RESTORATION ALTERNATIVE IDENTIFICATION REPORT
ALBUQUERQUE REACH
HABITAT ANALYSIS AND RECOMMENDATIONS STUDY,
MIDDLE RIO GRANDE ENDANGERED SPECIES COLLABORATIVE PROGRAM

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1.0 DEFINING A RESTORATION APPROACH

Factors limiting habitat availability throughout the Albuquerque Reach of the Middle Rio Grande (MGR) (hereafter referred to as the Albuquerque Reach) for the Rio Grande silvery minnow (*Hybognathus amarus*; silvery minnow) and the Southwestern Willow Flycatcher (*Empidonax traillii extimus*; flycatcher) are driven by interrupted hydrological processes through river modification and manipulation of river discharge and the introduction and proliferation of invasive phreatophytes (Mussetter Engineering, Inc. [MEI] 2002, 2006; SWCA Environmental Consultants [SWCA] 2008). Hydrologic modifications, including river regulation, diversion of water, and the structural alteration and development of the floodplain, are key factors that limit the availability of habitat for the silvery minnow and flycatcher.

Channelization and a reduced sediment supply have increased channel incision, resulting in a reduced diversity of aquatic habitats. These changes have reduced the availability of low-velocity habitat, decreased the amount of wetted area through the loss of meandering side channels, and isolated the main channel from its floodplain.

In the MRG, the construction of flood control dams on the mainstem and its primary tributaries have resulted in modified flows (including reductions in peak flows, increases in base flows, and, on occasion, truncated snowmelt and summer monsoon flows) and the realignment of the river channel, including river channelization activities, such as jetty jack installation. These factors have contributed to a system with modified hydrology and geomorphology, including isolating an incised main channel from the historic floodplain.

During summer months the loss of sinuous side channel, backwater, and oxbow habitats results in the loss of low-velocity habitat that is preferred by the silvery minnow. Channel incision results in a monotonous, high-velocity main channel habitat that is beneficial for water transport but detrimental for various life stages of silvery minnow. Habitat that is considered to be preferred by silvery minnow comprises only a small portion of the available habitat (Dudley and Platania 1997), making additional losses of an already rare habitat especially problematic (U.S. Fish and Wildlife Service [USFWS] 2007).

During spring runoff, the loss of floodplain connectivity results in the reduction of low-velocity refuge habitat during high flows (Schlosser 1991; Valett et al. 2005), habitats suitable for larval fish and egg retention (Porter and Massong 2003, 2004, 2006; Fluder et al. 2007; Hatch and Gonzales 2008), and nursery habitat for larval and proto-larval fish (Pease et al. 2006; Hatch and Gonzales 2008).

The impacts on the system can be summarized in the flow chart presented in Figure 1.1. In this conceptual model, the identified stressors would be manifested in ecological and geomorphic effects on the system. These are the conditions that may be observed and measured. The ecological and geomorphic conditions determine the changes in habitat attributes. Changes in habitat attributes operate in a deterministic manner to influence metapopulation responses.

An effective restoration program would operate to mitigate the stressors in order to restore the ecological and geomorphic condition of the system, which would in turn alter the habitat attributes and ultimately provide for a positive metapopulation response. In practice, it will not be possible to reverse the stressors, which is recognized as the constraints under which we operate. Habitat restoration is therefore often implemented to change the ecological and geomorphic conditions in order to affect the desired changes. We measure these changes through assessing whether desired habitat attributes are achieved and whether we are affecting a positive population response.

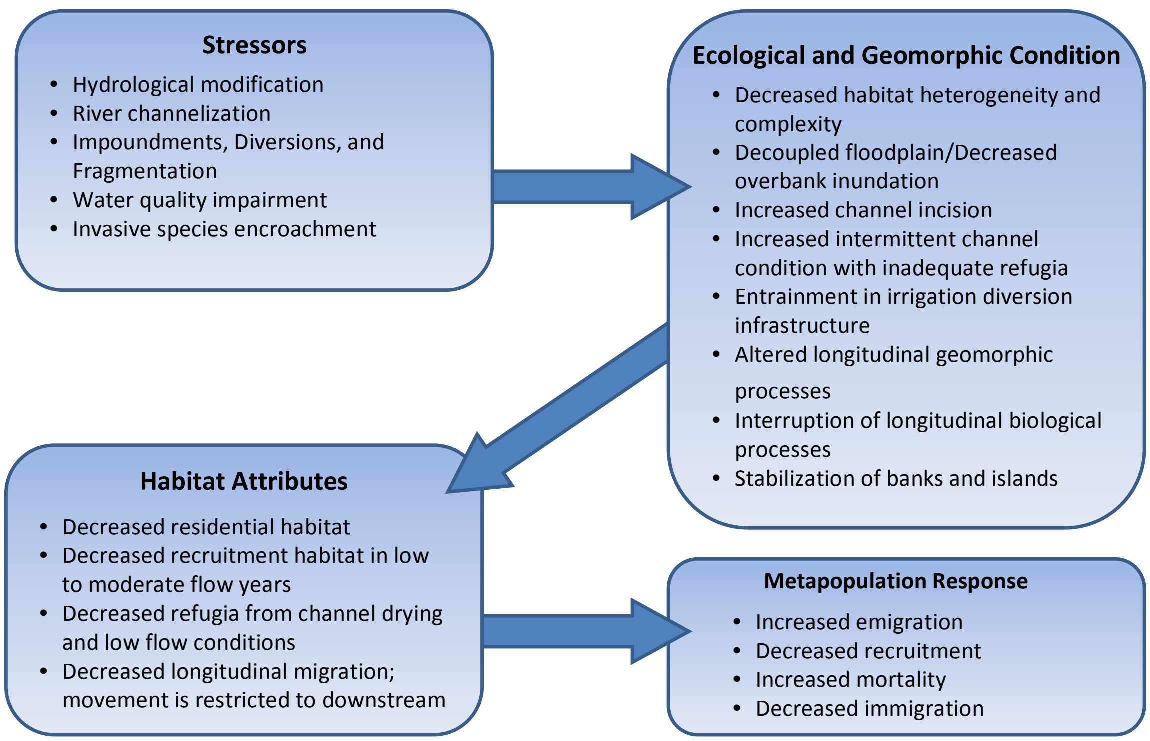

Figure 1.1. Flow chart depicting the Albuquerque Reach problem statement.

1.1.1 RESTORATION GOALS

The primary goal of this document is to provide recommendations to assist the Middle Rio Grande Endangered Species Collaborative Program (Collaborative Program) attain programmatic success for the Albuquerque Reach. The Collaborative Program is a partnership of concerned and/or affected stakeholders that currently includes 20 signatories. The Collaborative Program is organized to protect and improve the status of endangered species in and along the MRG of New Mexico while simultaneously protecting existing and future regional water uses. The two species of concern are the silvery minnow and the flycatcher.

The following goals serve to define the policy domain in which the Collaborative Program operates and the purposes of its cooperative existence:

1. Alleviate jeopardy to the listed species in the program area.
2. Identify and articulate the critical scientific questions that will help evaluate flexibility in the system that was not known to be there in 2003.

3. Understand the system well enough to develop adaptive management tools to support a sustainable Biological Opinion.
4. Conserve and contribute to the recovery of the listed species.
5. Stabilize existing populations.
6. Develop self-sustaining populations.
7. Protect existing and future water uses.
8. Report to the community at large about the work of the Collaborative Program.

Within that context, the actions of the Collaborative Program would:

1. Serve to prevent extinction, preserve reproductive integrity, improve habitat, support scientific analysis, and promote recovery of the silvery minnow and the flycatcher.
2. Promote overall ecosystem health through the restoration of key ecological and physical processes and restoration of aquatic and terrestrial community assemblages.
3. Promote the hydrological connectivity between the active river channel and the floodplain.

Habitat restoration in the Albuquerque Reach would involve the manipulation of the river channel applied in conjunction with passive restoration techniques to meet the life cycle needs of the silvery minnow and the flycatcher. The focus for the silvery minnow will be to apply restoration activities to meet demographic requirements. The focus for the flycatcher will be to improve breeding conditions.

1.1.2 RIO GRANDE SILVERY MINNOW

The principal goal for habitat restoration in the Albuquerque Reach is to:

1. Affect a positive metapopulation response that will maintain a viable population of silvery minnow in the MRG.

A viable population of silvery minnow is self-sustaining in the absence of active management intervention, and it is composed of a sufficient number of individuals to permit adaptation and long-term persistence to occur.[1] For silvery minnow management, a viable population is defined

[1] Because population viability is an element of the purpose and need for management intervention to achieve the goals of the Collaborative Program that benefit the silvery minnow, it is useful to review the information required for an assessment of population viability. This information pertains to 1) species composition (exotic congeners represent a documented threat to population viability); 2) effective population size (including sex ratio, variance in numbers of progeny contributed by any female, temporal fluctuations in reproductive success, overlapping generations, and breeding structure); 3) total population size; 4) proportion of breeding adults; and 5) rate of reproductive failure.

The viability of the silvery minnow in the MRG of New Mexico is governed by the physical and biological setting in which the species occurs, notably including spatial arrangement, persistence, quality and volume of habitat, supply of food (although contemporary population-level evidence of food resource depletion is lacking or confounded in the effects of other stressors), population dynamics, and maintenance of genetic diversity.

to have less than a 10% chance of extinction in 100 years (Mace and Lande 1991) and less than a 10% decline in any annual period. Specific objectives include:

1. A viable population of silvery minnow has successful reproduction at least two out of three years on average.
2. Spring samples that coincide with spawning for population monitoring have no more than one missing age class for age classes I–IV.
3. Viable populations of silvery minnow are free of non-native congeners (e.g., plains minnow [*Hybognathus placitus*]).

1.1.3 SOUTHWESTERN WILLOW FLYCATCHER

The principal habitat restoration goal for the flycatcher in the Albuquerque Reach is to:

1. Increase the size and stability of the MRG flycatcher metapopulation.

A primary need is to provide adequate breeding habitat within the Albuquerque Reach. Flycatchers are currently nesting in all reaches between the Albuquerque Reach and Elephant Butte Reservoir, but no nesting locations are known within or upstream of the Albuquerque Reach, presumably due to a lack of suitable habitat. Another need is to create riparian habitat connectivity along the Albuquerque Reach to create migration stopover habitat and facilitate the dispersal of resident flycatchers throughout the MRG riparian corridor.

Specific flycatcher habitat restoration objectives include:

1. Developing new flycatcher habitat near extant populations by providing and/or increasing the extent, distribution, and quality of nesting habitat close to (30–40 km [19–25 miles]) extant populations (i.e., the Isleta Reach). This will increase the stability of local sub-populations by providing new habitat through
    a. Replacing habitat in the event of destruction of some habitat elsewhere within the MRG.
    b. Creating new habitat for colonization, which will enhance connectivity between sites once occupied.
2. Providing migratory stopover habitat to enhance dispersal and migration throughout the MRG and Upper Rio Grande.
3. Facilitating the establishment of new, large populations in areas where none exist. Through habitat restoration, new large populations (e.g., >25 territories) would be established in areas where few or no flycatchers exist, but where there is a potential for suitable nesting habitat and population establishment.

2.0 RIO GRANDE SILVERY MINNOW HABITAT RESTORATION

2.1 APPROACH TO HABITAT IMPROVEMENT PLANNING

Information deficits presently preclude credible inferences about the determinative role of habitat in limiting silvery minnow population growth based on accurate information on the quantity and distribution of different habitats available to the species, along with direct measures of the consequences (growth, survival, and reproductive success) of occupying different habitat types. To be effective, habitat improvement planning for the various reaches of the MRG must be based on information about factors that limit membership of the species community at various spatial scales and thereby point to specific intervention measures needed to achieve desired management objectives. Spatial scales of environmental units possess a hierarchical structure whose physical attributes are accompanied by characteristic temporal scales that vary from 10^5–10^6 to 10^{-1}–10^0 years from landscapes to microhabitats, respectively (Frissell et al. 1986). The hierarchical nature of environmental units implies that the larger, more stable, environmental units impose limits on the smaller, more variable environmental units and thus lend themselves to statistically nested designs for detecting and understanding habitat-fauna linkages.

Effective strategic planning for silvery minnow conservation requires that environmental variables be examined to reveal nonrandom patterns of aquatic environments in the MRG to aid in determining how fish faunal assemblages are structured by underlying hydrologic, geomorphic, and biotic features of their environment. Conceptually, such partitioning of aquatic habitats is expected to facilitate comprehensive and coherent discussions of management circumstances (problems, constraints, and opportunities) and enable managers to anticipate whole-system effects of proposed management actions. Furthermore, managers will be more likely to plan effective management strategies and incorporate adaptive strategies if the array of aquatic habitats is partitioned into distinct management classes.

Partitioning implies that experimental subjects have been subdivided to form “like units.” This greatly simplifies the task of analysis where there is a great deal of inter-program heterogeneity, which is often intrinsic to management responsibilities that embrace a large geographic area. From a functional perspective, groups are partitioned into spatial subsets of the MRG by problem types, management opportunities, and purpose. In an analytical sense, this partitioning serves to reduce “within partition” variance that otherwise would emanate from different management problems, different management potentials, and different management intervention strategies, all of which would operate to produce differences in marginal gain per management dollar invested.

Two practical questions exist as important foci of this habitat improvement plan: 1) how are assemblages of fish species, specifically those that include silvery minnow, structured by underlying determinants of community composition? and 2) how can ecosystem processes and fish community structure be manipulated to achieve management goals? Answers to these and other related questions depend on an inventory of the spatial matrix of contemporary habitat features, including the nature and location of properly or adequately functioning states and degraded habitat states.

This spatial matrix of contemporary habitat features will form the basis for a common system of spatial coordinates on which to found management objectives and evaluators of program performance. The matrix will also provide an analytical framework for judging program worth and efficiency**.** Basic evaluators of program success can be expressed in terms of a planned state or in terms of the extent to which a problem is ameliorated by management actions.

2.2 SILVERY MINNOW DEMOGRAPHY

Understanding the links between species' fitness characteristics and habitat features is crucial for the effective management and restoration of running water ecosystems. Planning for the adequacy of conservation measures to overcome various habitat limitations ultimately requires that a quantitative relationship between habitat and population size be established for the species and that sufficient habitat be maintained to meet an established recovery target based on the habitat-population relationship. For the silvery minnow, this relationship, although unquantified, is known to vary profoundly by life stage and with varying hydrologic circumstances (Hatch et al. 2008). As such, habitat-population relationships will be complicated by the necessary consideration of age- or stage-specific estimates of survival (i.e., the fraction of the population that successfully recruits to the next age or life history stage) and separate relationships between habitat and abundance for each life stage over a range of hydrologic conditions.

Knowledge of how habitat quality and quantity sequentially limit the abundance of different life stages is fundamental to the identification of habitat essential to species conservation. To be successful, management actions for the conservation of small animal populations, such as the silvery minnow, must generally strive to increase the intrinsic rate of population growth while simultaneously minimizing the between-generation variance of the rate of population growth to reduce the probability of species extinction.

The problems that managers face in the MRG primarily involve systems of interconnected components that are problematic, the effective resolution of which demands systems-level analysis and intervention. Priority management strategies should contribute to the enhancement of silvery minnow reproduction and recruitment and serve to maintain critical source populations with sufficient parental stock to constitute viable populations.[2] These management purposes provide a structured context for organizing relevant information and for formulating and evaluating management alternatives for the conservation of the silvery minnow.

Birth, death, immigration, and emigration represent the primary population processes responsible for changes in population size. If an environmental factor or a management action is to influence

[2] A viable population has been defined as having a low probability of extinction within a specified time frame (Morris and Doak 2002) and large enough to maintain a specified effective population size (N_e), where effective size is a measure of the number of breeding individuals in an idealized population (Wright 1931; Crow and Kimura 1970). Relating population viability to effective size acknowledges the important role of effective size in minimizing inbreeding and maintaining genetic variance. Genetic variance is widely acknowledged to be necessary for adaptability and population persistence, and experiments show a clear linkage of adaptability and fitness with population size (Reed and Bryant 2000; Reed 2005). It is often cited that the maximum acceptable rate of loss of genetic diversity to avoid inbreeding depression is 1% per generation (Frankel and Soule 1981), which will occur on average with N_e equal to 50. However, Reed and Bryant (2000) found that even short-term population persistence required an N_e >50. Others have suggested that an N_e > 500 is necessary for a population to retain its adaptive potential (Franklin 1980). Theoretical assessments suggest that avoidance of long-term detrimental effects of mutation could require an N_e greater than 5,000 (Lande 1995; Lynch 1996), although it has been acknowledged that populations with an N_e > 1,000 can be viewed as genetically secure (National Research Council 2002).

population size, its influence must be registered through one of the primary population processes. As such, these processes represent leverage opportunities for directed management to achieve management purposes. The habitat-based determinants of silvery minnow persistence and population growth form the logical basis for formulating intervention strategies intended to enhance the short- and long-term prospects of species survival—intervention strategies that complement the species' life history, targeting age-specific schedules of reproduction, recruitment, and mortality.

The number, quality, and spatial arrangement of habitat features, along with inter- and intra-patch dispersal capability, greatly affect the ability of the silvery minnow to survive the effects of mortality-causing drought. In a temporally varying environment such as the MRG, the long-run population growth rate governs the vulnerability of a population to extinction. This concept is expressed mathematically as $r - Ve / 2$, where r is the intrinsic rate of population growth and Ve is the between-generation variance of population growth rate (National Research Council 1995). When $Ve / 2 > r$, the population will decline toward extinction deterministically. The expected time to extinction will vary with population size, depending on the ratio of the mean to the variance of the rate of population growth: $\sim r / Ve$ (National Research Council 1995). Age class strength and rates of population growth and mortality of the contemporary silvery minnow population are known to be highly variable in time and space, primarily due to stochastic environmental processes (e.g., drought) and density-dependent compensatory changes in population growth rates. As a general rule of conservation biology, the greater the environmentally driven fluctuations in population growth rate, the greater the risk of extirpation at early time horizons (Morris et al. 1999).

2.2.1 HABITAT-SPECIFIC DEMOGRAPHY

Dudley and Platania (1997) studied “habitat preferences” of the silvery minnow in the MRG at Rio Rancho and Socorro, and they characterize habitat preference and habitat availability in terms of water depth, water velocity, and stream substrate. Both juvenile and adult silvery minnow primarily used mesohabitats with moderate depths (15–40 cm), low water velocities (4–9 cm/sec), and silt/sand substrates (Dudley and Platania 1997). Such avoidance of swift water velocities by the silvery minnow is one means of conserving energy, a general life strategy shared by many lotic fish species (Facey and Grossman 1992). But it remains untested how rates of primary biological processes might be linked to the preferred habitat. Without knowledge of habitat-specific demography, observations of spatial variation in species density associated with various habitat features do not yield reliable inferences about species fitness or dynamics of populations inhabiting such areas (e.g., Pulliam 1988).

Stream depth, velocity, and substrate are often perceived as independent variables when in fact they covary. In many fisheries studies, available habitat is quantified with the implicit assumption that fish abundance is regulated by habitat availability. Yet, many examples exist in which year-to-year variation in fish abundance is large even though available habitat is held constant (e.g., Moyle and Blatz 1985). Conversely, at times of high abundance, fish are found in apparently marginal habitats from which they are otherwise missing. Other evidence suggests that short-term changes in flow, excluding events of total channel drying, cause changes in the distribution rather than the abundance of fish.

Contemporary field studies can only document habitat use relative to availability—not preference. Given the extensive and highly modified geomorphic and hydrologic conditions of the MRG, it is possible that preferred habitat conditions no longer exist. Not knowing the habitat conditions under which the silvery minnow might thrive greatly complicates efforts to improve habitat judged to be degraded. Nonetheless, evidence exists to suggest the silvery minnow is a eurytopic habitat generalist of the sand-bed-dominated MRG potamon. The results of studies by Hatch and Gonzales (2008), coupled with those reported by Cowley et al. (2006) and Buhl (2006), suggest that the silvery minnow is physiologically flexible—capable of surviving absolute extremes and diel fluctuations in chemical and physical conditions. Short of complete or near desiccation of habitat, the silvery minnow exhibits a capacity to withstand the wide variety of environmental conditions common to lotic and lentic habitats of the MRG potamon. However, an extensive literature base generally indicates a clear dependence between year-to-year variability of population size and discharge for a large variety of streams and fish species.

2.2.2 Simulations of Silvery Minnow Demography

The reproductive potential of a year class or life stage is dependent on the time to sexual maturity, the amount of future reproduction, and the age or stage probabilities of survival (Caswell 2001). In a fluctuating population, the reproductive value of future individuals depends on whether a population is increasing, decreasing, or remaining relatively static. The value of each future offspring is diluted when the finite rate of increase (λ) is greater than 1; the value of each offspring is increased when the population is decreasing ($\lambda < 1$). This line of reasoning represents a defensible basis for formulating management strategies to overcome environmental resistance to population growth. The more effective management strategies that target age-specific schedules of reproduction, recruitment, and mortality can be revealed through simulations of silvery minnow demography.

Monte Carlo simulations of silvery minnow demography, based on population projection methods (Caswell 2001), were conducted to evaluate population fates under randomly varied circumstances to estimate the probability that the population would be reduced to various bottlenecks of silvery minnow abundance that would be variously linked to the deleterious effects of inbreeding and maintenance of genetic variation. Simulations utilize software and modeling protocol developed by Cowley (2007). Required model inputs pertain to age-specific rates of species survival and fecundity.

Mathematically credible, even if only provisional, estimates of age-specific rates of silvery minnow survival were derived from life table analysis of silvery minnow length data (USFWS 2006) using a size-at-age relationship reported for the species by Cowley et al. (2006) as a rough guide for interpretation of silvery minnow age (Figure 2.1). For silvery minnows downstream of Isleta Diversion Dam during 2006, survivorship was estimated to be 0.0906, 0.4094, 0.2981, and 0.0000 for age classes I through IV, respectively (Hatch, SWCA, personal communication 2008).[3] Estimates of survival for Age 0 silvery minnows were not possible from the USFWS data source (silvery minnows were not uniformly vulnerable to capture given the survey methods); however, Hatch (SWCA, personal communication 2008) estimates that a rate of survival of

[3] Based on data from Lehtinen and Layzer (1988) and Taylor and Miller (1990), Rees et al. (2005) estimated survival rates for Age 0 and Age I plains minnow to be 0.1 and 0.04, respectively.

0.0074 is necessary just for Age 0 silvery minnow to achieve unity.[4] Barring conditions of cataclysmic drought, 0.0074 could reasonably be regarded as a low bound for a realistic estimate of survival for Age 0 silvery minnow.

Current understanding of silvery minnow age class strength and contemporary rates of survival and mortality can only be considered provisional; however, based on the chronological record of count-based indices of species status,[5] age class strength and the vital rates of birth and death are thought to be highly variable in time and space, primarily due to hydrologic variability linked either to strong recruitment or death.

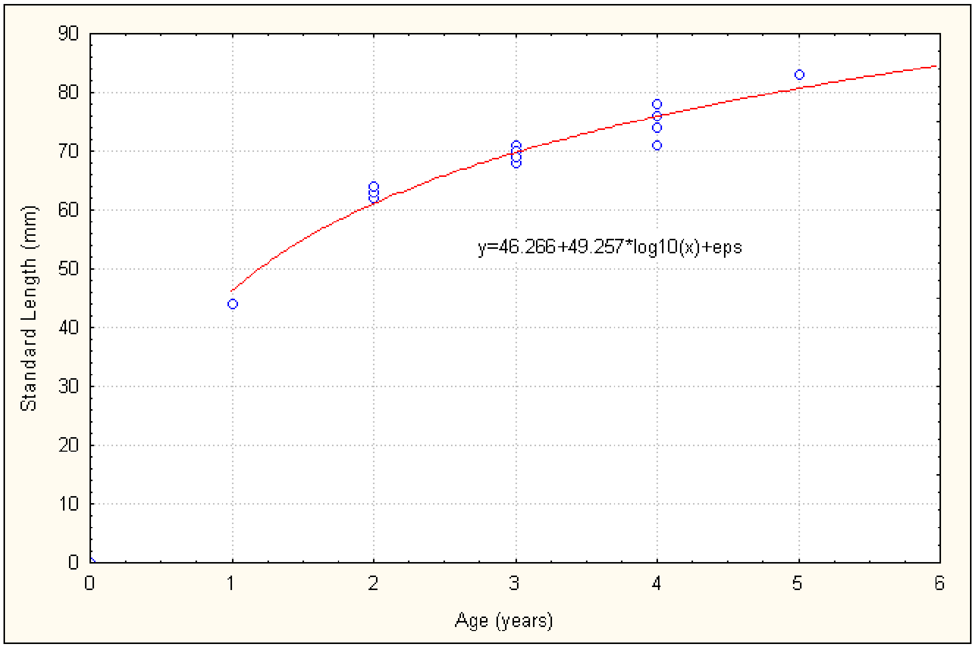

Figure 2.1. Age-size relationship for five age classes (I–V) of silvery minnow in an 1874 sample from San Ildefonso, New Mexico (from Cowley et al. 2006).

