>
<td>Improve wildlife habitat and protect adjacent farmland high flows.</td>
<td>700 P.fremontii, S.gooddingii, and Tamarix preyvila poles were planted in</td>
<td>70% of planted vegetation has survived, but majority show signs of stress (3).</td>
<td>Channelization of the Gila River and closing off of the secondary channel will probably further lessen water availability.</td>
</tr>
<tr>
<td>Gila River (1985)</td>
<td></td>
<td>trenches dug to the water table. Tamarix pentandra was cleared from the site</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>as part of a year round maintenance program.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25. Arlington Ponds</td>
<td>Improve wildlife habitat</td>
<td>375 S.gooddingii and P.fremontii poles were planted around the perimeter of the</td>
<td>Almost no survival of planted vegetation (4).</td>
<td>High salinity in the field and failure of irrigation system at the ponds were deemed primarily responsible for causing such low levels of establishment.</td>
</tr>
<tr>
<td>(1985)</td>
<td></td>
<td>two ponds and in a nearby field.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3 (continued).

<table>
<thead>
<tr>
<th>Site - Year Mitigated</th>
<th>Objectives</th>
<th>Techniques Used</th>
<th>Results</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>26. Sugar Dike</td>
<td>Increase dike stability</td>
<td>1700 <em>P. fremontii</em> and <em>S. gooddingii</em> poles were planted to water table along the toe of the dike.</td>
<td>&gt;20% of the planted vegetation has survived. <em>Tamarix chinensis</em> has regenerated prolifically (1).</td>
<td>Establishment of obligate riparian vegetation is possible even in the face of aggressive competition from saltcedar.</td>
</tr>
<tr>
<td>Gila River (1996)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27. 83rd Avenue Site, Phoenix (1990)</td>
<td>Rejuvenate riparian area damaged by Skunk Creek channelization.</td>
<td>15 <em>S. gooddingii</em> poles were planted in trenches dug by a backhoe. <em>Typha</em> sp. planted near low flow area.</td>
<td>Prolific regeneration of understory. 40% of the willows had survived to the fall of 1990. Cattails were in much better condition (1).</td>
<td>Perennial supply of water made potential for recovery high.</td>
</tr>
</tbody>
</table>

---

1 Year in parenthesis indicates the year that mitigation was completed.

2 Number in parenthesis indicates mitigation results as defined below:

(1) Objectives achieved;
(2) Objectives not yet achieved, but present conditions suggest that the objectives will ultimately be met;
(3) Objectives not yet achieved, and present conditions suggest that the objectives will never be met;
(4) Objectives not achieved;
(5) Too soon to categorize the results in any of the above categories.
Some projects, like Clay Mines Spring and McEuen Seep, used basic planting techniques to achieve modest objectives. In contrast, projects such as Coleman Lake, Canyon Creek, and Tubac were much more complex, involving large investments of time, money, and labor to accomplish immodest objectives.

There is also considerable difference as to how much the site changed from the time of mitigation to the time of the site visit (Table 2). Some of the sites, like Saw Mill Spring, Box Bar, Arlington Ponds, showed little change, while at other sites, like Tubac, Nogales Wash, and Aravaipa Creek, the change was tremendous. There are two general characteristics in common to all 27 riparian sites: 1) all 27 projects are located in riparian ecosystems that showed signs of degradation prior to the initiation of mitigation. Degradation was characterized by one or more of the following: reduced regeneration of riparian vegetation, reduced quantity and diversity of riparian vegetation, replacement of "original" riparian vegetation by vegetation not generally associated with healthy riparian environments (saltcedar (Tamarix chinensis)), annual grasses, seep willow (Baccharis glutinosa)), and accelerated erosion; and, 2) all projects were designed to fulfill specific project objectives.
Site Categories

The 5 categories and the number of sites classified into each category are shown in Figure 1. The total number of projects in the successful group and unsuccessful group does not suggest any meaningful trend. The fact that the majority of the projects included in this study were successful may be due, in part, to the methodology used to identify revegetation sites. The land managers contacted in the initial survey may have

Figure 1. Classification of the selected 27 projects based on how well they achieved their objectives.
been less likely to list or remember revegetation efforts that failed.

Revegetation projects along the Verde River exemplify those projects placed in Category 2. The objective of these projects was to establish bald eagle nesting sites. Thirty or more years of growth may be required before a newly planted cottonwood can be considered a potential nesting site for bald eagles (Hall and Forbis, pers. comm.). At the time of the site visit, cottonwood pole plantings along the Verde River were less than 10-years old. Consequently, the objective of this group of revegetation projects has not yet been realized. Nevertheless, the condition of surviving vegetation and the ecological condition of the site indicate a high probability that at least a few of the pole plantings will ultimately reach maturity and fulfill the project objective.

Site #21 (Rt. 85 site, Phoenix) exemplifies the type of site classified in Category #3. The primary objective of this revegetation project was to improve habitat conditions for wildlife. Although a high percentage of artificially-planted vegetation survived, many plants showed signs of stress (yellow leaves, stunted growth, and low foliage density). Furthermore, conditions needed to improve the health of the planted vegetation, namely a consistent water supply, will not be forth coming on this site. In this particular case, a secondary channel that contributes greatly to the site’s water availability, is scheduled to be closed off in the near future by the City of Phoenix. Such action will likely stress the artificially-planted vegetation further, reducing the likelihood that objectives will be fulfilled.
Successful Projects

Classifying the successful projects according to the percent survival of artificially-planted vegetation is useful to demonstrate the impact of environmental characteristics, land use patterns, and planting methods on establishment rates. The three categories and percent break down of the amount of successful mitigation in each category are given in Figure 2.

Figure 2. Classification of successful projects by percent survival of artificially-planted vegetation for 19 riparian sites in Arizona.
Figure 2 illustrates one very important characteristic of the successful projects considered in this study: high survival of artificially-planted vegetation was not necessary to fulfill project objectives. Of the 19 successful projects only 8 achieved a 20% or greater survival of artificially-planted vegetation (Figure 2 and Table 3).

There are two main reasons for this phenomenon. First, a number of projects simply did not need large survival rates of artificially-planted vegetation to achieve their objectives. Second, in 6 of the 19 successful projects, objectives were fulfilled primarily by prolific regeneration of natural riparian vegetation.

Successful projects which experienced less than twenty percent survival of artificially-planted vegetation

This group of projects demonstrate best how mitigation objectives were achieved despite a less than 20% survival of artificially-planted vegetation (Tables 3 and 4). There are two primary reasons why this group of projects was considered successful despite low survival of artificially-planted vegetation. First, high survival rates of artificially-planted vegetation was not necessary to fulfill objectives. Second, natural regeneration was strong enough to fulfill project objectives despite low survival rates of artificially-planted vegetation.

At Bartlett and Needle Rock only a few poles out of the total planting need to reach maturity to establish potential eagle nesting sites. At Canyon Creek, increasing the
Table 4. Successful projects with <20% survival of artificially-planted vegetation.

<table>
<thead>
<tr>
<th>Site</th>
<th>How Projects were Successful Despite Low Survival Rates of Artificially-Planted Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Canyon Creek (Site #3)</td>
<td>An increase in fish population was not necessarily dependent on improvement of riparian vegetation.</td>
</tr>
<tr>
<td>2. Gentry Creek (Site #4)</td>
<td>Natural regeneration of grasses like smooth broom, deer grass, western wheat, and clover, and willow is considered a positive first step in improving the ecological condition of the riparian ecosystem (none of these species were planted artificially).</td>
</tr>
<tr>
<td>3. Burro Creek (Site #12)</td>
<td>Ecological improvement of riparian vegetation outside the plantation overshadowed the low survival rates of artificially-planted vegetation.</td>
</tr>
<tr>
<td>4. Bartlett (Site #15)</td>
<td>Very low percent survival can still fulfill project objectives</td>
</tr>
<tr>
<td>5. Needle Rock (Site #16)</td>
<td>Very low percent survival can still fulfill project objectives</td>
</tr>
</tbody>
</table>

Game fish population depended primarily on how well tree trunks and boulders placed in the channel and stream bank stabilizing structures performed to establish deep pools and stabilize eroding stream banks. Whether or not artificial plantings survived was of secondary importance.

Unlike the three projects mentioned above, the remaining two projects of this group (Burro Creek and Gentry Creek) required regeneration of riparian vegetation to fulfill objectives. Both sites, however, experienced less than 5% survival of artificially-planted vegetation. This low rate of survival was compensated by recovery of natural riparian vegetation sufficient to stabilize stream banks and initiate bank building processes.
Sites with prolific natural revegetation

Projects that experienced prolific natural revegetation have both of the following characteristics: 1) Surviving artificially-planted vegetation comprise less than 5% of the total amount of on-site vegetation of the same species, and 2) the artificially-planted vegetation can not be seen as a distinct entity; i.e., surviving artificially-planted vegetation are not obviously distinguishable by size, color, and space from vegetation of the same species that regenerated naturally.

Six sites (the two projects that did not use artificial-revegetation are included in this group) are in this group: Tubac, Nogales Wash, Sheepshead Spring, Aravaipa, Coleman Lake, and Hassayampa River Preserve. As a group, these sites epitomize the potential resilience of riparian ecosystems. All of these sites experienced dramatic changes in both quantity and diversity of riparian vegetation between the time of mitigation and site evaluation (Table 2).

Projects at Aravaipa Creek (site #19), Tubac (site #5), and Nogales Wash (site #6) was initiated following severe flooding that destroyed vast quantities of riparian vegetation. So extensive was riparian damage in Aravaipa Canyon that many thought several generations would need to pass before riparian vegetation could recover to pre-flood conditions. Large quantities of vegetation were planted at all three sites to expedite the recovery of riparian vegetation.

Unlike Aravaipa, Tubac and Nogales Wash showed obvious signs of channel instability (incised river banks and rapid lateral channel movement) prior to the flood
event. In addition, artificial planting was done not merely to replace lost vegetation but, in conjunction with installation of bank stabilization structures (at both these sites stabilization jacks were used), to improve the stability of river banks that were further degraded during the severe flooding.

Seven years later, stands of riparian trees of similar height and density have established naturally along the reaches of all three sites. The results at Tubac are typical of these three sites. Surviving artificially-planted cottonwoods and willows at Tubac are roughly 10% of the total planted, yet they comprise less than 5% of the total number of cottonwoods and willows currently growing along the mitigated reach. Today, pole plantings can be discerned from natural growth only by examining each tree individually (even years after planting, trees grown from pole plantings can usually be distinguished quite easily from natural growth).

How much of the recovery at Tubac and Nogales Wash is due to installation of stabilization jacks is debatable. Vegetation patterns and densities both up and downstream from the mitigated reaches of the Santa Cruz River and Nogales Wash appear to compare favorably with those of vegetation established along the reach where mitigation was completed. This gives the impression that prolific natural riparian regeneration was likely whether or not bank stabilization structures were installed.

A flood of the October, 1983 magnitude (considered a 100- to 1000- year event) will, no matter how pristine the environment, destroy a considerable amount of riparian
vegetation. As destructive as they may seem, such large flood events are a natural part of the flood plain environment and one to which riparian vegetation is well adapted.

Large flood events seem to initiate a period of rejuvenation, removing old, decadent trees, reworking and then depositing alluvium. Recent alluvial deposits that are fully exposed to sunlight and free of competing vegetation are the most productive part of a riparian ecosystem and are commonly colonized quite rapidly (Heede 1981). The prolific natural regeneration of riparian vegetation at Aravaipa, Tubac, and Nogales Wash follows this pattern.

In slight contrast, prolific regeneration of riparian vegetation at Sheepshead Spring, Hassayampa River Preserve, and Coleman Lake did not occur until factors deemed responsible for causing site deterioration were addressed. This was accomplished by constructing a perimeter fence to control livestock at Sheepshead Spring and Coleman Lake and to control both livestock and recreation use at the Hassayampa River Preserve.

Successful projects which experienced greater than twenty percent survival of artificially-planted vegetation

The cause(s) considered responsible for site degradation were addressed prior to planting in six of the seven projects that experienced a greater than 20% survival of artificially-planted vegetation (Table 3). Walsh, Hall, Bammon, Simms, Anderson, and
Moore (pers. comm.) noted that addressing causes of site deterioration prior to planting was the key to high survival of artificially-planted vegetation.

The techniques used to address the probable causes of site degradation varied considerably. Bank stabilizing structures were used at North Tubac (site #6) and Seven Mile Wash (site #20) to slow accelerated bank erosion rates. At Francis Creek (site #11), improved livestock management decreased grazing intensities in riparian, as well as upland, grazing allotments. A perimeter fence constructed around McEuen Seep (site #17) eliminated livestock completely from that site. At Goose Flats (site #23), motorized augers were used to drill holes to water table prior to planting and a drip irrigation system was set up following planting to promote root development to the water table. Irrigation and major land excavation were used at 83rd Avenue (site #27) to overcome low water availability during the summer and to divert high flows away from the planted area during heavy rains. Finally, at Sugar Dike (site #26) heavy equipment was used to clear Tamarix chinensis (saltcedar) and auger holes to the water table.

Lessons learned from successful projects

Results indicate that chances of either successfully establishing large amounts of artificially-planted vegetation or promoting prolific natural regeneration increase when several important environmental characteristics are provided simultaneously. These characteristics are: a seed source (or parent vegetation capable of developing sprouts), sufficient water for seed germination and subsequent growth, and stable substrate void
of direct competition (Barbour et al. 1987). With one exception (Clay Mines Spring), all three of these characteristics for the 19 successful projects were either present at the onset or were provided during the project by implementing secondary mitigation (Table 5).

The use of secondary mitigation in 15 out of the 19 successful sites underscores the importance of using such techniques to address causes of site degradation. Channel stabilization structures were installed at Canyon Creek (site #3), Tubac (site #5), North Tubac (site #6), Nogales Wash (site #7), Sheepshead Spring (site #9), and Seven Mile Wash (site #20) to overcome channel instability. Improved livestock grazing schedules at Coleman Lake (site #2), Canyon Creek (site #3), Gentry Creek (site #4), Sheepshead Spring (site #9), Francis Creek (site #11), Burro Creek (site #12), McEuen Seep (site #17), and the Hassayampa River Preserve (site #22) reduced grazing intensity at these sites. Clearing vegetation prior to planting at Sugar Dike (site #26) was done to overcome aggressive competition from vegetation. Finally, irrigation was used at Goose Flats (site #23) and 83rd Avenue (site #27) to overcome low water availability.

Of the four successful sites that did not use secondary mitigation, three (Aravaipa Canyon (site #19), Bartlett Dam (site 15), and Needle Rock (site #16)) probably did not use secondary mitigation for lack of identifiable and treatable causes of deterioration. Loss of riparian vegetation at Aravaipa was caused by a flood of 100- to 1000-year magnitude. As discussed previously, flooding of such magnitude will cause damage no
Table 5. Successful projects categorized according to percent survival of artificially-planted vegetation for 19 riparian sites in Arizona.

<table>
<thead>
<tr>
<th>Site</th>
<th>Probable Cause of Deterioration</th>
<th>Type of Secondary Mitigation Performed</th>
<th>Water Availability</th>
<th>Obligate Riparian Vegetation Prior to Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>&lt;20% Survival</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1. Canyon Creek     | 1) Overgrazing by livestock  
2) Unstable stream bank  
3) Wide shallow stream channel  | 1) Fence construction, 2) Bank stabilizing structures; 3) Placement of boulders and large tree trunks in the channel | High               | Scattered old growth along stream channel.    |
| 2. Gentry Creek     | Overgrazing by livestock                                                                      | Fence construction for livestock management                                                              | High               | Scattered old growth along stream channel.    |
| 3. Burro Creek      | 1) Over-grazing by livestock;  
2) Low water table                                                                                   | 1) Implementation of improved livestock management system; 2) Irrigation                                | Low (in plantation) | High diversity of riparian species remained.   |
| 4. Bartlett         | Loss of natural river flow regimes due to dam construction.                                     | none                                                                                                     | Medium             | Old growth riparian trees scattered along river channel. |
| 5. Needle Rock      | Loss of natural river flow regimes due to dam construction.                                     | none                                                                                                     | Medium             | Old growth riparian trees scattered along river channel. |
| **Prolific Natural Comeback** |                                                                                               |                                                                                                         |                    |                                               |
| 6. Coleman Lake     | Overgrazing by livestock                                                                      | 1) Dynamite, 2) Fence construction for livestock management                                              | Very High          | No obligate riparian trees, with a much reduced understory. |
| 7. Tubac (Site #5)  | Flood plain instability enhanced by major flood event                                           | Use of stream bank stabilizing structure                                                                     | Medium             | Obligate riparian trees upstream.             |
| 8. Nogales Wash     | Flood plain instability enhanced by major flood event                                           | none                                                                                                     | High               | Obligate riparian trees upstream.             |
| 9. Sheephead Spring | 1) Overgrazing by livestock  
2) Lack of fine sediment in the stream channel                                                                | 1) Fence construction for livestock management 2) Construction of check dams                              | High               | Diverse riparian vegetation growth at spring source. |
Table 5 (continued).

<table>
<thead>
<tr>
<th>Site</th>
<th>Cause(s) of Degradation</th>
<th>Other Mitigation</th>
<th>Water Availability¹</th>
<th>Riparian Vegetation Prior to Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolific Natural Comeback</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Aravaipa Canyon (Site #19)</td>
<td>100 to 1000 year flood event</td>
<td>none</td>
<td>High</td>
<td>Scattered old growth along main channel and side canyons.</td>
</tr>
<tr>
<td>11. Hassayampa Preserve (Site #22)</td>
<td>Overgrazing by livestock and overuse by recreationists</td>
<td>Fence construction around the perimeter of the site</td>
<td>High</td>
<td>Scattered old growth on site and upstream.</td>
</tr>
<tr>
<td>&gt;20% Survival</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. N. Tubac (Site #6)</td>
<td>Flood plain instability enhanced by major flood event</td>
<td>Use of stream bank stabilizing structure</td>
<td>Medium</td>
<td>Obligate riparian trees upstream.</td>
</tr>
<tr>
<td>13. Francis Creek (Site #11)</td>
<td>Overgrazing by livestock</td>
<td>Improved livestock management system</td>
<td>Medium</td>
<td>Scattered old growth</td>
</tr>
<tr>
<td>14. McEuen Seep (Site #17)</td>
<td>Overgrazing by livestock</td>
<td>Fence construction for livestock management</td>
<td>Medium</td>
<td>No obligate riparian trees</td>
</tr>
<tr>
<td>15. Clay Mines Spring (Site #18)</td>
<td>Year-round livestock grazing and road construction</td>
<td>none</td>
<td>Medium</td>
<td>None</td>
</tr>
</tbody>
</table>

1. Water Availability refers to the condition of the riparian vegetation prior to any mitigation efforts.
Table 5 (continued).

<table>
<thead>
<tr>
<th>Site</th>
<th>Cause(s) of Degradation</th>
<th>Other Mitigation</th>
<th>Water Availability¹</th>
<th>Riparian Vegetation Prior to Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Seven Mile Wash (Site #20)</td>
<td>1) Stability of Stream-bank; 2) Water availability</td>
<td>Bank stabilizing structures</td>
<td>Medium</td>
<td>No obligate riparian trees, some <em>Baccharis glutinosa</em></td>
</tr>
<tr>
<td>17. Goose Flats (Site #23)</td>
<td>Low water availability due to consistently low water table</td>
<td>1) Irrigation  2) Holes augered prior to planting</td>
<td>Low</td>
<td>No obligate riparian trees</td>
</tr>
<tr>
<td>18. 83rd Avenue (Site #24)</td>
<td>Low Water Availability</td>
<td>1) Major land manipulation prior to and following planting; 2) Irrigation with water truck.</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>19. Sugar Dike (Site #26)</td>
<td>Vegetative Competition</td>
<td>1) Initial clearing of vegetation; 2) Holes augered prior to planting</td>
<td>Medium</td>
<td>None</td>
</tr>
</tbody>
</table>

¹ Site water availability is as defined below:

- **Very High** - Year-round water table fluctuations rarely drop 0.5 m below the soil surface;
- **High** - Year-round water table fluctuations rarely drop 1.0 m below the soil surface;
- **Medium** - Year-round water table fluctuations rarely drop 2.0 m below the soil surface;
- **Low** - Year-round water table fluctuations rarely drop 3.0 m below the soil surface;
- **Very Low** - Year-round water table fluctuations frequently drop 3.0 m or more below the soil surface.
matter how healthy the environment. At Bartlett and Needle Rock, deterioration of riparian vegetation is blamed in part on river impoundment. Secondary mitigation at these sites would have to involve altering releases from upstream dams, which most agency personnel have little opportunity to influence.

Although secondary mitigation was not used at Clay Mines Spring, creative planting design was used to overcome some of the causes of site degradation. Poles were harvested from trees growing in an area with highly saline soils so that they might be better adapted to resist the soils of the Clay Mine Springs area. Long poles (over 3 m) were used to prevent damage from cattle (grazing intensities were not changed at this site).

The eight sites in the ">20% Survival" category seem to have used riparian revegetation most efficiently. The results of this group (a relatively high survival rate of artificially-planted vegetation without prolific natural regeneration) seem to indicate that not only was riparian revegetation needed, but artificially-planted vegetation could survive at all the sites. The survival of artificially-planted vegetation in this group, as with the abundant regeneration of riparian vegetation in the "prolific group", seems to indicate that secondary mitigation overcame the causes of site degradation, thereby providing the site characteristics needed for establishment to occur.

Notice that prior to mitigation, seed sources of the appropriate riparian species were present in or near all of the sites that experienced prolific natural growth (Table 5). Furthermore, two sites in the >20% survival category (North Tubac and Francis Creek)
experienced prolific natural regeneration (though not prolific enough to obscure the results of the artificial plantings). These results indicate that riparian revegetation may not always be needed in areas where seed sources are available.

Summary

Three important lessons can be drawn from the group of successful projects:

1) Natural regeneration of riparian vegetation can be prolific when the following environmental factors are provided: a seed source, sufficient water availability for seed germination, tolerable intensities of direct competition from animals or plants.

2) The same environmental factors (except seed source) appear to be important for successfully establishing artificially-planted vegetation.

3) Flood disturbances, even those of great magnitude, are a natural part of riparian ecosystems and often, despite the initial destruction that they may cause, initiate processes of rejuvenation that can lead to prolific recovery of riparian vegetation.

4) Addressing the causes of site degradation is the most important factor in achieving project objectives.
Unsuccessful Projects

The projects of this group have the following characteristics (Table 6):

1 - Desiccation and/or flooding were deemed responsible for preventing five of the six projects from achieving objectives;

2 - Prior to mitigation, seed sources of desired riparian species at all of the sites were either lacking or minimal;

3 - Objectives could only be achieved through successful establishment of artificially-planted vegetation.

The combination of #2 and #3 (above) made achieving objectives in this group of projects difficult. Unlike the project objectives for some of the projects in the "successful group," the project objectives for this group required the establishment of specific riparian vegetation species that had little chance of being established naturally (due to the lack of appropriate natural seed sources). Furthermore, secondary mitigations (see Research Methods for definition and examples of secondary mitigation) used with this group of projects, such as clearing competing vegetation and installing irrigation systems, were designed to improve the chances that artificially-planted vegetation would survive. They, therefore, were only indirectly associated with achieving project objectives and did not specifically address the causes of site degradation. This contrasts with the secondary mitigations used in many of the successful projects (e.g., bank stabilization structures, improved grazing schedules, land forming techniques), which
Table 6. Summary of unsuccessful projects - causes of degradation, mitigation used, water availability, presence of seed sources, and factors responsible for unsuccessful results on selected riparian sites in Arizona.

<table>
<thead>
<tr>
<th>Site</th>
<th>Probable Cause of Site Degradation</th>
<th>Secondary Mitigation Used</th>
<th>Water Availability¹</th>
<th>Obligate woody Riparian Vegetation on Site Prior to Mitigation</th>
<th>Factor(s) Deemed Responsible for Unsuccessful Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Saw Mill Spring</td>
<td>Overgrazing by elk and cattle.</td>
<td>None</td>
<td>Very High</td>
<td>Ruspus arizones</td>
<td>Unknown</td>
</tr>
<tr>
<td>(Site #11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Gleason Flat</td>
<td>Overgrazing by livestock and unstable stream channel.</td>
<td>None</td>
<td>Medium</td>
<td>None</td>
<td>Desiccation and flooding</td>
</tr>
<tr>
<td>(Site #10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Rex Bar</td>
<td>Alteration in natural flood regime caused by dam construction.</td>
<td>Irrigation</td>
<td>Low (upper flood plain) Medium (secondary channel)</td>
<td>None</td>
<td>Desiccation</td>
</tr>
<tr>
<td>(Site #13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Horseshoe Lake</td>
<td>Alteration in natural flood regime caused by dam construction, competition from cattle and saltcedar.</td>
<td>None</td>
<td>Tremendous variability from year to year, with large annual fluctuations</td>
<td>Tamarix chinensis with isolated Salix gooddingii (little evidence of natural regeneration)</td>
<td>Desiccation and flooding</td>
</tr>
<tr>
<td>(Site #14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Highway 70</td>
<td>Competition from cattle and saltcedar, also change in natural hydraulic regime.</td>
<td>Site cleared of vegetation prior to mitigation</td>
<td>Low</td>
<td>Tamarix chinensis</td>
<td>Damage from nearby construction</td>
</tr>
<tr>
<td>(Site #21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Rt. 85-Phoenix</td>
<td>Change in natural flood regime and competition from saltcedar.</td>
<td>Site cleared of vegetation prior to mitigation</td>
<td>Medium</td>
<td>Tamarix chinensis</td>
<td>Desiccation</td>
</tr>
<tr>
<td>(Site #24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Arlington Ponds</td>
<td>Saline soils and competition from saltcedar.</td>
<td>Irrigation</td>
<td>Medium</td>
<td>Tamarix chinensis</td>
<td>Desiccation and high soil salinity.</td>
</tr>
<tr>
<td>(Site #25)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Site water availability is as defined below:

Very High - Year-round water table fluctuations rarely drop 0.5 m below the soil surface; High - Year-round water table fluctuations rarely drop 1.0 m below the soil surface; Medium - Year-round water table fluctuations rarely drop 2.0 m below the soil surface; Low - Year-round water table fluctuations rarely drop 3.0 m below the soil surface; Very Low - Year-round water table fluctuations frequently drop 3.0 m or more below the soil surface.
were capable of fulfilling project objectives with or without successful establishment of artificially-planted species.

Establishing vegetation artificially was more difficult because deteriorating conditions at five of the sites (all except for Saw Mill Spring) were considered to be caused by not one, but several factors (Table 6). Conditions at these sites may indicate that the environments have changed to the extent that establishing obligate, native riparian vegetation is no longer a realistic option (at least in the short term).

Horseshoe Lake probably epitomizes the type of site where the ability to mitigate causes and/or symptoms of riparian degradation have been reached. Pollock (pers. comm.) observed that the deterioration of riparian vegetation at Horseshoe Lake has been caused by both direct and indirect impacts. Water availability, competition from vegetation and animals, and substrate stability were all considered causes of site degradation. Ideally, all of these factors should be addressed before planting vegetation artificially.

Impoundment of the Verde River is considered to be one of the principal causes of riparian vegetation deterioration at Horseshoe Lake. Large, unnatural swings in water availability are generated as Horseshoe Reservoir fills and empties in response to water demands of the city of Phoenix. The combined difference between high and low water levels for Bartlett and Horseshoe reservoirs during 1989 was over 40% of full capacity (Boner et al. 1989). Regulation of riverflow has destroyed riparian vegetation directly, by inundating large areas for extended periods of time and then leaving the same areas
high and dry and, indirectly, by altering natural river flows, probably influencing the reproductive potential of many riparian species.

Forbis and Pollock (pers. comm.) noted that it is very difficult to plant in areas that experience large swings in water availability. Finding micro-sites that offer protection to newly planted vegetation from flooding (boulders or slightly elevated landforms) or from desiccation (secondary channels or in small depressions where water availability is high) is often not difficult. However, locations that offer protection from both inundation and drought are extremely rare. This is especially true at Gleason Flat and Horseshoe Lake, where flat and barren terrain provided even less opportunity to find such an ideal micro-site.

In addition to the direct and indirect influences of river impoundment, riparian vegetation above Horseshoe Dam is also impacted by livestock grazing and competition from *Tamarix chinensis* (saltcedar). Saltcedar appears to be better adapted to the unnatural environment created by the impoundment of the Verde River. Saltcedar is established in dense thickets along many parts of the reservoir and probably competes directly with native riparian trees for space, water, and nutrients.

Agency personnel are often unable to treat the causes of degradation at sites where deterioration is caused by factors far removed from the immediate area. This was the case at Horseshoe Lake and Box Bar, where river impoundment is deemed largely responsible for site deterioration, and at Highway 70 and Gleason Flat, where numerous land use changes up- and downstream from the site are considered to be responsible for
degradation. In such situations, agency personnel are often left with few realistic options. Pollock (pers. comm.) noted that conditions at Horseshoe Lake left agency personnel with two basic possibilities: 1) do nothing; 2) plant vegetation artificially and hope for the best (the effects of grazing, in light of other impacts, were considered too small to warrant mitigation).

**Overcoming low water availability**

Babocomari Creek (site #8), Burro Creek Plantation (site #12), Box Bar (site #13), Arlington Ponds (site #25), Goose Flats (site #23), and 83rd Ave. (site #27) all incorporated various irrigation strategies in their planning design to induce root growth of artificially-planted species to low lying water tables. Only at Goose Flats, where secondary mitigation was performed (see Supplement), did planted vegetation successfully established in high numbers. At Box Bar only the vegetation planted in the secondary channel (where water availability is naturally high) along with two stunted cottonwoods on the upper flood plain survived to the time of the site visit. None of the planted vegetation survived after the irrigation system broke down at Arlington Ponds and after it was turned off at the Burro Creek Plantation. At 83rd Avenue, survival of some of the artificially-planted vegetation is probably due more to water supplied naturally, than to water supplied through irrigation. Over one-third of the vegetation planted at Babocomari River has not survived through the first growing season due to failures of the irrigation system.
These results illustrate the difficulty of establishing an artificial moisture gradient to a deep water table. This appears to be especially true in remote locations where irrigation system maintenance becomes an even larger problem.

Summary - Lessons Learned from Unsuccessful Projects

1) Establishing native, obligate riparian vegetation at sites where the major cause of degradation cannot be addressed can be difficult.

2) Establishing native, obligate riparian vegetation can be exceedingly difficult when the primary cause of degradation is deemed to be either low water availability or extreme fluctuations in water availability.
DISCUSSION

Identifying the Causes of Site Degradation

Analysis of successful and unsuccessful projects indicates that addressing the causes of site degradation prior to planting is extremely important in achieving project objectives. Identifying the causes of site deterioration and designing methods of treatment should, therefore, be the first priority of any mitigation plan.

Generally, natural regeneration will occur when three environmental characteristics are provided concurrently: a seed source (or parent vegetation that can sprout), sufficient and timely water availability for seed germination and subsequent establishment, and stable substrate devoid of direct competition (Barbour et al. 1987). Prior to mitigation, all 27 sites were characterized by reduced densities and diversities of riparian vegetation, possibly indicating that one or more of the key ingredients necessary for natural regeneration were either absent or being obstructed.

Interrupting natural river flow, a drop in the water table, intense competition from animals and plants, and unstable substrate were all cited as probable causes of site deterioration among the successful projects (Table 5). All of these factors have acted to reduce the potential for natural propagation of riparian species. If artificial revegetation is used without addressing the causes of site degradation, it seems likely that whatever is preventing or slowing the establishment of riparian vegetation naturally will also prevent the establishment of riparian vegetation artificially.
Secondary Mitigation

The type of secondary mitigation used varied from site to site and its manifestation depended upon what agency personnel deemed the major cause of site degradation. Construction of a perimeter fence at Coleman Lake and Sheepshead Spring to eliminate livestock, irrigation at Goose Flats to overcome low water availability, landforming at 83rd Avenue, and installation of bank stabilization structures at Tubac, Nogales Wash, and Seven Mile Wash are examples of secondary mitigation used to treat site problems.

The prevalent use of secondary mitigation (15 of 19) in the successful group suggests that they may play an important role in determining the degree of success for any given site (Table 5). Secondary mitigation is designed either to address the cause(s) of site degradation or to overcome the symptoms of site degradation. The success of secondary mitigation, therefore, probably has more of an impact in determining the overall outcome of some mitigation efforts than percent survival of artificially-planted vegetation.

The ability of secondary mitigation to overcome the causes of site degradation depends primarily on how closely the causes of degradation are associated to the site. Causes of degradation directly associated with the site, such as livestock overgrazing and overuse by recreationists, are usually much easier to identify and, at least technically, much easier to treat than degradation caused by factors far removed from the site.
Prior to mitigation, livestock would graze Coleman Lake every year all summer long. In this case, the cause of degradation was fairly obvious and developing plans to lessen its impact were relatively straightforward. In contrast, the drop in water availability at Goose Flats (Colorado River) is somewhat more difficult to understand.

Observations of vegetation changes along the Colorado River reveal a complex cycle of deterioration of cottonwood/willow stands that may have been instigated by impoundment and withdrawal of Colorado River water (Ohmart et al. 1977). Manipulation of the Colorado River has greatly altered its natural flow regime and reduced the total volume of flow. It is, however, very difficult to prove a direct link between flow manipulation of the Colorado River and degradation of riparian habitat at Goose Flats, especially when there are other factors to consider (e.g., climatic and land use changes).

The loss of native riparian vegetation along much of the Lower Colorado River does, however, strongly suggest that the causes of degradation at Goose Flats are not directly associated with that particular site. Therefore, mitigation implemented at Goose Flats did not treat the causes of degradation, but rather the symptoms of degradation. The symptoms of degradation at Goose Flats were reduction in both quantity and diversity of riparian vegetation caused by lower water availability.

Monetary, jurisdictional, and man-power constraints often limit the ability of agency personnel to treat the causes of degradation in situations, such as Goose Flats, where causes of degradation are far removed from the immediate site area. The success
of projects that addresses only the symptoms of degradation rather than the causes of degradation depends not only on the ability of secondary mitigation to overcome degradation symptoms, but also on the degree to which the original causes of degradation persist. Even if irrigation at Goose Flats performs perfectly and successfully promotes root growth to the water table, continued growth and vegetation health will depend on the degree of drought persistence and water releases from upstream dams. In comparison, the ability of secondary mitigation at Coleman Lake to treat the causes of degradation depends primarily on fence maintenance, which is under the control of agency personnel.

This should not lessen the importance of using secondary mitigation techniques even when the causes of site degradation cannot be treated directly. Results at Goose Flats, Tubac, Nogales Wash, Bartlett, Needle Rock, Seven Mile Wash, and Sugar Dike indicate that success can be achieved even when secondary mitigation cannot treat the causes of degradation directly. Identifying the causes of degradation and determining their magnitude may not only help to plan mitigation better suited to the local environment, but may also clarify the potential of riparian revegetation to overcome degradation.
Determining Riparian Revegetation Potential

Riparian revegetation is most effective in areas where artificially-planted vegetation survives to fulfill project objectives without being obscured by natural regeneration (of the same species that was artificially-planted). In this study, only 10 of the 27 projects fall into this definition (to those with >20% survival in Table 5, I have added Bartlett Dam (site #15) and Needle Rock (site #16)). This seems to imply that in the majority of cases riparian revegetation was used in areas where artificially-planted vegetation could not grow because factors causing site degradation were not addressed, or where it was not needed due to dramatic natural regeneration.

Riparian revegetation could be used more effectively if land managers could ascertain the appropriateness of planting vegetation artificially for each site prior to planting vegetation. The "appropriateness" of using riparian revegetation for a given site could be determined if we could ascertain the degree to which the factors responsible for site degradation can be overcome and determine the likelihood that prolific natural regeneration will occur.

From the results of this study, two check lists have been developed to determine the potential effectiveness of using riparian revegetation for a particular riparian site. The first check-list is composed of factors considered responsible for degrading riparian ecosystems (i.e., factors that may also reduce the chances for successful establishment of artificially-planted vegetation). The second check-list is used to determine the potential that natural regeneration may make riparian revegetation unnecessary.
If none of the factors on the first check list are a problem, or if they can be overcome, then the second check-list should be used to determine the potential for natural regeneration. If the chances of natural regeneration appear low then riparian revegetation may be a viable option.

Check-list #1 - Will Artificially-Planted Vegetation Survive?

Causes of ecological degradation of the sites analyzed in this study can be placed into three general categories: 1) Disturbances caused by direct impacts, 2) geomorphological instability; 3) changes in hydrologic characteristics. Although these impacts will be discussed separately, their influence on a riparian environment is rarely separate. Many respondents have noted that although there may be one primary cause of degradation, there are often several underlying factors that have also contributed to site deterioration.

Like all types of ecosystems, riparian ecosystems are able to withstand certain frequencies and intensities of disturbances. Ecological deterioration occurs only after the frequency and intensity of these disturbances exceed the ecosystem’s ability to recover from them.

The ability of a riparian ecosystem to recover is dependent upon an array of environmental factors that describe not only the site, but upstream and downstream reaches, and the upper parts of the watershed as well. These environmental factors include: initial ecological condition of the site, depth and type of soil, water availability,
riparian vegetation characteristics, slope and dimensions of the channel, surrounding topography.

The potential for recovery is also influenced by the intensity and number of disturbances affecting the ecosystem. Degradation is more likely as the intensity and number of disturbances affecting a site increase. Bell (pers. comm) noted that deterioration of Canyon Creek was probably accelerated by the combined impacts of beaver activity, livestock grazing, and recreation-use.

1 - Direct Impacts

Seventeen of the 27 riparian ecosystems considered in this study identified direct impacts as being at least partially responsible for the ecological deterioration of the site. Direct impacts fall into one of three categories: over-grazing by livestock and/or wildlife, competition from non-riparian or non-native vegetation, and human recreation activities.

1.1 - Livestock

In the southwest, riparian ecosystems are often the only areas where year-round water and forage are available, making them valuable to several, often conflicting, uses (such as wildlife, livestock, and human recreation activities). The reduced number of healthy riparian ecosystems has increased competition between these different uses.

This study and others (Duff 1979; Busby 1979) indicate that livestock can cause considerable damages to riparian ecosystems. Respondents point out, however, that it
is not livestock grazing that damages riparian ecosystems, but livestock overgrazing. Overgrazing occurs when land is grazed repeatedly without intervening periods of rest of sufficient length for recovery. The number of livestock, length of grazing period, and length of rest required to sustain grazing without deteriorating the ecological condition of the land varies tremendously from one riparian ecosystem to the next.

Overgrazing by livestock was deemed primarily responsible for the deteriorating ecological condition of six sites (Coleman Lake, Gentry Creek, Sheepshead Spring, Francis Creek, Burro Creek, and McEuen Seep) and a major contributing factor in six others (Saw Mill Spring, Canyon Creek, Clay Mines Spring, Seven-Mile Wash, Highway 70 Bridge, and Hassayampa River Preserve). Ecological degradation at Coleman Lake, Canyon Creek, Gentry Creek, Sheepshead Spring, McEuen Seep, and Hassayampa River Preserve was deemed so severe that livestock were excluded completely, and at Burro Creek and Francis Creek livestock access has been greatly curtailed.

Goodwin, Bell, Zarlingo, Richter and Richter, Hall (pers. comm.), and Platts and Wagstaff (1984) noted that removing or greatly curtailing livestock grazing in some areas is often a prerequisite for recovery. The prolific regeneration of riparian vegetation that has occurred at these sites following the exclusion of livestock seems to support this view.

All sites in this study that used livestock management as a mitigation tool enforced livestock grazing patterns by installing fencing. Fencing riparian systems from livestock grazing is a common practice in the western U.S. (Manci 1989). Several authors have
summarized various methods for controlling livestock, including barriers, stream crossings, and water access points (Reichard 1984; Platts and Nelson 1985).

Although short-term exclusion of cattle from a degraded riparian area may be necessary, total long-term exclusion may not be the answer. Some evidence suggests that rested riparian areas with prolific regeneration may attract more livestock, thus causing increased deterioration (Coconino National Forest - Riparian Implementation Plan). The main challenge to land managers is to work with ranchers to develop grazing management plans compatible with the local riparian environment (Hall, pers. comm). To accomplish this, the land manager must know how the proposed livestock management system will affect stream-side vegetation and how this vegetation is important to the particular stream system (Elmore 1989). Anseth (1983) and Kauffman et al. (1983) describe different types of grazing management plans associated with riparian ecosystems.

Management plans should be flexible and capable of adjusting to annual precipitation fluctuations, rate of ecosystem recovery, and degree of degradation. Grazing intensities at Burro Creek (site #12) and Coleman Lake (site #2) have been increased to take advantage of dramatic regeneration of riparian vegetation. Elmore and Beschta (1987), however, noted the importance of keeping livestock management prescriptions strict, even if forage goes unused. They observed that "unused forage" is necessary to maintain the integrity of the system. Increasing livestock concentrations or grazing at inappropriate times during the year simply because forage is available can
quickly deteriorate the riparian area to its pre-mitigation level. Working closely with
the permittee can greatly improve the efficiency with which new management plans are
implemented. Opening and closing gates, development of off-site water and forage
facilities, and fence and stop-gap maintenance are made easier with permittee cooperation
(Hall and Zarlingo, pers. comm.). Maintaining fence integrity is as important as
installation. Damage to even a very small section of fence can allow livestock
transgression, disrupting recovery processes for the entire area that the fence encloses.
Hall (pers. comm.) noted, for example, that considerable damage was done to the Burro
Creek plantation when one cow managed to gain entrance through an open gate.
Livestock and wildlife movement, human activities, and broken tree limbs are among the
many causes of fence damage.