The survival pattern produced from life table analysis of data derived from USFWS (2006) is consistent with a Type III survivorship curve (Figure 2.2), indicating that future population growth or decline will be modulated most profoundly by the younger age classes. A stable age class distribution skewed toward Age 0 fish profoundly reduces effective population size (Cowley 2007). This suggests that marginal gains of management to improve the effective population size of the silvery minnow will be maximized through collective actions that improve the rate of survival of young-of-year.

[4] Consider that an average-sized female silvery minnow can produce approximately 3,000 eggs. Working backwards, assume a rate of survival from Age 1 to Age 2 of 0.09. This results in 270 fish (i.e., 3,000 × 0.09); 135 of each sex, assuming a 50:50 sex ratio. From this, just to achieve unity (i.e., just to replace one's self) requires a rate of survival of 0.0074 (i.e., 1/135).

[5] The referenced chronological record of count-based indices of species status is derived variously from records of the Division of Fishes, Museum of Southwestern Biology, University of New Mexico and the American Southwest Ichthyological Research Foundation.

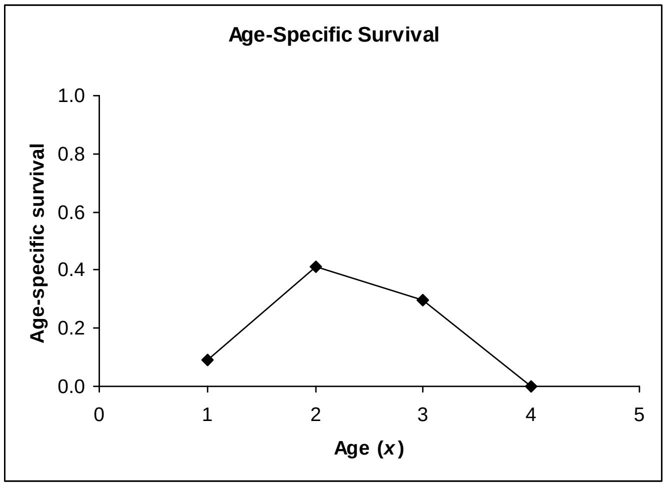

Figure 2.2. Age-specific survivorship curve for silvery minnow (derived from data presented in USFWS 2006).

As presented, the foregoing estimates of silvery minnow survivorship represent static measures and are, therefore, poor at elucidating dynamic relationships between environmental factors, which vary over time and space, often stochastically, and rates of critical biotic processes. It should not be assumed that the silvery minnow experiences a single rate of survival over time and space. While informative, *grand index* expressions of survival rates can give the false impression of environmental stasis. A grand index does not reveal the variability in survival rates that accompanies environmentally driven variation in habitat quality and quantity that is known to be extreme in the MRG. Habitat patch quality in the MRG is heterogeneous. Differential occupancy of different kinds of patches is an important determinant of the species' long-term prospects of survival.

Although fecundity of silvery minnow has not been systematically or extensively investigated, it is reasonable to expect that fecundity increases with standard length and total body weight as noted by Taylor and Miller (1990) for the plains minnow. We employ the mathematical relationship of mature ova to fish length reported for the plains minnow by Taylor and Miller (1990) to develop a theoretical fecundity of the silvery minnow.[6] This hypothetical fecundity-size relationship for the silvery minnow was generated for the range of sexually mature silvery minnow reported by Hatch and Gonzales (2008) and for fish lengths in which a positive relationship between fecundity and standard length existed (Figure 2.3).

[6] Taylor and Miller (1990) report the number of mature ova in plains minnow to be significantly correlated to standard length ($F = 7284.83 – 271.62[SL] + 2.71[SL^2]$; $r = 0.96$; $P<0.0001$). They also report the number of mature ova in plains minnow to be significantly correlated to total body weight ($F = -610.21+ 311.97[SL]$; $r = 0.96$; $P<0.0001$).

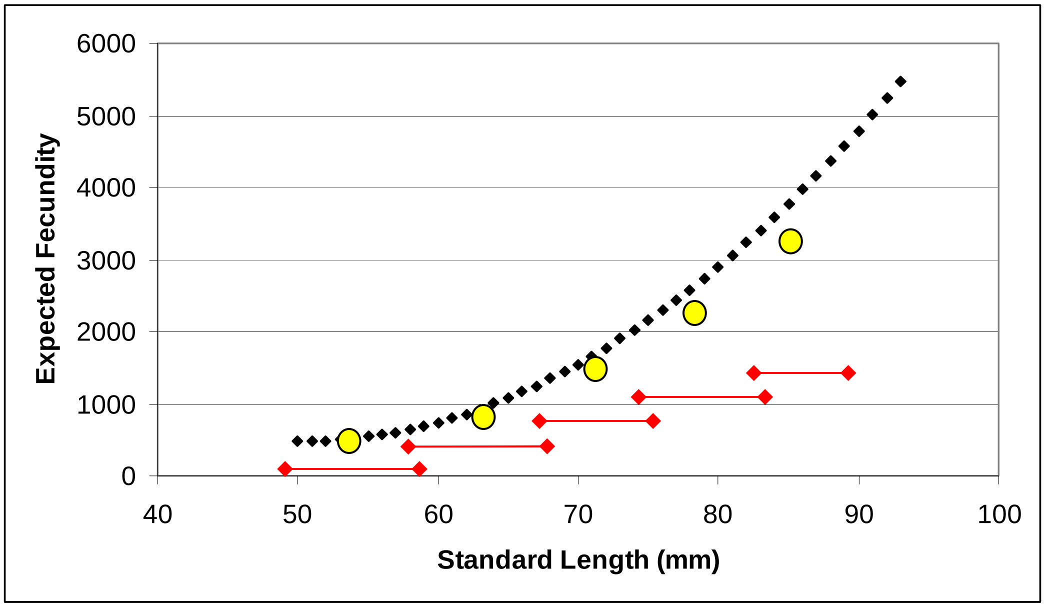

Figure 2.3. Theoretical fecundity of silvery minnow (based on a relationship of mature ova to fish length reported for plains minnow by Taylor and Miller [1990]).

The model includes provisions for specifying input parameters regarding age-specific survival and fecundity. The model also accommodates user-defined parameters that are incorporated in model simulations to better represent silvery minnow population dynamics that include variation in inter-annual rates of survival and year class reproductive output, along with random rates of population-wide missing young-of-year age classes that result from reproductive failure or the failure of Age 0 fish to recruit to the Age 1 year class due to various stressors. Density dependence constraints have not been included in simulations.

Simulations were carried out for a 100-year period and replicated 1,000 times for a practical range of Age 0 failure rates (i.e., 0.0 to 0.5). Simulated probability of extinction was estimated by dividing the number of populations that went extinct by the number of replicates. A synthesis of model outputs pertaining to a series of low population probabilities and extinction probabilities that vary as a function of population-wide age class failures appears in Table 2.1.

Because viable population size increases as the failure rate for the younger age classes increases, it is prudent to maximize survival and manage for larger population sizes to accommodate temporal variation in demography and habitat quality (Cowley 2007). However, large population size does not appreciably reduce a population's risk of extinction under high environmental variation that leads to a weak or missing young-of-year age class.

Table 2.1. Critical Population Probabilities Derived from Monte Carlo Simulated Silvery Minnow Demography

Age Class Failure Rate	Population Bottleneck Probabilities					Probability of Long-term N_e <500	Probability of Extinction Over 100 Years
	<50	<100	<150	<200	<250		
0.0	0.000	0.000	0.001	0.002	0.003	0.019	0.000
0.1	0.074	0.108	0.124	0.145	0.155	0.188	0.018
0.2	0.483	0.537	0.562	0.584	0.606	0.603	0.296
0.3	0.876	0.906	0.915	0.923	0.930	0.917	0.790
0.4	0.989	0.995	0.995	0.995	0.996	0.995	0.981
0.5	0.998	0.998	0.998	0.998	0.998	0.998	0.998

Note: Tabulated values are probabilities that the population would be reduced to various bottlenecks of abundance that would be variously subjected to the deleterious effects of inbreeding and maintenance of genetic variation to evaluate population fates under randomly varied circumstances.

2.3 HABITAT DETERMINANTS OF SILVERY MINNOW PERSISTENCE AND POPULATION GROWTH

2.3.1 ADAPTATION TO FLOW DISTURBANCE REGIMES

Ecologically, floods and drought represent flow disturbance regimes in the MRG that serve to differentially advantage or disadvantage species, thereby regulating species diversity and species abundance across a range of spatial and temporal scales. Frequent and predictable extremes in flow tend to operate selectively to produce life history strategies in native fish species that optimize the allocation of resources to critical life functions, notably including maintenance, growth, and reproduction. Adaptive traits emerge over evolutionary time that enables species to survive flow disturbance regimes (Lytle and Poff 2004).

The mode of adaptation determines an organism's vulnerability to flow patterns, including disturbance regimes. Generalist species tend to dominate variable discharge running water ecosystems in response to uncertainty of critical resources, whereas ecological specialists tend to be more common in streams that have predictable discharge (Horwitz 1978; Poff and Allan 1995). Species exposed to strong environmental variation within generations often exhibit a broad tolerance to diverse conditions through physiological flexibility (Levins 1968; Matthews 1987). Understanding the links between species' fitness and flow regime is crucial for the effective management and restoration of running water ecosystems.

The species of diatoms foraged by the silvery minnow provide information about the environmental conditions of the Rio Grande. Shirey (2004) has compiled frequencies of diatoms with varying environmental associations with trophic state, saprobity, oxygen saturation, pH, salinity, and nitrogen uptake metabolism. Shirey's (2004) results show that the silvery minnow forages in nutrient-enriched eutrophic conditions, with 40% of the diatoms typically found in highly productive waters and 10% indicative of highly enriched environments with high production of organic matter. Shirey (2004) finds further evidence of nutrient-enriched waters in 1874. At this time, there was a clear dominance (approximately 90%) of mesosaprobous taxa, which are associated with low to moderate oxygen saturation and moderate to high biological oxygen demand (Van Dam et al. 1994). More than 20% of the diatom taxa were obligate nitrogen heterotrophic species (Shirey 2004), indicating a requirement for continuously elevated concentrations of nitrogen (Van Dam et al. 1994). A majority of the diatom species foraged by the silvery minnow were alkaliphilous. Thus, the gut content analyses indicate that the silvery minnow can tolerate nutrient-enrichment, alkaline waters, and low oxygen concentrations (Cowley et al. 2006).

Laboratory studies of silvery minnow physiological tolerance by Buhl (2006) are consistent with the findings of Shirey (2004) and Cowley et al. (2006). Maximum lethal limits (LL_{50}) for temperature and maximum lethal concentrations (LC_{50}) of dissolved oxygen and ammonia for the silvery minnow have been investigated by Buhl (2006) for four age groups of silvery minnow (i.e., 3–4 days post-hatch [dph] larvae, 32–33 dph juveniles, 93–95 dph juveniles, and 11-month old subadults) in reconstituted water that simulated conditions in the MRG. Larvae and juveniles were determined to be more tolerant of high temperatures and hypoxic conditions (LL_{50} 35ºC–37ºC [95ºF–98.6ºF]; LC_{50} 0.6–0.8 mg/l dissolved oxygen) compared to subadults (LL_{50} 32ºC – 33ºC [89.6ºF–91.4ºF]; LC_{50} 0.9–1.1 mg/l dissolved oxygen). Based on nominal total ammonia concentrations, Buhl (2006) found larvae were about twice as sensitive (96-h LC_{50} for all pulses, 16–23 mg/l as N) as both juvenile age groups (96- h LC_{50} for all pulses, 39–70 mg/l as N).

Planning for the provision of habitat to overcome flow disturbance regime limitations requires that a quantitative relationship between habitat and population size be established for the species and that sufficient habitat be maintained to meet an established recovery target based on the habitat-population relationship. The importance of each population segment to species persistence and population growth will depend on relative rates of birth, death, growth, and survival, as well as various expressions of habitat quality, including habitat size and stability, and a suite of associated natural and anthropogenic threats (e.g., point sources of mortality-causing water pollution). The more expansive perennial habitats are vital to silvery minnow survival due to enhanced temporal environmental stability intrinsic to such habitats. These habitats have a heightened capacity to support silvery minnow across generations and often exist as the source stock to repatriate empty habitat patches. Habitat patches that are subject to periodic discontinuity of flow exhibit variation in the long-term frequency, magnitude, and predictability of mortality-causing events, and as such, vary in their ability to support silvery minnow across generations.

The implications of diminished wetted habitat for the conservation of the silvery minnow will be different for population sources versus population sinks. Naturally, the loss of habitat that affects source populations will have a greater impact on long-term population trajectories than it would on sink populations. Predicting silvery minnow population dynamics under randomly varying circumstances, including situations in which species persistence is threatened by the loss of large tracts of habitat, must ultimately account for exchanges between population sources and sinks and how rates of birth, death, and dispersal vary between different habitat patch types and how these processes affect population persistence.

2.3.2 Reproductive Biology—Hydrologic Dynamics Linkages

Because the reproductive biology and early life history of the silvery minnow is intricately linked to hydrologic dynamics of the basin, it is instructive to characterize the natural hydrologic characteristics that would have occurred in the MRG with sufficient predictability and frequency to produce, through selection, traits adaptive to the peculiar environmental circumstances of the MRG. Flow records from Otowi for the period of 1895 to 1930 provide a perspective of the relatively unaltered hydrograph for the northern portion of the MRG. Figure 2.4 illustrates both the infrequent extremes (maximum and minimum discharge values) and the more frequent, but extreme conditions (i.e., plus or minus two times the standard error) associated with the long-term average dynamics of the relatively unaltered flow regime in the northern portion of the MRG (at the U.S. Geological Survey [USGS] gage at Otowi).

Assuming autocorrelation among MRG gages, it is expected that the hydrologic patterns exhibited at Otowi would be repeated at points downstream, differing primarily in magnitude of discharge. Of the variable hydrologic conditions common to the MRG, the more frequent extremes in long-term average dynamics of the flow regime are most important from an evolutionary perspective. In theory, such conditions would have conceivably been affiliated with silvery minnow mortality and would have occurred with sufficient predictability and frequency to have served as a selective basis for life-history adaptation.

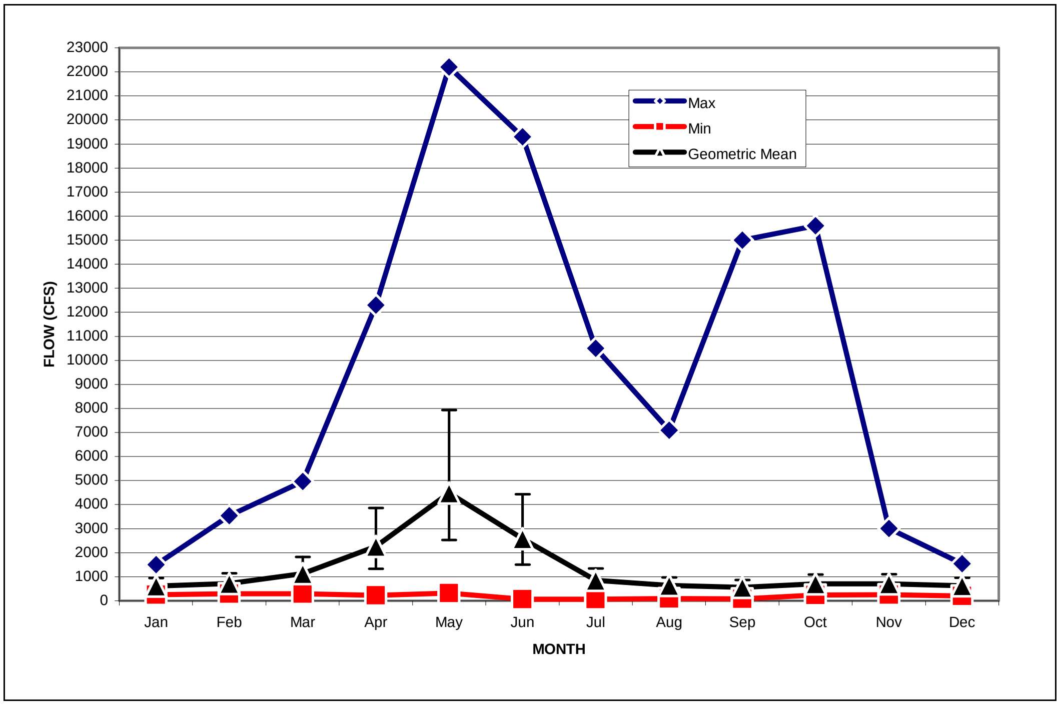

Figure 2.4. Monthly discharge statistics at the Otowi, New Mexico, stream flow gage for the period of 1895–1930 (with a hiatus in records from January 1, 1906–June 30, 1909). Error bars on geometric mean flow represent plus or minus two times the standard error (accounting for skewed distribution). Data are derived from flow records published by the USGS (2009).

A notable consequence of anthropogenic modification of the natural flow regime in the MRG is the elimination of extreme high-flow events. Compared to the early settlement hydrograph (pre-1931), the contemporary (post-1975) hydrograph is characterized by reduced monthly average flow, most profoundly for April through June, and reduced variation across and between months. Analysis of the Albuquerque gage (USGS 08330000) pre-Cochiti Dam and post-Cochiti Dam confirms this trend (Table 2.2). However, broad temporal patterns in the hydrologic regime have been retained over time. The highest hydrologic discharge events in the MRG have remained linked most predictably over time to snowmelt, the height of which generally occurs each year during May, but also occurs with high frequency as early as April and as late as June. Variability in flow is generally greatest at values in excess of the mean (i.e., variation in discharge is acentric about the mean). The periodicity and volume of high discharge events associated with runoff from monsoon rains is stochastic in nature and is therefore inherently less predictable than snowmelt-associated discharge. Whereas temporal aspects of snowmelt discharge have remained relatively predictable over time, the magnitude of snowmelt discharge was generally higher and more variable historically compared to the contemporary flow regime. Generally, average discharge in the MRG has diminished with increasing distance from headwater tributaries, predictably resulting in fish mortality as flows are frequently reduced to base discharge with attendant extremes in water quality and periodic cessation of flow over extensive reaches of river, especially outside the influence of runoff from snowmelt and monsoonal rains (Baldwin 1938).

Table 2.2. Flow Duration Data (cfs) – Rio Grande at Albuquerque

Percent Exceedance	Pre-Cochiti Annual	Post-Cochiti Annual	Pre-Cochiti Spring	Post-Cochiti Spring
10%	2,500	3,400	4,700	5,100
50%	590	800	910	1,750
90%	40	310	130	470

Presuming that the variable aspects of the hydrograph depicted in Figure 2.4 emulates to some degree the "natural" circumstance that presided over a period of adaptive evolution of silvery minnow, it is not surprising that the species coordinates its spawning with periods of hydrologic abundance. Likewise, it seems adaptive that, in the context of suboptimal conditions, the timing and duration of silvery minnow spawning seems strategically more aligned with an opportunistic approach to reproduction—spanning a range of conditions and time that correspond to different possible future environmental states with variable probabilities for species recruitment (Lytel and Poff 2004). Indeed, low-flow spawning by silvery minnow, although limited, has been documented during 2006, resulting in recruitment of silvery minnows to at least the juvenile stage (USFWS 2007).

Dudley and Platania (2008) confirm the importance of spring runoff events to silvery minnow recruitment. Silvery minnow densities in October were positively correlated with peak discharge and duration of high flows during the May through June spawning season (Dudley and Platania 2008). Silvery minnow densities were lowest in the period from 2001 to 2004, which corresponded to periods of reduced spring runoff (Figure 2.5). Silvery minnow densities dramatically in the period of 2005 to 2007, particularly in 2005 following a prolonged high-flow spring runoff event. Prolonged inundation of vegetated overbank areas and inundated habitats within the channel (such as bankline features and backwaters) were cited as essential habitats to the successful recruitment of early life-stage fish (Dudley and Platania 2008).

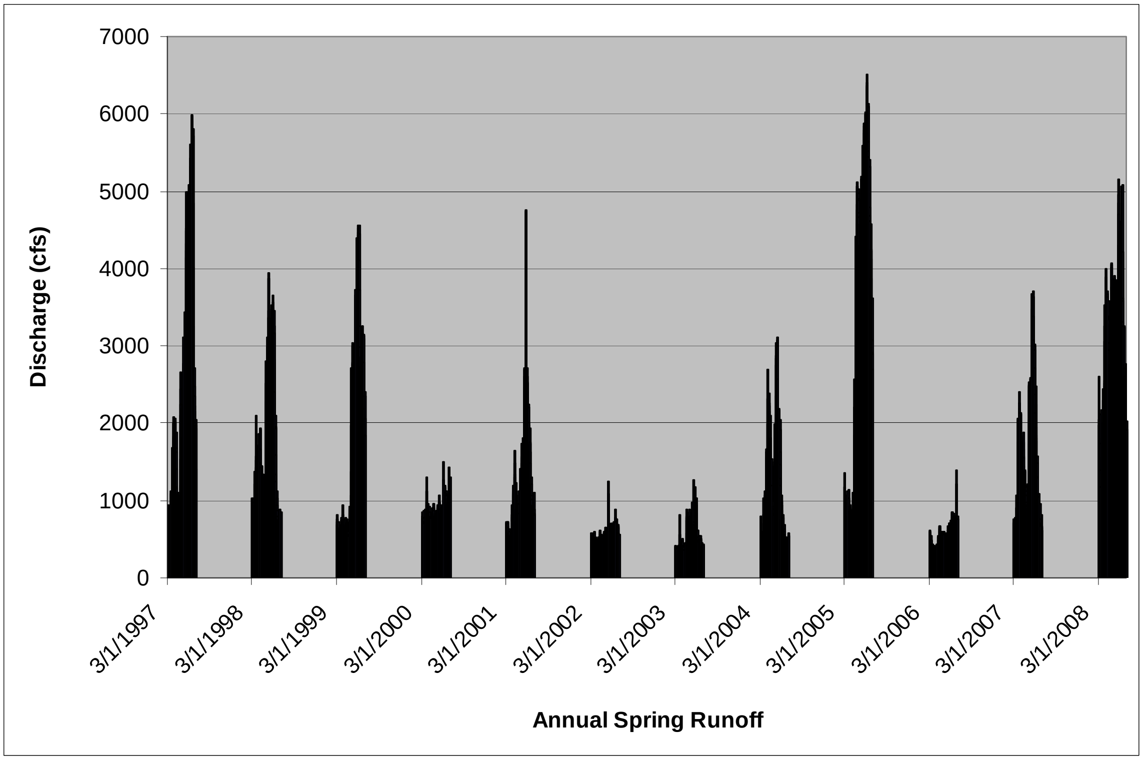

Figure 2.5. Spring runoff peak discharge for the period 1997–2008 for the Albuquerque gage (USGS 08330000). Runoff period presented is March through June in each year.

Note that in 2001, the peak discharge was for a brief period of only a couple days. Analysis of Dudley and Platania (2008) data indicates that this was a poor recruitment year, varying only slightly from the previous year. Hatch and Gonzales (2008) suggest that flows that inundate the floodplain will contribute to strong silvery minnow recruitment classes so long as the sustained duration of river channel-floodplain coupling is maintained above a minimal threshold that will provide time for the parental stock to occupy the floodplain and spawn, for embryo development and hatching, and for young-of-year to develop to the juvenile stage to successfully evacuate the draining floodplain habitats We hypothesize that moderate to high flows that inundate the floodplain for a minimum period of 7 to 10 days is required to stimulate silvery minnow recruitment.