Respondents of this study generally agree that continued livestock grazing and
artificial revegetation are not compatible. Cottonwood and willow seedlings (both choice
forage plants for livestock) should be protected from livestock during the first two
growing seasons following planting (Hall, Forbis, Bell, Goodwin; pers. comm.). Several
strategies have, however, used simple, imaginative alterations to basic planting
techniques that have established vegetation artificially despite continued livestock
pressure. Bammon and Sims (pers. comm.), for example, used long poles (over 3.5 m)
that were less vulnerable to trampling and grazing, and although objectives were not
achieved at Saw Mill Spring, Goodwin (pers. comm.) still considers the strategy of
planting non-palatable species around palatable species worthy of future consideration.
1.2 - Wildlife

Of the sites considered in this study, wildlife contributed to riparian degradation at two sites (Saw Mill Spring and Canyon Creek) and probably influenced the rate of recovery following mitigation at five others (Coleman Lake, Francis Creek, Burro Creek, Horseshoe Lake, and Bartlett Dam). Respondents noted that elk, deer, and beaver can substantially impact riparian ecosystems when present in sufficient numbers (Goodwin, Forbis, Hall; pers. comm.).

Elk (Goodwin, pers. comm.) and deer (Johnson 1965) can damage a riparian ecosystem by trampling and over-grazing. Elk contributed to site degradation at Saw Mill Spring (site #1), and elk and mule deer influenced recovery rates after mitigation at Saw Mill Springs (site #1) and Coleman Lake (site #2). Beaver influenced mitigation results at Canyon Creek (site #3), Gleason Flats (site #10), Francis Creek (site #11), Burro Creek (site #12), and Horseshoe Lake (site #14). Hall, Pollock, and Forbis (pers. comm.) noted that beaver can do considerable damage to artificially-planted woody riparian vegetation, especially if the vegetation is planted in an area where alternative sources of woody vegetation are scarce.

Beaver cages (chicken wire wrapped around the base of the tree) were used at Canyon Creek, Gleason flat, and Francis Creek to protect planted trees from beaver. Hall and Forbis (pers. comm.) noted that beaver cages were generally successful in protecting planted vegetation from beaver damage, as long as water levels did not
commonly inundate the mitigated area to a depth where beaver could swim up and consume above-cage vegetation growth.

Respondents generally agree that excluding wildlife from the site is usually not worth the effort. Fence enclosures are usually no match for beaver and need to be constructed sturdier and higher than typical livestock enclosures to affect elk and deer. Trapping beaver and moving them off-site requires large expenditures of time and labor. This strategy met with only marginal success at Canyon Creek. Furthermore, removing all beaver from a site may not be beneficial. Brayton (1984) and Braasch and Tanner (1989) noted that, in some situations, beaver can positively influence rehabilitation processes by constructing dams that slow water flows, thereby lessening streambank erosion.

1.3 - Recreation Activities

Human recreation activities were deemed at least partially responsible for deteriorating the ecological condition Canyon Creek (site #3) and Hassayampa River Preserve (site #22), and influencing mitigation results at Saw Mill Spring (site #1) and Seven Mile Wash (site #20). Recreation activity has been greatly curtailed at the Hassayampa River Preserve, but remains roughly the same at Saw Mill Spring and Canyon Creek.

Direct human impacts such as off-road vehicle use and areas where large numbers of people are constantly present can produce profound negative impacts to riparian
ecosystems. Richter and Richter (pers. comm.) noted that greatly curtailing off-road vehicle use and eliminating a trailer park had much to do with the dramatic recovery of riparian vegetation at the Hassayampa River Preserve.

Establishing vegetation artificially in an area where direct human impacts are significant can be difficult. At Saw Mill Spring and Seven-Mile Wash, direct human impacts were not deemed a major factor in site deterioration, but were considered important in influencing the establishment of artificially-planted vegetation. At both sites, planted poles and whips were pulled out of the ground by humans. Sims and Goodwin (pers. comm.) noted that some people who pulled up planted vegetation were probably ignorant of its purpose. Future projects may prevent such impacts by posting signs that briefly explain pole plantings and project objectives.

1.4 - Vegetation

Abundant growth of species such as saltcedar (*Tamarix chinensis*), bermuda grass (*Cynodon dactylon*), arrowweed (*Pluchea sericea*), and seep willow (*Baccharis glutinosa*) usually is an indication that a riparian environment is degraded. With the possible exception of saltcedar, these species are usually not the cause of degradation of native riparian species; rather they appear to out-compete native species after the riparian environment has already been impacted by other factors.

Saltcedar is an aggressive colonizer that has established in dense thickets along many parts of the Gila (Marks 1956; Turner 1974) and Colorado Rivers (Robinson 1965)
since the 1940's. Saltcedar's high rate of seed production, longer period of seed production, and ability to withstand relatively long periods of inundation make it difficult to eradicate and probably allow it to displace native riparian species (Warren and Turner 1975; Ohmart et al. 1977; Richter and Richter, pers. comm.).

It seems probable that saltcedar not only inhibits natural riparian regeneration, but negatively impacts the growth and establishment of artificially-planted riparian vegetation as well. Hall and Moore (pers. comm.) noted that clearing saltcedar prior to planting will improve establishment rates of planted species. This may be true even though saltcedar can come back more aggressively following the initial clearing. Results at Sugar Dike and Highway 70 Bridge demonstrate that artificially-planted riparian vegetation can successfully establish despite prolific saltcedar regeneration.

Anderson and Ohmart (1982) noted that bermuda grass roots (found wrapped around root systems of newly planted trees at depths of 2.4 m) probably competed with the root systems of newly planted trees. In addition, they noted that southern pocket gophers and larvae of Apache cicadas, which are attracted to bermuda grass, can damage newly planted vegetation by eating roots (gophers) and increasing the trees' vulnerability to disease (Apache cicadas). They found a significant negative correlation in both survival and biomass production between vegetation planted in areas with bermuda grass and in areas where bermuda grass was either absent or removed prior to planting.
2 - Water Availability

Results indicate that availability of water at the root zone during the growing season is the most important factor determining the feasibility of establishing artificially-planted vegetation in a riparian ecosystem. Six projects used irrigation to overcome low water availability: Babocomari River (site #8), Burro Creek Plantation (site #12), and Box Bar (site #13), and Goose Flats (site #23), Arlington Ponds (site #25), and 83rd Avenue (site #27). Results from all of these projects indicate even the most efficient irrigation systems require frequent attention to repair and refuel pumps, patch, replace, and realign pipes, and unclog emitters. Even if the above maintenance problems are considered, the largest obstacle may be that most irrigation systems simply do not provide sufficient water to wet the soil from the soil surface to the level of the water table. Forbis (pers. comm.) noted that previously employed irrigation systems were capable of wetting only 1 to 2 cubic meters of soil, which may not be sufficient to wet the entire soil profile in areas where the water table drops 2 to 3 m below the soil surface. In some cases root development only occurred within the wet profile and vegetation was left high and dry when irrigation was stopped (Hall and Forbis, pers. comm.; Goldner 1981). Anderson (pers. comm.) has developed a method that has proven successful in producing tap-root development in species that predominantly produce lateral root systems (see Supplemental Chapter for details).

Using large cottonwood and willow poles to reach low water tables has allowed agency personnel to plant in areas of low water availability. York (pers. comm.) and
Swenson and Mullins (1985) have had success planting poles over 7 m long in areas where the water table is over 4 m below the soil surface.

In such conditions, however, success is dependent upon several factors: 1) mechanized equipment is necessary to either drill or punch the pole down the soil (which means that the site needs fairly accessible); and, 2) the consistency of overlying alluvium needs to be such that holes can be dug or drilled. Digging or drilling into alluvium with a high composition of rocks and cobbles may make many sites with of low water tables off-limits to revegetation. In addition, one should question the logic in planting obligate riparian vegetation in an area that may no longer be considered riparian. If vegetation needs to be established for wildlife habitat improvement or for general ecological improvement, then planting non-obligate riparian species may be a practical alternative.

Site water levels should be monitored for at least one year prior to planting. The depth to water table and magnitude of water table fluctuation, especially during the growing season, can help land managers determine planting depth and irrigation schedules. This information will help define the desirability of planting vegetation artificially in that area (York and Hall pers. comm.; Swenson and Mullins 1985).

3 - Geomorphic Stability

Many rivers in the southwest appear to be going through an erosion cycle characterized by frequent lateral channel movement and accelerated bank and channel bed incision. Such instability can lead to deep arroyos and cut banks along water courses
In this study, nine sites have characteristics that indicate enhanced instability: Tubac (site #5) and North Tubac (site #6) on the Santa Cruz River; Gleason Flats (site #10) on the Salt River; Box Bar (site #13), Horseshoe Lake (site #14), Bartlett Dam (site #15), and Needle Rock (site #16) on the Verde River; Sugar Dike (site #26) on the Gila River; and Goose Flats (site #23) on the Colorado River. Nogales Wash (site #7) and Babocomari Creek (site #8), two smaller drainage systems, also show signs of instability.

Ideally, mitigation should treat the causes of instability. Land management organizations often attempt to mitigate upper parts of watersheds before low lying riparian areas. Hall (pers. comm.) noted that this approach at Burro Creek (mitigation began along Francis Creek and then moved down the watershed to Burro Creek) had a great deal to do with the success achieved there.

Causes of channel disequilibrium, however, are often not directly associated with the channel reach experiencing instability. Land use changes far removed from the site that alter soil and water runoff characteristics can trigger instability, thereby initiating fluvial adjustments processes that can influence large portions of the drainage system. These adjustment processes are complex. Different channel reaches in the same drainage system are commonly out-of-phase with one another as they move through periods of aggradation and degradation (Schumm et al. 1984). Postponing mitigation efforts until after an unstable channel reach has attained a new equilibrium may improve the chances
for success (Van Haveren and Jackson 1986; Jackson and Van Haveren 1984; Gore and Bryant 1988).

Despite the complexity of fluvial adjustment processes, Schumm et al. (1984), Elliott (1979), and Love (1979) (studies of Oaklimiter Creek, Rio Puerco, and Chaco Arroyo respectively) have shown that the evolutionary sequence of events that take place when a river adjusts its morphology to accommodate changes in discharge and sediment load can be predicted. These adjustment processes have been found to slow with the passage of time, eventually reaching the point where mitigation efforts can be effective (Begin and Schumm 1979).

The adjustment model of Oaklimiter Creek consists of five channel reach types (I to V) that depict conditions of total disequilibrium to dynamic-equilibrium (Schumm et al. 1984). Reach types I through V are encountered consecutively in a downstream direction, at a given location through time as the channel evolves.

Type I reaches are located above active nickpoints and are characterized by a "U" shaped cross section with little or no sediment storage. Type II reaches are located immediately downstream of nickpoints, and are characterized by highly variable sediment accumulation, steep vertical banks, and highly variable width-depth ratios (F-values). Type III reaches are characterized by rapid channel widening that occurs after critical bank height has been exceeded. In Type IV reaches, channel widening continues but at a much reduced rate, and sediment accumulation in the bed of the channel range between 0.75 and 1.5-m. Type V reaches have attained a new dynamic equilibrium and are
characterized by decreased rates of erosion, increased alluvial deposition, with corresponding increase in F-values.

The time it takes a particular channel to move through the different stages of adjustment depends primarily on discharge, sediment load, bed and bank stability, tributary influences, and channel slope (Schumm et al. 1984). Channel adjustment processes will tend to be more rapid where gradients are steep and banks are composed predominantly of material that can be eroded easily (e.g., sand).

Attainment of Type IV reach marks a decrease of instability sufficient to allow mitigation to be used with a greater expectation of success (Schumm et al. 1984). The problem facing land managers becomes one of identification. How then can land managers discern between a type III reach (a reach characterized by enhanced instability) and a type IV reach (a reach characterized by greater stability)?

Channel widening and alluvial deposition increase F-values (width-depth ratios) and dynamic equilibrium is reached when a critical F-value (dependent on watershed size) is attained. At this point, the slope of a previously unstable channel is reduced (via channel incision) and the channel widened (via bank failure) to the point where stream capacity to transport sediment is diminished and alluvial deposition begins. Deposition along the toes of incised banks is an important topographic clue that stability is returning. Bank stability increases as sediment is deposited at the toes of banks which, in turn, slows the rate of channel widening. Further deposition produces a meandering thalweg
under low-flow conditions. Alternate bars controlling the location of the thalweg become vegetated, which induces further vertical and lateral buildup (Schumm et al. 1984).

Mitigation at Tubac was probably more successful than at Gleason Flats because it was timely. Similar patterns of natural regeneration of vegetation and alluvial deposition both up and downstream from the mitigated reach appear to show that this portion of the Santa Cruz River, at least compared to Gleason Flats, had greater stability and, therefore, was more responsive to mitigation.

A rough estimate of stability can be obtained by visually inspecting the channel reach in question. Channel dimensions and topographic features of the Santa Cruz River at Tubac appear to be similar to those of a channel returning to a dynamic equilibrium. The top width of the channel is between 55 m and 65 m, and incised banks range 3 m to 4 m above the primary flood plain (giving F-values between 13.75 and 21.7). Alluvial deposition of 1 m is common along the toes of the banks, and during low flow a thalweg meanders between dense islands of regenerating riparian vegetation.

In contrast, morphological characteristics of the Salt River channel at Gleason Flats indicate an environment that is still unstable. The channel is incised to a similar degree as Tubac, but is narrower (equating to lower F-values than at Tubac). Lack of natural regeneration of riparian vegetation and alluvial deposition along the toes of the incised banks indicates that further channel widening is probably inevitable.

Planted vegetation is especially vulnerable to flooding damage during the first couple of years following planting. This appears to be true no matter how stable the
drainage system. A channel reach that has widened sufficiently (one that is stable) offers a much wider range of micro-sites, each with its own susceptibility to flooding and desiccation.

Forbis (pers. comm.) concluded that the environment at Gleason Flats was simply too hostile for establishing vegetation. The deeply incised and narrow channel at Gleason Flats forced agency personnel to plant either in the main channel (where scouring flows are common) or on the abandoned flood plain (where the level of the water table commonly drops 3 m or more below the soil surface). In comparison, alluvial deposition along the incised banks at Tubac offers a variety of microsites that are protected from most flows and yet are not greatly removed (vertically) from the water table.

Planning mitigation based solely on the examination of a specific channel reach, however, may waste mitigation efforts or even perpetuate the instability. Schumm et al. (1984) cautioned that renewed instability can quickly return to a channel reach if downstream nickpoints are present. Mitigation of a specific channel reach should, therefore, be planned only after the rest of the drainage system is examined. Such a holistic view will allow conservation techniques to work with natural river adjustment processes, rather than against them, by allowing agency personnel to better predict the direction, type, and magnitude of channel adjustment (Brookes 1985; Harvey and Watson 1986; Heede 1981; Keller and Brookes 1984; Leopold 1977; and Schumm et al. 1984). Such practical advice assumes that agency personnel are able to acquire sufficient information concerning the fluvial system. Due to monetary, man-power, and time
constraints, such an assumption may not be realistic. Such background information was not acquired to any great extent at either Tubac or Gleason Flats.

A cursory inspection of the immediate stream channel will at least provide information concerning short-term channel stability, which, depending upon project objectives, may be sufficient to make a decision concerning the use of riparian revegetation. Heede (1986) noted that our inability to predict future stream developments makes such short-term planning dangerous. He went on to state that mitigation should go beyond the short term and incorporate contingencies in the mitigation design to meet future considerations.

There are several papers that provide valuable information on the use of various types of structural measures. Schultze and Wilcox (1985) review several bank stabilization devices used in revegetation projects in California's central coast area, and Patterson et al. (1981) review streambank stabilization techniques used by the Soil Conservation Service in California.
Check-List #2 - Possibility of Prolific Natural Regeneration

Results at Coleman Lake (site #2), Tubac (site #5), Nogales Wash (site #7), Sheepshead Spring (site #9), Aravaipa Creek (site #19), and Hassayampa River Preserve (site #22) indicate that natural regeneration of riparian vegetation can be so prolific as to make artificial revegetation unnecessary. If such prolific natural regeneration can be predicted, future use of riparian revegetation in areas where it is not needed may be avoided. Results indicate that prolific natural regeneration is highly probable when all of the following characteristics pertain to a particular riparian site:

None of the factors listed in the first check list are considered major problems:

1) Intensity and frequency of direct impacts are not sufficient to significantly impact the site;

2) The stream channel is not experiencing enhanced instability;

3) The water table does not drop below the root zone for extended periods of time.

In addition (Check-list #2),

4) Water availability and the timing of high flows allow natural regeneration to occur;

5) Natural seed sources are available.

4 - Water Availability

Successful germination and establishment of most riparian species is dependent not only on year round water availability, but also on the occurrence of flow events
sufficiently large to rework and deposit new alluvium during the time when riparian trees disseminate seed. Natural propagation of some riparian species can, therefore, be affected by alterations in natural river flow despite adequate year-round water availability.

Degradation of riparian vegetation along the Colorado River (Ohmart et al. 1977) and Verde River (Forbis and Pollock, pers. comm.) is attributed, in part, to the impact impoundment structures have had on natural flow regimes. Flow of the Verde River has been regulated by Bartlett Dam (completed in 1939) and Horseshoe Dam (completed in 1945) for over 40 years. High spring flows, captured in reservoirs, are now released over a much longer time period. Buffered spring flows may not have sufficient power to deposit reworked alluvium and seed in areas sufficiently removed from the base flow area. This can result in seedling establishment in areas vulnerable to scouring from even modest flooding.

The ability of newly established seedlings to grow to maturity following germination depends, in part, on the availability of water. Degradation of riparian vegetation prior to mitigation at Goose Flats, Babocomari River, and Horseshoe Lake, as well as loss of artificially-planted vegetation at Burro Creek and Box Bar, was mainly due to consistently low water availability during the growing season. Monitoring water availability for at least one year prior to initiating mitigation will allow agency personnel to better assess the likelihood that riparian vegetation will regenerate naturally.
5 - Natural Seed Sources

Seed sources of desired species need to be available before natural regeneration can occur. This overly simplistic statement becomes much more complex when "available" is defined. Does "available" mean that seed sources need to be on site, or can upstream seed sources provide viable seed for downstream sites? Results at Tubac (site #5), North Tubac (site #6), Francis (site #11), and Burro Creek (site #12), observations made by Forbis, Hall, and York (pers. comm.), as well as information from studies by Brady et al. (1985), Everitt (1968), Farmer and Bonner (1967), Fenner et al. (1984), Glinski (1977), McBride and Strahan (1984), Reichenbacher (1984), Strahan (1981), and White (1979) indicate that seed disseminated upstream can be deposited, germinate, and establish in downstream locations.

For land managers considering the potential for natural regeneration, the question becomes one of distance. At what point do seed sources become too far removed to supply seed? According to Scott (pers. comm.), this question is difficult because of the number of variables involved. Length of seed viability, amount of seed produced, rate of stream flow, and the timing of high flow events all probably influence where seeds are deposited and the distance seed can travel. In addition, Hardin’s (1984) study of seed characteristics of *P. deltoides* suggests that the age and density of trees in a given area may influence seed dissemination rates. His results indicate that younger trees seem to produce greater quantities of smaller, lighter seed than older trees. The seeds of older trees are, therefore, likely to be carried shorter distances by wind compared to seeds of
younger trees. This may negatively influence the ability of an older tree to establish seedlings in distant locations, especially if the tree is in an area removed from the main channel. Seed production of isolated trees may be reduced by pollen availability (Hardin 1984).

In this study, woody riparian seed sources were available near all sites that experienced prolific natural regeneration (Table 3). Results seem to indicate that upstream seed sources are capable of depositing viable seed in locations 1 to 2 km downstream. Following heavy flooding, scattered, mature woody riparian trees persisted in side canyons and along the main creek at Aravaipa, and up and downstream from Tubac and Nogales Wash. At Sheepshead Spring, the only viable upstream seed source was a very small group of cottonwood and willow trees growing near the spring just over 1 km from the site.

Prolific natural regeneration occurred following large flood events at Tubac (site #5), Nogales Wash (site #7), Sheepshead Spring (site #9), Aravaipa Creek (site #19), and Hassayampa River Preserve (site #22). Large floods seem to create conditions capable of producing prolific natural regeneration. This appears to be true even if the flooding does not occur during the time that most riparian trees disseminate seed.

The large floods during 1983, which removed substantial amounts of vegetation in Araviapa, Tubac, and North Tubac, occurred during the month of October and were, therefore, probably not responsible for depositing large amounts of riparian seed downstream. What the October flooding probably did do was produce seedbeds that
provided excellent conditions (reworked alluvium clear of competing vegetation) for the establishment and growth of riparian vegetation when riparian seed was deposited during spring flooding the following year. The results at sites included in the "prolific natural regeneration" group seem to indicate that it would be impractical to revegetate artificially in areas that have just experienced a large flood event (if natural seed sources are available). If possible, land managers should monitor a potential site for one or two seasons before revegetating. Such a monitoring period would allow land managers to better estimate the potential of natural regenerative processes.
CONCLUSIONS

Improvement of degraded riparian ecosystems by riparian revegetation has some limitations. Revegetation is most effectively used in riparian environments that are capable of supporting artificially-planted vegetation and, yet are not prone to prolific natural regeneration (Table 7).

Table 7. Defining the most efficient use of riparian revegetation.

<table>
<thead>
<tr>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site conditions not conducive for establishing vegetation artificially</td>
<td>Site conditions where riparian revegetation can be used most effectively</td>
<td>Site conditions describing a high probability that prolific natural regeneration of riparian vegetation will occur</td>
</tr>
<tr>
<td><strong>Geomorphology</strong></td>
<td><strong>Factors listed in Windows 1 &amp; 3 do not apply;</strong></td>
<td>*<strong>Causes of riparian degradation (factors in Window 1) are either overcome or not considered a problem.</strong></td>
</tr>
<tr>
<td><em>Stream channels show signs of enhanced instability;</em></td>
<td><strong>and Natural seed sources are not available; or The ability of natural seed sources to influence the site has been obstructed.</strong></td>
<td><strong>In addition:</strong></td>
</tr>
<tr>
<td><em>Uplands are degraded.</em></td>
<td></td>
<td><em><strong>Seed sources are present.</strong></em></td>
</tr>
<tr>
<td><strong>Water Availability</strong></td>
<td></td>
<td><em><strong>Flood events of sufficient strength to rework flood plain alluvium regularly occur.</strong></em></td>
</tr>
<tr>
<td><em>Water table frequently drops well below the root zone.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Direct Competition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Significant impacts from human, wildlife, livestock.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>High density of undesirable species of vegetation.</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Many degraded riparian ecosystems are too instable to support riparian vegetation (e.g., stream channel instability, intense livestock use, low water availability). In most cases these disturbances will hamper the establishment of artificially-planted vegetation to the same degree as they have natural regenerative processes. These disturbances need to be addressed before vegetation can be planted artificially.
Riparian revegetation has a greater chance of being successful when the causes of site degradation are identified and addressed. In the majority of successful projects, the causes of site degradation were addressed, either indirectly or directly, by using secondary mitigations such as bank stabilization structures, check dams, irrigation, and improved land management strategies in their overall project design. The ability of these secondary mitigations to overcome the causes of site degradation appeared to have a more significant impact on the overall results of the mitigation than revegetation.

Other degraded riparian ecosystems (represented as the area on the right side of Table 7) are capable of recovering without revegetation. Results at the Hassayampa River Preserve and Sheepshead Spring demonstrate the ability of natural regeneration to accomplish objectives once the causes of degradation have been addressed. Results at Aravaipa and Tubac, and Nogales Wash demonstrate the potential for prolific regeneration following large flood events. In all of these cases, artificial-revegetation had little to do with the successful results experienced.

The uniqueness of riparian environments requires that revegetation planners determine the appropriateness of using riparian revegetation on a site by site basis. Such a decision can be made by: 1) determining the potential that riparian vegetation can be artificially established (using check-list #1); and 2) determining the potential that natural regeneration of riparian species will occur (using check-list #2).

The more thoroughly factors incorporated in both check-lists are analyzed, the greater the potential that riparian revegetation will be used effectively. Such an analysis
will give the revegetation planner a good understanding of the riparian environment, which should allow a better match between the site environment and the physiological requirements of the vegetation being planted.

Thorough pre-planting site analysis takes time and costs money. To make such an investment, organizations considering riparian revegetation have to be convinced that the expenditure will pay off in the long term. The incentive may primarily depend upon project objectives and the cost of planting vegetation. Projects that require the survival of only a small percentage of planted vegetation to achieve objects and are able to acquire large quantities of propagules for little cost (like the revegetation projects along the Verde River), may opt to plant large quantities of vegetation with little pre-planting monitoring, with the hope that at least a few will survive.

Such a strategy, however, is probably inviting disaster. Several respondents (Hall, Bammon, Forbis, pers. comm.) noted that the potential of revegetation success for a given site can be better determined if sites are monitored one year prior to initiating mitigation. Waiting one year may allow agency personnel to realize some of the following benefits:

1) Agency personnel could better predict the potential of prolific natural regeneration. Inspecting Aravaipa Canyon one year following the 1983 flood probably would have revealed signs that prolific natural regeneration was occurring, possibly preventing the initiation of such a large scale riparian revegetation effort.
2) Monitoring ground water fluctuations for at least one year would allow agency personnel to better determine the likelihood that planted vegetation would survive. Of the factors considered in check-list #1, the most important for determining the likelihood that artificially-planted vegetation will survive is water availability at the root zone level. Artificially-planted obligate riparian vegetation will not survive if developing root systems are not able to reach the water table. This means that poles should be planted to the water table and the root systems of seedlings have to be irrigated until they reach ground water. A knowledge of the depth of the water table and its fluctuations during the growing season helps in predicting the effectiveness of riparian revegetation and the potential that natural regeneration will occur, as well as, planning irrigation schedules.

Monitoring ground water does not require the installation of expensive wells or equipment. A perforated PVC pipe that is buried and spot checked several times during the course of the growing season can provide considerable information concerning water table depth and water table fluctuation.

3) Channel measurements can be taken over the course of a year to gain a better understanding of channel stability. This includes taking note of deposition and vegetation changes that may indicate lack of, or a return to, stability.

Despite the limitations mentioned above, results indicate that riparian revegetation could be effective in 3 specific situations:

1) Establishing riparian species in degraded riparian areas isolated from natural seed sources. In this study, Clay Mines Spring is probably the best example. Bammon (pers.
comm.) noted that although small and isolated, these types of sites can provide valuable habitat for many wildlife species. Their remote location makes natural regeneration highly improbable, making revegetation an ideal solution if the causes of degradation can be adequately addressed.

2) Establishing riparian vegetation along rivers whose flows have been altered by impoundment structures. Although impounded rivers may reduce the ability of riparian vegetation to reproduce naturally, they may provide a suitable environment for establishment and growth of artificially-planted vegetation. Buffered flows downstream from impounded structures may offer a more consistent year-round water supply with reduced numbers of scouring floods.

3) Plantings along the Gila River indicate that cottonwoods and willows can be successfully established in areas choked by saltcedar. Revegetating after clearing saltcedar may not only provide a means of reintroducing native, obligate riparian species, but also a means of fighting saltcedar (some studies have indicated that saltcedar is shade intolerant).

In many instances, riparian vegetation may have been planted in areas where water availability is reduced to such an extent that the area may no longer be riparian. In such situations, revegetation projects should consider using non-obligate riparian species. Using such species would greatly expand the areas suitable for planting.
SUMMARY OF SELECTED RIPARIAN SITES

The following list summarizes the 27 riparian sites included in this study. The sites were selected during the mail and telephone questionnaires. Two sites were not visited (Gleason Flats and Horseshoe Lake) due to time constraints and their remote locations. Nevertheless, they were included in this study because the information gained from respondents, literature, and maps was considered adequate for understanding mitigation results and the site environment.

Riparian revegetation work was performed in all but two sites (Sheepshead Spring and Hassayampa River Preserve). These sites were included because they demonstrated that riparian vegetation can come back from degraded condition without using artificial plantings.

All sites are summarized by the following sub-headings: name of site, site location, name of respondent, date of mitigation initiation, objective of mitigation, species of vegetation used during the revegetation process, size of the site, prior uses of the site area, methodology used, results of mitigation, and additional comments made by the respondent that were considered important in understanding the results. A rough idea of the locations of each site is given in Figure 3.
Figure 3. Map of Arizona showing locations of the 27 selected riparian sites.
Site #1 - Saw Mill Spring

Location: Hutch Mountain, 56 kilometers SE of Flagstaff, Coconino National Forest

Respondent: Greg Goodwin, USFS, Coconino National Forest

Date: Project began in 1985.

Objective: Reestablish woody riparian communities and improve habitat for bird and fish species.

Species Used: Salix bebbiana (Bebb Willow) and Alnus tenuifolia (Thin Leaf Alder).

Size of Revegetation Site: 1.6 km of stream reach.

History: Overgrazing by cattle and elk (Cerus elaphus) was deemed predominantly responsible for producing accelerated streambank erosion and impairing regeneration of woody riparian species. Preservation of woody riparian species is considered especially important for bird and fish habitat (especially for the survival of the Little Colorado River Spinedace (Lepidemeda vittata)).

Major riparian tree species include: remnant Salix bebbiana, Salix scouleriana, with scattered Potentilla fruiticosa and Alnus tenuifolia, with understory consisting predominantly of Bromus spp., Poa pratensis, and Carex spp. Major surrounding tree species include: Quercus gambelii and Pinus ponderosa.

Methodology: Prior to mitigation, a deferred rotation grazing system was implemented. This area is now grazed by 1045 head of cattle for two months every other summer.
Twenty-five *Alnus tenuifolia* (thin-leaf alders) and 100 *Salix bebbiana* (bebb willow) were planted in and immediately adjacent to the stream channel. Cuttings were harvested during the early spring (just prior to the break in dormancy). The majority of cuttings were from 1 to 3 year-old stems of willow and alder species located in nearby drainages. Prior to planting, willow cuttings were rooted in aerated buckets containing the root stimulator indolebutyric acid (IBA) and alders were rooted in 3.9-l (1-gallon) containers. Holes were dug manually to a depth of at least 25 cm. Logging slash was placed around the plantings. Slash is considered important in stabilizing willows which had poorly developed roots at the time of planting.

**Results:** None of the planted vegetation survived to the time of site evaluation 5 years later. Alders did not survive through the first year.

**Additional Comments:** Many of the plantings were pulled out of the ground by campers. Reasons for the establishment failure of the others were not readily apparent. Flooding was not seen as a major factor due to the high elevation of the Saw Mill Spring Site which precludes it from flooding intensities characteristic of many of the lower elevation sites.

According to the respondent, survival may have been reduced by elk and livestock use. Although survival of plantings was poor, respondent still considered alder, which is not
palatable to livestock or elk, a good nursery species for willow (or other palatable species).

Site #2 - Coleman Lake

Location: 11 km south of Williams, AZ, on the Kaibab National Forest.

Respondent: Vern Zarlingo, Kaibab National Forest, U.S.F.S.

Date: Mitigation began in 1976 and was completed in 1981.

Objective: General habitat improvement, especially for waterfowl and elk.

Species Used: Agropyron spp. (tall wheatgrass, intermediate wheatgrass, pubescent wheatgrass), Bromus inermis (smooth brome), Dactylis glomerata (orchard grass), and Phleum spp. (timothy) Salix sp.

Size of Revegetation Site: 28-ha of wet meadow surrounded by 24-ha of mountain grassland. The watershed surrounding the lake is 93-ha.

History: Coleman Lake is the only natural year-round water source in the area. Over 1,000 head of cattle grazed this site from May 15 to November each year, causing considerable damage to riparian vegetation. Forage utilization was over 80% and even plants such as Typha spp. were grazed heavily. At the time of planting, site vegetation consisted predominantly of annual grasses. The lake was reduced to a series of shallow mud puddles and soil erosion was greatly accelerated.
Methodology: Water sources for livestock were developed off-site and in 1976 livestock were excluded from the site completely (total number of livestock in the area was reduced to 330 head) when a livestock exclusion fence over 4 km long was installed around the perimeter of the site. Today, Coleman Lake is grazed by mule deer (Odocoileus hemionus) and elk (Cervus elaphus), and by cattle only by permission from the U.S.F.S (usually alternate years only during October). Over half of the exclusion fence is outside the meadow, enveloping a portion of an aspen stand.

Cool-season grasses were drilled on the uplands and broadcast on the wetter lowlands (roughly 13.4 kg/ha). Dynamite charges and heavy tractors were used to create 13 raised mounds in the center of the lake that are surrounded by pools of water over 1 m deep. Reed canarygrass, millet, and root sections of Typha spp. and Scirpus spp. were planted in areas of high water availability.

Results: A waterfowl nesting survey completed in 1980 found a dramatic increase in nesting activity at Coleman Lake.

Diversity and quantity of perennial grass and forb species increased on the upper and lower parts of the site. Species that have come back dramatically include: Phragmites communis (reedgrass), Scirpus spp., Eleocharis spp., Equisetum spp., Iris spp., and Polygonum spp.; Potamogeton spp. and Ranunculus spp. cover large portions of the water surface and Typha spp. has established in large numbers in areas of high
moisture availability. *Populus tremuloides* seedlings has established in large numbers in the northern part of the site enclosed by the fence.

**Additional Comments:** According to Vern Zarlingo, the key to the success of this project was removing the livestock. This was especially important during the first couple of years following the completion of the project when newly-established vegetation was most vulnerable to grazing. Development of off-site water sources was a major factor in gaining permittee cooperation.

High year-round water availability contributed greatly to the site’s resilience. Much of the regeneration was deemed to be the result of natural processes, not artificial (this was especially true where water availability was very high).

**Site #3 - Canyon Creek**

**Location:** 26 km NE of Young, Tonto National Forest, Pleasant Valley Ranger District.

**Respondent:** Gary Bell, Buck McKinney, U.S.F.S.

**Date:** September, 1987 (took two days to complete).

**Objective:** Improve habitat for fisheries

**Species Used:** *Populus angustifolia*, *Salix* spp., and *Bouteloua gracilis*.

**Size of Revegetation Site:** 4 ha along 3.2 km of stream reach.

**History:** Prior to mitigation, Canyon Creek was grazed year-round by 150 head of cattle and accommodated about 10 beaver per km. The combination of these two factors
was considered primarily responsible for reducing the quantity and diversity of riparian vegetation and accelerating streambank and channel erosion. Shallow, muddy pools and incised banks were common. The overstory consisted of scattered old-age *Populus angustifolia* and *Salix* spp., and the understory consisted mostly of *Poa fendleriana* and *Bouteloua gracilis*.

Degradation of the riparian and aquatic environment and continued sport-fishing use (Canyon Creek is one of the most heavily fished streams in Arizona) severely reduced the fish population. By the early 1980’s, surveys recorded large reductions in the populations of all major game fish. Concern over the plight of Canyon Creek sparked the involvement of Trout Unlimited, which in turn helped to focus U.S. Forest Service attention on improving the overall condition of Canyon Creek.

**Methodology:** In 1979, the grazing schedule was reduced to allow 150 yearlings to graze in June through October. Livestock were excluded completely in the fall of 1985 by a perimeter fence.

In September 1987, volunteer and Forest Service personnel planted vegetation and used heavy equipment to place large tree trunks and boulders in the channel and along banks to stabilize banks, create pools, increase cover, and divert narrow channels. One hundred and fifty *Populus angustifolia* poles (2.5 m long) and 600 *Salix* sp. whips (30 cm to 35 cm long) were planted within the enclosure. Cottonwoods were planted on the active flood plain between 2 and 5 m from the main channel and wrapped with
chicken wire to protect them from beaver damage; willows were planted predominantly along the stream banks. Holes were dug to water using rebars. Blue gramma (*Bouteloua gracilis*) was used to provide quick ground cover in areas considered vulnerable to erosion.

Willows were used because they offer good stream bank protection, cottonwoods were used to provide overstory shading.

**Results:** Five percent overall survival of planted woody species. Blue gramma has established in isolated stands. Extensive natural regeneration of watercress has occurred. A survey of the fish population following completion of mitigation revealed a 325% increase in brown trout.

**Additional Comments:** According to the respondents, removing livestock from the area was significant in promoting stream bank rebuilding processes and initiating regeneration of understory vegetation. Gary Bell views the regeneration of watercress as the first essential step in stream bank rebuilding. Reasons for the high mortality rate of the planted woody vegetation are not known. No obvious damage from beaver was observed.
Site #4 - Gentry Creek

Location: T9N R15E, sections 16 and 21, of the Gila Salt River Meridian, Tonto National Forest, Pleasant Valley Ranger District. Gentry Creek drains into Cherry Creek

Respondent: Buck McKinney and Anthony Miller, U.S.F.S.

Date: The project was completed in two phases. The first phase began in August of 1989, the second phase in December of 1989.

Objective: Increase density of riparian vegetation and reduce stream water velocity to protect stream banks.

Species Used: Salix sp.

Size of Revegetation Site: 24 ha

History: Year-round livestock grazing was deemed primarily responsible for reducing the density and diversity of riparian vegetation along the creek channel. Prior to mitigation, riparian vegetation in Gentry Creek was reduced to mature, low density willow overstory with little regeneration of broadleaf trees or herbaceous understory. According to Buck McKinney, the narrow topography of the canyon makes this site exceedingly vulnerable to overgrazing and mass erosion events. The primary motivation for using artificial planting was to prevent such mass erosion events from occurring.

Methodology: Livestock exclusion fence was constructed around the perimeter of the site and stop-gaps were constructed where the fence intersected the stream. Salix sp. whips were cut during September, placed in cold storage, and planted three months later, during December 1989. A volunteer group from Phoenix used hand tools to dig holes
for over 2000 willow cuttings. The cuttings were planted in a variety of ways; some vertically, others horizontally, still others in trenches. Most were planted within 1 m of the stream channel.

**Results:** About 5% of the planted vegetation survived to the time of the site visitation. Over half of the whips were no longer on site, probably washed away by subsequent high flows. Most of the whips that remain showed little or no sign of root growth. Natural regeneration of smooth brome, deer grass, Kentucky blue grass, clover, and western wheat grass provides evidence that the flood plain is rebuilding.

**Additional Comments:** An exceedingly dry year immediately following completion of mitigation work may be responsible for the high mortality rate of planted vegetation.

Post-mitigation maintenance of fence, especially water gaps, is very important to the continued reclamation of this site.

**Site #5 - Tubac**

**Location:** Due east of Tubac, Arizona, immediately adjacent to the Tubac Elementary School along the west side of the Santa Cruz River.

**Respondent:** John York, Soil Conservation Service.

**Date of Mitigation:** 1983

**Objective:** Stabilize stream banks.
Species Used: Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*).

Size of Revegetation Site: 267-m reach of the Santa Cruz River.

History: High flows during October of 1983 removed considerable riparian vegetation and cut deeply into already incised stream banks on both sides of the Santa Cruz River channel. The widening of Santa Cruz channel threatened the Tubac Elementary School.

Immediately prior to mitigation, the channel was almost devoid of vegetation. Scattered old growth *Populus fremontii* and *Salix gooddingii* survived flooding both up- and downstream from the mitigated reach. Mesquite bosque (*Prosopis juliflora*) dominates the abandoned terraces.

Methodology: Five hundred *Populus fremontii* and 50 *Salix gooddingii* poles were planted in front of and among stabilization jacks that were installed along 270 m of the west bank of the Santa Cruz River. All poles were harvested from old cottonwood and willow growth just south of Tubac. Prior to planting, holes were dug to the water table with motorized augers, the butt of each pole was chopped up to increased water absorption and then placed in water treated with rootone F (a rooting hormone). Most poles were planted the day they were cut, and the tops of the poles were painted with an oil base paint to prevent excessive transpiration. Poles were 10 to 15 cm in diameter and 2.5 m long.
Stabilization jacks were initially installed without revegetating, but later, after the jacks had washed away, cottonwood and willow poles were used in conjunction with the replacement jacks.

**Results:** Soil deposition along the toe of banks (1.5 m in some places) and prolific regeneration of riparian vegetation indicate increased channel stability. Densities of over 250 trees (4.5 meters or more tall, basal diameters between 10 and 15 cm) per 30 m of channel reach are common (roughly two cottonwoods for every willow). Major midstory species include *Baccharis glutinosa*, *Rhus glabra*, and many 1- to 2-year old *Salix gooddingii* and *Populus fremontii* seedlings. Dominant understory species include *Elymus canadensis*, *Carex* spp., *Phragmites communis*, and *Bidens* spp.

Similar densities and patterns of trees, as well as channel characteristics up- and downstream indicate that channel widening processes have slowed all along this portion of the Santa Cruz River, and not just along the mitigated reach (the same appears to be true for North Tubac and Nogales Wash). This seems to indicate that natural regeneration, and not artificial revegetation, is responsible for most woody riparian vegetation regeneration on these sites.

**Additional Comments:** According to John York, the keys to establishing riparian revegetation artificially are choosing a site that has high water availability, planting poles
before dormancy is broken, and stabilizing the site as part of the overall plan that takes into consideration the entire watershed.

Planting woody riparian vegetation in conjunction with bank stabilization devices is a technique often employed by the SCS. Jacks help to stabilize stream banks by promoting soil deposition and also protect newly planted vegetation from high flows. After a few years, established root systems strengthen banks and above ground growth helps to anchor the jacks. The entire system becomes stronger as more soil is deposited during subsequent high flows.

Site #6 - North Tubac

Location: 5 km north of Tubac, along the western side of Santa Cruz River.

Respondent: Don Welsh, Soil Conservation Service.

Date: The project began in 1984 and was completed in one week.

Objective: Stabilize river banks.

Species Used: Salix gooddingii (Goodding Willow).

Size of Revegetation Site: 355-m reach of the Santa Cruz River.

History: High flows during October 1983 removed large quantities of riparian vegetation and aggravated already incised river banks along the western side of the channel. Private property on the western side of the channel was considered vulnerable to subsequent flooding unless the stream banks could be stabilized. Incised river banks
range from 1.5 to 3 m high, delineating the boundary between the active riparian channel and the abandoned flood plain.

The channel was almost devoid of vegetation at the time of mitigation. Scattered old growth *Populus fremontii* and *Salix gooddingii* survived flooding both up and downstream from the mitigated reach. Mesquite trees dominate the abandoned terraces.