Prolonged low-flow conditions are also expected to adversely affect silvery minnow populations. Low-flow conditions that result in fish mortality may be linked to climatic variability[7] exacerbated by extractive us of water in the basin. Dudley and Platania (2008) suggest that

[7] Dating back at least to recent prehistoric times, conditions of extreme climatic and hydrologic variation have prevailed over much of the Southwest, including the Rio Grande Basin. During the Holocene Epoch, deep and long-lasting periods of drought have punctuated various millennially spaced episodes of increased precipitation, the most recent of which coincided with the Little Ice Age (Castigilia and Fawcett 2006). The most significant recent long-lasting periods of drought occurred during the years between approximately A.D. 300 and 500 and again between approximately A.D. 1400 and 1600 (Grissino-Mayer 1996). Compared to these late prehistoric and early historic periods of drought, periods of aridity and variation in water supply over the past 400 years have been mild, including the period of aridity during the 1950s—the most severe drought of the twentieth century.

October densities of silvery minnow were negatively correlated with extended low-flow periods. In particular, poor spring runoff and low-flow conditions leading to intermittent channel drying, which occurs in the Isleta Reach, were cited as conditions that lead to reduced silvery minnow survival. Suggested contributing factors include crowding, stress, contaminant concentration, and poor habitat quality.

In the Albuquerque Reach, the river has not experienced intermittent drying since the closure of Cochiti Dam under current hydrologic management scenarios. However, prior to the closure of Cochiti Dam, the historical record indicates that intermittent channel drying had occurred, albeit relatively infrequently. FLO-2D[8] modeling suggests that the Albuquerque Reach would not experience intermittent drying during extremely dry years, but that very low flow conditions could persist throughout the lower parts of the reach.

2.3.3 METAPOPULATION FEATURES

An overarching theme, one critical to the consideration in the conservation of small animal populations, pertains to spatial aspects of the structure of silvery minnow populations. Spatially structured populations are generically referred to as "metapopulations." A population's spatial structure depends fundamentally on habitat quality, spatial configuration of subpopulations, and dynamics of species abundance, as well as the dispersal characteristics of individuals in a population. Effective recovery efforts for species inhabiting variable environments require the consideration of processes operating at multiple scales, ranging from landscape-level processes that create and maintain residential and refugial habitats, along with floodplain habitats conducive to species spawning and recruitment, to fine-scale processes that govern local features of habitat regardless of overarching patterns of the river continuum (Vannote et al. 1980; Labbe and Fausch 2000). Clearly, the discussions of residential, refugial and floodplain habitats for silvery minnow are pivotal to the species' metapopulation structure and are of critical concern for species conservation. These concepts represent a logical basis for formulating intervention strategies that complement the species' life history, targeting age-specific schedules of reproduction, recruitment, and mortality intended to enhance the short- and long-term prospects of species survival. Pivotal concepts that pertain to the provision of residential and refugial habitats for the silvery minnow conservation include the following.

Source-Sink Population Structure

The fact that habitat patch quality in the MRG is heterogeneous and that the silvery minnow differentially occupies different kinds of patches is an important determinant of long-term population trajectories (Hatch et al. 2008). It is important to understand how demographic processes that affect population size vary over the array of available habitat patch types. In simple terms, population growth can be regarded as a function of reproduction, recruitment, age-specific schedules of mortality, and rates of dispersal in the form of immigration and emigration. Areas or locations where local reproductive success is greater than local mortality are referred to

[8] FLO-2D modeling was completed to simulate conditions when the Albuquerque Drinking Project passed the minimum of 196 cfs over the diversion dam as specified by the USFWS (2004). The simulation indicated a 20% reduction in peak flows between the diversion dam and the bottom of the study reach during summer months. Thus, the reach is not expected to experience channel drying but could experience very low flow periods.

as population *sources*.[9] Poorer quality patches that lead to low birth rates and high death rates are regarded as population *sinks*. To understand the patch dynamics of a population in which some individuals reside in source habitats and others in sink habitats, it is necessary to consider the population dynamics of each source and sink subpopulation, and then consider how the distribution of individuals in sources and sinks influences the dynamics of the greater source-sink system. In reality, mapping of silvery minnow source-sink population segments exclusively on the basis of population demographics will be effectively impossible. However, incorporation of auxiliary information relevant to the mortality-causing disturbance mosaic and gradients of habitat conditions should provide a robust and managerially meaningful basis for partitioning silvery minnow population sources and sinks (Hatch et al. 2008).

The importance of each population segment to species persistence will depend on relative rates of birth, death, growth, and survival, and various expressions of habitat quality, including habitat size and stability, and a suite of associated natural and anthropogenic threats. Distinguishing between source and sink populations is fundamental in the process of identifying populations essential for species persistence. Failure to distinguish this dichotomy among silvery minnow populations may result in protection of sinks instead of sources and unrealistic assessments of extinction risk. Likewise, identification of threats for different populations is essential for determining which populations are critical for species persistence, and whether recovery actions need to focus on increasing population size and habitat quality or on reducing risk from human impacts.

Source-sink theory is dependent on the identification of habitat patch types and understanding how silvery minnow population dynamics are structured by underlying physical, chemical, and climatic features of the local environment. The spatio-temporal dynamics of wetted habitat offers clues of the relative ease (or difficulty) of maintaining refugia for the silvery minnow. The frequency and interval duration of river expansion-contraction cycles, along with the extent of perennial habitat created by a given volume of water, are metrics of evaluation that would likely be useful in identifying sites where the maintenance of refugia would prove to be most economical in terms of required water resources. Likewise, areas where the abundance of silvery minnow is greatest would theoretically represent areas where the development and maintenance of refugia would prove most beneficial to the species. The areas in which the paired values for the suggested metrics of evaluation are greatest would conceivably represent the locations where silvery minnow refugia can be developed and maintained most economically.

The most important influence of the spatial arrangement of habitat types on overall species viability is the extent to which populations of silvery minnow at different sites share the same fate at the same time. The risk of extinction is reduced with an increased number of high-quality (extinction resistant) populations with independent fates. The larger residential patches offer a heightened level of resistance to mortality that often accompanies low or nonexistent river flows. Such habitats have the capacity to support silvery minnow across generations and often exist as the source stock to repatriate empty habitat patches (Lake 2003). Habitat patches that are subject to periodic discontinuity of flow are expected to vary in their ability to serve as silvery minnow

[9] Inference about habitat suitability requires knowledge about species abundance and rates of vital biological processes along with knowledge about how long-term patch dynamics are structured by underlying physical, chemical, and climatic features of their environment.

refugia, as manifested in the long-term frequency, magnitude, and predictability of mortality-causing events. The implications of diminished wetted habitat for the conservation of the silvery minnow will be different for population sources versus population sinks. Naturally, the loss of habitat that affects source populations will have a greater impact on long-term population trajectories than it would on sink populations.

Refugial habitats designed to reduce the mortality of future parental stock, often by even a fraction of a percent, can have profound effects on future population trajectories. An exponential increase in the number of silvery minnows, observed in surveys for fish that coincided with channel-drying events over the period of 2003 to 2005 (USFWS 2006, 2007) suggests that the species has an inherent capacity for high rates of population growth, apparently regulated by compensatory density-dependent factors operational over a wide range of parental stock abundance. Because viable population size increases as the failure rate for the younger age classes increases, it is prudent to maximize survival and manage for larger population sizes to accommodate temporal variation in demography and habitat quality (Cowley 2007).

The implications of diminished wetted habitat for the conservation of the silvery minnow will be different for river segments designated as population sources versus those designated as population sinks. Naturally, the loss of habitat that affects source populations will have a greater impact on long-term population trajectories than it would on sink populations. It is imperative that every effort be made to identify and conserve source populations in an effort to maximize overall capacity for population growth.

Prospects of species survival are enhanced to the extent that population densities can be maintained above levels subject to depensatory deterministic effects. Minimum population size needed to achieve some standard of viability will occur at the highest survival rate of young-of-year and no population-wide year class failures (Cowley 2007). Viable population size increases as the failure rate for the younger age classes increases. Therefore, it is prudent to maximize survival and manage for larger population sizes to accommodate temporal variation in demography and habitat quality (Cowley 2007).

2.4 HABITAT FEATURES

The variability of flow characteristics in the contemporary MRG, resulting either from natural or regulated causes, imparts a patchiness of environmental types at the scale of river segments, including the extremes represented by hydrologic abundance and periodic discontinuity of flow, with a continuum of intermediate types between these extremes. The magnitude and variance of flow within and between seasons is a direct determinant of silvery minnow reproduction, dispersal, and survival, the effects of which are reflected in patterns of species distribution and age composition (e.g., Hatch et al. 2008).

2.4.1 RESIDENTIAL HABITATS

Residential habitats comprise segments of the active river channel with contemporary long-term perennial flow patterns maintained at or above reach-specific, long-term seasonal baseline discharge volumes. Such habitats are conducive to the long-term persistence of the silvery minnow. River segments with predominant sand or finer substratum and contemporary long-term perennial flow patterns maintained at or above reach-specific, long-term seasonal baseline discharge volumes and contemporary long-term irrigation season-specific probabilities of flow intermittency less than 0.10 are classified as residential habitats. The larger perennial-flowing river segments offer a heightened level of resistance to environmentally driven fluctuations in population growth rate mortality.

Residential habitats encompass the silvery minnow habitat preferences suggested by Dudley and Platania (1997), including:

1. Water velocity: the silvery minnow is most abundant (86.5%) in areas with little or no water velocity (<10 cm/sec), seen occasionally (11.0%) in areas of moderate velocity (11–30 cm/sec), and seen rarely (0.8%) in habitats with water velocities greater than 40 cm/sec.
2. Water depth: the species is most commonly caught in depths of less than 20 cm (7.9 inches) or 31 to 40 cm (12.2–15.75 inches). Few use areas with depths greater than 50 cm (19.7 inches).
3. Substrate: the species is most commonly (91.3%) caught over silt. Sand is the second most common substrate (8.1%), while gravel and cobble account for less than 1% of the substrate frequented.
4. Mesohabitat diversity: the most frequently used habitats are eddies formed by debris piles (40.5%), pools (35.9%), and backwaters (13.8%), reflecting a preference for low-velocity areas. Main channel runs are the most abundant mesohabitat.

Residential habitats would also provide for seasonal habitat preferences. Habitat use differs from summer (April–September) to winter (October–March). Summer habitats include pools and backwaters. In winter, preferred habitat is found near instream debris piles; at that time, more than 70% of specimens are found in or adjacent to debris piles (Dudley and Platania 1996). Diminished water velocity appears to be a major factor influencing winter habitat selection. The species also shifts to deeper waters in the winter. Median depth shifted from 11 to 20 cm (4.33–7.87 inches) in the summer to 31 to 40 cm (12.2–15.75 inches) in the winter. Deeper areas generally have lower water velocities. Individuals are found almost exclusively over silt and sand substrata in both the summer and winter. However, all substrate classes, except boulders, are used to some degree.

Three residential habitat subtypes are proposed, including a low-flow (1,500–2,500 cfs) subtype characterized by deeper, highly variable thalweg depths and lower and highly variable width to depth ratios (W/D); intermediate flow (2,500–3,500 cfs) subtype characterized by intermediate thalweg depths and intermediate W/D; and a high flow (>3,500 cfs) subtype characterized by shallower, less variable thalweg depths and higher, less variable W/D.

2.4.2 Recruitment Habitat Features

Seasonally inundated floodplains of the pre-1930 (early development) era MRG routinely provided heightened heterogeneity of habitat and structural refugia for developing stages of fish relative to the active channel. Growth of the silvery minnow can be especially rapid in newly flooded habitats that support highly productive food chains founded on the bacterial conditioning of retained fine and course particulate organic material and newly inundated terrestrial vegetation. Heightened floodplain productivity is further enhanced by lower water exchange rates, heightened subsidy of allochthonous energy inputs at the aquatic-land interface, and heightened temperatures characteristic of such areas (Schlosser 1991; Valett et al. 2005). However, the productivity of these habitats can be lost if the river channel floodplain become uncoupled prematurely (i.e., before eggs hatch and fish mature to post-larval stages) or if flows are abruptly reduced and, as a consequence, strand fish.

Three floodplain habitat management class subtypes are proposed for the MRG to distinguish habitat segments lateral to the active river channel on the basis of the relative extent and duration of floodplain-river coupling and in terms of site attributes that determine the nature of localized biophysical/chemical processes[10] and environmental stability that collectively concern habitat quality. The timing and extent of floodplain-river coupling is vitally linked to species reproduction whereas ecosystem services and environmental stability relate to the utility of these areas as nursery habitats with cascading effects on species recruitment to the juvenile stage. Use of these discrete management classes will facilitate choosing appropriate management alternatives for different river segments and will facilitate prioritizing management efforts.

The three recruitment habitat management class subtypes span the range of possible levels of continuity of floodplain-river coupling and site attributes related to habitat quality. **High-flow recruitment habitat sites** constitute moderate water exchange (i.e., overall average water velocity less than 0.2 m/s) areas of at least 1 acre in which incipient inundation occurs at river discharges greater than 3,000 cfs. **Intermediate-flow recruitment habitat sites** constitute moderate water exchange (i.e., overall average water velocity less than 0.15 m/s) areas of at least 1 acre in which incipient inundation occurs at river discharges of 2,500 to 3,000 cfs. **Low-flow recruitment habitat sites** constitute low water exchange (i.e., overall average water velocity less than 0.10 m/s) areas of at least 1 acre in which incipient inundation occurs at river discharges of 1,500 to 2,500 cfs.

Sites within management class subtypes can be prioritized with respect to one another using data regarding the lowest level of incipient inundation, the maximal areal extent of inundation represented by low water exchange conditions over the contemporary range of flow, and maximum depth of inundation (greater depth confers enhanced temporal environmental stability). Low-flow lateral silvery minnow reproduction and nursery habitat sites comprise the highest priority sites for conservation and management protection to ensure strong recruitment over the highly variable range of discharge intrinsic to the MRG. Intermediate flow and high flow lateral sites represent high-priority candidate sites for habitat modification designed to improve reproductive success. These management classes would require progressively greater intervention to achieve a desired functioning condition.

Minimal sustained duration of river channel-floodplain coupling, including an extended period over which flow is gradually reduced to levels confined to the main channel, is essential to allow

[10] Biophysical/chemical processes include nutrient cycling (Meyer and Likens 1997), primary and secondary productivity enhanced by lower water exchange rates and heightened subsidy of allochthonous energy inputs at the aquatic-land interface and heightened temperatures characteristic of such areas (Schlosser 1991; Valett et al. 2005), water chemistry conditioning (Meyer 1979), and the generation of structurally complex aquatic habitats (Cowley 2006).

silvery minnow adults a chance to occupy the floodplain and spawn, to allow time for embryo development and hatching, and finally to allow sufficient time for young-of-year silvery minnow development to at least the juvenile stage to effectively enable fish to evacuate draining floodplain habitats. Higher levels of recruitment can be expected with longer periods of sustained floodplain inundation. The reproductive potential of a year class or life stage is dependent on the time to sexual maturity, the amount of future reproduction, and the age or stage probabilities of survival (Caswell 2001). In a fluctuating population, the reproductive value of future individuals depends on whether a population is increasing, decreasing, or remaining relatively static. The value of each future offspring is diluted when the finite rate of increase (λ) is greater than 1; the value of each offspring is increased when the population is decreasing ($\lambda < 1$).

2.4.3 REFUGIAL HABITATS

Past experience has demonstrated that periodic severe drought related perturbations, coupled with poor recruitment, have resulted in immediate reductions in silvery minnow abundance and weak age classes with negative consequences for population viability (e.g., Dudley et al. 2004). However, habitats designed to reduce the mortality of future parental stock, often by even a few percent, can have profound effects on future population trajectories by maintaining a positive capacity for population growth. Such refugial habitats that embrace habitat features that convey spatial and temporal resistance to species and communities impacted by biophysical disturbance are critical to the conservation of the silvery minnow.

While intermittent channel drying has not been observed under current water operations scenarios since the closure of Cochiti Dam, we propose two refugial habitat subtypes based on our understanding of the entire system and observed conditions in the adjacent Isleta Reach: 1) high intermittence disturbance habitats and 2) transitional habitats.

High intermittence disturbance habitats represent poorer quality patches due to their ephemeral nature and are linked to high rates of silvery minnow mortality. Accounting for these habitats in habitat improvement planning is important because intermittence results in silvery minnow mortality, and heightened environmentally driven fluctuations in population growth rate will place the species at risk of extirpation at early time horizons. We regard river segments with contemporary long-term irrigation season-specific probabilities of flow intermittency in excess of 0.45 to comprise high intermittence disturbance habitats.

River segments with contemporary long-term flow patterns that would qualify as **transitional (or intermediate) environmental types** are of particular managerial interest because provision and periodic maintenance of wetted habitat, including in the form of large and deep refugial pools, is more feasible in such areas compared to areas of high intermittence disturbance, especially when hydrological resources are limited. Two management classes of transitional environmental habitats are proposed based on variable probabilities for continuity of running water habitat in time and space, and in terms of site attributes that determine the nature of localized biophysical/chemical processes and environmental stability that collectively concern habitat quality. In this study, we hypothesize river segments with contemporary long-term irrigation season-specific probabilities of irrigation season flow intermittency between 0.10 and 0.20 to comprise **primary transitional habitats**, whereas probabilities of irrigation season flow intermittency between 0.20 and 0.45 comprise **intermittence refugia**. We hypothesize that the primary transitional habitats could occur in the Albuquerque Reach in a worst-case scenario where the minimum flows of 196 cfs are passed over the Albuquerque Drinking Water Diversion Dam.

Key Refugial Habitat Features

A single large population of a species is buffered from demographic stochasticity. Multiple small reserves can buffer an entire species from extinction due to local catastrophes and environmental stochasticity, but such populations are the ones that may be vulnerable to inbreeding depression, mutation load, and loss of adaptive potential.

Prospects of species survival are enhanced to the extent that population densities can be maintained above levels subject to depensatory deterministic effects. Minimum population size needed to achieve some standard of viability will occur at the highest survival rate of young-of-year and no population-wide year class failures (Cowley 2007). Viable population size increases as the failure rate for the younger age classes increases. Therefore, it is prudent to maximize survival and manage for larger population sizes to accommodate temporal variation in demography and habitat quality (Cowley 2007).

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Lateral Distribution of Prospective Refugial Habitats

The period of pool isolation is an important consideration in the provision and maintenance of refugial pools. Galat et al. (2004) found that larval fish taxa richness increased in lateral pools of the lower Missouri River with increased coupling with running water due largely to the addition of rheophilic larval taxa, including *Hybognathus* species. As running water habitats recede in the MRG, the period of pool isolation tends to be longer for those positioned lateral to the thalweg as opposed to those aligned along or adjacent to the thalweg. As such, pools associated with the thalweg will inevitably exhibit greater environmental stability over a longer period; certainly pools would be aligned with dispersal corridors during periods of extreme low flow.

Longitudinal Spacing of Pools

The theoretical longitudinal pool-riffle spatial sequencing in unbound rivers is five to seven times the stream width (Leopold and Langbein 1966). Earlier it was hypothesized that this spacing of refugial pools would allow for dispersal success of the silvery minnow and would serve to reduce mortality that often attends pulsed (short-term), small volume, expansion-contraction flow disturbances. In sand bed rivers, high sediment transport discharges are required to rework geomorphic surfaces that constitute the silvery minnow's habitat, including large and deep refugial pools (approximately 50–75 cm s^{-1} for coarse sand) (Allan 1995). This geomorphic process is enhanced by flow-deflecting objects (e.g., large woody debris), which serve to focus pool-scouring water velocity. Ideally, the incorporation of large woody debris (snags) in a habitat improvement project would be guided by estimates of the density of such habitat features before the MRG was channelized. Unfortunately, similar data for the MRG have not been located. As a surrogate, Sedell and Beschta (1991) offer early settlement records of the number of snags per kilometer for other large sand bed rivers, although that report includes few records for Southwest rivers.

Pool Morphology

Longer and deeper pools with abruptly steep sides (low surface area to depth ratio) were found to be inherently superior as refugial habitats for fish due primarily to their enhanced temporal environmental stability compared to smaller pools. Pools that are at least 1.5 m (4.9 feet) deep and at least 25 m (82 feet) on their long axes are common in the MRG following sustained high discharge (Hatch et al. 2008).

Functioning Condition and Habitat Coverage

Spatial characteristics of theoretical, randomly generated landscape models suggest that a species should be able to disperse from one suitable habitat patch to another so long as such habitat patches constitute more than 58% of the total available patches (Gardner et al. 1987). However, the distribution of suitable habitat patches in the MRG deviates from random spatial patterns, especially as flow in the river becomes discontinuous. How the distribution of suitable habitat patches deviate from a random spatial pattern is useful for revealing how ecosystems function, or fail to function, without the confounding effects of other select biological or physical processes. With absolute reduction and nonrandom distribution of suitable habitat patches, a significantly higher proportion of the remaining habitat (nearly 100%) must be maintained as suitable to effectively achieve a functioning condition nearly equivalent to that of a random spatial model with a suitable habitat threshold set at 58% (Gardner et al. 1987).

Habitat Refreshing

The periodic influx of water to refugial pools from unpolluted surface water or groundwater sources is necessary for the maintenance of suitable water quality to reduce the incidence of fish mortality due to disease. The periodic need for water refreshing/replenishing will vary inversely with the longitudinal spacing of pools and with pool depth and size.

3.0 SOUTHWESTERN WILLOW FLYCATCHER HABITAT RESTORATION

3.1 HABITAT REQUIREMENTS

The flycatcher requires at least two principal habitats—nesting habitats and migratory corridor stopover habitats—for two distinct portions of its spring and summer season lifecycle in the breeding regions of North America.

3.1.1 NESTING HABITAT

Flycatcher nesting habitat is critical to the recruitment and maintenance of the Rio Grande flycatcher metapopulation. The geographic distribution of breeding locations are also likely an important population variable in terms of both gene flow and the possible establishment of new flycatcher populations.

On the breeding grounds, male flycatchers typically arrive one to two weeks before females and establish relatively large territories using primary song, calls, and stereotypical physical displays. Once females arrive, male territory size typically decreases as females select nest sites and construct nests. If nesting is successful, both sexes rear offspring until fledglings are approximately two to three weeks old. Flycatchers are known to return to the same nesting area each year, but not necessarily the same nesting territories (USFWS 2002). Multiple breeding pairs often establish individual territories but nest together in a complex of non-overlapping territories within a single site. Most nesting sites contain one to five nesting pairs and territories, but some sites may contain up to 100 nesting pairs and territories, depending on the size of the site (Durst et al. 2008).

Food Resources

Adult and young flycatchers depend primarily on flying insects as food in and around the nesting territory until they migrate south in mid to late August. Insects such leafhoppers, beetles, bees, wasps, damselflies, and dragonflies are documented flycatcher food items across the Southwest (DeLay et al. 1999; Drost et al. 2001). Such insects are likely to be associated with the dense vegetation foliage and proximity to water (especially damselflies and dragonflies) that characterizes flycatcher nesting habitats. Dietary specialization is uncertain. Drost et al. (2001) concludes that flycatchers are dietary generalists, feeding on what insects are available and switching to those most abundant in their nesting territories.

Hydrology

Hydrology also is an important feature of flycatcher nesting habitat. Most occupied flycatcher nest sites are known to be associated with and often situated directly over lentic (standing or slow-moving) water (Cooper 1997; USFWS 2002). Such lentic environments include slow-moving streams, river backwaters, oxbows, marshes, and pond margins. Habitats that are suitable for flycatcher nesting habitat along moving streams are dependent on scouring floods, sediment deposition, periodic inundation, and groundwater recharge (USFWS 2002).