**Methodology:** Almost 400 *Salix gooddingii* poles were planted among stabilization jacks along a 355-m reach of the west bank of the Santa Cruz River. The poles were 1.5 to 2.0 m long, with a basal diameter of 10 cm. Holes were dug to the water table using motorized hand augers. Erosion control jacks were installed in 1983, but failed the same year. The following year jacks were installed in conjunction with willow poles.

Willow poles were harvested from an old willow stand just south of Tubac. Poles were soaked in water treated with IBA for several hours before they were planted.

*Arundo donax*, a reed species that is native to Asia, was also planted along the toe of the river bank and among the stabilization jacks. According to Don Welsh, Arundos are beneficial because they rapidly provide erosion protection as well as good habitat for wildlife.

**Results:** Prolific natural and artificial growth of riparian species, and alluvial deposition (approaching 1 m in some areas) along the toe of incised stream banks are signs of increased channel stability. Densities of 30 trees (4.5 m or more tall, with 7.5 to 15 cm
basal diameters) per 30 m of channel reach are common. The overstory is composed of \textit{Salix gooddingii} and \textit{Populus fremontii} in roughly a 2:1 ratio. Major understory species include \textit{Polypogon} spp. and \textit{Elymus canadensis}. An intermediate canopy layer is emerging, consisting mostly of \textit{Arundo donax}, and 1- to 2-year old cottonwood and willow seedlings. Natural regeneration was not as prolific as at Tubac and results of artificial planting can be discerned easily from natural growth.

Poles planted immediately adjacent to the banks have greater mortality rates than those planted in front of the jacks, closer to the active channel. This is probably due to relatively large differences in water availability between these two locations. Distance to water table just prior to the onset of monsoons (at the end of June) was over 1.5 m immediately adjacent to the incised banks and just over 0.5 m immediately adjacent to the active channel.

\textbf{Additional Comments:} The channel reach is grazed by horses. Their impact seems light in the face of such strong vegetation recovery. The intensity of use is not known.

\textbf{Site #7 - Nogales Wash}

\textbf{Location:} Adjacent to Firestone Gardens Road and Frontier Road, Nogales, 2 km south of Old Ruby Road, along the Nogales Wash.

\textbf{Respondent:} Don Welsh, Soil Conservation Service

\textbf{Date of Planting:} 1984
Objective: Stabilize stream banks

Species Used: *Salix gooddingii*

Size of Revegetation Site: 200-m reach of Nogales Wash.

History: Flooding during October of 1983 destroyed large amounts of riparian vegetation and greatly aggravated already incised banks to the point where loss of private property seemed inevitable.

Methodology: Side branches were cut from *Salix gooddingii* trees that had been washed downstream by the flood. Most of the side branches had taken root and measured over 0.5 m in length and 2.5 to 4.0 cm in diameter. As with the Tubac and North Tubac sites, plantings were soaked in water treated with IBA and planted among stabilization jacks.

Results: Prolific regeneration of vegetation and alluvial deposition approaching 2 m in some areas indicate the return of enhanced channel stability. Densities of over 60 trees (4.5-m or more tall, with 12.5 to 18 cm basal diameters) per 10 m of mitigated reach are common. Overstory is predominantly *Populus fremontii* and *Salix gooddingii*, in roughly a 1:1 ratio. Mid-story species include *Rhus glabra*, *Baccharis glutinosa*, and *Fraxinus cuspidata*, as well as 1.5-m high willow and cottonwood seedlings. Major understory species included *Hordium leporinum*, *Elymus canadensis*, and *Phragmites communis*. 
The pattern and density of woody vegetation on site seem to indicate that natural regeneration was responsible for the prolific regrowth of vegetation.

**Additional Comments:** Effluent contributions from the City of Nogales into Nogales Wash is probably significant enough to increase water availability. High water availability throughout the year may have had a role in producing such prolific regeneration and densities of riparian vegetation.

**Site #8- Babocomari River**

**Location:** Huachuca City, adjacent to the Huachuca City sewage treatment pond.

**Date of Planting:** Project began during the summer of 1989 and was competed during May 1990.

**Respondent:** Don Welsh, Soil Conservation Service

**Objective:** Stabilize banks of the Babocomari River near the Huachuca City sewage pond.

**Species Used:** *Salix gooddingii* (Goodding Willow).

**History:** The banks of the Babocomari River near the Huachuca City sewage pond have experienced severe erosion during the past several years and are heavily incised (2.5 to 3.0 m vertically separate the main channel from the abandoned flood plain). Continued channel widening at this location may jeopardize the integrity of the pond. Currently, the sewage pond lies only 50 m away from the Babocomari River channel.
Methodology: A rail and wire fence was installed in the channel during the summer of 1989, parallel to the section of stream bank that has experienced the worse erosion. The fence was constructed with steel poles 10 cm in diameter placed in concrete lined holes 2.5 m apart. Poles are connected with a chain-link fence, much like the fences installed around tennis courts and school playgrounds.

One hundred and eighty 2.5 m long (10- to 15-cm diameter) dormant willow poles were planted 1.5 m apart in holes 1.5 m deep, parallel to the fence, between the fence and the eroded banks of the river. The holes were dug using motorized augers, and after planting the tops of the poles were painted with an oil base paint to prevent sunburn and transpiration loss.

A drip irrigation system was installed following planting. The irrigation system consists of black PVC pipe connected to a series of 180 drip emitters, one for each willow pole. A water truck that comes once a day injects water into the irrigation pipes. Irrigation was considered necessary because the butts of the willow poles could not be placed to the level of the water table, which commonly drops to 3 m below the soil surface (well below the 1.5-m depth that the willow poles were planted). It is hoped that the irrigation will supply the water needs of the willow poles until roots can develop to the water table.

Results: It is too soon to judge how well this project will realize its objectives. Inefficiency in the irrigation system has already caused problems. The irrigation system
was not set up for several weeks following planting. As a result, some of the willow poles have dried out (68 out of the 180 poles need to be replaced). According to Don Welsh, even an efficient irrigation system may not be able to provide sufficient water to allow tree root development to such low water table levels.

The chain-link fence has already trapped debris from high flows, which may lead to increased rates of alluvial deposition.

Site #9 - Sheepshead Spring

Location: 9 km NW of Cornville, Coconino National Forest. Sheepshead stream is a tributary of Oak Creek.

Respondent: Greg Goodwin, Coconino National Forest

Date: 1981

Objective: Improve ecological condition of the riparian ecosystem.

Species Used: No plantings done.

Size of Revegetation Site: 1-km reach of stream.

History: Sheepshead Spring is perennial, but much of its flow is diverted during the summer months to irrigate nearby farmland. Prior to mitigation, the riparian area and much of the surrounding uplands were degraded by years of livestock overgrazing. The relatively unarmored, alluvial bottom makes the stream channel especially susceptible to damage from grazing. At the time of mitigation, riparian vegetation consisted of annual grasses, *Pluchea sericea*, *Eleocharis* spp., scattered old growth *Populus fremontii* and old
growth *Salix gooddingii* closer to the spring source. The channel bed had eroded to bedrock.

**Methodology:** Agency personnel decided that the site's high water availability and remnant woody riparian vegetation made artificial revegetation unnecessary. A 4-strand barbed wire fence was constructed around the site's perimeter to exclude livestock. Two check dams were constructed across the width of the channel to promote alluvial deposition. In addition, progressive livestock management schemes on the uplands have changed livestock grazing patterns from year-round to 20 days per year.

**Results:** Area behind the check dams filled with sediment 1 year following completion. Vegetation regeneration on this newly deposited alluvium has been prolific. *Populus fremontii* and *Salix gooddingii* seedlings have established (over 2.5 m tall) in a dense, well developed understory. Major understory species include *Typha* spp., *Setaria* spp., *Poa pratensis*, and *Cynodon dactylon*.

**Additional Comments:** According to the respondent, the key to success was working closely with the permittee to develop grazing patterns that would lead to ecological improvement of the uplands.
Site #10 - Gleason Flat

**Location:** On the Salt River, 60 km up-stream from Roosevelt, Tonto National Forest.

**Respondent:** Larry Forbis, USFS, Tonto National Forest

**Date:** Project initiated December of 1979 and completed in February of 1980

**Objective:** Develop seed source to ensure reproduction of future generations of cottonwoods and establish Bald Eagle nesting sites.

**Species Used:** *Populus fremontii* (Fremont Cottonwood)

**Size of Revegetation Site:** 40-ha

**History:** The impetus for this riparian revegetation project came from a lawsuit filed against the United States Forest Service by the Audubon Society. The suit charged the USFS with a technical violation of the Endangered Species Act, holding the USFS responsible for the deterioration of Bald Eagle nesting habitats (focusing primarily on the deterioration of cottonwood stands) in parts of central Arizona.

Prior to mitigation, the Gleason Flat site was grazed twice a year - late fall (before the winter rains) and then all summer long. According to Larry Forbis, this grazing schedule "hammered" the site, reducing natural regeneration of riparian species.

In addition, this reach of the Salt River channel shows obvious signs of instability (the channel has incised into banks leaving abandoned terraces along some reaches over 2.5 m above the active flood plain). Obligate riparian vegetation has suffered tremendously.

Abandoned flood plains are now inhabited primarily by *Prosopis juliflora* and the active flood plain by *Pluchea sericea* and *Baccharis glutinosa*.
Methodology: Six hundred 5-year old, dormant *Populus fremontii* trees were cut from the Gila River to make poles 10 to 15 cm in diameter and over 2.5 m long. The poles were kept wet during transport and upon reaching the Gleason site the butts were broken and placed into holes dug with a backhoe. Density of plantings was roughly 4 to 5 poles per ha. Poles were planted in the channel and on the abandoned flood plain. Chicken wire was wrapped around many of the cottonwood poles to protect against beaver. A form of rest rotation has been invoked to take as much grazing pressure off the Salt River as possible. This area is now getting spring and summer rest 3 out of 5 years and winter rest 3 out of 5 years.

Results: Only three of the 600 (0.5%) plantings survive today. These trees are about 15.5 m high with 25 cm in diameter.

Surviving vegetation is located immediately downstream from a large boulder that offers protection from abrasive high flows. Plantings that survived were prone to damage from beaver. The incised channel provided two dubious alternatives for planting vegetation: 1) On abandoned terraces were water availability was consistently low, and 2) in the active channel where vegetation was vulnerable to scouring floods (made more frequent and powerful when waters are confined to the relatively deep and narrow dimensions of the incised channel) and large fluctuations in the level of the water table.
Additional Comments: A backhoe may be required in situations where the terrain is rugged and the holes have to be dug deep. The chicken wire mesh proved a formidable obstacle to beaver. According to Larry Forbis, March, April, and May are the months when riparian ecosystems are most susceptible to damage by grazing.

Site #11 - Francis Creek

Location: Near Bagdad, AZ. Francis Creek is a tributary to Burro Creek.


Date: March 1981

Objective: General ecological improvement and communicating with local ranchers the need for implementing well-balanced grazing strategies.

Species Used: Populus fremontii

History: The cumulative effects of years of uncontrolled year-round grazing, combined with severe flood events that occurred during the winters of 1977-78, 1978-79, and 1979-80, destroyed a large amount of riparian vegetation and scoured the stream channel to bedrock in some areas. Streambank erosion rates were accelerated and the potential for further flood damage was considered very high.

Prior to mitigation, major woody, obligate-riparian species included scattered, old-growth Populus fremontii, Salix gooddingii, and Platanus wrightii. Although species diversity was quite high, regeneration was almost completely absent.
Methodology: Two hundred and fifty *Populus fremontii* poles, harvested from the Hassayampa River, were planted to the water table by volunteers, BLM personnel, and local ranchers. Holes were dug manually with shovels and crow-bars. Poles were cut as close to ground level as possible and kept wet until time of planting. Immediately before planting, 25 cm was cut off the base of each pole and most poles were wrapped with chicken wire immediately following planting.

The grazing schedule implemented in 1981 for Upper Burro Creek uses seven pastures (five in the riparian area). Each pasture is rested spring through summer on 2 out of 4 years and there is flexibility built into the system which allows the permittee to use optional pastures and periods of use.

Results: Forty percent of the planted vegetation has survived to the time of the site visit. Trees are over 9 m tall. Natural regeneration has also been prolific, outnumbering artificially-planted trees at least 2:1. Currently, naturally established trees stand 1.5 to 3.0 m below the artificially-planted trees. The majority of poles that survived were planted very near the channel and were caged.

Pole survival seemed to be low when beaver and cattle activity occurred in the same area. Bob Hall noted that some of the poles were attacked by ants. The effect of the ants on pole mortality is not known, and dusting with insecticide produced mixed results.
Additional Comments: According to the respondent, improvements could not have occurred without the cooperation of local ranchers and dedication on the part of BLM administration. The high quality of volunteers had a great deal to do with the success of the plantings.

Site #12 - Burro Creek

Location: 90 km SE of Kingman, AZ. Just north of Bagdad, AZ.


Date: Project was started in 1981 and completed in 1985.

Objective: General ecological improvement and communicating with local ranchers the need for implementing well-balanced grazing strategies.

Species Used: Populus fremontii (Fremont Cottonwood), Salix gooddingii (Goodding Willow), and Platanus wrightii (Arizona sycamore).

History: Upper Burro Creek was subjected to random year-round grazing prior to mitigation. Grazing combined with severe flood events that occurred during the winters of 1977-78, 1978-79, and 1979-80, destroyed a large amount of riparian vegetation. Although diversity of riparian vegetation was high (Table 3), natural regeneration was greatly reduced. Little soil-building was taking place and potential for catastrophic flood damage was considered quite high. Many parts of the channel were scoured to bedrock.
Methodology: Seventy-five *Platanus wrightii*, *Salix gooddingii*, and *Populus fremontii* seedlings were planted inside a 3-ha enclosure (called the plantation). Seedlings were harvested from the Hassayampa River near Wickenburg. Seedlings were irrigated 2 to 3 times per week, 6 hours per session. The irrigation system was powered by a 3-hp pump during the first three summers; during the forth and fifth summers, after pump maintenance became overwhelming, water was gravity fed into the system from pressure releases from the Bagdad water pipeline.

The grazing system that was implemented affects both Francis and Burro Creek, and is described in the Francis Creek methodology.

Results: None of the plantings survived past the fifth year. According to Bob Hall, there are three major reasons for lack of survival: 1) severe flooding one year after project completion caused considerable damage to the plantation; 2) many of the seedlings were grazed and trampled when the fence enclosure was breached by cattle on at least one occasion; 3) drying winds and a relatively low water table made seedlings vulnerable to desiccation, especially during periods when the irrigation system broke down (level of the water table in the plantation area commonly drops between 240 and 300 cm below the soil surface during the dry season). Natural regeneration of obligate riparian vegetation since 1981 has dramatically increased overstory canopy cover and biomass. Stream banks have stabilized and soil buildup from 1.0 to 1.5 m is common. Water availability has also increased - portions of Burro Creek that were ephemeral are
now perennial. Natural regeneration of understory vegetation, especially *Melilotus* spp., is also seen as a sign of increased stability.

**Additional Comments:** Most of the success is attributed to the improved grazing schedule, which has protected seed sources and decreased the potential for catastrophic flood occurrences. This has allowed natural stream dynamics to rejuvenate the stream system.

The respondent emphasized the need to pay considerable attention to logistics. This is especially true when an irrigation system is used, requiring additional personnel for maintenance. As with Francis Creek, long-term success largely depends on working with local ranchers.

**Site #13 - Box Bar**

**Location:** 5 km south of Bartlett Reservoir, along the Verde River.

**Respondent:** Larry Forbis, Tonto National Forest, USFS.

**Date:** 1979

**Objective:** General ecological improvement and investigating riparian revegetation feasibility.

**Species Used:** *Populus fremontii* (Fremont Cottonwood) and *Salix gooddingii* (Goodding Willow).

**Size of Revegetation Site:** 10 ha
History: Regeneration of obligate, woody riparian vegetation along portions of the Verde River has declined in recent years. Impact of Horseshoe and Bartlett Dams on the natural flow regime of the Verde River has been blamed for much of this degradation.

The Box Bar site is composed of two distinct areas: an upper flood plain and a lower secondary channel. The upper flood plain, which lies between the main Verde River channel and the lower secondary channel, is 1.5 to 2.0 m higher than the secondary channel. The water table in the secondary channel stays within 1 m of the surface for most of the year, while on the flood plain the water table drops over 2 m beneath the soil surface.

Prior to mitigation, on-site vegetation was predominantly *Prosopis juliflora* and *Coleogyne ramosissma*. Scattered old growth *Populus fremontii* and *Salix gooddingii* are present both up and downstream from the Box Bar site. The Box Bar site was planted initially by Ohmart (Center for Environmental Studies, Northern Arizona University), then turned over to the USFS in 1979.

Methodology: Six hundred *Populus fremontii* and *Salix gooddingii* were planted as poles, cuttings, containerized seedlings, and rooted cuttings. Over 95% of the vegetation was planted on the upper flood plain. Poles were 1.5 to 2.0 m long, 6 to 10 cm in diameter, and were planted to the water table with a hydraulic auger. Forty-five centimeter long cottonwood cuttings were harvested from nearby trees, rooted in a nursery, and placed in holes 30 cm deep. Willows and cottonwood seedlings (leftovers
from a past revegetation project) were also planted. All holes were dug with shovels. Rooting hormones (rootone-F and IBA) and coated water-soluble, slow-release fertilizer were also used.

A culvert (about 1 m in diameter) was installed in the secondary channel to provide water for the irrigation system. All plants were irrigated 7 days a week, 2 to 4 hours per day (2 gallons of water per hour) for the first three summers.

A three-strand wire fence was constructed around the site to control livestock. During the past several years a rest rotation schedule has been implemented; the site is rested 3 out of 5 summers and 3 out of 5 winters.

Results: Two percent of the planted vegetation survived to the time of the site visit. All survivors, except for two stunted (just over 2 m tall) cottonwood trees, were located in the secondary channel. All survivors are cottonwoods, those in the secondary channel are over 7 m tall.

Additional Comments: The irrigation system was not able to promote root growth to the water table. The relatively high water availability in the secondary channel is undoubtedly significant in promoting the establishment of vegetation there.

During 1979, Bartlett Dam was closed for repairs. Water releases during this time were substantially reduced, and as a result, many plants were left high and dry. This may have not only influenced the results of the artificial planting effort, but also
contributed to the demise of large old-growth cottonwood stands upstream from the Box Bar site.

Surface materials largely determine the kind of propagule that can be used and the equipment needed to plant the vegetation. A surface of cobbles may preclude using cuttings or seedlings, necessitating the use of poles that can be pounded through surface debris. Heavy equipment may also be required.

Site #14 - Horseshoe Lake

Location: North end of Horseshoe Lake.


Date: Project began during October of 1981 and was completed during December of 1981.

Objective: Provide nesting habitat for Bald Eagles.

Species Used: Populus fremontii (Fremont Cottonwood)

Size of Revegetation Site: 160 ha

History: As with the Gleason Flat project, the impetus for this riparian revegetation project came from the lawsuit filed by the Audubon Society versus the USFS concerning loss of Bald Eagle nesting sites. In response to the lawsuit, the Forest Service developed the "Blue Book Plan," which proposed the development of Bald Eagle nest sites along the Verde and Salt Rivers. This site was grazed prior to the start of the project, but the frequency of grazing and concentration of cattle in the area are unknown. Before the
onset of this project, there were pockets of old *Salix gooddingii*, surrounded by *Tamarix chinensis*, and *Prosopis* spp.

**Methodology:** Over 1000 *Populus fremontii* seedlings and 202 *Populus fremontii* poles were planted at the lake site. Hand augers were used to dig holes and talc preparation of IBA was used on the poles. Beaver cages were also placed around the poles.

**Results:** All the seedlings were destroyed by flooding during 1983. As of 1984, only 13 of the cottonwood poles were alive and 6 of these had been chopped in half by beaver. By November 1986 none of the poles were alive.

**Additional Comments:** Environmental characteristics of this site are hostile to establishing vegetation. Large swings in the level of the water table are common, leaving the site inundated for extended periods of time (especially during the winter and spring) and then dropping to over 2 m below the soil surface for the remainder of the year.

Inundation renders poles more vulnerable to beaver. Water levels above the height of the cages allow beaver to swim to the poles and eat the above-cage growth.
Site #15 - Bartlett Dam

Location: 3.2 km downstream from Bartlett Dam on the Verde River Flood Plain.

Respondent: Don Pollock, Tonto National Forest, USFS.

Date: The project began during August of 1980 and was completed in January of 1981.

Objective: Reestablishment of cottonwoods for Bald Eagle nest sites.

Species Used: *Populus fremontii* (Fremont Cottonwood)

Size of Revegetation Site: Scattered plantings along a 4.5-km reach of the Verde River.

History: The impetus for this project came from the lawsuit filed by the Audubon Society (as described in Site #10).

Prior to mitigation, on-site vegetation consisted of two cottonwood trees with a sparse understory of *Pluchea sericea* and *Coleogyne ramosissma*. The surface was largely open cobble and sandy areas. The site had not been grazed for several years prior to the onset of the project.

Methodology: Two hundred and fifty-three *Populus fremontii* poles were planted along 4.5 km of the Verde River, beginning 3.2 km south of the Bartlett Dam. The poles were obtained from The Santa Cruz River, just north of Nogales, and from Tempe, along the Salt River Bottom. The poles were 6 meters long and had a basal diameter of 6 to 8 cm. A YACC crew was hired to dig holes to a depth of 1.5 m (the level of the water table) with post hole diggers.
Prior to planting, poles were subjected to a variety of treatments: time release fertilizer, Hormex (a rooting hormone), chopping up the butt of the pole, and painting the distal end with tree paint. The treatments varied considerably from one pole to the next. In addition, mulch was used to keep temperatures down at the base of the poles, and hardware cloth was placed around the trunks of some of the poles to prevent beaver damage.

**Results:** Nineteen percent survival of planted vegetation. Twenty-two percent of the poles that were planted died from beaver predation (most of these had not been caged), and 59% died when Bartlett Dam was shut down for a month and a half during the first fall following the planting. There were no obvious differences in survival among the different pre-planting treatments.

**Additional Comments:** According to Don Pollock, the most important factor determining the survival of the cottonwood poles is site selection. There are trade offs between planting close to the water's edge or farther away on the flood plain. Water availability is usually high immediately adjacent to the active channel; however, so is susceptibility to flood and beaver damage. The reverse seems to be true farther away from the channel. Ideally, poles should be planted where water availability is high, yet where topographic features provide protection from high flows (large boulders for example).
Site #16 - Needle Rock

Location: 5.0 km south of Bartlett Dam on the Verde River.


Date: The project was initiated in January of 1982 and completed in March of 1982.

Objective: Provide additional Bald Eagle nesting sites between Bartlett reservoir and Fort McDowell.

Species Used: *Populus fremontii* (Fremont Cottonwood)

Size of Revegetation Site: Scattered plantings along 325 ha of the Verde River.

History: Primary impetus for this project was the lawsuit filed by the Audubon Society (as describe for site #10).

This site also experienced flooding during 1978, 1979, and 1980 but was not as severely affected as the Bartlett Project site because the channel is somewhat wider, allowing floods to dissipate their energy over a greater area. As with the Bartlett site, the Needle Rock site is largely at the mercy of the timing and quantity of Bartlett Dam releases.

Methodology: Two hundred and ninety-seven *Populus fremontii* poles were planted in much the same manner as at the Bartlett Project site. Beaver cages were not used in this case because the poles were not planted as close to the water’s edge as at the Bartlett site.
Results: Eighteen percent of planted trees survived to the time of the site visit. Although the survival rate of the poles was fairly low, the poles that did survive had good growth (over 9 m tall) and will probably survive to the adult stage.

This site was greatly affected by livestock and human recreation activities. The respondent estimated that over 50% of the poles were destroyed by cattle, vandalism, and recreational activity. In addition, 16% dried up and died because of the 1.5-month dam closure during the fall.

Additional Comments: According to Don Pollock, one of the most important factors in determining the success of a particular revegetation project is site selection (see "additional comments", Bartlett Project).

Site #17 - McEuen Seep

Location: 8 km due west of Fort Thomas. McEuen Seep is a tributary of the Gila River.


Date: 1981

Objective: Decrease erosion rates and improve wildlife habitat.

Species Used: *Populus fremontii* (Fremont Cottonwood), *Platanus wrightii* (Arizona Sycamore), *Juglans major* (Arizona Walnut) and *Muhlenbergia rigens* (deer grass).

Size of Revegetation Site: 0.2-ha
History: Perennial water and shade provided by several large mesquite trees made this site an ideal water hole for livestock. Prior to mitigation, the McEuen Seep area was used year-round by cattle, leading to considerable degradation. By 1979, all obligate riparian vegetation had been completely destroyed, and accelerated erosion rates produced gullies that, in several locations, went to bedrock.

Methodology: In cooperation with the permittee, an alternative water source was developed, eliminating livestock pressure from McEuen Seep. *Platanus wrightii* seedlings were cut out of Baneta Creek, *Juglans major* seedlings were grown from seed, and *Populus fremontii* were planted as cuttings. Shovels and digging bars were used to dig to the water table (no more than 50 cm deep). *Muhlenbergia rigens* was planted to increase biodiversity and bind surface soil.

Vegetation was planted as follows: 1981 - two cottonwoods were planted, 1983 - six walnut seedlings were planted, 1987 - 2 cottonwoods, 15 sycamores, and 7 walnuts were planted (walnut seedlings were planted on higher ground where there was more shade), and deer grass, harvested from other areas, was planted in 1989.

Results: According to Al Bammon, this site is basically a "walnut" site (walnuts are well adapted to this site’s soil and moisture characteristics). Walnuts have had a fairly high success rate; 8 walnuts, 3 cottonwoods, 2 sycamores and 2 willows have survived.
Walnuts and cottonwoods are over 9 m tall. Many of the sycamores may have died because they were planted in areas where they did not receive adequate sunlight.

The plantation was breached by cattle on several occasions, damaging newly planted vegetation. The fence was damaged by floods and fallen tree branches.

**Additional Comments:** According to Al Bammon, planting a variety of different tree species is very important when attempting to increase wildlife diversity. As the diversity of the vegetation increases so should the diversity of wildlife. Attention should be given to the adaptability of each species used to the micro-sites where they are planted. For example, Arizona sycamore should be planted in areas that receive full sunlight. At this site there were problems caused by the water table dropping below the root level. Post-planting maintenance should be a part of any artificial planting design.

**Site #18 - Clay Mines Spring**

**Location:** 1.6 km west of Fort Thomas, Arizona.

**Respondent:** Al Bammon, Bureau of Land Management

**Date:** Mitigation began in 1987; work is ongoing.

**Objective:** Wildlife habitat improvement and livestock forage improvement.

**Species Used:** *Populus fremontii* (Fremont Cottonwood) and *Salix exigua* (Coyote Willow).

**Size of Revegetation Site:** 140 m²
History: Year round livestock grazing and construction of an access road immediately over the spring have contributed to the deterioration of the site. Year-round grazing has continued since the completion of this project. According to Al Bammon, the productivity of the site prior to the revegetation effort was very low but, due to the presence of year round water, the productive potential of the site is high. In 1987, on-site vegetation included *Tamarix pentandra*, *Prosopis juliflora*, and *Cynodon dactylon*.

Methodology: The site is considered saline, therefore, trees were harvested from saline sites along the Gila River. Digging bars and shovels were used to plant 3-m long poles over 1 m deep.

The planting schedule was as follows: 1 cottonwood was planted in 1987, 2 cottonwoods were planted in 1988, and 1 cottonwood and 1 coyote willow were planted in 1989. Large poles were used because they were deemed less vulnerable to trampling and grazing by livestock.

Results: Four surviving *Populus fremontii* are almost 6 m tall, the surviving *Salix exigua* is almost 5 m tall.

Additional Comments: According to Al Bammon, it is important to have modest objectives that can be easily achieved. Using large poles can produce successful results despite continued grazing pressure. This is important because it demonstrates that
successful riparian revegetation can occur in some cases despite lack of cooperation by livestock managers.

Site #19 - Aravaipa Creek

Location: Araviapa Canyon, Arizona.


Objective: Expedite recovery of riparian vegetation following the 1983 flood.

Date: Plantings began during 1983 and continued until the following year.

Species Used: Populus fremontii (Fremont Cottonwood), Salix gooddingii (Goodding willow), and Juglans major (Arizona walnut).

Size of Revegetated Area: 25 ha

History: Araviapa Canyon is highly valued for its scenic beauty (the canyon is used year-round by recreationists - mostly hikers and campers) and is also considered prime habitat for a variety of wildlife species. The surrounding uplands have been impacted by road construction and livestock grazing, which has, according to Al Bammon, influenced runoff patterns to the detriment of the riparian ecosystem. Grazing of the riparian lowlands has changed from year-round (prior to mitigation) to several weeks out of the year on permission.

High flows during 1983 eliminated a great deal of riparian vegetation, leaving some sections of Aravaipa Creek completely barren. Damage was so extensive that many thought 8 years would be required before riparian vegetation could recover to its
pre-flood state. A more rapid recovery was thought possible by artificially planting riparian vegetation.

**Methodology:** Revegetation work was done at three different locations along Araviapa Creek at three different times. In 1983, 30 *Populus fremontii* and 23 *Juglans major* were planted along a 0.8 ha portion of the creek near the Brandenburg Mountains. In 1984, 700 *Salix gooddingii* and 500 *Populus fremontii* were planted along 8 ha of the wilderness area and another 600 poles of the same species were planted along 16 ha of creek banks. All cottonwoods were planted as poles, willows were planted as poles and cuttings, and walnuts were planted as seedlings.

Aside from the plantings, the only other mitigation performed was periodic saltcedar control (three times per year saltcedar branches are clipped from the main bole of the tree) and construction of a livestock fence around the wilderness area (the fence was installed in 1974).

**Results:** Those plantings that have survived (estimated 5% to 10% of total planted) are obscured by prolific regeneration of riparian vegetation. The current ecological condition of the riparian vegetation in Aravaipa Canyon is good. Diversity of riparian vegetation in the canyon is high and the multi-level upper canopy shows that regeneration following the 1983 flood is on-going. According to the respondent, the combination of decreased grazing intensity in the canyon and on the surrounding uplands with the natural rejuvenation forces of stream dynamics are largely responsible for improving the
ecological condition of Aravaipa Canyon and the side canyons. Riparian regeneration along the banks of Turkey Creek, for example, has increased stream bank storage capacity, resulting in perennial water flow.

Additional Comments: Site selection was the main factor that determined whether or not a particular pole or cutting survived. Many of the plantings were placed too close to the creek and were destroyed, for the most part, by subsequent flooding, while those that were planted on relatively high ground survived. Al Bammon noted that natural revegetation was quite capable of doing all that the project accomplished and more.

Site #20 - Seven Mile Wash

Location: 1.6-km NW of Seven Mile Wash and the San Carlos River confluence.

Respondent: Bill Sims, Bureau of Indian Affairs, San Carlos Agency.

Date: Project began during the spring of 1984.

Objective: Improving site aesthetics and wildlife habitat and stabilize stream banks.

Species Used: *Populus fremontii* (Fremont Cottonwood) and *Salix gooddingii* (Goodding Willow).

Size of Revegetation Site: 0.1 ha

History: Year-round livestock grazing has heavily impacted this site and adjacent lowlands. Much of the area was heavily trampled and grazed, and diversity and quantity of riparian vegetation was drastically reduced (the only vegetation in the area prior to the
beginning of the project was mesquite). The level of the water table drops to over 1 meter below the soil surface during the dry season.

Methodology: *Populus fremontii* poles and *Salix gooddingii* poles and whips were planted after rip-rap was installed. Poles were about 4 m long and 7 cm to 10 cm in diameter. Long poles were deemed less susceptible to cattle damage (the site area was not fenced). The proximity of the Seven Mile Wash site to large concentrations of willows at San Carlos left this site relatively free of grazing pressure.

Results: Currently, just over 40% of the poles that were planted have survived. The willow whips did not establish in large quantities.

Additional Comments: Poles planted closer to the stream bank had a greater survival rate than those planted farther away.

**Site #21 - Highway 70 Bridge**

**Location:** 1 km southeast of highway 70 bridge, along south bank of the Gila River.

**Respondent:** William Sims, Bureau of Indian Affairs, San Carlos Agency.

**Date:** The project began in 1986.

**Species Used:** *Populus fremontii* (Fremont Cottonwood) and *Salix gooddingii* (Goodding Willow).

**Size of Revegetation Site:** 0.1 ha
Objective: Stabilize stream banks.

History: This site has been impacted by uncontrolled year-round grazing, flood damage (especially from the floods of 1983 and 1984), and the invasion of Tamarix pentandra. The water table in this area frequently drops to over 1 m beneath the soil surface during the dry season.

Methodology: Thirty-five Populus fremontii and 35 Salix gooddingii poles were harvested from the San Carlos River. Poles were 3 m in length and 10 cm to 20 cm in diameter. A backhoe was used to dig down to the water table. Saltcedar was cleared with a bulldozer prior to planting.

Results: Ninety percent of the artificially-planted vegetation survived through the first year following the project's completion. However, construction during 1988 destroyed most of the artificially planted vegetation.

Additional Comments: According to Bill Sims, using wide, sturdy poles helped considerably to ensure survival in the face of continued grazing pressure.
Site #22 - Hassayampa River

Location: Hassayampa River Preserve, Wickenburg, AZ

Respondent: Brian and Holly Richter, Nature Conservancy

Objective: Restoration of the ecological processes, structural integrity, and species composition of the Hassayampa River Preserve to what it would be had the area not been impacted by human influences.

Species Used: No active revegetation performed.

History: In 1987, The Nature Conservancy took over management responsibilities of 8 km of the Hassayampa River near Wickenburg. Prior to this, the area was heavily impacted by off-road vehicles and long-term overgrazing. Density and diversity of riparian vegetation was reduced to scattered adult *Populus fremontii* and *Salix gooddingii* with sparse understory predominantly composed of *Cynodon dactylon*. Vegetation on the upper flood plain consisted primarily of *Prosopis* spp. with an understory of *Bromus* spp. Absence of riparian vegetation along river banks led to accelerated runoff and erosion rates, which in turn contributed to down cutting of the river banks and scouring of the stream channel.

The Nature Conservancy is using passive means to rehabilitate this area; i.e., no active revegetation effort has been undertaken. The only active measure that has been performed is construction of a fence around the perimeter of the preserve. Human impact is now greatly regulated and cattle are excluded completely.
During the past 3 years, much time and effort have been focused on creating a representative list of the Preserve’s fauna and flora so that changes in their diversity and density can be documented. Such documentation will help considerably to characterize natural recovery trends and processes in restoration efforts. One of the tools that has been used to assist in the documentation of these trends is the establishment of photo points. One look through the collection of photographs taken during the past 3 years reveals the remarkable dynamics and resilience of this riparian area.

**Results:** The Hassayampa River Preserve of today bears little resemblance to photographs taken just 3 years ago. During the first 2 years of Nature Conservancy management, stream side herbaceous species such as *Paspalum distichum* and *Typha* spp. began to regenerate prolifically. The herbaceous cover induced sediment deposition, building and strengthening streambank terraces. Regeneration of *Salix gooddingii* and *Populus fremontii* became prolific once the floodplain’s elevation was above the surface water level.

Successive years of cottonwood and willow recruitment have substantially restructured the forest community by adding younger stands and promoting establishment of a dense shrub layer composed predominantly of *Baccharis glutinosa* and *Pluchea sericea*. Recurrent flooding along the low lying areas has encouraged regeneration of native grasses and forbs. According to Brian and Holly Richter, the resurgence of vegetation that has taken place since the Preserve was founded has precipitated a chain
of events that may ultimately lead to the Hassayampa River reverting back to its' "original" cienega form.

Site #23 - Goose Flats

Location: Near Cibola Wildlife Refuge, Colorado River.


Date: June 1988

Objective: Wildlife habitat improvement.

Species Used: Populus fremontii (Fremont Cottonwood), Salix gooddingii (Goodding Willow), Atriplex lentiformis (quail bush), Lycium sp. (wolfberry), Prosopis pubescens (screwbean mesquite), Prosopis juliflora (honey mesquite), Cercidium floridum (blue palo-verde).

History: High flows during 1983-84 destroyed the majority of Populus fremontii, Salix spp., and Prosopis spp. Many of the survivors were destroyed by a fire in 1987. As a result, this area of the Colorado River was no longer suitable for many indigenous wildlife species, like the yellow-billed cuckoo (Coccyzus americanus) and summer tanager (Piranga rubra). Improving the habitat for wildlife became a priority for the California Department of Fish and Game, which took control of this site in 1988.

Methodology: During June 1988, the area was cleared of Tamarix chinensis and Pluchea sericea with a D-7 caterpillar. Saltcedar that resprouted was sprayed with herbicide (roundup). A wire fence was installed around the site during July to control
beaver and off-road vehicles. Holes 38 cm in diameter and about 2.5 m deep were augered to give a density of roughly 250 holes per ha (total of 3,330 holes for the site). Holes were loosely refilled to provide a path to the water table for irrigation water. A drip irrigation system was installed that was designed to deliver 2 gallons of water per hour.

All vegetation was planted as seedlings in 1-gallon containers. In addition, *Populus fremontii*, *Salix gooddingii*, *Prosopis* spp. and *Atriplex lentiformis* already on site were encouraged by removing competing vegetation and, in some cases, providing irrigation.

**Results:** The survival rate of all planted vegetation was 80% following the first summer of growth. Using the mean depth to water table, Anderson predicted that 10-year survival rates will be roughly 70%. Probability of increased wildlife use in this area is deemed quite high.

**Additional Comments:** Augering holes prior to planting and irrigating refilled holes can promote root development to the water table. This was deemed especially important for the survival of species like cottonwoods and willows (species that typically produce shallow, lateral root systems) in areas of low water availability. Augering prior to planting breaks up tightly compacted soil particles. Water placed on top of the holes will
take the path of least resistance, moving down the loosely packed column instead of laterally. Root systems will follow this moisture gradient to the water table.

Anderson noted that the percent mortality experienced in this project during the next 10 years will greatly depend upon water releases down the Colorado River. Even if the water flow is lower than anticipated, Anderson predicts that the site will become high quality wildlife habitat in the near future. The results of this project also indicate that very low EC levels are not conducive to growth of planted vegetation.

Site #24 - Route 85

Location: Downstream from where Route 85 bridge crosses the Gila River, west of Phoenix.

Respondent: Catsby Moore, Flood Control District - Environmental Program Manager, Phoenix.

Date: Dec. 1985

Objective: Improve wildlife habitat and protect farmland along the Gila River.

Species Used: *Populus fremontii*, *Salix gooddingii*, and *Tamarix* sp.

Size of Revegetation Site: 0.8 ha

History: *Tamarix* sp. invasion and lower natural flood frequency is deemed largely responsible for the decline of *Populus fremontii* and *Salix gooddingii* stands in this area.

Methodology: About 700 cottonwood and willow poles were planted in trenches dug to the water table. Poles were 3 to 4 m long, about 8 cm in diameter, and buried to
approximately one-third their length. A species of tamarix that produces only by root sprouts was also used in this revegetation project. Saltcedar was cleared in the channel as part of year long maintenance program.

**Results:** Seventy percent of planted vegetation survived to the time of the site visit. Most of the vegetation show signs of stress (yellow leaves and stunted growth). Most of the willows are about as tall as they are wide (average size is 2.5 m tall, 2 m at widest point). The benefits of these plantings to wildlife are debatable. Channeling of the Gila River and future closure of the secondary channel that provides the site with most of its water will undoubtedly further stress planted vegetation.

**Additional Comments:** According to Catsby Moore, the availability of water is extremely important in determining the success of a particular revegetation project. Many of the poles did not survive because they were placed too far away from the river where they could not reach the ground water.

**Site #25 - Arlington Ponds**

**Location:** Arlington, AZ; on lands owned and administered by the Arizona Game and Fish Department.

**Respondent:** Catsby Moore, Flood Control District - Environmental Program Manager, Phoenix.

**Date:** January 1985
Objective: Improve wildlife habitat

Species Used: *Populus fremontii* and *Salix gooddingii*

History: This site has been overrun by saltcedar. This aggressive colonizer will make future establishment of native obligate riparian species difficult.

Methodology: The area was cleared of saltcedar prior to planting. Three hundred and seventy-five *Populus fremontii* and *Salix gooddingii* poles (150 willow and 225 cottonwood) were planted in two areas. Twelve oval clusters, consisting of about 30 trees each, were planted in a field immediately adjacent to the ponds, and 15 poles were planted around the periphery of the 2 ponds. Holes were augered 1.5 m deep prior to planting.

Results: None of the trees survived to the time of the site visit. Those planted around the periphery of the ponds showed no growth initiation and probably died from desiccation when irrigation failed and pond waters receded during the first year following planting. Lack of survival in the field was considered to be caused by the high saline content of the soil.

Additional Comments: Supervision and maintenance following completion are as important to project success as the initial planting effort.
Site #26 - Sugar Dike

Location: Arlington, AZ; off of Arlington Ave.

Respondent: Catsby Moore, Flood Control District - Environmental Program Manager, Phoenix.

Date: December 1986

Objective: Strengthen dike and reduce erosion rates.

Species Used: *Salix gooddingii*, *Populus fremontii*, and *Tamarix aphylla*.

History: The dike was constructed to protect adjacent land from high flows. Vegetating the dike was deemed a practical solution to accelerated erosion rates.

Methodology: A caterpillar tractor was used to clear the site of saltcedar prior to planting. Dormant *Populus fremontii* and *Salix gooddingii* poles were cut (1,750 total) from riparian stands downstream from 115th Ave. and planted in holes augered to a depth of 1 m. The top of each pole was painted to avoid excessive water loss, and the butts were soaked until planted. *Tamarix aphylla* was planted along the upper sides of the dike by the land owner.