Along the MRG, Moore and Ahlers (2008) compare site hydrology data (dry all season, saturated/flooded then dry, saturated all season, flooded all season) to flycatcher nest productivity measures (success, productivity, predation, and brood parasitism rates). The researchers report that 95% of flycatcher nests are within 50 m of water. Regardless of distance to water and hydrology under the nest, nest success, predation, and brood parasitism rates are similar among all hydrologic conditions. However, in areas that are flooded all season, first nests are more successful than subsequent nests, and successful nests that are either above saturated soil all season or above standing water all season produce more young than successful nests that are above dry soil all season. Therefore, standing water and/or saturated soil under flycatcher nests may increase productivity and juvenile flycatcher survivorship because flycatchers that fledge late in the season have lower survival rates than those that fledge early in the season (Paxton et al. 2007; McLeod et al. 2008).

Vegetation

Flycatchers nest only in dense riparian vegetation near surface water and/or saturated soil. Regardless of plant species composition, occupied nest sites always have dense vegetation within 3 to 6 m (10–20 feet) of the ground surface and are situated over standing water and/or saturated soil. Studies from the lower Colorado River, the Salt River, and the MRG demonstrate consistent findings that flycatchers prefer nesting sites within the mid-level riparian vegetation canopy layer from 3 to 6 m (10–20 feet) above the ground, where vegetation structure is complex and dense from the ground level to just above average nest heights (~3 m [10 feet] above ground level) (Sogge and Marshall 2000; Allison et al. 2003; McLeod et al. 2008; Moore 2007; Moore and Ahlers 2008). This unimodal vertical structure is similar to the Type III vegetation structural type identified by Hink and Ohmart (1984). Flycatchers construct their nests within cup-like structures of multiple small diameter tree stems, which frequently occur within willow (*Salix* spp.) tree branches (McCabe 1991).

Most flycatcher studies across the Southwest have found nesting habitat to be composed of native plant species, especially willow, but 22% have been found to be composed of non-native saltcedar (*Tamarix* spp.; *T. ramossimus* and *T. chinensis*) and Russian olive (*Eleagnus angustifolia*) (Durst et al. 2008). Along the MRG, the greatest numbers of flycatcher nests are known from the San Marcial Reach and Rio Grande delta, at the upper end of Elephant Butte Reservoir. Most of those nesting sites have been found in dense native willow stands, which also are more common there than along upstream reaches (Moore 2007; Moore and Ahlers 2008). Moore (2007) and Moore and Ahlers (2008) found most flycatcher nesting sites in the San Marcial Reach to be located within dense stands of Goodding's willow (*Salix gooddingii*) (also referred to as black or tree willow) and to a lesser extent in mixed stands of both Goodding's willow and coyote willow (*Salix exigua*).

Upstream from the San Marcial Reach, both flycatcher nesting territories and dense, tall-canopy willow stands were uncommon, and flycatcher nests were often found in saltcedar stands with a similar dense mid-canopy structure. Both *Salix* species still dominated the stem counts at those upstream nesting sites (Moore and Ahlers 2006a, 2006b, 2008; Moore 2007), and the most nests were found in mixed stands of native and exotic tree species. While there are no negative effects known to be associated with flycatchers nesting in saltcedar compared to willow (Paxton et al. 2007; McLeod et al. 2008), the majority of flycatcher nesting sites that are known from the MRG are in dense willow stands in the southern MRG, indicating a preference for willow stands, or some suite of environmental factors associated with willow stands, over saltcedar stands.

The flycatcher nesting locations that are nearest to the Albuquerque Reach are those reported from within the Isleta Reach, immediately to the south. All nesting flycatchers within the Isleta Reach are known south of the Isleta Pueblo boundary, and most are located near the confluence of the Rio Puerco and south through the Sevilleta National Wildlife Refuge to the confluence of the Rio Salado (Parametrix 2008a). Moore and Ahlers (2006a, 2006b) reported 15 nesting flycatcher pairs between the Rio Puerco and Rio Salado in 2006, while only 4 nesting flycatcher pairs were found north of the Rio Puerco to the south boundary of the Isleta Pueblo during the same time. Flycatcher-occupied nesting habitats within the Isleta Reach tended to located near the main river channel, located in vegetation stands dominated by exotic saltcedar (six nests over 2006 and 2007), mixed stands of native willows and exotic saltcedar and Russian olive (nine nests over 2006 and 2007), or sands of largely native willows (five nests over 2006 and 2007) (Parametrix 2008a).

Microclimate

Low-elevation riparian environments in the Southwest are characterized by extreme high ambient temperatures, low relative humidity, and frequent winds. The microclimates associated with dense and tall willow stands growing over standing water or saturated soils may be a key component to flycatcher habitat. McLeod et al. (2008) studied stand structure and microclimate parameters of known flycatcher nesting sites along the Lower Colorado River. They concluded that greater canopy closure, taller canopy height, and dense foliage at or immediately above nest height may facilitate a more favorable nesting microclimate with cooler ambient temperatures and higher relative humidity. They suggested that those microclimate characteristics may be useful parameters in predicting preferred flycatcher riparian nesting habitat within the larger expanses of riparian vegetation. Values associated with these microclimate values could be used as target conditions for flycatcher habitat restoration.

3.1.2 Habitat Patch Size, Shape and Spatial Arrangement

Riparian nesting habitats for flycatcher tend to consist of particular patches of the appropriate vegetation composition and structure and hydrology as stated above, surrounded by other less suitable types of habitats or environments. Cooper (1997) found flycatcher nesting habitat patches to range from 0.1 to 70 ha (0.25–173 acres) along the Rio Grande. Across the Southwest, the mean size of flycatcher nesting habitat patches were 8.5 ha (21 acres), but the majority of nesting habitat patches were smaller, with a median size of 1.8 ha (4.4 acres) (USFWS 2002). Mean nesting habitat patches supporting 10 or more nesting pairs of flycatchers were 24.9 ha (61.5 acres) (USFWS 2002). Flycatchers do not nest in linear riparian habitat patches less than 10 m (33 feet) wide along confined floodplains (USFWS 2002).

The size, shape, and configuration of flycatcher nesting territories were will documented along the Salt River in Arizona by Cardinal et al. (2005). They found that territory size of 15 breeding males changed across the breeding season, between pre-nesting, nesting, and post-nesting periods. Pre-nesting and nesting territories averaged less than 0.5 ha (1.2 acres) in size, and post-nesting (fledglings present) territories increased to about 100 ha (247 acres) in size. The shapes of nesting territories tended to have similar lengths to widths. In the particular area studied, Cardinal et al. (2005) found nesting pairs to be grouped in clusters across favorable habitat with contiguous, non-overlapping territories. These findings indicate that flycatchers along the Salt River tend to nest in groups in large patches of favorable habitat. Moore and Ahlers (2008) also found flycatcher nesting sites in the San Marcial Reach of the MRG to be clustered together across large patches of favorable habitat, but they did not measure the sizes or shapes of individual territories. Although flycatchers are known to aggregate their nesting territories in large sites of suitable habitat, major portions of those large habitat patches tend to be unoccupied; the flycatcher does not pack its territories into all available space (USFWS 2002).

3.1.3 MIGRATORY STOPOVER HABITATS

In addition to nesting habitat, migratory stopover habitat along rivers is an important component of overall flycatcher habitat requirements in the Southwest. In order to reach and select nesting sites, migrating adult flycatchers must first transverse vast geographic distances from Neotropical wintering areas to potential nesting sites along the MRG. These migration stopover habitats, even though not used for breeding, are likely important for both reproduction and survival. For most long-distance Neotropical migrant passerines, migration stopover habitats are needed to replenish energy reserves to continue north- or southbound migration.

Migration routes used by flycatchers are not well documented, though more is known of northbound migration in spring than the southbound migration in fall because spring is the only time that migrant flycatchers sing and can therefore be distinguished from other *Empidonax* species. During northbound migration, all subspecies of willow flycatchers use riparian habitats similar to breeding habitat along major river drainages in the Southwest, such as the Rio Grande (Finch and Kelly 1999), Colorado River (McKernan and Braden 1999), and San Juan River (Johnson and Sogge 1997). Yong and Finch (1997) found that migrating flycatchers favor young, native riparian willow habitats along the MRG.

4.0 HABITAT RESTORATION RECOMMENDATIONS

The Albuquerque Reach is important for the conservation of the silvery minnow and the flycatcher. There are several important characteristics of the reach, but none more so than the hydrologic condition. Unlike the Isleta Reach and San Acacia Reach, the Albuquerque Reach does not experience frequent intermittency of flows. That is to say, the Albuquerque Reach, under current water operations, does not dry. This condition is expected to persist, although the downstream subreaches could experience extremely low flows should the Albuquerque Drinking Water Project pass a minimum of 196 cfs over the diversion structure.

Because of its relative importance, there has been much work completed in the Albuquerque Reach, and additional work is planned. The New Mexico Interstate Stream Commission (NMISC) has implemented numerous riverine restoration projects within the river channel. The U.S. Army Corps of Engineers (Corps) has begun construction on the Route 66 project and is in the planning phases for the Bosque Feasibility Study (BFS), an extensive, reach-wide series of riparian and riverine treatments. The City of Albuquerque has implemented riverine and riparian restoration work, and the Bureau of Reclamation (Reclamation) has completed the Albuquerque Overbank Project, one of the first restoration projects to be completed in the Albuquerque Reach. Work completed or planned by the Pueblos of Santa Ana[11], Isleta[12], and Sandia[13] adds to the myriad restoration activities in the Albuquerque Reach. While all activities are well planned and follow the guidelines set forth in the 2004 Habitat Restoration Plan (Tetra Tech 2004), there is a lack of coherency to the planning, implementation, and evaluation of habitat restoration projects. Our objective is to provide a structured context from which to evaluate the efficacy of current and proposed restoration projects. As a planning tool, we propose a Habitat Restoration Model that will allow the Collaborative Program and its signatories to prioritize and evaluate whether proposed restoration projects will provide benefits to the target species.

Our analysis was conducted from the North Diversion Channel to the Isleta Pueblo boundary. The subreaches immediately below Angostura Diversion Dam to the Pueblo of Santa Ana and between the Pueblo of Santa Ana and the North Diversion Dam were not included in the analysis. The areas that are not included in the Pueblos of Santa Ana and Sandia offered little opportunity for further work, because of channel conditions not conducive to additional restoration work, the presence of private and pueblo lands, or the implementation of existing projects.

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[11] The Pueblo of Santa Ana has implemented the Rio Grande Restoration Project with its federal partners. Elements include the construction of backwater wetlands and the gradient restoration facilities, overbank inundation channels on bank-attached bars, construction of willow swales, and restoration of the bosque.

[12] The Pueblo of Isleta has implemented habitat restoration projects to benefit the silvery minnow and the flycatcher. The Pueblo of Isleta is currently completing the Pueblo of Isleta Subreach Habitat Analysis and Recommendations study.

[13] The Pueblo of Sandia has completed the Pueblo of Sandia Subreach Habitat Analysis and Recommendations study (SWCA 2008). The Pueblo of Sandia has also completed the Management of Exotics for Recovery of Endangered Species (MERES) project and removed non-native phreatophytes throughout much of the bosque.

4.1 HABITAT RESTORATION MODEL CHARACTERISTICS

Habitat restoration recommendations presented in this study are based on an examination of habitat needs and existing conditions. The habitat models presented above represent the ideal conditions based on current knowledge and understanding of the system. Through the analysis of existing conditions, we can determine deviations from the habitat model. The resulting restoration model identifies similar units, which we call **conservation units**. We identify four conservation units, representing a range from intact units with most, if not all, habitat elements present to heavily disturbed areas with most habitat elements absent. The four conservation units are:

1. Core Conservation Units (CCU)
2. Reserve Conservation Units (RCU)
3. Primary Restoration Units (PRU)
4. Secondary Restoration Units (SRU)

Areas that meet all of the required habitat elements to meet the critical lifecycle needs for the target species are considered CCUs. These areas would have the highest conservation priority. CCUs for the silvery minnow and the flycatcher are not found in the Albuquerque Reach. RCUs would have most required habitat elements present and thus would require a minimal effort to restore to the CCU condition. These areas would have the highest restoration priority. PRUs would have a greater departure from the CCU condition and thus would require a greater level of effort to restore to the CCU condition. Finally, the SRUs would have the greatest departure from the CCU condition and would require extensive restoration to obtain the CCU condition. These areas would have the lowest priority.

Through an analysis of geomorphic, hydrologic, and biotic conditions in the Albuquerque Reach and taking into consideration the habitat requirements, as described above, we have identified and mapped conservation units in the Albuquerque Reach (Appendix A). The restoration model developed for the Albuquerque Reach is summarized in Table 4.1.

Table 4.1. Conservation Unit Characteristics and Management Level for Silvery Minnow Habitat

Conservation Unit	Existing Habitat Features			Geomorphic Characteristics	Spatial Features	Management Level
	Residential	Recruitment	Intermittent Disturbance			
Core Conservation Unit (CCU)	High habitat heterogeneity over range of flows	Floodplain inundation: <3,000 cfs for a minimum of 7–10 days	No drying events; may have primary transitional refugia	High W/D over range of flows (e.g., low variability of W/D) over discharge range from 500–5,000 cfs)	High spatial heterogeneity (longitudinally) to facilitate dispersal	Priority area; maintain current condition
Reserve Conservation Unit (RCU)	High to moderate habitat heterogeneity over range of flows	Floodplain inundation: >3,000 cfs	No drying events; may have primary transitional refugia	Decreasing W/D over range of flows, but low variability of W/D from 500–5,000 cfs.	High to moderate longitudinal spatial heterogeneity	Restoration required to obtain CCU condition; minor environmental modification required
Primary Restoration Unit (PRU)	Monotypic low habitat heterogeneity over range of flows	No floodplain inundation	Potential for Intermittent drying or extremely low discharge periods	Decreasing W/D over range of flows, but low variability of W/D from 500–5,000 cfs.	Low to moderate longitudinal spatial heterogeneity	Transitional habitats; restoration required to obtain CCU condition; moderate to extensive environmental modification required
Secondary Restoration Unit (SRU)	Monotypic low habitat heterogeneity over range of flows	No floodplain inundation, or infrequent floodplain inundation events	Potential for frequent channel drying events or	Decreasing W/D over range of flows, but low variability of W/D from 500–5,000 cfs.	Low longitudinal spatial heterogeneity	Transitional habitats; restoration required to obtain CCU condition; extensive environmental modification required; supplemental water sources may be required

4.1.1 Silvery Minnow Restoration Model Characteristics

Silvery Minnow Habitat Characteristics

Silvery minnow conservation units are defined based on the characteristics of the three primary habitat types: residential, recruitment, and intermittence refugia. Using depth-averaged channel hydraulic conditions derived from the 250-foot FLO-2D model results (Appendix B), we were able to define characteristics for residential, recruitment, and refugial habitat conditions within the Albuquerque Reach. Parameters analyzed include average W/D, average thalweg depth, average velocity, average top-width, and average energy slope. Of these parameters, we found the W/D to be a useful diagnostic tool. Other parameters, because they are averaged for the reach, lacked the requisite resolution. The habitat types and the parameters used to define them are presented in Table 4.2.

We identified three **residential habitat** subtypes: low discharge (<1,500 cfs), intermediate discharge (1,500–3,500 cfs), and high discharge (> 3,500 cfs). *Low residential habitat* is found in river sections where the channel is confined. Often channel incision is evident and the river stays within its banks at moderate to high discharge events. This is represented in a decreasing W/D over the range of flows modeled. These areas tend to have the deepest average thalweg depth and the highest average velocity. The *intermediate residential habitat* is found in river sections where there are islands and bank-attached bars, but these may not be inundated over the range of flows modeled resulting in a decreasing W/D ratio. These areas have intermediate average thalweg depths and average velocities. The *high residential habitat* represents areas where bank-attached bars and islands experience inundation over the range of flows modeled. The W/D ratio remains relatively constant over the range of flows modeled. These areas have the shallowest average thalweg depth and the lowest average velocity.

The three **recruitment habitat** subtypes based on the need to provide consistent recruitment classes over a range of flows to meet the objective of providing recruitment no less than two out of three years. *High-flow recruitment habitat subtypes* would be inundated at a river discharge greater than 3,000 cfs. These areas would be found in the floodplain with modification and areas are associated with high-flow events and strong recruitment classes. Effort will be given to increasing the area and frequency of overbank inundation throughout the Albuquerque Reach. *Intermediate-flow recruitment habitat subtypes* would be inundated at a river discharge varying from 2,500 to 3,000 cfs. These areas typically occupy higher bank-attached bars and channel margins. *Low-flow recruitment habitat subtypes* would be inundated at a river discharge between 1,500 and 2,500 cfs. These are primarily bank-attached bars and would be expected to be inundated on an annual basis. Restoration of the secondary and tertiary recruitment habitat subtypes is important to maintain recruitment classes on an annual basis.

While the Albuquerque Reach has not experienced intermittent channel drying since the closure of Cochiti Dam, the reach has experienced drying during the pre-Cochiti era.[14] FLO-2D simulations were run by Wolf Engineering to model the minimum flow of approximately 200 cfs to be passed over the Albuquerque Drinking Water Project (USFWS 2004) suggests a 20% reduction in the peak between the diversion dam and the bottom of the study reach. Thus, we do

[14] Minimum flow analysis conducted by Wolf Engineering for this project suggests that in the Pre-Cochiti era there was a 10% chance that the flows would be less than 12 cfs for a seven-day period.

not expect intermittency refugia habitat needs within the Albuquerque Reach. However, very low flows passing over the diversion dam would result in river discharges of less than 200 cfs in the southernmost subreaches. We classify these sections as the **primary transitional refugial habitat** subtype.

Table 4.2. Silvery Minnow Habitat Model

Habitat Type	Habitat Subtype	Geomorphic/Hydrologic Characteristics				Other Characteristics
		Discharge Range (cfs)	Average W/D*	Average Thalweg Depth (feet)*	Average Channel Velocity (feet/sec)*	
Residential	Low	<1,500	96–111	3.1–5.9	1.3–3.2	Moderately low probability (<0.10) of channel drying
	Intermediate	1,500–3,500	139–151	3.2–5.4	1.1–2.6	Very low probability (<<0.10) of channel drying
	High	>3,500	181–187	2.5–5.2	1.2–2.5	Extremely low probability (<<<.010) of channel drying
Recruitment	Primary	>3,000	–	–	–	Velocity < 0.33 feet/s, > 1 acre
	Secondary	2,500–3,000	–	–	–	Velocity < 0.33 feet/s, > 1 acre
	Tertiary	1,500–2,500	–	–	–	Velocity < 0.33 feet/s, > 1 acre
Refugial	Primary Transitional	<200	–	–	–	Primary transitional habitat with low probability (0.10–0.20) of channel drying
* W/D, thalweg depth, and channel velocity averaged over range of flows, from 500–5,000 cfs.						

Other characteristics that were considered in determining the conservation units are **habitat heterogeneity** and **longitudinal spatial variability**. Habitat heterogeneity refers to the diversity of low-velocity habitat available over a range river discharge. Habitat heterogeneity is a result of bank-attached bars, islands, and channel margin banklines that experience inundation throughout the range of river flows. Longitudinal spatial variability refers to the longitudinal variability in channel width, W/D, and thalweg depth. In looking at the aerial imagery, it is easy to pick out areas where the channel is narrower and where the channel is wider. This can also be represented graphically (Figure 4.1) by looking at the average W/D and the variability over the range of flows. The error bars associated with each W/D point is an indication of the variability of W/D. High variability suggests that the W/D decreases over higher flows indicating that the channel is confined at the higher flows. Low variability suggests that W/D remains relatively constant over the range of modeled flows indicating the inundation of bank-attached and channel margin feature throughout the range of flows. Maintaining high longitudinal spatial variability in adjacent subreaches is desirable because it provides habitat for fish to migrate to at a variety of flows. For example, during low-flow periods, fish may migrate to narrower sections and then migrate to wider areas with inundated bank-attached bars and channel margins.

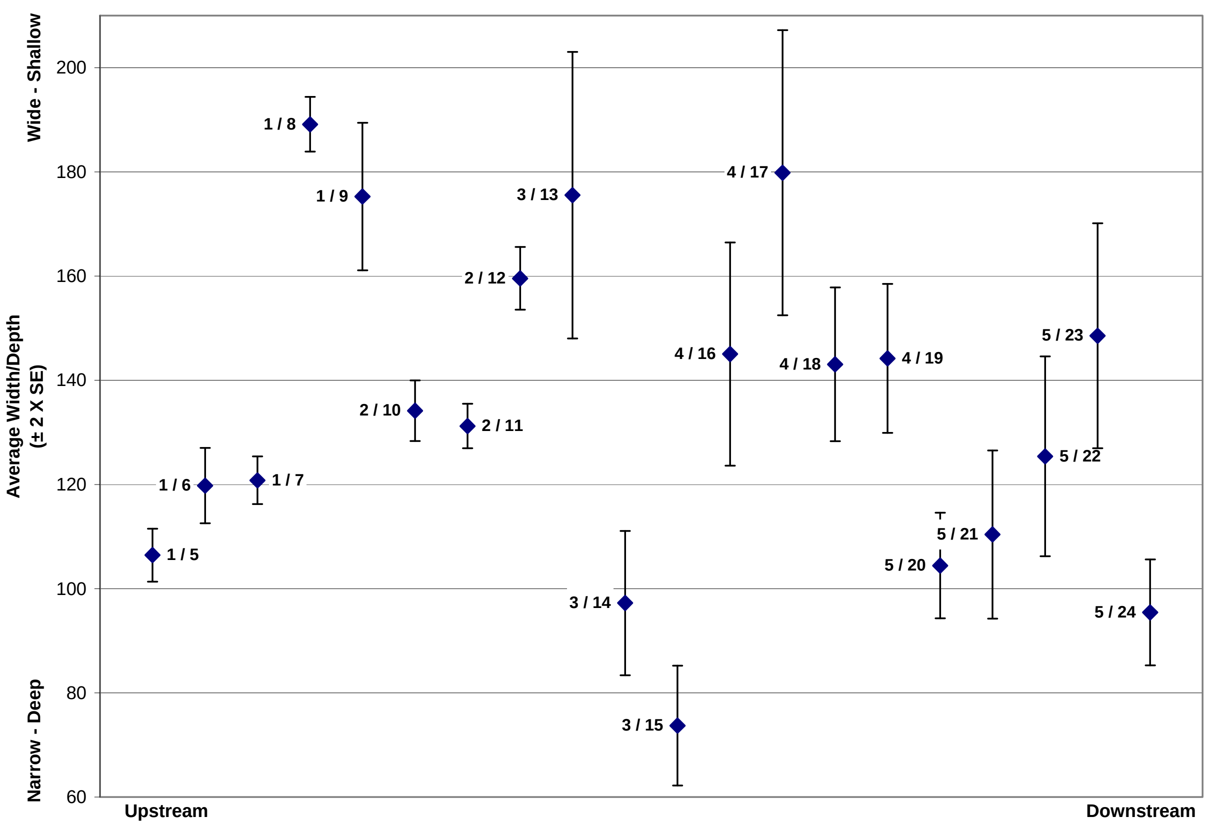

Figure 4.1. Longitudinal spatial diversity. The W/D is plotted with the standard error bars for each subreach. Low variability indicates that the W/D remains relatively constant throughout the range of modeled flows. High variability suggests that W/D decreases with increasing flows.

4.1.2 FLYCATCHER RESTORATION MODEL CHARACTERISTICS

Given that migrating flycatchers are known to prefer riparian habitats similar to nesting habitats, and show a preference for willow stands, habitat restoration along the Albuquerque Reach should emphasize the establishment of native willow stands for migrating flycatchers and nesting sites. Habitat restoration needs presented below generally combine nesting and migratory habitat, since both should be similar.

The premise of the overall flycatcher habitat model is that persistent Rio Grande water on the floodplain or lateral channels is necessary to produce dense and tall willow stands composed of Goodding's and coyote willow, with persistent standing water or saturated soil underneath, and consisting of patches at least 1 ha (2.5 acres) in size to provide habitat for the flycatcher. Such habitat sites that are occupied by nesting flycatchers would represent suitable MRG flycatcher nesting habitat, and such sites would be considered CCUs. Currently, no such sites are known within the Albuquerque Reach, but they do occur in reaches to the south, or down-river. Such sites may also be considered as reference sites relative to environmental characteristics to be achieved for habitat restoration goals. Such sites also would provide suitable migratory stopover habitat.

Alternatively, sites providing ephemeral wetlands and sparse and/or short (< 4 m [13 feet] tall) willow stands are lacking one or more significant environmental characteristics to be considered potential habitat for flycatchers. Such sites are considered RCUs, and those missing environmental characteristics may potentially be obtained through habitat restoration. Such RCU sites have the potential to become CCU sites through habitat restoration.

In order to develop habitat restoration plans relative to the flycatcher within the Albuquerque Reach, the attributes or characteristics of flycatcher CCU and RCU sites must be defined. Table 4.3 provides a matrix of the characteristics of CCUs and RCUs for the Albuquerque Reach and the MRG. Table 4.3 also provides specific vegetation and microclimate characteristics that are recommended for flycatcher CCU conditions, based on parameters measured by McLeod et al. (2008) from nest sites along the lower Colorado River (Table 4.4). Again, based on current evaluations of geographic information system (GIS) habitat data and actual flycatcher survey data, no known flycatcher nesting sites, nor habitat sites with CCU conditions are known within the Albuquerque Reach. GIS analysis does indicate several potential RCU sites within the Albuquerque Reach.

Table 4.3. Conservation Unit Characteristics and Management Objectives for Flycatcher Habitat

Conservation Unit	Geomorphology	Hydrology	Vegetation	Spatial Features	Management Objectives
Core Conservation Unit (CCU)	Floodplains, oxbows, and side channels	Persistent wetland, standing water or saturated soils much of the year, especially April–August; floodplain inundation at 1,500 cfs	*Salix* spp., especially Gooddings Willow; dense canopy up to 5 m (16 feet) high	>1.0 ha (2.5 acres) in size, up to 200 ha (494 acres); similar diameter to width for small patches, linear but > 50-m (164-foot) width for large patches	Maintain current condition
Reserve Conservation Unit (RCU)	Floodplains, oxbows, side channels, and islands	Ephemeral wetland, standing water or saturated soils or high potential for such; floodplain inundation at 3,000+ cfs	*Salix* spp. and/or *Tamarix* spp., present, but not dense; < 5 m high (16 feet); high potential for *Salix* spp. to develop dense stands with restoration	>1.0 ha (2.5 acres) in size, up to 200 ha (494 acres); similar diameter to width for small patches, linear but > 50-m (164-foot) width for large patches	Restoration required to obtain CCU condition
Primary Restoration Unit (PRU)	See RCU above; similar to CCU	See RCU above; inundation at 4,500+ cfs; moderate potential for persistent (April–August) standing water or saturated soils with restoration	See RCU above; high potential for *Salix* spp. to develop dense stands with restoration (e.g., groundwater depth < 1.5–2.1 m [5–7 feet], low soil salinity/sodicity)	See RCU above; high potential to develop large patch sizes	See RCU above; minor environmental modification required
Secondary Restoration Unit (SRU)	See RCU above; not similar to CCU	See RCU above; inundation at 4,500+ cfs; low potential for persistent (April–August) standing water or saturated soils with restoration	See RCU above; low potential for *Salix* spp. to occupy site with restoration (e.g., groundwater depth > 1.5–2.1 m [5–7 feet], high soil salinity)	See RCU above; low potential for large patch sizes	See RCU above; major environmental modification required

Table 4.4. Vegetation Variables, Management Actions, Microclimate Response, and Recommended Ranges for the Creation of Suitable Nesting Habitat for the Flycatcher along the Lower Colorado River and Tributaries

Vegetation Variables	Recommended Statistical Range of Variable (mean ± standard error)
Canopy height (m)	6.1 ± 0.1
Canopy closure (%)	92.8 ± 0.3
No. shrub stems (<2.5 cm diameter at breast height [dbh]) per ha	<6714.9
No. shrub stems (2.5–8.0 cm dbh) per ha	8349.1 ± 246.1
No. shrub stems (>8.0 cm dbh) per ha	893.1 ± 60.0
Percent basal area that is native	41.4 ± 2.2
Vertical foliage density (hits) above nest	69.0 ± 2.1
Vertical foliage density (hits) at nest	N/A
Vertical foliage density(hits) below nest	<48.2

Microclimate Variables	Recommended Statistical Range of Variable (mean ± standard error)
Soil Moisture	
Mean soil moisture (mV), 2005–2007**	751.9 ± 15.5
Temperature	
Mean maximum diurnal temperature (°C)	43.0 ± 0.2
Mean diurnal temperature (°C)	31.1 ± 0.1
Mean no. of 15-min. intervals above 41°C each day	4.5 ± 0.3
Mean minimum nocturnal temperature (°C)	16.4 ± 0.1
Mean nocturnal temperature (°C)	24.6 ± 0.1
Mean daily temperature range (°C)	**19.6 ± 0.2**
Humidity	
Mean diurnal relative humidity (%)	53.0 ± 0.6
Mean diurnal vapor pressure (Pa)	2,200.2 ± 26.0
Mean nocturnal relative humidity (%)	64.6 ± 0.5
Mean nocturnal vapor pressure (Pa)	**1,964.7 ± 20.6**

Adapted from McLeod et al 2008

4.2 Restoration and Management Strategies

4.2.1 Restoration Treatments

The Albuquerque Reach is not very geomorphically active. The channel response to the recent high flows in 2005 has been to stabilize the system through enlarging existing bars and islands resulting in little channel migration or channel geometry changes. Thus, it is difficult for small localized projects to sustain their desired outcome (D. Wolf, personal communication 2009). Individual, site-scale restoration treatments would be combined into larger projects to affect key ecological or geomorphic factors that limit silvery minnow or flycatcher populations. Within each conservation unit, key factors and processes were identified that are hypothesized to affect silvery minnow and flycatcher populations. We propose a set of restoration strategies in each conservation unit to address the key factors for the silvery minnow and the flycatcher. Restoration strategies developed for each conservation unit will employ a variety of treatments and hydrologic management options.

The habitat restoration treatments proposed by Tetra Tech (2004) provide a starting point for developing a "toolbox" of available treatments and strategies available for implementing habitat restoration for the silvery minnow and the flycatcher. Restoration treatments typically involve the manipulation of bank-attached bars, islands, banklines, or floodplains to construct a desired mesohabitat feature. These mesohabitat features are thought to provide key habitat elements that meet various lifecycle needs for the silvery minnow or breeding habitat for the flycatcher. This approach has typically been taken for habitat restoration projects in the MRG (e.g., SWCA 2009). Each treatment would affect the geomorphic or ecological condition in such a manner to enhance a residential, recruitment, or refugial habitat feature in a specific manner. The treatment objectives would provide the basis for monitoring and for measuring the species response.

Hydrological management of the system is an important component of the restoration and management strategy and is intended to compliment physical manipulation of the riverine and riparian environments. Parametrix (2008b, 2008c) suggests that decreasing the slope of the receding limb of the hydrograph will enable root elongation for willows and cottonwoods and thus enhance natural recruitment of these species. Similarly, slowing the rate of decline of the receding limb of the hydrograph following high-flow runoff seasons would be expected to provide benefits to the silvery minnow through decreasing the probability of stranding fish in the floodplain. The proposed restoration treatments are summarized in Table 4.5.

Table 4.5. Restoration Treatments

	Treatment	Description	Benefits of Treatment	Silvery Minnow Habitat Feature Target	Flycatcher Habitat Target
Residential Habitat	High-flow ephemeral channels	Construction of ephemeral channels on islands to carry flow from the main river channel during high-flow events.	Normally dry, but creates shallow, ephemeral, low-velocity aquatic habitats important for silvery minnow egg and larval development during medium and high-flow events.	Provides habitat heterogeneity over a range of river discharge.	Improves breeding and migratory habitat.
	Island/Bar modification	Creation of shelves on islands and bars to increase inundation frequency. This technique is targeted for islands and bars that have an overtopping discharge greater than 3,500 cfs and exceedance days per year less than 10 days.	Increases habitat availability by increasing the inundated area at lower flows. May also destabilize bars and islands, slowing the rate of vegetation stabilization and/or armoring and facilitating sediment mobilization.	Provides habitat heterogeneity over a range of river discharge.	
	Island/Bar destabilization	Clearing of vegetation, including above- and belowground biomass, on stabilized islands and bank-attached bars to encourage the redistribution of sediments.	Could encourage the redistribution of sediment and natural fluvial geomorphic processes.	Provides/Maintains habitat heterogeneity over a range of river discharge.	
	Removal of lateral confinements	Elimination or reduction of structural features and maintenance practices that decrease bank erosion potential	Could increase floodplain sinuosity and width with more diverse channel and floodplain features, resulting in increased low-velocity habitat for silvery minnow.	Provides habitat heterogeneity over a range of river discharge.	Improves breeding and migratory habitat.
	Passive restoration	Allows for higher magnitude peak flows to accelerate natural channel-forming process and improve floodplain habitat.	Increases sinuosity and allows for development of complex and diverse habitat, including bars, islands, side channels, sloughs, and braided channels.	Provides/maintains habitat heterogeneity over a range of river discharge.	Improves breeding and migratory habitat.
	Sediment management	Increase of sediment supply through mobilization behind dams, arroyo reconnection, or introduction and redistribution of spoils associated with construction of mesohabitat features.	Enhances geomorphic function of the river system through encouraging natural fluvial processes.	Provides habitat heterogeneity over a range of river discharge.	
	Hard structures	Engineered structures, such as bendway weirs constructed along the channel margins to facilitate lateral channel migration and creation of pools and eddies.	Facilitates the increase in sinuosity, which allows for the development of complex and diverse habitat including bars, islands, side channels, sloughs, and braided channels. Creates aquatic habitat diversity by providing pools and slackwater areas.	Provides habitat heterogeneity over a range of river discharge. Low-flow Recruitment Habitat at low discharge (<3,000 cfs).	
	Gradient-control structures	Low head weirs constructed perpendicular to the channel with aprons to simulate natural riffles.	Creates aquatic habitat diversity by producing variable flow velocities and depths.	Provides habitat heterogeneity over a range of river discharge.	
Recruitment Habitat	Creation of backwaters and embayments	Areas cut into banks and bank-attached bars to allow water to enter to create slackwater habitat, primarily during mid- to high-flow events, including spring runoff and floods.	Increases habitat diversity by increasing backwaters, pools, eddies at various depths and velocities. Intended to retain drifting silvery minnow eggs and to provide rearing habitat and enhance food supplies for developing silvery minnow larvae.	Creates secondary and tertiary recruitment habitat along channel margins.	Improves breeding and migratory habitat through encouraging natural revegetation or active planting.
	Creation of bankline benches	Removal of vegetation and excavation of soils adjacent to the main channel to create benches that would be inundated at a range of discharges.	Provides shallow water habitat at a range of discharges that could provide spawning habitat and increased retention of silvery minnow eggs and larvae. Increased inundation would benefit native vegetation, potentially increasing habitat for the flycatcher.	Creates secondary and tertiary recruitment habitat at channel margins channel margin,	Improves breeding and migratory habitat through encouraging natural revegetation or active planting.
	Floodplain coupling - overbank inundation channels	Construction of ephemeral channels in the floodplain to carry flow from the main river channel during high-flow events.	Creates shallow, ephemeral, low-velocity aquatic habitats in the bosque during high-flow events. Provides silvery minnow egg retention and larval habitat associated with silvery minnow spawning. Enhances hydrologic connectivity with the floodplain. Could improve flycatcher habitat.	Creates primary recruitment habitat through providing floodplain inundation at target river discharge (3,000 cfs).	Improves breeding and migratory habitat through encouraging natural revegetation or active planting.
	Floodplain coupling - lower bankline	Removal of natural berms that are associated with channel margins. Removal of the berms may increase the frequency of floodplain inundation where modeling indicates floodplain inundation occurs at higher flows.	Creates shallow, ephemeral, low-velocity aquatic habitats in the bosque during high-flow events. Provides silvery minnow egg retention and larval habitat associated with silvery minnow spawning. Enhances hydrologic connectivity with the floodplain. Could improve flycatcher habitat.	Creates primary recruitment habit through providing floodplain inundation at target river discharge (3,000 cfs).	Improves breeding and migratory habitat through encouraging natural revegetation or active planting.

Table 4.5. Restoration Treatments

	Treatment	Description	Benefits of Treatment	Silvery Minnow Habitat Feature Target	Flycatcher Habitat Target
Recruitment Habitat, continued	Floodplain vegetation management	Management of vegetation within the floodplain through actively planting desired native vegetation and controlling non-native vegetation to restore riparian habitat.	Increases habitat availability and diversifies habitat structure for the flycatcher in heavily disturbed sites. Combined with passive restoration techniques to promote natural revegetation, actively planting has the potential to increase flycatcher habitat availability.	Provides canopy cover to moderate diel variation in water temperature in floodplain water catchments.	Improves breeding and migratory habitat through control of non-native phreatophytes and actively planting native riparian vegetation.
	Arroyo connectivity	Clearing of vegetation and/or excavation of pilot channels to bring stranded arroyos to grade with the mainstem Rio Grande.	Could re-establish eddies associated with the mouths of arroyos, which may help to retain silvery minnow eggs and larvae, and increase the supply of sediment to the river.	Improves secondary and tertiary recruitment habitats at low to moderate river discharge.	
	Water operations coordination to provide river channel/floodplain coupling over a minimal sustained period	1) Management of water operations to provide floodplain inundation every 2 out of 3 years and 2) management of receding limb of the hydrograph to minimize silvery minnow entrainment in the floodplain.	Meets silvery minnow goals of ensuring recruitment classes no less than every two out of three years.	Improves recruitment habitat function and frequency.	Improves breeding and migratory habitat and facilitates regeneration of willow habitat through maintaining water availability to elongating root systems.
Refugia Habitat	Large woody debris (LWD)	Placement of trees, root wads, stumps, or branches in the main river channel or along its banks to create pools.	Creates low-flow refugial habitat (pools and slow-water habitats), provides shelter from predators and winter habitat, and provides structure for periphyton growth to improve food availability for silvery minnow.	Provides low-flow refugial habitat. Enhances spatial sequencing of pools and pool morphology through providing and maintaining channel pools; creates eddies to maintain opening at backwaters and embayments for recruitment habitat.	
	Strategic use of irrigation infrastructure to maintain critical reaches of wetted surface habitat	Use of irrigation returns and other infrastructure to maintain or refresh wetted pools during channel drying events.	Maintains wetted surface habitat during periods of intermittent channel drying.	Increases survivorship during stress periods.	Maintains or improves breeding and migratory habitat through ensuring hydrologic conditions throughout the flycatcher breeding season.
	Strategic utilization of wells to maintain critical reaches of wetted surface habitat	Supplemental water through shallow groundwater pumping to maintain or refresh wetted pools during channel drying events.	Maintains wetted surface habitat during periods of intermittent channel drying.	Increases survivorship during stress periods.	Maintain or improve breeding and migratory habitat through ensuring hydrologic conditions throughout the flycatcher breeding season
	Supplement main channel flow with contingency water supply	Supplemental water to refresh or minimize intermittent channel drying	Maintains wetted surface habitat during periods of intermittent channel drying.	Increases survivorship during stress periods.	
	Fish passage	Installation of fish passage structures at impoundments to improve longitudinal connectivity of river.	Allows upstream movement of silvery minnow and reduces habitat fragmentation.	Facilitates migration.	

4.2.2 RESTORATION STRATEGIES

Restoration strategies are targeted to improving the condition for each conservation unit. Within each conservation unit, key factors and processes were identified that limit the status of the silvery minnow and the flycatcher. Key factors and processes for the silvery minnow include geomorphic factors, demographic processes, and infrastructure constraints. Geomorphic factors are related to the habitat conditions and include the extent of coupling of riverine and riparian habitat, the degree of habitat heterogeneity, longitudinal spatial diversity, availability of refugia habitat, and degree of channel incision. Demographic processes refer to the population responses to the condition of the habitat and include the population growth potential, annual variability in recruitment and age class survival, retention of eggs and larvae, and downstream emigration. Infrastructure constraints, which may inhibit or the implementation of habitat restoration projects were also identified. These include features such as bridges, proximity to levees, and so on.

For the flycatcher we identified geomorphic factors, biological factors, and demographic processes. Geomorphic factors addressed the degree of groundwater and surface water coupling in the floodplain with the river channel. Biological factors include nest parasitism and vegetation structure. Demographic processes include the distance from distance from known nesting territories and the degree of possible human-induced breeding season disturbance.

We then used this information to develop a set of restoration strategies for the silvery minnow and the flycatcher in each identified conservation unit. Table 4.6 summarizes the restoration strategies for the Albuquerque Reach.

Table 4.6. Restoration Strategies

Conservation Unit	Tile #	Silvery Minnow Factors	Silvery Minnow Restoration Strategies	Flycatcher Factors	Flycatcher Restoration Strategies
SRU	1-5 1-6 1-7	**Geomorphic Factors** ▪ Lateral uncoupling of riverine/ riparian habitat ▪ Reduced volume and aerial extent of residential habitat ▪ Longitudinal monotony of residential geomorphic habitat features ▪ Longitudinally altered processes (e.g., channel incision transition zone) **Demographic Processes** ▪ Low population growth potential ▪ Reduced egg and larvae retention ▪ Downstream emigration processes ▪ Large inter-annual variation in reproductive success	▪ Enhance riverine restoration work planned by the Pueblo of Sandia ▪ Establish channel-margin recruitment habitat at low (1,500–2,500 cfs) river discharge	**Geomorphic Factors** ▪ Hydrologic decoupling – surface water ▪ Hydrologic decoupling – groundwater (?) **Biologic Factors** ▪ Inadequate breeding habitat structure ▪ Nest parasitism/predation **Demographic Processes** ▪ Distance from known occupied nesting territory	▪ Establish willow-dominated (Gooddings willow and coyote willow) habitat along channel margins and bank-attached bars ▪ Reduce and control non-native phreatophytes to a minor component of the floodplain vegetation
RCU-1	1-8 1-9 2-10 2-11	**Geomorphic Factors** ▪ Lateral uncoupling of riverine/ riparian habitat ▪ Longitudinal monotony of residential geomorphic habitat features **Demographic Processes** ▪ Low population growth potential ▪ Reduced egg and larvae retention ▪ Large inter-annual variation in reproductive success **Infrastructure Constraints** ▪ Bridge crossings (Alameda, Paseo del Norte) ▪ Levee encroachment ▪ Albuquerque Drinking Water Project	▪ Connect floodplain at moderate (3,000 cfs) river discharge ▪ Provide channel margin recruitment habitat at low (1,500 cfs) river discharge ▪ Reconnect arroyos	**Geomorphic Factors** ▪ Hydrologic decoupling – surface water ▪ Hydrologic decoupling – groundwater (?) **Biologic Factors** ▪ Inadequate breeding habitat structure ▪ Nest parasitism/predation **Demographic Processes** ▪ Distance from known occupied nesting territory	▪ Create willow-dominated habitat in conjunction with low-flow channel margin silvery minnow recruitment habitat

Table 4.6. Restoration Strategies

Conservation Unit	Tile #	Silvery Minnow Factors	Silvery Minnow Restoration Strategies	Flycatcher Factors	Flycatcher Restoration Strategies
PRU	2-12 3-13 3-14 3-15	**Geomorphic Factors** ▪ Lateral uncoupling of riverine/ riparian habitat ▪ Reduced volume and arial extent of residential habitat ▪ Longitudinal monotony of residential geomorphic habitat features **Demographic Processes** ▪ Low population growth potential ▪ Reduced egg and larvae retention ▪ Large inter-annual variation in reproductive success **Infrastructure Constraints** ▪ Bridge crossings (Montaño) ▪ Levee encroachment ▪ Jetty jacks	▪ Connect floodplain at moderate (3,000 cfs) river discharge ▪ Provide channel margin recruitment habitat at low (1,500 cfs) river discharge ▪ Increase residential habitat heterogeneity	**Geomorphic Factors** ▪ Hydrologic decoupling – surface water ▪ Hydrologic decoupling – groundwater (?) **Biologic Factors** ▪ Inadequate breeding habitat structure ▪ Nest parasitism/predation **Demographic Processes** ▪ Distance from known occupied nesting ▪ Human-induced breeding season disturbance (?)	▪ Establish large areas of willow-dominated habitat at the Montaño Oxbow ▪ Implement outreach targeted to adjacent developments and Rio Grande Valley State Park users during breeding season.
RCU-2	4-16 4-17 4-18 4-16 5-20 5-21 5-22 5-23 5-24	**Geomorphic Factors** ▪ Inadequate intermittence refugia **Demographic Processes** ▪ Large inter-annual variation in reproductive success ▪ Floodplain stranded young-of-year **Infrastructure Constraints** ▪ Bridge crossings (I-40, Bridge Road) ▪ Tingley Beach ▪ Levee encroachment ▪ Albuquerque Wastewater Treatment Plant	▪ Connect floodplain at moderate (3,000 cfs) discharge in areas currently inundated at high river discharge (>6,000 cfs) ▪ Increase channel margin recruitment habitat at low (1,500 cfs) river discharge ▪ Provide intermittence refugia in event of extremely low flows ▪ Develop supplemental water supply to maintain wetted surface habitat during extremely low flow events ▪ Reconnect South Diversion Channel	**Geomorphic Factors** ▪ Hydrologic decoupling – surface water ▪ Hydrologic decoupling – groundwater (?) **Biologic Factors** ▪ Inadequate breeding habitat structure ▪ Nest parasitism/predation **Demographic Processes** ▪ Distance from known occupied nesting ▪ Human-induced breeding season disturbance (?)	▪ Establish large areas of willow-dominated habitat in floodplain areas inundated at moderate (3,000 cfs) river discharge.

Silvery Minnow Restoration Strategies

Silvery minnow habitat restoration strategies focus on providing mesohabitat features that will improve residential, recruitment, and refugia habitat types. Residential habitat would be enhanced through the provision of varying mesohabitat features designed to be inundated at a range of river discharges. This would provide areas for silvery minnow to find low-velocity areas out of the main channel flows, which would be expected to affect demographic processes through decreasing the death rate and decreasing downstream emigration.

Recruitment habitat restoration would focus on providing floodplain inundation at flows of 3,000 cfs. As discussed above, inundation of the floodplain has been associated with large recruitment classes. However, it is equally important to provide recruitment habitats at intermediate and low flows that would normally be contained to the active river channel. These features, to be constructed on the channel margins and along bank-attached bars, would provide stability through minimizing the loss of an age class. While these recruitment classes would be expected to be smaller, they would nonetheless be important to maintaining a viable population.

Provision of refugia habitats of the primary transition subtype would be important in the southern portions of the Albuquerque Reach. It is in this subreach where river discharges could be extremely low in a worst-case scenario where the Albuquerque Drinking Water Project passes the minimum flow over the diversion dam.

Individual, site-scale restoration treatments would be combined into larger projects to affect geomorphic factors and demographic processes within a specified conservation unit. Proposed restoration treatments would also work in conjunction with completed (e.g., NMISC [SWCA 2007a], Pueblo of Sandia [SWCA 2008], Corps Route 66 [Corps 2008a], and City of Albuquerque [SWCA 2007b]) and proposed restoration projects (e.g. Corps BFS [Corps 2008b]).

Flycatcher Restoration Strategies

Habitat restoration strategies targeting flycatcher habitat will focus on techniques designed to increase or simulate floodplain or overbank flooding, and the creation of densely vegetated persistent wetlands, dominated by native willow species, especially Goodding's willow, greater than 1 ha (2.5 acres) in size. Flycatcher habitat restoration would create dense native willow-dominated vegetation patches that are above or adjacent to moist soil or standing water. Such patches are intended to be dense with complex branch structure up to 4 m (13 feet) tall. Active restoration techniques that will be employed primarily for silvery minnow habitat restoration also may provide benefits to the flycatcher. For example, backwater wetlands may be planted with willows, which should benefit both species. The restoration strategies for enhancing flycatcher habitat include the following:

1. Increase bosque inundation and/or increase the availability of groundwater resources to create perennial wetlands environments with native willow vegetation, especially Goodding's willow.
2. In existing wetland areas, create willow-dominated patches of sufficient density (especially Goodding's willow but also coyote willow), structure, and spatial extent through active planting or promoting natural revegetation to attract breeding flycatchers.

3. Enhance flycatcher migratory stopover habitat through restoring diverse native riparian willow habitats and restoring the riparian corridor.