Results: Over 50% of the trees have survived. Most are over 6 m tall, with bases 15 cm in diameter. *Tamarix pentandra* has come back dramatically, forming dense stands that surround the clusters of planted cottonwoods and willows.
Additional Comments: High water availability and protection offered by the dike provide a good environment for establishing vegetation. Catsby Moore noted that the land owner’s willingness to work with Flood Control had a major positive impact on the results of this project.

Site #27 - 83rd Avenue

Location: 83rd Ave., Phoenix, along Skunk Creek, just upstream from the bridge.

Respondent: Catsby Moore, Flood Control District - Environmental Program Manager, Phoenix.

Date: January 1990

Species Used: *Salix gooddingii* (Goodding Willow) and *Typha spp.* (Cattails).

Size of Revegetation Site: 3.2 ha

Objective: Protect riparian vegetation deemed vulnerable to channelization of Skunk Creek (Skunk Creek was channelized for storm water purposes).

History: Road and channelization work threatened riparian vegetation established where Skunk Creek flows under the 83rd Avenue overpass. Riparian vegetation directly affected by the construction was transplanted to areas upstream.

Methodology: Fifteen *Salix gooddingii* poles were harvested from willows removed by channelization. A backhoe and an auger were used to plant the willow poles at least 1
m deep. Poles were 2.5 to 3.5 m long and 8-cm in diameter. *Typha* sp. were taken out of the low flow area and placed near low flow area.

**Results:** Prolific understory development including *Cynodon dactylon*, *Muhlenbergia rigens*, *Elymus* spp., *Carex* spp., and *Phragmites communis*. Five of the *Salix gooddingii* poles show healthy shoot development.

**Additional Comments:** Catsby Moore noted that selecting plant species adapted to site conditions is an extremely important consideration for all riparian revegetation projects. In this project, a perennial supply of water made the site favorable to *Salix* spp. and *Typha* spp.
SPECIES USED IN SELECTED REVEGETATION PROJECTS

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Site Where Vegetation Was Planted¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona Sycamore (<em>Platanus wrightii</em>)</td>
<td>12</td>
</tr>
<tr>
<td>Arizona Walnut (<em>Juglans major</em>)</td>
<td>17</td>
</tr>
<tr>
<td>Bebb Willow (<em>Salix bebbiana</em>)</td>
<td>1</td>
</tr>
<tr>
<td>Coyote Willow (<em>Salix exigua</em>)</td>
<td>18</td>
</tr>
<tr>
<td>Fremont Cottonwood (<em>Populus fremontii</em>)</td>
<td>5,10-21,23,24-26</td>
</tr>
<tr>
<td>Goodding Willow (<em>Salix gooddingii</em>)</td>
<td>6-8,12,13,19-21,23-27</td>
</tr>
<tr>
<td>Narrow-leaf Cottonwood (<em>Populus angustifolia</em>)</td>
<td>3</td>
</tr>
<tr>
<td>Thin Leaf Alder (<em>Alnus tenuifolia</em>)</td>
<td>1</td>
</tr>
<tr>
<td>Shrub Species</td>
<td></td>
</tr>
<tr>
<td>Quail Bush (<em>Atriplex lentiformis</em>)</td>
<td>23</td>
</tr>
<tr>
<td>Honey Mesquite (<em>Prosopis juliflora</em>)</td>
<td>23</td>
</tr>
<tr>
<td>Screwbean Mesquite (<em>Prosopis pubescens</em>)</td>
<td>23</td>
</tr>
<tr>
<td>Wolfberry (<em>Lycium sp.</em>)</td>
<td>23</td>
</tr>
<tr>
<td>Grass Species</td>
<td></td>
</tr>
<tr>
<td>Blue Gramma (<em>Bouteloua gracilis</em>)</td>
<td>3</td>
</tr>
<tr>
<td>Deer Grass (<em>Muhlenbergia rigens</em>)</td>
<td>17</td>
</tr>
<tr>
<td>Tall Wheatgrass (<em>Agropyron</em>)</td>
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</tr>
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</table>
### SPECIES USED IN SELECTED REVEGETATION PROJECTS (continued)

<table>
<thead>
<tr>
<th>Grass Species (continued)</th>
<th>Site Where Vegetation Was Planted(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate Wheatgrass (Agropyron)</td>
<td>2</td>
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<tr>
<td>Pubescent Wheatgrass (Agropyron)</td>
<td>2</td>
</tr>
<tr>
<td>Smooth Brome (Bromus inermis)</td>
<td>2</td>
</tr>
<tr>
<td>Orchard Grass (Dactylis glomerata)</td>
<td>2</td>
</tr>
<tr>
<td>(Phleum spp.)</td>
<td>2</td>
</tr>
</tbody>
</table>

\(^1\) Number corresponds to a particular site. For example, "1" refers to site #1 (Saw Mill Spring).
CONSIDERATIONS IN DEVELOPING A RIPARIAN REVEGETATION PLAN

Objective of Revegetation

The objective of revegetation should be as well defined as possible. A revegetation plan should describe the initial condition of the degraded area as well as the characteristics desired for the end result. Both of these should be described as thoroughly as possible, relating channel geometries, hydrologic characteristics, wildlife densities, vegetation species distribution, population sizes, and community structures. A realistic picture of the end result of revegetation work can be obtained by analyzing areas upstream and downstream from the degraded area.

A thorough riparian revegetation plan requires an interdisciplinary approach. The revegetation plan should take into consideration data compiled from aquatic and riparian biologists, soil scientists, hydrologists, plant propagationists, and watershed managers.

Selecting Planting Material

Burkhart (1987) noted that species selection for revegetation projects is one of the most critical decisions facing a revegetation planner. He observed that, ideally, species should be picked in precise proportion to what is thought to be the original site plant composition. Although this should be the aim of any revegetation project, practicality suggests consideration of other factors, including ease of production and the probability that the species will survive (Burkhart 1987). Vegetation should be selected on a site-
specific basis (Chapman et al. 1982) using plant species found on site or close by (Zarlingo, pers. comm). This consideration, along with those proposed by Burkhart, may still leave the revegetation planner with a plethora of vegetation possibilities from which to chose. Results from this study indicate that appropriate planting material for a given site can best be determined by considering three additional factors: 1) wildlife and livestock use; 2) water availability; 3) project objectives.

Wildlife and Livestock Use

Intensity of wildlife and livestock use is an important consideration for determining the most appropriate species of vegetation, as well as the type of propagule, to be used in revegetation. In this study, artificially-planted vegetation was damaged by beaver (Francis Creek (site #11), Bartlett Dam (site #15), Horseshoe Lake (site #14)), elk (Saw Mill Spring (site #1)), and livestock (Burro Creek (site #12), Needle Rock (site #16)). Monitoring livestock and wildlife use before planting will help land managers choose the species of vegetation that would have the greatest chance of surviving in the face of continued livestock and wildlife pressure, and design planting strategies for protecting newly planted seedlings (see also Protecting Revegetation Projects from Livestock and Wildlife).

If newly planted vegetation faces heavy grazing, it may be wise to choose nonpalatable species, or plant non-palatable species around palatable species (Goodwin pers. comm.). *Alnus tenuifolia* (thinleaf alder) is a good example of a species that may
have high potential in this regard. Thinleaf alder is unpalatable to livestock, can be rooted quite easily from cuttings, and seems to improve the productivity of species planted in close association with it (Tarrant and Trappe 1971). Planting large poles may also allow revegetation managers to overcome heavy grazing intensities without changing grazing patterns (Sims and Bammon, pers. comm.).

Water Availability

The results of this study indicate that water availability is one of the most important site characteristics for determining the feasibility of revegetation, and also for choosing the most appropriate species of vegetation for the revegetation project. Monitoring the water table for at least one year prior to planting can provide the information needed to make such decisions.

Revegetation planners should not assume that all riparian sites are capable of supporting obligate riparian species. In this study, the hydrologic environments of several sites have changed to such an extent that they may no longer be "riparian". The hydrologic environments of Box Bar (upper flood plain of site #13), Horseshoe Lake (site #14), and Babocomari River (site #8), which formerly supported healthy stands of obligate riparian species, have changed considerably during the last 20 years. These sites currently experience large fluctuations in the water table or have consistently low water table levels making establishment of many obligate, woody riparian species difficult, if not impossible.
In situations where water availability is questionable, it may be wise to use non-obligate riparian species instead of obligate riparian species. Studies indicate that it may be feasible to grow mesquite with little or no irrigation if the soil is properly trenched and if the area is planted when precipitation is most likely (Murphy 1988). Other species that show promise in this regard are palo verde (Cercidium floridum) and quail bush (Atriplex lentiformis).

**Project Objectives**

Of the factors already listed, project objectives probably have the greatest impact in determining appropriate planting material for a revegetation project. Grass species at Coleman Lake were used to provide habitat for waterfowl, willows were planted at North Tubac to increase stabilize stream banks, and cottonwoods were planted along the Verde River to establish nesting sites for bald eagles.

Once the general class of vegetation is determined (grass, shrub, and tree species) revegetation planners should pay attention to other considerations. Anderson and Ohmart (1982) stressed that no matter what the objectives are, the selection and arrangement of planted species should be considered to achieve the best possible value for wildlife. Anderson et al. (1978) stressed the importance of establishing grasses and shrubs, as well as trees, for maximum wildlife benefit. A revegetation project that uses a variety of different species can allow revegetation planners to accomplish both long- and short-term
objectives. Annuals and shrub species can produce quick results while revegetation managers wait the one or two decades needed for trees to reach their full potential.

Annuals should be encouraged during the first year because they can develop rapidly, quickly offsetting initial losses from clearing. Annuals can provide habitat for winter birds and decrease erosion rates (Anderson et al. 1978). Perennial shrub species are capable of replacing annuals during the following years, which will, in turn, gradually give way to tree species.

Stevens (unpub. report) noted that chances for revegetation success increase as the number of plant taxa used in the revegetation project increase. He specifically recommended using shrub species that generally have a wider range of adaptation than their natural distribution.

**Type of Propagule**

The revegetation projects analyzed in this study used four types of propagules: poles, seedlings, rooted cuttings, and seeds. The results of this study and literature review indicate that the choice of propagule can be important in determining the effectiveness of revegetation. Certain propagules have advantages over others depending on project design and site conditions. The choice of propagule should, therefore, be made on a site-by-site basis.
Poles

Poles have several advantages over direct seeding and cuttings. Poles tend to be less vulnerable to flooding and livestock damage, and their size allows them to be planted in areas where water tables consistently fall several meters below the soil surface. York (pers. comm.) noted that large poles (over 4 m long) can be successfully used and may even have several advantages over smaller poles, including ability to reach deep water tables and less vulnerability to drying (due to larger biomass). Swenson and Mullins (1985) planted poles over 4 m in length on the Rio Grande floodplain just south of Albuquerque, New Mexico. They reported high establishment and growth (over 75 cm/year) rates.

Poles should be planted to the anticipated depth of the water table as it occurs during the growing season. Hall, York, Bammon, and Forbis (pers. comm.) noted that it is not uncommon to find areas where the level of the water table fluctuates over 1 m throughout the year. They recommended monitoring ground water fluctuations for at least one year prior to planting to better ascertain the level of ground water during the growing season.

Survival rates seem to be higher when poles are harvested and planted when they are dormant (York 1985; Swenson and Mullins 1985). Poles can be harvested any time during the dormant season (November to February). In contrast, the optimal period for taking greenwood cuttings is only 15 to 20 days and their survival rate is lower (Swenson
Poles should be harvested from areas that have similar soil chemistry, especially in regard to salinity (Bammon, pers. comm.).

Poles should be planted in areas that experience flooding or ponding less than 3 weeks during the growing season. Sites characterized by coarse textured soils and salinity levels of 3,000 ppm or less seem to be ideal for planting cottonwood and willow poles (York, pers. comm.). Poles and whips planted at Coleman Lake (site #2), Canyon Creek (site #3), and Gentry Creek (site #4) may not have established because of fine textured soils. Soils that contain significant amounts of clay may not allow adequate drainage, depriving root systems of oxygen.

Anderson and Laymon (1988) noted several disadvantages in using poles. They commented that harvesting several thousand poles may decimate local populations of young trees. In addition, they generally experienced lower productivity with pole plantings than with potted seedlings. The revegetation manager is also limited to a narrow field of species capable of growing from poles.

Planting recommendations for poles include the following (York, Forbis, Hall; pers. comm.):

1) Poles should be harvested before buds appear or sap begins to rise.

2) Poles should be taken from the nearest available source to maximize adaptability to the planting site and reduce genetic contamination (York 1985).

3) Healthy trees, 3- to 5-years old, should be selected. Ideally these trees should be growing in areas where they receive large amounts of sunlight. Lateral branches as well
as the bole of the tree can be used. Harvest only poles that can be planted within a 48-hour period.

4) Cut tree into appropriate length. The length should be based on depth to ground water. Most pole plantings used poles 3 to 5 m in length, 6 to 15 cm in diameter. Several respondents have recommended making an angle cut on the bottom and a flat cut on the top of the poles. This should prevent planting the poles bottom side up.

5) Remove lateral branches on the harvested pole.

6) Transport poles as quickly as possible to the planting site. Dormant poles should be stored in water if travel time is 12 hours or greater. Some respondents recommend transporting poles top end up in barrels 1/2 of a water and a root hormone mixture (1oz. of rootone F per 35 gallons of water is commonly used). Poles should be planted 24 to 48 hours following harvest.

7) There are many methods by which poles can be planted to the level of water table. The choice of methodology is primarily determined by site accessibility, depth to water table, and soil consistency. Remote locations may eliminate using heavy equipment. Motorized augers have been used extensively, but are limited primarily to sites that do not have large amounts of cobbles or stones. Backhoes have also been used effectively, but are limited by their size and cost.

8) Scarify the portion of the pole that is to be planted below ground. This action appears to promote root growth. Some respondents recommend removing the bottom 12 cm before scarifying to avoid trapping air bubbles.

9) Holes should be back filled carefully to eliminate air spaces.

10) Some of the respondents have recommended placing mulch at the base of poles to reduce temperatures and trap moisture.

11) Paint all cut surfaces above ground with white paraffin or tree paint. Paint appears to reduce transpiration losses through the cambium and may seal out pathogens.
Containerized Seedlings

Using seedlings in lieu of poles can give the revegetation manager a much greater choice of vegetation. Local nurseries commonly can provide revegetation projects with a plethora of native species, which may allow revegetation managers to choose species better adapted to specific site conditions. From their revegetation experiences along the Colorado River, Anderson and Ohmart (1982) observed that seedlings produced better results than poles.

All nursery grown species should be hardened off in full sun without misting applications for at least two weeks prior to transport to the planting site (Burkhart 1987). Do not prune roots or shoots immediately before planting. Such action, though necessary, may be detrimental to a newly transplanted plant and, if performed, should be done at least two weeks before planting to give the plant sufficient time to heal (Burkhart 1987). Garrett (1977) found that after one growing season, root development, height, and diameter growth were greater for eastern cottonwood seedlings when planted at 25 m height than at 50 cm. He noted that 25-cm seedlings had larger root systems concentrated in the upper 25-cm of soil and were therefore better equipped to use surface moisture than the 50-cm seedlings. Cottonwood and willow seedlings can be grown from cuttings taken from local native stock. The cuttings should be allowed to take root and develop in a greenhouse for 2 or 3 months.
Rooted Cuttings

As part of her recommendations from experiences revegetating flood control channels in the Santa Clara Valley Water District, Goldner (1981) noted that project costs can be significantly reduced if plants are established from rooted cuttings as opposed to larger container stock. He concluded that placing smaller plants at high densities seemed to be a good method for controlling weeds, as well as providing quick cover for wildlife.

Shaw (1983) noted that some native plant species can be more easily and economically produced from cuttings than from seed. She listed several species that can be easily rooted from cuttings, including: *Salix* spp. (willow), *Populus* spp. (poplar), *Artemisia abrotanum* (oldman wormwood), *A. absinthium* (absinthium), and *Ribes* spp. (currant). Several species have been successfully established by rooting cuttings, including: *Salix* spp., *Populus fremontii*, *Populus deltoides* (eastern cottonwood), *Populus augustifolia* (narrowleaf cottonwood), *Alnus tenuifolia*, and *Potentilla fruticosa* (shrubby cinquefoil).

Cuttings should be taken during the dormant period from healthy, vigorous plants, growing in full sunlight. Wood from the previous season’s growth should be selected. Individual cuttings should include at least two nodes and may be 10 to 75 cm in length and 0.6 to 3.8 cm in diameter (Shaw 1983). Anderson and Ohmart (1979) noted that cuttings started in a nursery tend to survive and grow better than direct plantings to the field. Cuttings should be allowed to callus for several weeks in cold storage before
planting in nursery beds. Good results have been obtained when dormant cuttings are painted 5 to 10 cm apart within rows with at least one bud above ground.

In their riparian implementation plan, the Coconino National Forest developed the following guidelines for making willow and narrowleaf cottonwood cuttings:

1) Cuttings should be taken during the early spring prior to the breaking of dormancy.

2) Choose long, straight 1- to 3-year old stems. Cut at approximately a 45 degree angle with sharp pruning shears.

3) Remove all lateral branches and the terminal end of each cutting. Then cut into shorter lengths 30 to 60-cm long. Make certain that the distal and proximal end of the cuttings do not become reversed. Cuttings will usually fail if proximal is placed in the ground instead of the distal end.

4) Place cuttings in small bucket of water to keep moist during transportation and to facilitate treatment with root promoting compounds. Adding various combinations of Vitamin B-1, rootone, and granular plant food seems to help initiate root development. Roots should develop within 4 days. Water should be aerated during this time with an aquarium pump.

5) Allow cuttings to air dry for 30 to 60 minutes before planting. Make holes with planting bar at an angle of 45 to 60 degrees. Cuttings should be buried to leave approximately 1/4 of the stem exposed.

6) If cuttings need to be stored, they should be kept moist and placed out of direct sunlight. If basal end dries, make a new cut prior to treatment.

Direct Seeding

Seeding sites directly provides some advantages over transplanting. Direct seeding is generally less expensive because it avoids costs incurred when seedlings are grown in a nursery or when poles are harvested from sites far removed from the
mitigated area. In addition, direct seeding of some species with long seed viability allows seeded species to remain dormant through adverse conditions. Under the same conditions seedlings, cuttings, and poles may not survive (Manci 1989). Ambrose et al. (1983) noted, however, that direct seeding of woody vegetation generally tends to be less successful than planting seedlings or cuttings. Burkhart (1987) noted two major problems that can occur when native plant seeding is used. First, when seasonal rainfall is the sole source for moisture, it is possible that seeds will never receive the appropriate amount of moisture, or they may receive enough moisture for germination to occur, but not enough for continued establishment. For these reasons he recommended using irrigation whenever possible in seeding operations. Second, many native seeds need pretreatment (e.g. scarification, heat treatment), which costs time and money. Burkhart suggested that revegetation planners avoid seed mixtures that require pretreatment or, prior to purchasing the seeds, make certain that the seed company has completed pretreatment procedures.

Ambrose et al. (1983) discusses different methods of seeding and seeding rates, including drilling, hydroseeding, and cyclone seeders. Shaw (1983) reviews many aspects of growing native shrub species, including purchase, collection, cleaning and storage of seed, testing seed quality, conditioning, sowing techniques, seeding rates and depth, irrigation procedures, weed control, and fertilization. Stevens (unpub. report) made several recommendations for seeding native shrub species in temperate climates. Direct seeding should occur in the late fall and winter. Some species, like winterfat
(Ceratoides lanata) and some of the Atriplex spp., can be seeded in the early spring. Fall and winter seedings can help overcome the inherent dormancy of many species and insure that seeds are in the ground when adequate moisture is available. Seeding during this time of year can also reduce loss to seed-eating mammals, insects, and birds.

A list of seeds and species used in revegetation projects along the Lower Colorado River is included in Murphy (1988).

Preparing the Site for Planting

In many situations, removing undesirable species of vegetation and tilling to the water table can greatly improve the chances that artificially-planted vegetation will survive. These steps should be considered when developing a riparian revegetation plan.

Removing Undesirable Species

Undesirable vegetation can out compete artificially-planted vegetation. Anderson and Laymon (1988) observed that several of their riparian revegetation projects along the Colorado and Rio Grande rivers were severely impacted by intense competition from weeds. They concluded that implementing weed control programs may be one of the most important pre- and post-planting activities that a revegetation manager can perform. Murphy (1988) noted that weeds can especially become a problem when irrigation is implemented. She recommended mechanically removing all competitor species
(saltcedar, *Tessaria sericea* (arrowweed), and burmuda grass) and treating the area with a herbicide prior to planting.

Saltcedar's ability to survive complete submergence (for as long as 70 days), to regenerate from rhizomes, and to disseminate seed for extended periods of time gives it several advantages over native riparian species and makes it very difficult to control (Warren and Turner 1975). Several authors have documented the success of various techniques in controlling saltcedar. Hallingsworth et al. (1979) studied how saltcedar growth rates were affected by several types of herbicides and Graf (1983) evaluated several methods for controlling saltcedar, including chain cutting, plowing, burning, herbicides, biological control, and drowning.