4.3 Conceptual Habitat Restoration Projects

We have identified several large-scale projects. Each proposed project includes a number of individual restoration treatments and incorporates existing and proposed habitat restoration projects. The projects are presented from upstream to downstream and are ordered by conservation unit classification. The Restoration Matrix presented in Appendix C summarizes each project. Conceptual habitat restoration projects are presented in a series of aerial photos in Appendix D.

4.3.1 Secondary Restoration Unit (SRU)

The SRU is within the Pueblo of Sandia Subreach. The project area consists of the floodplain area to the west of the river. The Pueblo of Sandia has identified riverine habitat restoration projects through the Pueblo of Sandia Subreach Habitat Analysis and Recommendation Report (SWCA 2008). Additionally the Corps BFS identifies restoration opportunities, some of which overlap with Pueblo of Sandia projects. Within this reach there is little opportunity to conduct meaningful work for the benefit of the silvery minnow and the flycatcher, although vegetation management of the bosque on the west bank would be beneficial.

Proposed restoration projects are limited to creating bankline benches to provide channel margin recruitment habitat at flows ranging from 1,500 to 2,500 cfs. These types of features would add value to the proposed restoration project the Corps and the Pueblo of Sandia plan on implementing.

4.3.2 Reservation Conservation Unit 1 (RCU-1)

Project Site # 1 – North Diversion Channel Active River Channel Improvements

General Description

The area proposed for restoration is in the RCU-1 beginning at River Mile (RM) __ and extending downstream to RM __. The restoration area is adjacent to the outfall of the North Diversion Channel. Within this reach the river has variable cross section geometry with a series of bank-attached bars and islands that are covered with mature vegetation. There are four Reclamation river monitoring cross sections within the 3,048 m (10,000-foot reach) (including one long-term cross section, CO-34) that reflect recent changes in the active channel. The invert slope of the active channel varies between 0.0008 and 0.0016. The left and right bank elevations are relatively consistent through this reach and vary between 1.2 and 1.5 m (4–5 feet) above the thalweg. The W/D is relatively consistent throughout the in-channel range of flows.

Proposed Project

The project objective is to enhance residential habitat diversity and increase intermediate and low-flow recruitment habitat. The project is intended to work in concert with bar modification projects already accomplished by the NMISC, as well as future bar and overbank projects planned by the NMISC and the Corps. Components of the project include bankline benches modifications on the west side of the river, two floodplain inundation channels within the west-side overbank area, backwater embayments at the inlet and outlet of each side channel, and the stabilization of two bars on the east side of the river. Other bars and islands within the project reach have been destabilized with vegetation removal by the NMISC. It is important that all the activity planned within this subreach occurs within reasonable proximity in time in order to obtain the desired high-flow channel hydraulic response. Destabilization of the bars and the creation of the side channels would be accomplished such that additional low-depth, low-velocity habitat is created. The spoils material from the channel and embayment excavation would be used to create bank-attached bars on the opposite side of the river. These bars would be stabilized with willow plantings or possibly bendway weirs.

Anticipated Channel Morphology Response

In addition to creating a more active channel, the objective is to improve the channel response to North Diversion Channel flooding. By stabilizing the proposed sand bars on the east side of the river (with willow plantings, bendway weirs, or other stabilization techniques), the levee would be better protected. During flooding, the river is expected to attack the west bank altering the channel morphology and shifting the thalweg to the west side. Some bank destabilization is proposed for the west bank to encourage channel shifting. With sufficiently frequent bankfull discharge (on the order of once every two to three years based on an adaptive management program), the channel would maintain a higher width to depth ratio and would maintain the sand bars vegetation free. A slight increase in channel sinuosity should be observed over time, and the river would tend to meander slightly to the west.

Project Habitat Improvements

The projected habitat improvements would increase residential habitat diversity through the range of flows and increase high-flow recruitment habitat. The project would arrest the channel narrowing in the reach and improve the aquatic habitat diversity during high flows. With appropriate frequency of bankfull discharge, the channel sand bars would remain mobile and free of vegetation, increasing the active channel habitat by approximately 20% of surface area. This is critical for this project to have long-term habitat benefits.

Project Site # 2 – Paseo del Norte High-flow Side Channels

General Description

The area proposed for restoration extends from the confluence of the Calabacillas Arroyo at the upstream end downstream to the Paseo del Norte Bridge. This subreach is relatively dynamic, and the active channel width varies reasonably well throughout the reach, most likely due to the sediment loading from the Calabacillas Arroyo. The invert slope of the active channel through this reach is slightly steeper than other reaches within the Albuquerque Reach and is approximately 0.0014 feet/feet. The left and right bank elevations vary slightly throughout the reach and are generally between 1.8 and 2.4 m (6–8 feet) (relative to channel thalweg). The W/D is average for the range of in-channel flow. There are six reclamation river monitoring cross sections within the reach that reflect the recent channel conditions and depict the effects of sediment loading and channel diversity attributable to the Calabacillas Arroyo.

Proposed Project

The objective of this project is to create recruitment habitat and high-flow residential habitat through the use of floodplain side channels. The project consists of four floodplain inundation channels (three within the west overbank and one within the east overbank), each with excavated embayments at the inlets and outlets and a reworking of the deposited material at the Calabacillas Arroyo confluence with the river. The side channels would follow remnant flow lines as much as possible to minimize excavation on the project. The inlet and outlet points of these channels would need to be carefully analyzed and designed in order to prevent sedimentation and potential closure. The elevations of the channels would be set such that they would attain water at main channel discharges between 2,000 and 3,500 cfs. The side channels would add overall channel diversity at mid to high flows by creating additional low-depth, low-velocity habitat for the fish. The work proposed for the mouth of the Calabacillas Arroyo would consist of vegetation removal and reworking the deposited material to create residential and possibly refugial habitat for the fish during high flows.

Flycatcher habitat would be established in relation to the floodplain inundation channels and embayments and backwaters. Connecting the floodplain inundation channels with the proposed Corps BFS willow swales and wetland features would be expected to increase productivity of the swale through inputs of nutrients and sediments carried by inundation flows . Inundation of the swales would be expected increase the attractiveness of the sites as breeding habitat. Planting Goodding’s willow in the swales and along the floodplain channel margins is recommended. Coyote willow plantings could be implemented in the backwaters and embayments. These may develop naturally without intervention, depending on the frequency of channel inundation.

Anticipated Channel Morphology Response

There would be no significant change in the overall channel morphology of the reach. With sufficiently frequent bankfull discharge (on the order of once every two to three years), the channel would maintain its diversity and favorable heterogeneity throughout the reach.

Project Habitat Improvements

The projected silvery minnow habitat improvements would include more shallow low-velocity habitat at mid to high flows and increase retention and residential habitat during high flows. More diverse channel geometry at high flows would retain more fish in the Albuquerque Reach. With appropriate frequency of bankfull discharge, the existing active channel sand bars would remain mobile and free of vegetation, preserving the diversity of active channel habitat at the range of in-channel flow.

Flycatcher habitat would be improved through the establishment of dense willow stands associated with frequently inundated floodplain.

4.3.3 PRIMARY RESTORATION UNIT (PRU)

Project Site # 3 – Montaño Bridge Wetlands Creation

General Description

The area proposed for restoration is a 1.6-km (1-mile) reach of the west-side floodplain between the La Orilla drain outfall to the Montaño Bridge. This overbank area is not currently inundated by a discharge less than 7,000 cfs. There are a series of jetty jack lines that extend from the active channel westward onto the floodplain throughout the reach that should be removed. In this reach, the river has a relatively uniform cross section at high flows. At low flows, however, there is some variation in the channel geometry with alternating sand bars along the reach. There is one island, adjacent to the drain outfall, encroached with mature vegetation. The invert slope of the active channel varies between 0.001 in the upper half of the reach to 0.0002 near the Montaño Bridge. The left and right bank elevations are relatively uniform throughout the reach and vary between 2.1 and 2.4 m (7 and 8 feet) (relative to channel thalweg). The W/D for the range of flows up to bankfull discharge is about the average W/D for most of the Albuquerque Reach. There are three three river monitoring cross sections within the 1.6-km (1-mile) reach (including one long-term section, CO-35) that provide recent context regarding changes in the active channel.

Proposed Project

The objective of this project is to provide for floodplain inundation through creating wetlands, backwater, and floodplain side channel habitat in conjunction with enhancing the residential habitat in the active channel. An overbank channel would be excavated that meanders through the floodplain as shown in Appendix D. This channel would be connected to the river at the upstream and downstream ends by excavating a “mouth” at the active channel line. Also, the upstream end of the overbank channel would be connected to the La Orilla drain outfall. A large wetland area would be developed at the downstream end of the site near the Montaño Bridge. The downstream river channel connection would include a larger backwater habitat area. A hydraulic control (such as a gated weir) would be constructed in the drain to divert flow through the overbank channel to the wetlands during low-flow conditions. A downstream hydraulic control would also be constructed near the wetland/backwater interface to permit the wetlands to be periodically drained and to allow native fish to return to the river during the descending limb of the hydrograph. The elevations of the control structures at the river connection points would be set such that water can be introduced to the side channel and wetland area at main channel discharge of 1,500 cfs.

During summer months, the drain would provide water to enhance the riparian wetland habitat. Jetty jacks on the west floodplain would be removed with the floodplain channel excavation. As part of an ongoing series of projects, the NMISC has implemented island modification and island destabilization treatments, including vegetation clearing on the two existing islands within the project subreach. These islands may require further destabilization and would be reworked as part of the overall project. The enhanced river channel (from the NMISC island destabilization work) would be maintained by sufficient frequency of bankfull discharge and an adaptive management program.

This site provides an opportunity to establish large patches of flycatcher habitat associated with the floodplain wetlands. Goodding's willow would be planted as a part of the floodplain inundation channel. Coyote willow plantings are appropriate at the channel edge associated with the embayments and backwaters.

Anticipated Channel Morphology Response

There would be no significant change in the overall channel morphology of the reach. With sufficiently frequent bankfull discharge (on the order of once every two to three years based on an adaptive management program), the channel would maintain a higher W/D and would sustain vegetation-free sand bars.

Project Habitat Improvements

The projected silvery minnow habitat improvements include creation of high-flow recruitment habitat upstream of the Montaño Bridge and at the location of the upstream overbank channel inlet and enhanced residential habitat. Flycatcher habitat would be enhanced through implementing active planting of Goodding's willow and coyote willow at the constructed wetlands. It is proposed that the fish would enter the floodplain side channel at both ends and use the wetland area during high flows. As the flow recedes, the fish would seek return to the river channel. Hydraulic controls at both the upstream and downstream ends would enable the wetlands to be maintained throughout the year. Augmentation flow would be diverted from the drain return during low-flow conditions to sustain the wetlands during stress periods. The downstream control can also be used to drain and dry out the wetland periodically. Observation of the inlet and outlet conditions following high flows would be necessary to perform any required sediment deposition maintenance. With appropriate frequency of bankfull discharge, the reworked channel sand bars would remain mobile and free of vegetation, increasing the active channel habitat by approximately 10% of surface area.

Flycatcher habitat improvements would result from the establishment of large tracts of Goodding's willow. Goodding's willow is not prevalent in the Albuquerque Reach; however, it achieves the height and stem structure that coyote willow often does not. The large area, in relative proximity to the Montaño Oxbow, and the opportunity to provide a consistent water supply make this area an extremely attractive option.

<u>Project Site # 4 – Oxbow Wetland Enhancements</u>

General Description

The river channel is relatively uniform through the broad bend reach near the Montaño Oxbow. The reach is generally free of vegetated sand bars and islands. The area proposed for restoration is a 1,219-m (4,000-foot) subreach along the west overbank of the river at the oxbow site. The oxbow wetland area typically is saturated through connection to groundwater. The invert slope of the active channel adjacent to the oxbow is approximately 0.0009 feet/feet. The left and right channel bank elevations are relatively uniform, varying between 1.8 and 2.1 m (6–7 feet) above the thalweg. The W/D for low flows is more favorable for the silvery minnow and less beneficial as flow increases. There are three Reclamation cross sections within the reach that reflect the changes in the active channel since the 1990s. This subreach of the river is unique within the

Albuquerque Reach in that it retains some semblance of the historical floodplain attributes. This is a high-priority area that currently functions as historic riparian floodplain.

Proposed Project

The project objective is to enhance the wetland function in the oxbow by creating more permanent connections to the river channel at the upstream and downstream ends of the oxbow. This would be accomplished by excavating side channels, inlets and outlets at an appropriate river discharge stage. The upstream wetland inlet channel would connect the existing drain outfall and the oxbow meander. The downstream wetland connection would require excavating a short channel to the river. Since the wetland area already functions satisfactorily, the primary focus would be making the wetlands more accessible to fish during high flows and controlling the wetting and drying of the wetlands during stress periods. The drain flow can be used to sustain the wetlands during dry periods, and a downstream hydraulic control (weir gate) can be used to drain the wetlands occasionally. The elevations of the control structures at the downstream river connection point would be set such that water can be introduced to the side channel and wetland area at a main channel discharge of 3,500 cfs.

The Montaño Oxbow wetlands are expected to be managed for flycatcher habitat through the Corps BFS. Vegetation management should include establishing large stands of willow habitat. We recommend establishing Goodding's willow in and around the oxbow wetland and coyote willow closer to the river.

Anticipated Channel Morphology Response

The project would enhance the long-term hydrologic connectivity between the wetlands and the river and improve fish access to the wetlands during high flows. The wetland sustainability would be supported by a slight migration of the river channel to the west stimulated by bank destabilization between the inlet and outlets to the wetlands. The lateral shift of the channel by 15 m (50 feet) or so would be accompanied by some sand bar development on the east bank. There would be no significant change in the overall channel geometry of the reach.

Project Habitat Improvements

The projected habitat improvements include enhanced wetlands functionality and fish access. It is proposed that the fish would enter the wetlands from both ends and use the wetland area during high flows. Hydraulic controls (gated weir) at both the upstream and downstream ends would enable the wetlands to be maintained throughout dry years. Augmentation flow from the drain would be diverted to the wetlands during stress periods. The downstream control can also be used to drain and dry out the wetland periodically. Observation of the inlet and outlet conditions following high flows would be necessary to perform any required sediment deposition maintenance.

The Montaño Oxbow is a critical area for establishing flycatcher breeding habitat because of its consistent water supply and relative large size. This site, in conjunction with Project Site # 3 above will provide relative close, large habitat patches. Thus this site is a priority for flycatcher habitat restoration.

4.3.4 RESERVE CONSERVATION UNIT 2 (RCU-2)

Project Site # 5 – I-40 High-flow Side Channel

General Description

The area proposed for restoration is a 1.6-km (1–mile) river reach upstream of Interstate 40 (I-40), extending to just downstream of I-40. This reach is relatively straight and narrow with a high bluff along the entire west side, located approximately 122 m (400 feet) from the west bank of the active channel. Largely due to the bluff, the river is pinched through this reach. The invert slope of the active channel through this reach is approximately 0.0009 feet/feet. The opportunity for overbank flooding in this reach is not significant as the bank elevations vary between 1.8 and 2.1 m (6–7 feet) above the channel thalweg. The W/D is favorable for fish habitat at low flows, but it decreases at higher flows, becoming less favorable. There are three short-term Reclamation river monitoring cross sections within the reach that reflect the recent channel conditions.

Proposed Project

The project is designed to provide residential habitat at higher flows by creating parallel side channels through the west overbank. In addition to the upstream and downstream connection points to the active channel, it would have two mid-channel connection points in which small embayments would be excavated to promote and enhance the reconnection to the river at a range of flows. The channel would be aligned along the lowest remnant channel threads and existing low-lying areas in an effort to minimize excavation. The side channels would add overall channel diversity at mid to high flows by creating additional low-depth, low-velocity habitat for the silvery minnow. The site would be closely analyzed and modeled for water surface elevations in order to successfully get flow into the overbank channel. The elevations of the river connection points would be set such that water can be introduced to the side channel at a main channel discharge of 2,500 cfs.

Close analysis of the response to high flows at both ends is required because the downstream end may keep a higher water surface elevation due to the existing island near the downstream reconnection point. This could inhibit flow through the side channel. As analysis progresses, it may be recommended that this island/bar be reworked to create a more predictable water surface at the proposed outlet.

Coyote willow plantings would be implemented at the base of the bluff. These plantings would consist of two rows and would extend throughout the length of the ephemeral channels. The intent of the willow plantings is to provide additional protection of the bank.

An additional backwater feature is proposed on the bank-attached bar, known locally as "Mickey's bar," just downstream of I-40. The proposed backwater would enhance the work previously completed. Analysis of bar inundation using the June 2008 (high) and July 2008 (intermediate) flow imagery provided by the Collaborative Program indicates that the bar is inundated during the moderate flows; however, there is some pooling and potential for isolating the silvery minnow. The proposed backwater would create additional low-flow recruitment habitat and facilitate drainage of the bar. The strategic placement of large woody debris at the opening of the backwater may help keep the backwater open.

Anticipated Channel Morphology Response

The objective of this project is to create residential habitat diversity through a relatively long floodplain side channel. There would be no significant change in the overall channel morphology of the reach. Should the island/bar near the bottom of this reach be reworked as part of this project, there would be a slight increase in residential habitat diversity across the range of active channel flows. With sufficiently frequent bankfull discharge (on the order of once every two to three years based on an adaptive management program), the channel would maintain a slightly higher W/D.

Project Habitat Improvements

The projected habitat improvements would include more shallow low-velocity habitat at higher flows and possibly increase recruitment habitat during high flows. The project would decrease the uniformity of flow conditions during high flows. With appropriate frequency of bankfull discharge the existing active channel sand bars would remain mobile and free of vegetation increasing the diversity of active channel habitat at low flow.

Flycatcher habitat would be provided through the establishment of coyote willow along the base of the bluff.

<u>Project Site # 6 – Bridge Street Floodplain Coupling</u>

General Description

The area proposed for restoration is a 1.6-km (1–mile) river reach centered on the Bridge Street river crossing. The river makes a wide, southwesterly turn through this reach and has a relatively constant active channel width of 183 m (600 feet) at bankfull discharge. At lower flows the active channel exhibits alternating sand bars and two mid channel sand bars downstream of Bridge Street. The invert slope of the active channel through this reach is approximately 0.0009 feet/feet. The left bank of the active channel is slightly lower than the right bank through this reach; thus, there is the opportunity for overbank inundation along the outside of the channel curve in this reach. Existing condition FLO-2D simulations support this, as overbank inundation is predicted for discharges in the 6,000 to 6,500 cfs range. The average W/D through this reach is more favorable for residential habitat at higher discharges than other reaches through Albuquerque Reach. There are four short-term Reclamation river monitoring cross sections within the reach that reflect the recent channel conditions.

Proposed Project

The project is designed to provide recruitment habitat at mid to higher flows by creating a floodplain/active channel coupling at a more frequent peak discharge. The project involves lowering the bank of the left side of the active channel in three locations. The three locations have been selected in areas where a discernable natural levee has formed on the active channel bank. These natural levees are the result of accumulated sediments due to the establishment of vegetation along the bank (Hudson 2005). These natural levees can be removed at relatively low cost, opening additional overbank areas to inundation. Observation of 1999 contour data for the proposed locations for the bank lowering indicates appreciable acreage can be inundated with relatively minor excavation. The banks would be lowered such that overbank inundation would begin at main channel discharges between 3,000 and 3,500 cfs. At the furthest downstream bank lowering site, two small embayments would be excavated in the overbank to provide additional habitat and help augment the return to the main channel for the fish as flows recede.

Flycatcher habitat improvements would include the proposed Corps BFS willow swales and additional Goodding's willow or coyote willow plantings associated with the Corps BFS water feature.

Anticipated Channel Morphology Response

The objective of this project is to create primary and secondary recruitment habitat by enhancing floodplain inundation. While there would be no significant change in the overall channel morphology of the reach, the increased frequency of floodplain inundation would result in more favorable W/D for mid to high flows through the reach. With sufficiently frequent bankfull discharge (on the order of once every two to three years), the channel would maintain this higher width to depth ratio as the natural levees would not re-establish themselves.

Project Habitat Improvements

The projected habitat improvements would include shallow, low-velocity nursery habitat at higher flows. It is anticipated that between 124 to 247 ha (50–100 acres) of floodplain inundation can be created at these sites for main channel discharges near the 3,000- to 3,500-cfs range.

Flycatcher habitat would be improved through increasing the frequency of floodplain inundation. The proposed Corps BFS willow swales would be enhanced through increased inundation. Additionally, flycatcher habitat plantings associated with the Corps BFS water feature would be expected to be maintained through the consistent water supply this feature would provide.

Project Site # 7 – Rio Bravo Floodplain Coupling

General Description

The area proposed for restoration is a 457-m (1,500-foot) river reach upstream of the Rio Bravo Bridge river crossing. The river makes a southeasterly turn through this reach and has a relatively constant active channel width of 183 m (600 feet) at bankfull flow. At lower flows the active channel exhibits a large sand bar on the inside portion of this curve. The invert slope of the active channel through this reach is slightly steeper than the other reaches through Albuquerque, as it slopes at approximately 0.0010 feet/feet. The banks of the active channel are approximately 1.8 m (6 feet) above the active channel thalweg. Thus, slightly more excavation would be required to achieve the desired channel/floodplain coupling at this project location. While the inside area of a channel bend is not the ideal location to promote floodplain coupling, it is proposed to implement this project on a trial basis to weigh the merits of pursuing additional bank-lowering projects in other reaches. Existing condition FLO-2D simulations support general overbank flooding as it is predicted for discharges in the 6,000- to 6,500-cfs range. The average W/D through this reach is more favorable for residential habitat at mid-range flows at the project site. There is one short-term Reclamation river monitoring cross section within the reach that reflects the recent channel conditions.

Proposed Project

The project is designed to provide recruitment habitat at mid to higher flows by creating a floodplain/active channel coupling at a more frequent peak discharge. The project involves lowering the bank of the east side (inside portion of channel bend) of the active channel in one location. As with the Bridge Street sites, this location has been selected in an area where a discernable natural levee has formed on the active channel bank. This natural levee can be removed at relatively low cost, opening additional overbank area to inundation. Observation of 1999 contour data for the proposed location for the bank lowering indicates appreciable acreage can be inundated with relatively minor excavation. The bank would be lowered such that overbank inundation would begin at main channel discharges between 3,000 and 3,500 cfs. One small embayment would be excavated in the overbank to provide additional habitat and to help augment the return to the main channel for the fish as flows recede.

Anticipated Channel Morphology Response

The objective of this project is to create primary and secondary recruitment habitat by enhancing overbank flooding. While there would be no significant change in the overall channel morphology of the reach, the localized increased frequency of overbank flooding would result in more favorable W/D for mid to high flows in the area of the bank lowering. With sufficiently frequent bankfull discharge (on the order of once every two to three years based on an adaptive management program), the channel would maintain this higher W/D as the natural levee would not re-establish itself.

Project Habitat Improvements

The projected habitat improvements would include shallower, low-velocity nursery habitat at higher flows. It is anticipated that between 10 to 20 acres of floodplain inundation can be created at this site for main channel discharges near the 3,500-cfs range.

Project Site # 8 – South Diversion Channel River Channel Improvements

General Description

The area proposed for restoration is a 3.2-km (2–mile) river reach adjacent to and downstream of the outfall of the South Diversion Channel. This area has received a lot of attention with the NMISC, City of Albuquerque, and the Corps all working in the area. Nonetheless, there remains a great deal of potential to implement restoration projects to bring all these projects together into a large habitat restoration project that could serve as the centerpiece for silvery minnow habitat restoration in the Albuquerque Reach.

This reach has experienced channel narrowing through bar vegetation encroachment and bar attachment to the banks. The river has become slightly sinuous in response. The invert slope of the active channel through this reach is approximately 0.0009 feet/feet. Downstream of the confluence the opportunity for overbank flooding is high as the bank elevations vary between 1.2 and 1.5 m (4–5 feet) above the channel thalweg. The W/D for low flows is favorable for residential habitat but decreases at higher flows, becoming less favorable and indicating channel confinement. There are three Reclamation river monitoring cross sections within the reach that reflect the recent channel conditions and depict the channel narrowing.

Proposed Project

The project is designed to work in concert with existing City of Albuquerque island restoration efforts and NMISC and Corps island/bar and overbank restoration projects planned in this subreach. The proposed enhancements would add channel diversity by reworking the bars and islands and constructing a series of high-flow side channels within the overbanks in the 3.2.-km (2–mile) reach, which would improve aquatic habitat diversity. Vegetation would be removed and embayments would be excavated at the inlet and outlet of each high-flow side channel. In addition, vegetation would be removed from select stabilized sand bars and the bars would be destabilized to increase active channel width. The elevations of the river connection points for the side channels would be set such that water can be introduced at main channel discharges between 1,500 and 3,500 cfs.

A key feature is the relatively large embayment on the west side (Treatment # PR8-8). This feature is intended to provide a large feature that is connected to several other features. This type of feature provides an opportunity to test hypotheses regarding silvery minnow use of the floodplain and would be expected to be a key feature of a monitoring program. The feature is similar to a feature recently constructed by the NMISC in the Isleta Reach near Belen (SWCA 2009).

Flycatcher habitat improvements, consisting of Goodding's willow and/or coyote willow, would be completed in conjunction with the water feature proposed by the Corps BFS upstream of the South Diversion Channel. Additionally, floodplain inundation channels on the east bank, downstream of the South Diversion Channel, are designed to connect the willow swales proposed by the Corps BFS.

Anticipated Channel Morphology Response

The purpose of the project is to improve the channel dynamics and increase habitat diversity. By arresting the channel narrowing, the channel may straighten slightly and increase the W/D in response to reworking the existing vegetated islands. One of the objectives would be to enable the channel to respond beneficially to South Diversion Channel flooding by forcing the flows to the right bank and develop a sand bar along the left bank downstream of the diversion. It is anticipated that sand bars would form in this reach during the recessional limb, and the focus should be to keep the vegetation from stabilizing the bar. With frequent bankfull discharge (on the order of once every two to three years), the channel would maintain the sand bars free of vegetation. The high-flow channels would provide added low-flow recruitment habitat for the fish during the spring spawn.

Project Habitat Improvements

The projected habitat improvements would increase habitat heterogeneity through providing low-flow residential habitat and increasing the availability of intermediate to high-flow residential habitat. More diverse channel geometry at high flows would increase silvery minnow retention in the Albuquerque Reach and decrease downstream emigration. Silvery minnow drifting downstream of this reach during high flows are more likely to pass the Isleta Diversion Dam and be lost to the Albuquerque Reach. The project would arrest the channel narrowing in the reach and decrease the uniformity of flow conditions during high flows. With appropriate frequency of bankfull discharge, the channel sand bars would remain mobile and free of vegetation, increasing the active channel habitat. This is critical for this project to have any long-term habitat benefits. As with the proposed effort at the North Diversion Channel confluence, it is important that all the activity planned within this subreach occur within a reasonable time frame in order to obtain the desired high-flow channel hydraulic response.

Additional flycatcher habitat would be established in conjunction with features proposed by the Corps BFS. These features would be expected to provide a consistent water source to maintain inundation during the breeding season.

Project Site # 9 – I-25 High-flow Side Channels

General Description

The area proposed for restoration is a 2.4-km (1.5–mile) river reach upstream of Interstate 25 (I-25) crossing over the river. This reach is relatively narrow when considered from levee to levee. The active channel has average width through the reach and is fairly straight. The channel exhibits some braiding with small active sand bars at low flows. For much of this subreach the river is in proximity (<91 m [<300 feet]) to the west levee. The invert slope of the active channel through the reach is slightly flatter than upstream reaches (attributable to the approaching Isleta Diversion Dam) and is approximately 0.0008 feet/feet. There is opportunity for overbank flooding in this reach as the bank elevations vary between 1.5 to 1.8 m (5 and 6 feet) above the channel thalweg. The W/D is favorable for residential habitat at low flows, but it becomes less favorable with higher flows. There are four Reclamation river monitoring cross sections within the reach that reflect the recent channel conditions and depict the channel narrowing.

Proposed Project

The project is designed to relieve some of the pressure from the west edge of the active channel by constructing three mid- to high-flow side channels within the east overbank. The proposed channels would include excavated embayments at each inlet and outlet. In addition, the two southernmost channels would include mid-channel excavated depressions to further increase favorable habitat. The three channels and excavated depressions would be sighted along remnant channel threads and existing low-lying areas in an effort to minimize excavation. The side channels would add overall channel diversity at mid to high flows by creating additional low-depth, low-velocity recruitment habitat. The floodplain depressions would be planted with Goodding's willow to increase flycatcher habitat.

Anticipated Channel Morphology Response

The objective of this project is to create high-flow recruitment habitat through the creation of floodplain inundation channels. There would be no significant change in the overall channel morphology of the reach. With sufficiently frequent bankfull discharge (on the order of once every two to three years based on an adaptive management program), the channel would maintain a higher W/D and would sustain vegetation free sand bars.

Project Habitat Improvements

The projected habitat improvements would include more shallow low velocity habitat at higher flows as well as increase residential habitat during high flows. More diverse channel geometry at high flows would retain more fish in the Albuquerque reach. Fish drifting downstream of this reach during high flows are more likely to pass the Isleta Diversion Dam and be lost to the Albuquerque Reach. The project would decrease the uniformity of flow conditions during high flows. With appropriate frequency of bankfull discharge, the existing, active channel sand bars would remain mobile and free of vegetation increasing the diversity of active channel habitat at low flows.

This area, along with the Project Site # 8 above are important areas for restoring flycatcher habitat, as these areas are in relative proximity to existing occupied territories on the Isleta Pueblo (Smith and Johnson 2005, 2008). The creation of the floodplain depressions and increasing the frequency of floodplain inundation would provide large areas of potential flycatcher habitat. Additionally, the willow swales proposed in the Corps BFS would benefit from the floodplain inundation channels.

4.4 HYDROLOGICAL ALTERNATIVES

4.4.1 WATER OPERATIONS COORDINATION

Water operations coordination is an important component of a successful restoration strategy for both the silvery minnow and the flycatcher. Both species are tied to the hydrology of the system and require periods of inundation to complete their life cycles. As shown above, the silvery minnow requires the inundation of floodplain and channel margin habitats for a minimum of 10 days to complete spawning and larval development to the point where they are strong enough to enter the current. Flycatcher nesting success is strongly correlated to inundated floodplains.

Water operations coordination goals include:

1. Providing recruitment flows of a minimum of 3,500 to 5,000 cfs for a period of 10 to 25 days every 2 out of 3 years.
2. Reducing flows on the receding limb of the hydrograph slowly to avoid stranding silvery minnow in floodplain nursery habitats.

Water operations coordination would be expected to provide the following benefits:

1. Meet the objective of reproductive success no less than two of three years.
2. Minimize stranding and isolation of year-of-young silvery minnow.
3. Enhance natural recruitment of cottonwood and willow species (see Parametrix 2008b and 2008c).
4. Maintain channel function to redistribute sediment and scour out young seedlings to minimize island and bar hardening.

We recognize that there are constraints on the system, not the least of which is the current drought conditions and the over-allocation of the system. Nonetheless, water operations coordination will be an important component of a successful habitat restoration program. The Corps and Reclamation has made great strides with the recently completed Upper Rio Grande Water Operations (Corps, Albuquerque District, U.S. Department of Interior, Bureau of Reclamation, and New Mexico Interstate Stream Commission 2007). We encourage continuation of this process so that as we learn more about the lifecycle needs of the silvery minnow and its habitat requirements, water operations may be tweaked to provide a sufficient quantity of water at the appropriate time to better meet the needs of the species as well as meet the requirements of the Rio Grande Compact and the needs of the water users.

4.4.2 Low-flow Supplemental Sources

During extremely low-flow events, it may be desirable to provide supplemental water sources to maintain critical reaches of wetted surface habitat. These supplemental water sources may include:

1. The strategic use of irrigation infrastructure, such as irrigation returns, wasteways, and drains.
2. The strategic use of wells.

The purpose of using these supplemental water sources would be to keep sections that are in danger of drying wetted or to refresh isolated refugial pools. While current hydraulic modeling suggests that the river is not expected to dry, it is possible for the river to experience extremely low flows, which could create disconnected pools. The reach where this is most likely to occur is in the RCU-2 area. This is an important reach as it has the highest potential for supporting strong silvery minnow populations. There is the potential to develop recruitment habitat that provides a desirable age-class structure, and there is sufficient residential habitat heterogeneity to support the silvery minnow.

The development of low-flow supplemental water contingencies would require further analysis, including monitoring the restoration projects, population responses, and modeling river flows.

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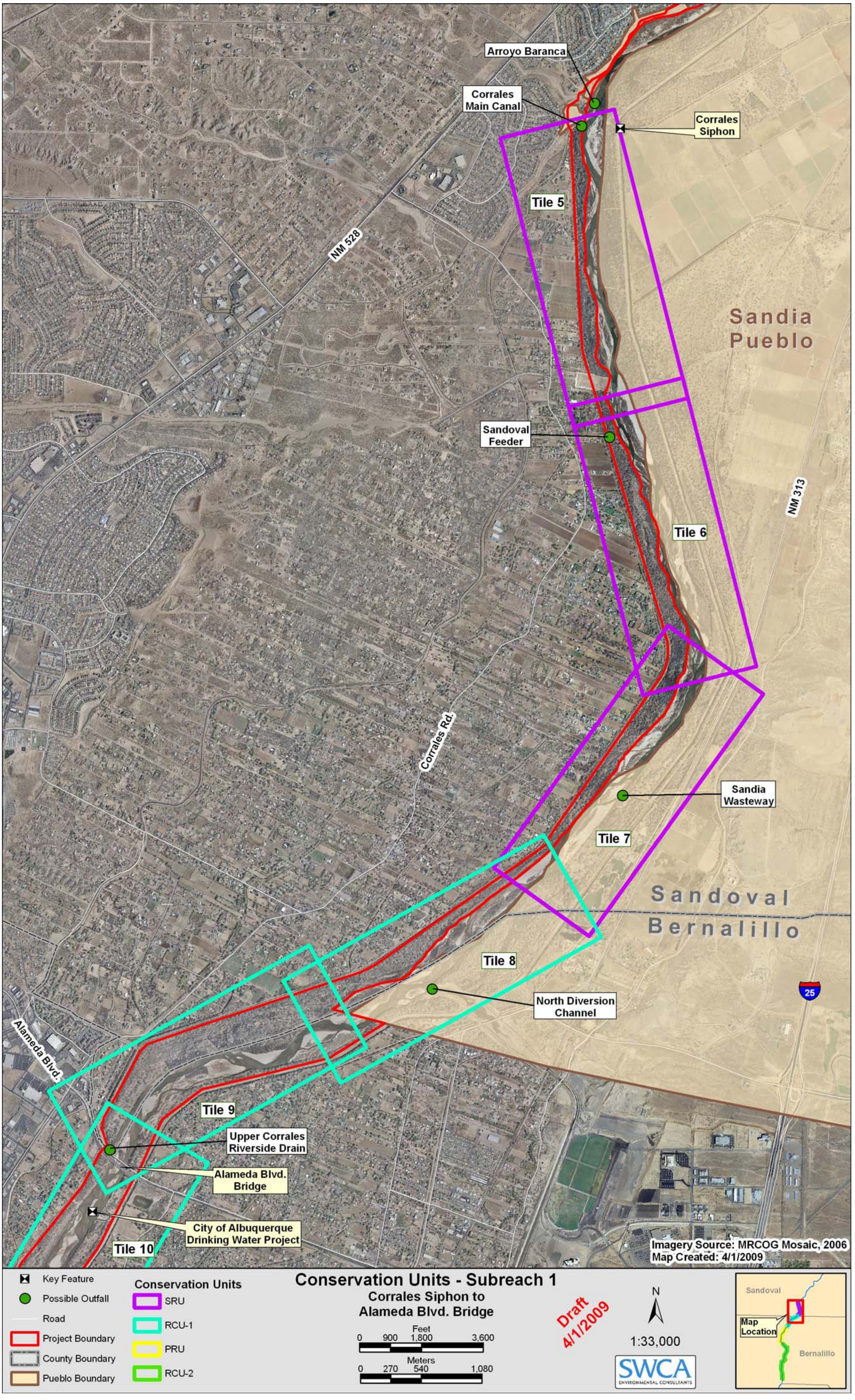
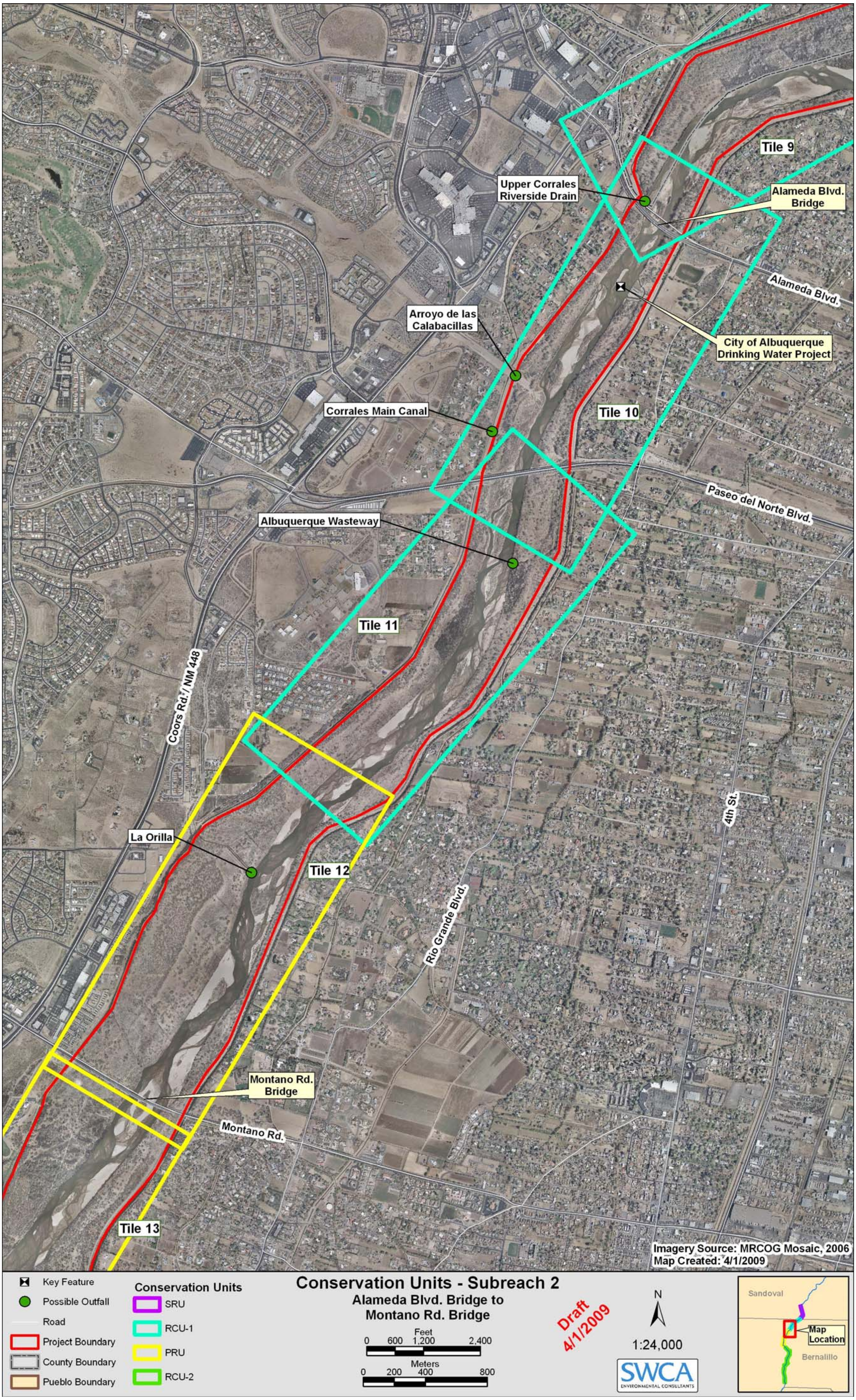
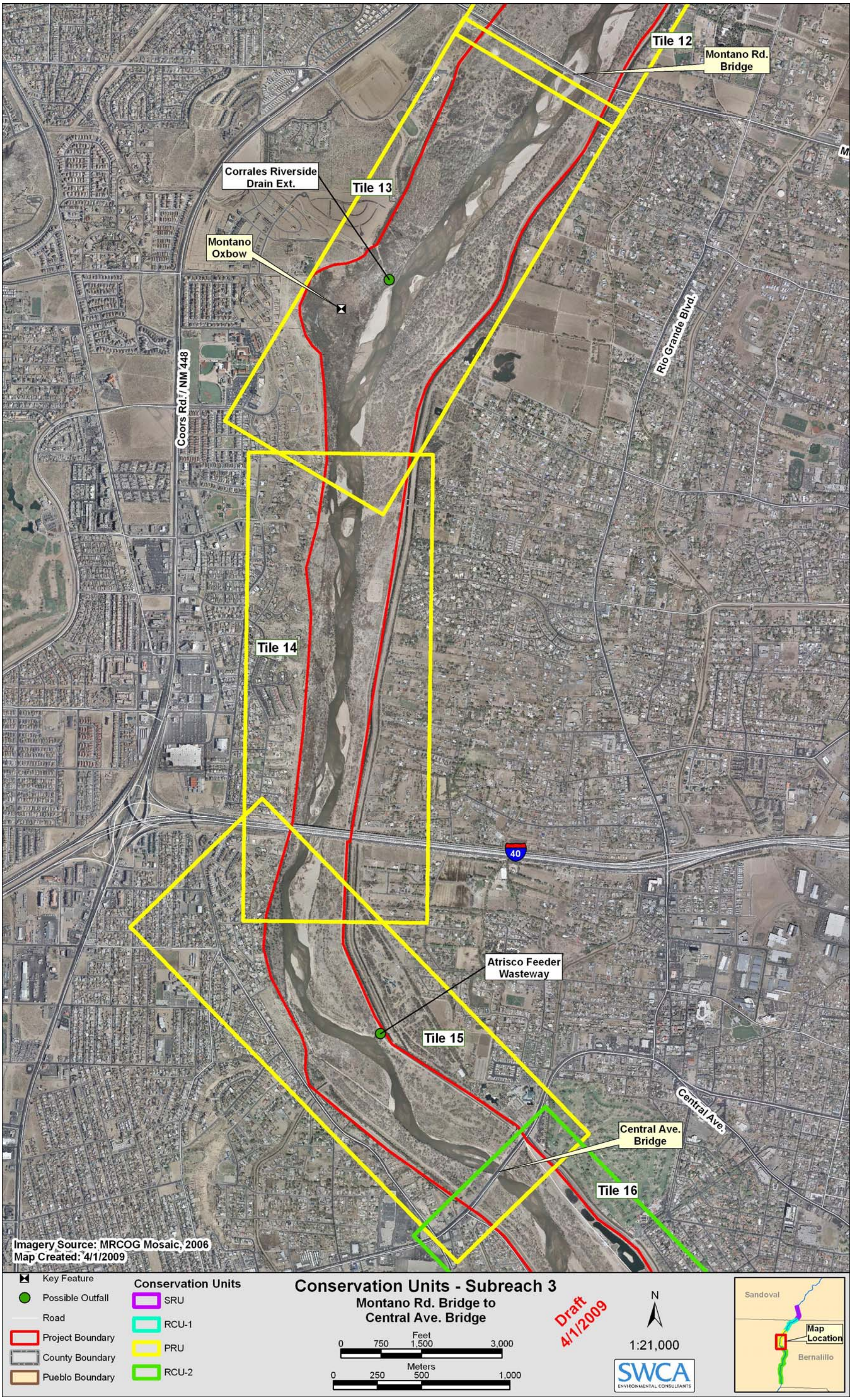
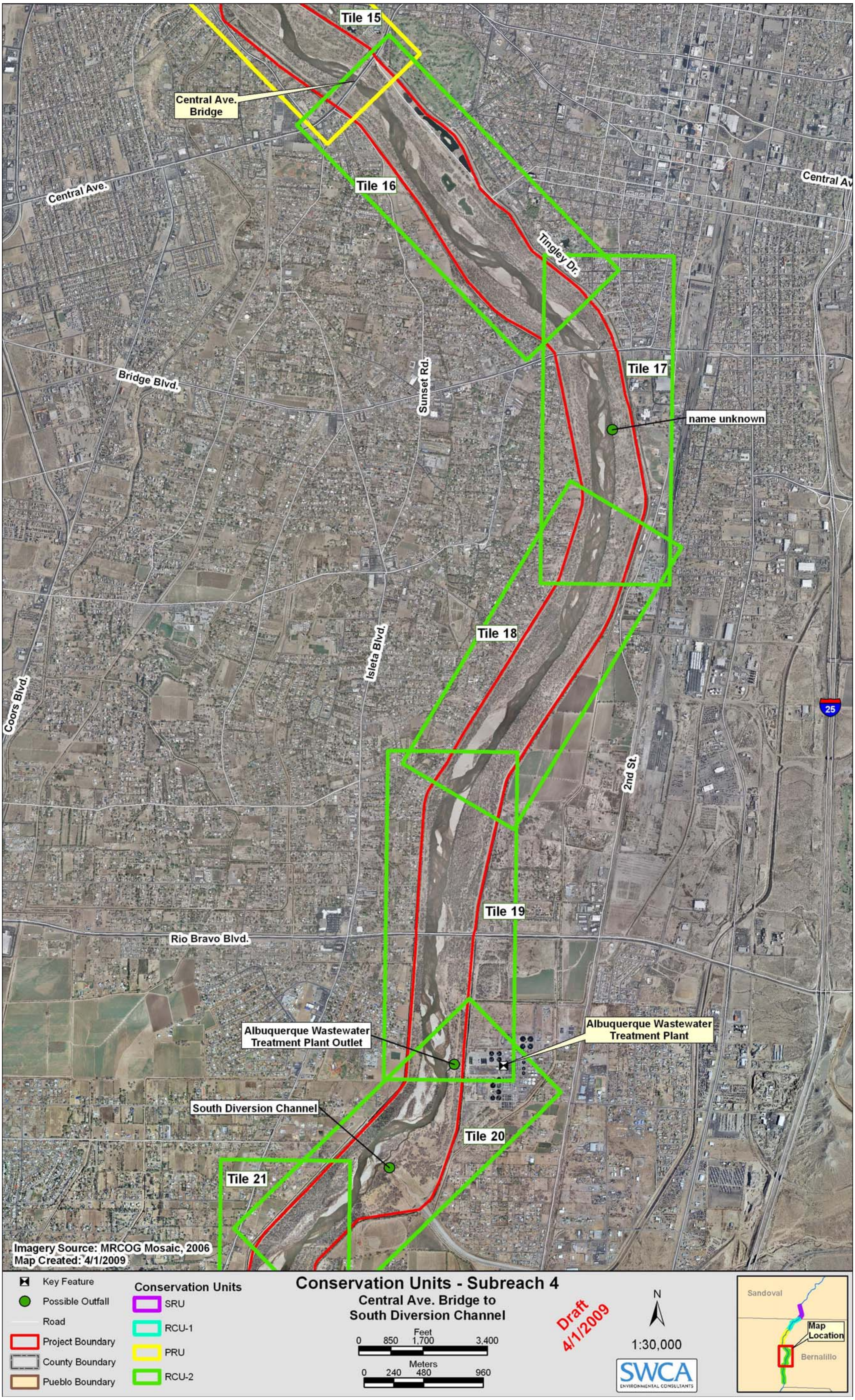
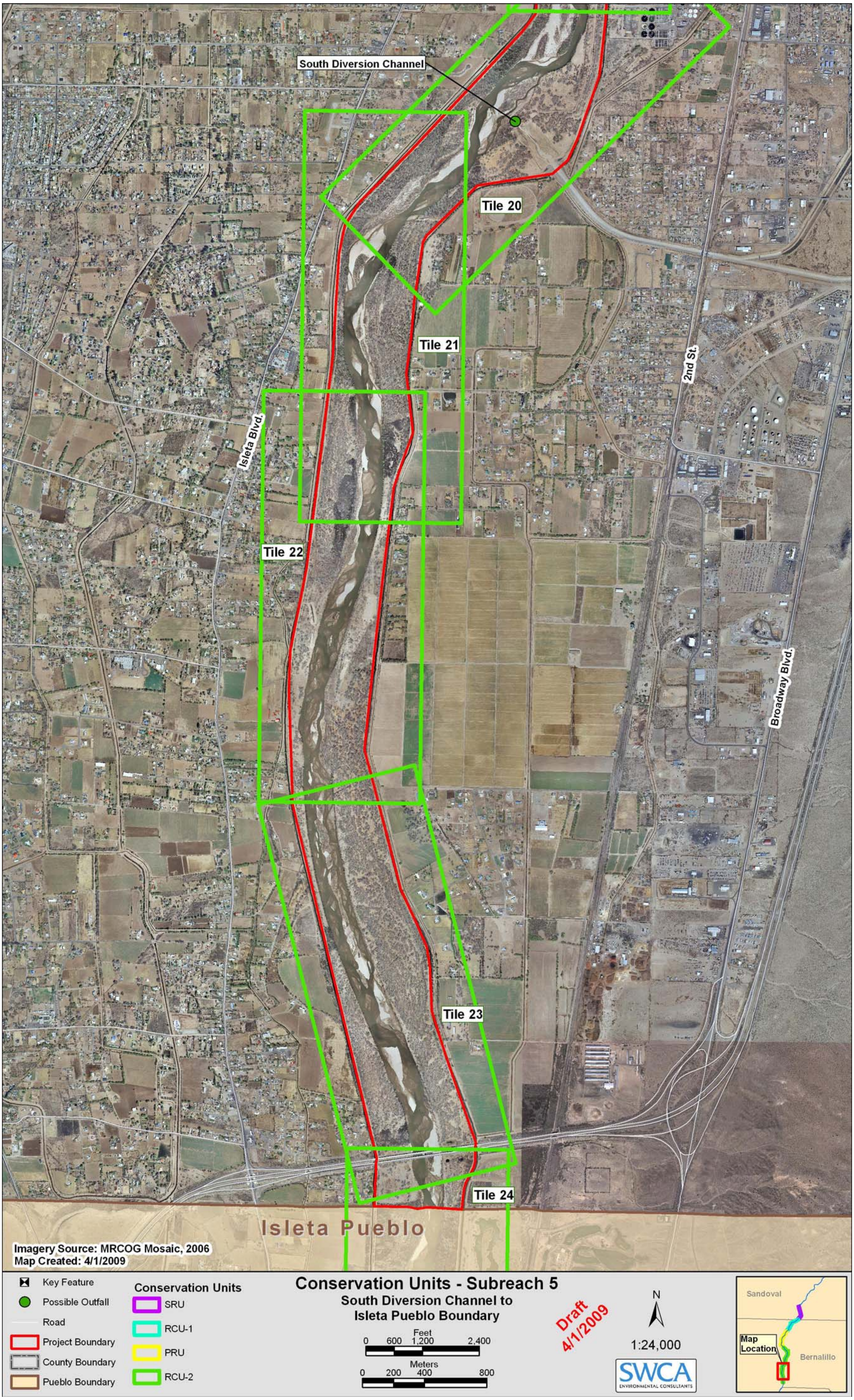
Appendix A
Conservation Unit Maps