Clearing competing vegetation prior to planting can be especially important when revegetation is accomplished via direct seeding. Slow developing shrub species are likely to die if weedy species are not removed before seeding (Stevens, unpub. report). Most shrub species are not likely to establish in stands of dominant annuals such as buttercup (*Ranunculus testiculatus*) and Russian thistle (*Salsola pestifer*).

Clearing should be done selectively to avoid destroying valuable wildlife habitat. Anderson and Ohmart (1982) recommend leaving all native trees and large snags because of their high habitat value for many bird species.
Tilling to the Water Table

Tilling (digging or drilling) to the water table prior to planting has demonstrated good results (Anderson and Miller 1988). Tillage breaks up compacted soil and clay lenses, allowing irrigation water to flow to the water table with less resistance. Anderson (pers. comm.) uses a 38-cm diameter motorized auger to drill holes to the water table. He then refills holes with displaced alluvium or mulch, and then plants potted seedlings. Such a strategy has produced tap root-like development in species like cottonwood and willow that typically have shallow lateral root systems. Trees planted after tilling to the water table were significantly taller, had greater total growth and foliage volume, and experienced less mortality rates than trees planted in areas that were not tilled (Anderson and Laymon 1988). Anderson and Ohmart (1982) noted that the cost of drilling to the water table (about $2/hole) is justified by the increase in growth and survival of planted species, decreased irrigation requirements, and reduced labor costs.

Deep tillage can be accomplished by drilling with a motorized auger or digging with a backhoe, or with a variety of manual instruments. It is important to make certain that no air spaces remain in the hole after poles are planted. Holes should be carefully back filled; air spaces left in the holes appear to be detrimental to developing vegetation.
Planting Location

Whether or not artificially-planted vegetation survives depends largely on where it is planted. Hall, Pollock, and Forbis (pers. comm.) noted that survival rates of planted vegetation can vary considerably even within one particular area. This can be true even when the species and planting methodologies are identical. Results of several revegetation projects have shown that only a few meters can separate favorable planting sites from unfavorable ones.

To improve the chances for success, the revegetation planner needs to match the physiological requirements of the selected plant species to the environmental conditions of the planting site. The micro-site characteristics that appear to be most important to the survival of artificially-planted vegetation are: 1) susceptibility to flooding and desiccation, 2) the soil environment (especially texture and salinity), and 3) availability of sunlight. A revegetation planner needs to understand how each of the species chosen for the revegetation project is adapted to these three parameters.

Flooding and Desiccation

Results of this study show that flooding and desiccation can severely damage newly planted vegetation. Most obligate riparian species can establish and survive only in areas protected from flooding and yet characterized by high water availability (root systems are at or below ground water level year round). Cottonwood seedlings, for example, appear to benefit from water in the lower portion of the root zone, but will
likely die if the water table saturates the upper soil profile for extended periods of time (Broadfoot 1973).

Finding locations that can protect vegetation from flooding as well as desiccation is often very difficult. Revegetation planners are often skirting a thin line between planting vegetation in areas too far removed from river base flow (reduced vulnerability to flooding, but greater vulnerability to desiccation) and areas too close to the water edge (reduced vulnerability to desiccation, but enhanced vulnerability to flooding).

Boulders, large logs, and relatively high terrain can protect vegetation from high flows. At Gleason Flat, for example, the only plants to survive were those planted immediately downstream from a large boulder that offered protection from scouring high flows. Features such as low lying depressions, secondary channels, and organic debris can trap sufficient water, allowing vegetation to survive through periods of drought. At Box Bar planted vegetation survived and grew best in the secondary channel where water availability was greater.

Micro-sites that offer protection from flooding and desiccation (e.g., depressions behind large boulders) are more common in sites characterized by high variability in surface composition and topography. This is one reason why sites like Horseshoe Lake, which are characterized by relatively homogeneous terrain, can be very difficult to plant successfully. Vegetation planted in sites with relatively unvarying topography and surface composition is likely to be affected to roughly the same degree by any of a
number of disturbances. This may increase the chances that none of the planted vegetation will survive.

The dynamics of riparian ecosystems make it impossible for revegetation planners to predict with great certainty a micro-site's vulnerability to flooding and desiccation. However, monitoring ground water levels and the frequency and intensity of flooding can allow revegetation managers to at least avoid planting in the most hostile sites (areas that are influenced by 1- to 2-year floods and areas that commonly experience large drops in the water table). This leads to a certain amount of guess work. Even the most carefully planned revegetation project can be devastated by a rare flood or drought. To increase the likelihood that at least some of the vegetation will be planted in favorable locations, revegetation planners often plant multiple rows of cuttings up bank slopes, perpendicular to streams, rivers, or lakes.

Soil Environment

Soil salinity and texture appear to be two characteristics of the soil environment important to the survival of planted vegetation. Soil salinity should be checked before planting (Anderson et al. 1978). Anderson and Laymon (1988) found that high soil salinity levels (greater than 2.0 μS/mm) may have detrimental affects on growth rates of cottonwoods and willows, and recommended planting in relatively salt-free (< 1200 ppm) soils. To prevent damage to newly planted saplings in areas where soil salinity is
questionable, Anderson and Ohmart (1982) recommend leaching pre-augered holes for 48 consecutive hours.

McBride and Strahan (1984) found that sediment texture influenced natural establishment of several obligate riparian species on gravel bars. *Salix* spp. tended to establish at higher rates where surface sediment was less than 0.2 cm, *Populus fremontii* established at the greatest density on intermediate sediment sizes (0.2-1.0 cm), and *Baccharis viminea* dominated on larger sediments. Such preferential establishment may also apply to artificially-planted vegetation. Goodwin and McKinney (pers. comm.) noted that one possible explanation for low survival rates at Canyon Creek (site #3) and Gentry Creek (site #4) was the fine texture of sediment, which tended to hold water for extended periods of time.

**Sunlight Availability**

It is important for revegetation planners to consider the tolerance of each species to shade. Bammon (pers. comm.) noted that poor results using *Platanus wrightii* (Arizona Sycamore) may have been caused by planting in areas characterized by insufficient direct sunlight. Many of the woody species used in the revegetation projects in this study are pioneer species that are relatively intolerant to shade. *Platanus wrightii* (Reichhardt 1987), *Populus deltoides* (Hosner and Minckler 1963) and *Salix* spp. and *Populus fremontii* (Hall and Forbis, pers. comm.) thrive in areas that receive large quantities of direct sunlight.
Time of Planting

Winter to early spring (February to April) is the best time for planting in desert riparian areas because of higher water availability and lower evaporation rates (Anderson and Ohmart 1982). Few riparian revegetation projects have been attempted during the fall, but this may be a possibility. Under equal irrigation regimes, growth rates of *Atriplex* planted from seed did not differ between March and September plantings (Mills and Tress 1988).

Planting during early spring can give seedlings time to develop root systems before the onset of the hot summer season. Stevens (unpub. report) recommended 4 rules for transplanting either barefoot or containerized seedlings: 1) never allow roots to dry, 2) keep plants cool, 3) compact soil around root systems at planting time, and 4) plant only when soil moisture is adequate.

The time of planting may be determined by when secondary mitigation can be most efficiently implemented. At Coleman Lake, for example, much of the revegetation work had to wait for a dry period when heavy equipment would not bog down in mud.

Obtaining sufficient quantities of vegetation for revegetation projects has become much more difficult in recent years (York, pers. comm.). Revegetation managers need to plan ahead to assure that sufficient quantities of vegetation are available during the time of planting. Nurseries should be given advanced notice as to the type and quantity of plants desired. If poles are going to be used, the harvesting location should be located well before the planting date.
Other Considerations

Irrigation

Recommended irrigation schedules vary considerably due to differences in evaporative demands from one location to the next. From their revegetation experiences along the Lower Colorado River, Anderson and Ohmart (1982) recommend starting irrigation no later than March and irrigating for at least 150 consecutive days at about 113.5 l per tree per day. In an area where soil texture did not change significantly within a 2-m depth, root growth of 2 m was attained after 4 months of watering at about 150 to 200 l per day per tree (Anderson et al. 1978). Forbis (pers. comm.) noted that 30 liters per tree per day for the first three years following planting was not sufficient to establish artificially-planted woody vegetation at Box Bar.

Maintenance is extremely important when irrigation is used. Hall, Forbis, and Pollock (pers. comm.) noted that irrigation systems are prone to frequent break downs. This needs to be taken into consideration during the planning stages. Money and personnel need to be allotted for maintaining the irrigation system.

Planting in Conjunction with Bank Stabilizing Structures

Results at Tubac (site #5), North Tubac (site #6), and Nogales Wash (site #7) demonstrate the potential of planting vegetation in conjunction with stream bank stabilizing structures to increase stream bank stability. Stabilization structures may slow flood waters sufficiently to protect newly planted vegetation when it is most vulnerable.
Using stabilization structures with revegetation may lead to more rapid stream bank stability than using either of the methods alone (York 1985).

This strategy, however, should be approached with caution. Heede (1981) cautioned that all watershed rehabilitation treatments should be based on an understanding of basic geomorphic processes. A stream bank that requires stabilization structures to slow erosion may be too unstable for establishment and growth of many species of vegetation. Whether or not revegetation should be used depends on the degree of instability and the ability of stabilizing structures to lessen instability to the point where vegetation can be established.

Heede (1981) reviewed basic geomorphic processes that should be considered prior to installing stabilization structures. He noted that ranking of network gullies will help considerably to determine the most efficient placement of physical structures. Heede (1981) also discussed design criteria for check dam treatments and vegetation-lined waterways. Schultz and Wilcox (1985) produced a list of planting recommendations for use with various types of bank stabilizing structures.

Root Hormones

Root growth can be promoted on cuttings of various species. Shaw (1983) recommended using indolebutyric acid, naphthaleneacetic acid, or indoleacetic acid. She noted that concentrations of indolebutyric acid between 500 and 10,000 ppm are commonly used, with higher concentrations apparently more effective for hardwood
cuttings. Anderson and Laymon (1988) recommend using indolbutric acid on willow and cottonwood cuttings. They observed significant differences in development between groups of plants treated with IDA and those that were not.

A variety of hormones were used on cuttings and poles planted in the revegetation projects included in this study. None of the respondents, however, were convinced that the results were worth the effort. It seems probable that factors other than root hormones play a greater role in determining pole establishment and survival (e.g., water availability). Further study is needed to determine the effectiveness of root hormones in promoting root growth in wild land situations.

Shaw (1983) noted that fungicides such as captan or benomyl can be applied in combination with rooting compounds.

**Mulch**

Mulching seems to be especially important when an area is revegetated by direct seeding. Proper mulching can conserve moisture, reduce wind and water erosion, and provide a blanket of protection for seedlings that have little resistance to spring frosts (Stevens, unpub. report).

Abbey (1988) noted that covering seeded slopes with various types of mulch (e.g., organic matting or blankets) is especially important in preventing seed losses from runoff, minimizing evaporation, and generally by protecting seed. Manci (1989) noted
that the greater efficiency of matting composed of straw, wood, coconut fibers, or synthetic materials may be worth the added expense.

Pollock (pers. comm.) recommended placing mulch around newly planted poles and seedlings to reduce moisture loss and high temperatures.

**Fencing**

Fencing riparian systems from livestock grazing is a common practice in the western U.S. (Manci 1989). Several authors have summarized various methods for controlling livestock, including barriers, stream crossings, and water access points (Reichard 1984; Platts and Nelson 1985).

**Tree Cages**

Tree cages are commonly made with 3.25 cm mesh chicken wire wrapped around the tree more than once. Tree cages can protect newly planted seedlings from rabbits (*Sylvilagus auduboni*), cotton rats (*Sigmodon hispidus*), deer, burros, beaver, and even cattle (Anderson and Ohmart 1982). Hall (pers. comm.) noted that tree cages can be a formidable obstacle to beaver when they are installed correctly and maintained. He observed that the majority of cottonwoods planted along Francis Creek that were protected with tree cages survived despite a fairly high and active beaver population. Pollock (pers. comm.), however, cautioned that tree cages cannot protect trees when they
are frequently subjected to high waters that enable beaver to swim to the trees and eat above cage growth.

Post-Planting Management

Monitoring

Monitoring of revegetation efforts is an important step that is often not included in the revegetation plan. Monitoring allows the revegetation manager to evaluate vegetation changes, providing the opportunity to improve results by altering revegetation strategies or altering secondary mitigation techniques. Through successful monitoring, past mistakes can be corrected and applied to future revegetation projects.

Monitoring should occur through all phases of the revegetation project. During the first several years following planting, monitoring should concentrate on the health of the trees, root growth, and depth of soil saturation (if irrigation is being used). Carothers et al. (1989) noted that an experienced person can gain much information by simply inspecting trees, noting leaf color, presence of salt burn, and relative growth rate.

Weed Control

Addressing weed management should be a fundamental part of any revegetation project (Anderson, pers. comm.). In many cases, revegetation failure could have been avoided. Several authors have noted the detrimental effect weeds have had on artificially
-planted vegetation. Anderson and Ohmart (1982) recommend not planting if bermuda grass or extensive growth of other vegetation is present. They recommend weeding planted trees throughout the first summer.

Goldner (1981) noted that irrigation design can greatly impact weed proliferation.

Noteworthy Literature

Manci (1889) compiles literature from many different sources concerning many aspects of riparian ecosystem rehabilitation.

Arizona Riparian Council Protection and Enhancement Committee (1990) compiles literature dealing with various riparian issues, including: bank stabilization, beavers, livestock management, natural history, phreatophyte control, plant propagation, revegetation techniques, and seedlings and regeneration.

Murphy’s (1988) evaluation provides additional information learned from revegetation experiences along the Lower Colorado River.
RIPARIAN REVEGETATION MAIL QUESTIONNAIRE

Name & Address

Name of Organization

Phone:

1) Describe the riparian revegetation project in which you were involved. Please include the following in the description: project location, objective, and very brief methodology, and date of completion.

2) List the plant species and the type of propagule used.

3) Briefly describe other mitigating measures.

4) Was the revegetation project a success? Why or why not?

5) Is there anyone else that I could contact that is involved with riparian revegetation work?

6) May I contact you for a follow up evaluation?
RIPARIAN REVEGETATION TELEPHONE QUESTIONNAIRE

Site Description

Site Name: Site Number:
Location: Name of Respondent:
Employee of:
Date of project initiation Date of project completion

Size of site

(1) Which of the following best describes how the site is currently being used?
(A) Recreation, (B) Wildlife Habitat, (C) Livestock Grazing,
(D) None, (E) None of the above

(A) Recreation Yes__ No__
Comments:

(i) What is the predominant recreation activity in the area?
Camping __
Hiking __
Bird Watching __
Other (describe)

(ii) Is there any difference between the current level of recreation activity and the level of recreation activity that existed before the project began?
The level of activity is about the same __
More recreation activity before the project began __
More recreation activity following the completion of the project than before the project began __
Do not know __
(B) Wildlife Habitat

(i) What wildlife species were most threatened by the degradation of the site area?

(ii) Have these species benefitted from the revegetation project?
   Yes__
   No__
   Don’t know__

(iii) If yes, how have they benefitted? If no, why have they not benefitted?

(C) Livestock Grazing

(i) What type of livestock are using the site?
   Cattle __
   Goats __
   Sheep __
   Other ______________

(ii) Describe the intensity of use prior to mitigation.

(iii) Is there a difference between the current grazing schedule and the schedule which existed prior to mitigation? Explain.

(D) Other
Comments:
(2) What was the objective of the revegetation project?
Decrease Erosion Rates __
Bank Stabilization __
Habitat Improvement __
Livestock Forage Improvement __
Recreation Enhancement __
Other

(4) What factor, or combination of factors, were deemed responsible for degrading the site?
Recreation Impacts __
Livestock over-grazing on site __
Livestock over-grazing of uplands surrounding the site __
Wildlife over-grazing on site __
Wildlife over-grazing of uplands surrounding the site __
Urban development __
Pollution __
Upland deterioration __
Other

(a) If more than one was checked, which was most significant?

(5) On a scale of 1 to 5, with 5 being the most severe, how severe were the problems before the revegetation project began? __
Comments (describe the problem):

(6) Was there any indication that site vegetation could regenerate naturally? Yes __
No __

(a) If Yes - What were the indications?
(7) Was the condition of the uplands prior to mitigation?
Unknown __
Poor __
Fair __
Good __
Excellent __
Comment:

(b) How did the uplands impact the project site?

(c) If unknown - Why were the uplands not considered?

DATA

Site environmental information used to plan mitigation.

(8) Information concerning water table fluctuations.

(i) What did the data reveal about the magnitude of water table fluctuations throughout the year? (answer in meters) ___ ___ ___

(ii) How did the water table fluctuation data affect the planning the revegetation project?

(iii) What methodology was used to collect the data?
Explain:

(iv) Over how long of a period was the data collected?
(9) Information concerning regarding the flood frequencies and flood magnitude?
   Yes __
   No __

   (i) What did the data reveal regarding flood magnitude and frequency? (answer in 
       # of major flood events per year) __ __/year

   (ii) How was the flood data collected?

   (iii) How long a period was the data collected?

   (iv) How was the data used in planning the revegetation project?

(10) Information concerning precipitation quantity and patterns.
    Yes __
    No __

    (i) What type of precipitation data was available?

    (ii) How was the precipitation data used in planning the revegetation project?

    (iii) How was the precipitation data collected?
(11) Information concerning soil type.
Yes _
No _

(i) What type of soil data was obtained?

(ii) How was this data collected?

(iii) How was this data used in planning the revegetation project?

(12) Survey of vegetation.
Yes _
No _

(i) List the primary species which were on site before the project’s initiation.
_____________, _______________, _______________, _______________,
_____________, _______________, _______________, _______________,
_____________, _______________, _______________, _______________,

(ii) Were these species controlled?
Yes _
No _

(iii) If yes, describe the control method?
Herbicide _
Burn _
Mechanical control _
Other _
Comments: _
Species used in the revegetation project

(13) What type of vegetation was planted?
   Trees _
   Shrubs _
   Grass _
   Other _

Tree Species

(14) If only tree species were used:

(i) Why were tree species and not a grass or shrub species used?
   Comment:

(15) What tree species were used?

(16) What type of tree propagule was used?
   Poles _
   Containerized seedlings _
   Cuttings _
   Seed _
   Other _

(17) Describe the methodology that was used to plant the tree species.

(18) How many propagules were planted? (# of propagules/acre or lbs. of PLS/acre)

(19) Were root hormones used? Yes _ No _ Comment:
Shrub Species

(20) If only shrubs were used:
(i) Why were shrub species used and not grass or tree species? 
Comment:

(21) What type of shrub species were used?

(22) What type of shrub propagule was used in the project?
   Poles __
   Cuttings __
   Containerized seedlings __
   Seed __
   Other __________________

(23) Describe the methodology that was used to plant the shrubs?

(24) How many shrub propagules were used in the project (# of propagules/acre or lbs. of PLS/acre)?

(25) Were root hormones used?
   Yes __
   No __
   Comment:
Grass Species

(26) If only grasses were used:

(i) Why were grasses used in the revegetation project and not trees or shrubs?

(27) What type of grass species were used?

(28) Describe the methodology that was used to plant the grass species.

(29) How much seed was used (answer in lbs. of PLS/acre)?

(30) Was mulch used during or after the planting process.
   Yes __  Comment:
   No __

If a mixture of species was used:

(31) Why was a mixture of species used?

(i) What advantage was realized by using a mixture of species instead of just one species?

(32) Describe the mixture - what type of species were used and in what proportions.
Post-Planting Management

(33) Describe post-planting considerations.
   irrigation __
   fence __
   monitoring __
   other __

(34) Irrigation
   (i) Describe the irrigation system

   (ii) How often were the plants watered during the period immediately following the revegetation project? (answer in # of watering/day or # of watering/week and the quantity associated with each watering).

(35) Fencing
   (i) Describe the fence design

   (ii) Why was fencing used?
      Wildlife control __
      Livestock control __
      Control of theft and/or vandalism __
      Other __

   (iii) How long have ______________ been separated from the project site area?
(iv) How successful was the fence design?
Comments:

(36) What animals most influenced the site after mitigation was completed?
Cattle __  Moose __  Beaver __
Sheep __  Deer __  Other ___________
Goats __  Rodents __

(i) Describe the impact that the livestock and/or livestock had on the project site area after the completion of the project?
Severe impact __
Moderate impact __
Little or no impact __
Comments:

(37) What other post-planting management was involved?

Results

(38) What were the survival rates of the propagules?
(answer in % survival)
One year after the project's completion __
Two years __
Three years __
Four years __
Five years __

(39) Describe outstanding differences between the site environment at the time of mitigation and today.
(40) On a scale of 1 to 5, how successful was the project in fulfilling its objectives? (with "5" representing a project that was almost 100% successful in fulfilling its objectives) Comment:

(41) Is there any one factor that was largely responsible for the project's success?

(42) Is there any one factor that was largely responsible for the project's failure?

(43) Do you know anyone else involved with riparian revegetation work?
LITERATURE CITED


PERSONAL COMMUNICATIONS


Moore, Catsby. Maracopa County Flood Control. 2801 W. Durango, Phoenix.