Arroyo Baranca
Corrales Main Canal
Corrales Siphon
Tile 5
NM 528
Sandia Pueblo
Sandoval Feeder
NM 313
Tile 6
Corrales Rd.
Sandia Wasteway
Tile 7
Sandoval
Bernalillo
Tile 8
North Diversion Channel
25
Alameda Blvd.
Tile 9
Upper Corrales Riverside Drain
Alameda Blvd. Bridge
City of Albuquerque Drinking Water Project
Tile 10
Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/1/2009
Key Feature
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Units
SRU
RCU-1
PRU
RCU-2
Conservation Units - Subreach 1
Corrales Siphon to
Alameda Blvd. Bridge
Feet
0 900 1,800 3,600
Meters
0 270 540 1,080
Draft 4/1/2009
N
1:33,000
SWCA
Sandoval
Map Location
Bernalillo


Tile 9
Upper Corrales Riverside Drain
Alameda Blvd. Bridge
Alameda Blvd.
City of Albuquerque Drinking Water Project
Arroyo de las Calabacillas
Corrales Main Canal
Tile 10
Paseo del Norte Blvd.
Albuquerque Wasteway
Tile 11
Coors Rd. / NM 448
4th St.
La Orilla
Tile 12
Rio Grande Blvd.
Montano Rd. Bridge
Montano Rd.
Tile 13
Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/1/2009
Key Feature
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Units
SRU
RCU-1
PRU
RCU-2
Conservation Units - Subreach 2
Alameda Blvd. Bridge to
Montano Rd. Bridge
Feet
0 600 1,200 2,400
Meters
0 200 400 800
Draft
4/1/2009
N
1:24,000
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Map Location
Bernalillo


Tile 12
Montano Rd. Bridge
Corrales Riverside Drain Ext.
Tile 13
Montano Oxbow
Rio Grande Blvd.
Coors Rd. / NM 448
Tile 14
40
Atrisco Feeder Wasteway
Tile 15
Central Ave.
Central Ave. Bridge
Tile 16
Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/1/2009
Key Feature
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Units
SRU
RCU-1
PRU
RCU-2
Conservation Units - Subreach 3
Montano Rd. Bridge to Central Ave. Bridge
Feet
0 750 1,500 3,000
Meters
0 250 500 1,000
Draft 4/1/2009
N
1:21,000
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Map Location
Bernalillo


Tile 15
Central Ave. Bridge
Central Ave.
Central Ave
Tile 16
Tingley Dr.
Tile 17
Bridge Blvd.
Sunset Rd.
name unknown
Tile 18
Isleta Blvd.
Coors Blvd.
25
2nd St.
Tile 19
Rio Bravo Blvd.
Albuquerque Wastewater Treatment Plant Outlet
Albuquerque Wastewater Treatment Plant
South Diversion Channel
Tile 20
Tile 21
Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/1/2009
Key Feature
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Units
SRU
RCU-1
PRU
RCU-2
Conservation Units - Subreach 4
Central Ave. Bridge to South Diversion Channel
Feet
0 850 1,700 3,400
Meters
0 240 480 960
Draft 4/1/2009
N
1:30,000
SWCA ENVIRONMENTAL CONSULTANTS
Sandoval
Map Location
Bernalillo


South Diversion Channel
Tile 20
Tile 21
Tile 22
Tile 23
Tile 24
2nd St.
Isleta Blvd.
Broadway Blvd.
Isleta Pueblo
Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/1/2009
Key Feature
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Units
SRU
RCU-1
PRU
RCU-2
Conservation Units - Subreach 5
South Diversion Channel to
Isleta Pueblo Boundary
Feet
0 600 1,200 2,400
Meters
0 200 400 800
Draft
4/1/2009
N
1:24,000
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Map Location
Bernalillo

Appendix B
Depth Averaged Channel Hydraulic Conditions Summary

	Sub Reach / Sheet #																				
Discharge (cfs)	1 / 5	1 / 6	1 / 7	1 / 8	1 / 9	2 / 10	2 / 11	2 / 12	3 / 13	3 / 14	3 / 15	4 / 16	4 / 17	4 / 18	4 / 19	5 / 20	5 / 21	5 / 22	5 / 23	5 / 24	5 / 25
	Width to Depth Ratio (W/D)																				
500	108	133	125	173	211	147	142	144	269	145	113	218	272	185	188	135	165	192	222	123	279
1000	116	137	129	179	204	145	138	164	223	121	94	182	229	172	169	123	139	158	185	116	284
1500	117	131	129	191	193	143	136	168	197	108	83	162	201	160	160	115	123	140	165	109	289
2000	114	125	126	195	184	139	133	171	180	99	75	149	184	150	151	109	113	128	152	101	293
2500	111	120	123	197	177	134	132	169	167	93	70	139	172	142	143	103	105	119	142	95	301
3000	107	116	121	198	169	133	131	165	157	88	66	131	162	135	136	99	100	112	134	90	302
3500	103	113	118	196	162	131	128	160	149	84	63	125	154	129	131	95	95	107	128	86	303
4000	100	110	115	192	156	127	126	156	143	81	60	119	147	124	126	91	91	103	123	82	303
4500	96	107	112	187	151	124	123	151	137	78	58	115	141	119	122	88	88	99	118	79	303
5000	94	105	109	183	146	120	121	148	132	76	56	111	136	115	118	86	85	96	114	76	303
≤ 1500 AVG	113.5	133.8	128.0	181.1	202.7	144.9	139.0	158.6	229.8	124.5	96.5	187.2	234.0	172.3	172.2	124.4	142.3	163.1	191.0	115.7	283.9
≤ 1500 ST ERR	5.4	3.1	2.7	10.1	10.3	2.6	3.7	15.0	41.8	22.0	18.0	32.9	41.1	14.9	16.6	11.4	24.3	30.4	33.6	7.9	5.7
1500<AVG≤3500	108.5	118.5	122.2	196.5	172.9	134.1	131.2	166.2	163.6	91.0	68.4	135.9	168.0	138.8	140.0	101.3	103.3	116.7	139.2	92.7	299.9
1500<STD ERR≤3500	4.6	5.5	3.4	1.1	9.5	3.5	2.3	5.0	13.3	6.5	5.5	10.3	13.1	9.3	8.7	6.0	7.7	9.0	10.3	6.5	4.7
> 3500 AVG	96.6	107.4	111.7	187.3	151.1	123.6	123.4	151.6	137.2	78.2	58.1	115.1	141.5	119.5	121.8	88.5	88.0	99.3	118.5	78.9	302.9
> 3500 ST ERR	3.3	3.0	3.3	5.3	5.7	4.6	3.1	4.4	6.2	3.0	2.2	4.9	6.5	4.8	4.5	3.2	3.9	4.1	5.0	3.8	0.0
Overall AVG	106.4	119.8	120.8	189.1	175.3	134.2	131.2	159.6	175.5	97.2	73.7	145.1	179.8	143.0	144.2	104.4	110.4	125.4	148.5	95.4	296.0
Overall ST ERR	5.1	7.2	4.6	5.3	14.2	5.8	4.3	6.0	27.5	13.9	11.5	21.4	27.4	14.8	14.3	10.1	16.1	19.2	21.6	10.2	5.8
	Thalweg Depth (ft)																				
500	3.3	3.3	3.2	2.5	2.3	2.8	2.8	2.8	2.3	2.6	2.8	2.3	2.1	2.7	2.7	3.1	2.7	2.6	2.5	2.8	3.8
1000	4.0	3.9	3.8	3.1	2.8	3.4	3.4	3.5	2.7	3.2	3.5	2.9	2.5	3.3	3.2	3.7	3.2	3.2	3.0	3.3	4.5
1500	4.5	4.3	4.2	3.5	3.2	3.9	3.9	3.9	3.1	3.7	3.9	3.3	2.9	3.8	3.6	4.1	3.7	3.6	3.3	3.8	4.9
2000	4.8	4.6	4.5	3.8	3.4	4.2	4.2	4.2	3.4	4.1	4.4	3.6	3.2	4.1	3.9	4.4	4.0	4.0	3.7	4.1	5.3
2500	5.1	4.9	4.8	4.0	3.7	4.5	4.5	4.4	3.6	4.4	4.7	3.8	3.4	4.4	4.2	4.7	4.3	4.3	3.9	4.4	5.7
3000	5.3	5.1	5.0	4.2	3.9	4.8	4.7	4.7	3.8	4.7	5.0	4.1	3.6	4.6	4.4	4.9	4.6	4.6	4.2	4.7	6.0
3500	5.5	5.3	5.2	4.4	4.1	5.0	4.9	4.8	4.1	5.0	5.3	4.3	3.8	4.9	4.6	5.1	4.8	4.8	4.4	4.9	6.3
4000	5.7	5.6	5.4	4.6	4.3	5.2	5.1	5.0	4.3	5.3	5.6	4.5	4.0	5.1	4.8	5.4	5.1	5.0	4.6	5.2	6.7
4500	5.9	5.7	5.6	4.7	4.4	5.4	5.3	5.2	4.4	5.5	5.8	4.7	4.2	5.3	5.0	5.6	5.3	5.2	4.8	5.4	7.1
5000	6.1	5.9	5.7	4.8	4.6	5.6	5.5	5.3	4.6	5.7	6.1	4.8	4.3	5.4	5.2	5.7	5.5	5.4	4.9	5.7	7.4
≤ 1500 AVG	3.9	3.8	3.7	3.0	2.8	3.3	3.4	3.4	2.7	3.1	3.4	2.8	2.5	3.3	3.2	3.6	3.2	3.1	2.9	3.3	4.4
≤ 1500 ST ERR	0.7	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.5	0.7	0.7	0.5	0.5	0.6	0.6	0.5	0.6	0.6	0.5	0.6	0.6
1500<AVG≤3500	5.2	5.0	4.9	4.1	3.8	4.6	4.6	4.5	3.7	4.6	4.8	3.9	3.5	4.5	4.3	4.8	4.4	4.4	4.0	4.5	5.9
1500<STD ERR≤3500	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4
> 3500 AVG	5.9	5.7	5.5	4.7	4.4	5.4	5.3	5.2	4.4	5.5	5.8	4.7	4.2	5.2	5.0	5.5	5.3	5.2	4.8	5.4	7.1
> 3500 ST ERR	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.4
Overall AVG	5.0	4.8	4.7	4.0	3.7	4.5	4.4	4.4	3.6	4.4	4.7	3.8	3.4	4.3	4.2	4.7	4.3	4.3	3.9	4.4	5.8
Overall ST ERR	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.7	0.7	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.6	0.7

	Velocity (ft/sec)																				
500	1.2	1.1	1.2	1.1	1.1	1.2	1.1	1.3	0.9	1.0	1.2	1.0	0.9	0.9	1.0	1.1	1.1	0.8	0.9	1.3	0.9
1000	1.5	1.4	1.5	1.4	1.4	1.4	1.4	1.5	1.2	1.4	1.6	1.3	1.3	1.2	1.3	1.5	1.4	1.1	1.2	1.7	1.4
1500	1.7	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.4	1.6	1.9	1.6	1.5	1.4	1.5	1.7	1.7	1.4	1.4	1.9	1.7
2000	1.9	1.8	1.9	1.7	1.8	1.7	1.8	1.8	1.6	1.8	2.2	1.8	1.7	1.5	1.7	2.0	1.9	1.6	1.6	2.1	2.0
2500	2.1	2.0	2.1	1.9	2.0	1.9	2.0	1.9	1.8	2.0	2.4	2.0	1.9	1.7	1.9	2.2	2.1	1.8	1.8	2.4	2.3
3000	2.2	2.1	2.2	2.0	2.2	2.0	2.2	2.1	2.0	2.2	2.7	2.2	2.1	1.8	2.0	2.4	2.3	1.9	2.0	2.5	2.5
3500	2.4	2.3	2.4	2.1	2.3	2.1	2.3	2.2	2.1	2.4	2.9	2.3	2.3	2.0	2.2	2.5	2.5	2.1	2.2	2.7	2.7
4000	2.6	2.4	2.5	2.3	2.5	2.2	2.4	2.3	2.3	2.5	3.1	2.5	2.4	2.1	2.3	2.7	2.7	2.2	2.3	2.9	2.9
4500	2.7	2.5	2.7	2.4	2.6	2.3	2.6	2.5	2.4	2.7	3.2	2.6	2.6	2.2	2.4	2.9	2.8	2.4	2.5	3.1	3.0
5000	2.8	2.6	2.8	2.5	2.7	2.4	2.7	2.6	2.5	2.8	3.4	2.8	2.7	2.4	2.6	3.0	2.9	2.5	2.6	3.2	3.1
≤ 1500 AVG	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.5	1.2	1.3	1.6	1.3	1.2	1.1	1.2	1.4	1.4	1.1	1.2	1.6	1.3
≤ 1500 ST ERR	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.4	0.5
1500<AVG≤3500	2.1	2.0	2.1	1.9	2.1	1.9	2.1	2.0	1.9	2.1	2.5	2.1	2.0	1.8	1.9	2.3	2.2	1.8	1.9	2.4	2.4
1500<STD ERR≤3500	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
> 3500 AVG	2.7	2.5	2.7	2.4	2.6	2.3	2.6	2.4	2.4	2.7	3.2	2.6	2.6	2.2	2.4	2.8	2.8	2.4	2.5	3.1	3.0
> 3500 ST ERR	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1
Overall AVG	2.1	2.0	2.1	1.9	2.0	1.9	2.0	2.0	1.8	2.0	2.5	2.0	2.0	1.7	1.9	2.2	2.1	1.8	1.8	2.4	2.3
Overall ST ERR	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.3	0.4	0.4	0.5
	Top Width (ft)																				
500	334	420	379	440	489	387	384	388	586	362	316	492	565	490	481	419	422	486	536	349	279
1000	442	512	468	555	571	467	463	543	591	380	322	503	575	561	529	449	432	494	544	390	284
1500	500	547	524	664	607	525	514	633	594	390	324	511	578	594	565	464	435	498	549	406	289
2000	525	563	551	737	627	562	549	704	596	399	326	516	579	613	580	473	437	501	552	413	293
2500	545	574	574	792	642	586	584	744	597	406	328	520	581	619	587	479	440	503	554	416	301
3000	551	583	594	834	649	616	608	761	599	411	329	523	582	621	591	482	443	505	557	417	302
3500	554	593	602	860	653	640	625	770	600	416	331	524	583	623	594	484	446	507	558	419	303
4000	555	603	606	872	657	651	639	775	601	421	333	525	584	624	597	486	450	509	560	421	303
4500	556	610	610	877	660	657	647	778	602	425	336	526	584	625	599	487	453	512	561	422	303
5000	557	614	613	879	663	659	651	781	603	429	339	526	585	626	601	488	454	514	563	422	303
≤ 1500 AVG	425.3	492.7	456.9	553.1	556.0	459.5	453.6	521.4	590.5	377.3	320.7	502.1	572.3	548.4	525.2	444.0	429.6	492.8	543.1	381.8	283.9
≤ 1500 ST ERR	97.0	75.8	84.7	129.0	69.7	79.9	75.6	143.6	4.6	16.6	4.5	11.3	7.7	61.2	48.7	26.6	7.3	6.8	7.3	34.0	5.7
1500<AVG≤3500	543.5	578.3	580.2	805.7	642.5	600.9	591.6	744.6	598.0	407.9	328.5	520.7	581.1	619.0	588.1	479.5	441.3	503.7	555.3	416.1	299.9
1500<STD ERR≤3500	13.2	12.8	22.6	53.6	11.4	33.9	32.8	29.5	1.7	7.5	2.2	3.3	1.5	4.1	5.9	4.6	3.6	2.6	2.9	2.8	4.7
> 3500 AVG	556.3	609.1	609.7	875.7	659.9	655.5	645.6	778.0	602.3	424.9	335.9	525.7	584.3	624.8	598.9	487.0	452.2	512.1	561.4	421.6	302.9
> 3500 ST ERR	1.3	6.7	3.7	4.1	3.5	4.8	7.1	3.9	1.3	4.8	3.1	0.9	0.8	1.2	2.4	1.6	2.3	2.9	1.7	1.1	0.0
Overall AVG	511.9	561.9	552.1	750.9	621.8	574.9	566.4	687.7	597.0	403.8	328.4	516.6	579.4	599.6	572.5	471.1	441.1	503.0	553.5	407.5	296.0
Overall ST ERR	45.7	37.3	48.4	96.6	34.5	57.8	56.3	82.7	3.4	13.6	4.3	7.2	3.9	27.4	24.5	13.9	6.3	5.4	5.3	14.4	5.8

	Energy Slope (ft/ft)																				
500	0.00064	0.00062	0.04550	0.04404	0.04823	0.04909	0.03954	0.05960	0.00075	0.00061	0.00059	0.00059	0.00089	0.00053	0.00060	0.00078	0.00070	0.00049	0.00070	0.00059	0.00016
1000	0.00063	0.00059	0.05868	0.05603	0.06154	0.05695	0.05087	0.06859	0.00073	0.00059	0.00057	0.00059	0.00088	0.00049	0.00059	0.00077	0.00066	0.00048	0.00069	0.00057	0.00017
1500	0.00063	0.00058	0.06863	0.06355	0.07309	0.06013	0.05998	0.07543	0.00072	0.00058	0.00057	0.00059	0.00087	0.00047	0.00059	0.00077	0.00064	0.00049	0.00066	0.00055	0.00018
2000	0.00063	0.00057	0.07814	0.06978	0.08317	0.06311	0.06826	0.08164	0.00072	0.00058	0.00057	0.00060	0.00087	0.00047	0.00059	0.00076	0.00063	0.00049	0.00065	0.00054	0.00020
2500	0.00063	0.00057	0.08632	0.07543	0.09223	0.06849	0.07424	0.08789	0.00072	0.00057	0.00057	0.00060	0.00087	0.00046	0.00059	0.00076	0.00062	0.00049	0.00066	0.00052	0.00021
3000	0.00063	0.00056	0.09353	0.08088	0.10039	0.07270	0.08014	0.09483	0.00072	0.00057	0.00057	0.00061	0.00087	0.00046	0.00059	0.00076	0.00061	0.00050	0.00066	0.00052	0.00022
3500	0.00063	0.00056	0.10088	0.08635	0.10792	0.07598	0.08602	0.10216	0.00071	0.00057	0.00057	0.00061	0.00087	0.00046	0.00059	0.00076	0.00061	0.00050	0.00066	0.00051	0.00023
4000	0.00064	0.00056	0.10800	0.09198	0.11478	0.07918	0.09110	0.10900	0.00071	0.00057	0.00057	0.00061	0.00087	0.00046	0.00059	0.00076	0.00060	0.00050	0.00066	0.00050	0.00024
4500	0.00064	0.00056	0.11483	0.09752	0.12135	0.09209	0.09610	0.11544	0.00070	0.00056	0.00058	0.00062	0.00088	0.00046	0.00059	0.00076	0.00059	0.00051	0.00066	0.00050	0.00022
5000	0.00063	0.00056	0.12112	0.10284	0.12730	0.48008	0.10075	0.12241	0.00070	0.00056	0.00058	0.00062	0.00088	0.00046	0.00059	0.00076	0.00059	0.00051	0.00065	0.00050	0.00022
≤ 1500 AVG	0.00063	0.00060	0.05760	0.05454	0.06095	0.05539	0.05013	0.06787	0.00074	0.00059	0.00058	0.00059	0.00088	0.00050	0.00059	0.00077	0.00066	0.00049	0.00068	0.00057	0.00017
≤ 1500 ST ERR	0.00001	0.00002	0.01340	0.01136	0.01436	0.00656	0.01182	0.00917	0.00002	0.00002	0.00001	0.00000	0.00001	0.00003	0.00001	0.00001	0.00003	0.00001	0.00002	0.00003	0.00002
1500<AVG≤3500	0.00063	0.00057	0.08972	0.07811	0.09593	0.07007	0.07717	0.09163	0.00071	0.00057	0.00057	0.00061	0.00087	0.00046	0.00059	0.00076	0.00062	0.00050	0.00066	0.00052	0.00022
1500<STD ERR≤3500	0.00000	0.00000	0.00974	0.00712	0.01065	0.00556	0.00764	0.00885	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00001	0.00002
> 3500 AVG	0.00063	0.00056	0.11465	0.09745	0.12114	0.21712	0.09598	0.11562	0.00070	0.00056	0.00058	0.00062	0.00087	0.00046	0.00059	0.00076	0.00059	0.00051	0.00066	0.00050	0.00023
> 3500 ST ERR	0.00000	0.00000	0.00758	0.00627	0.00723	0.26307	0.00557	0.00774	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.00001	0.00000	0.00000	0.00001
Overall AVG	0.00063	0.00057	0.08756	0.07684	0.09300	0.10978	0.07470	0.09170	0.00072	0.00057	0.00057	0.00060	0.00088	0.00047	0.00059	0.00076	0.00062	0.00050	0.00066	0.00053	0.00021
Overall ST ERR	0.00000	0.00001	0.01571	0.01188	0.01663	0.08265	0.01269	0.01312	0.00001	0.00001	0.00000	0.00001	0.00000	0.00002	0.00000	0.00001	0.00002	0.00001	0.00001	0.00002	0.00002

Appendix C
Appendix C Restoration Matrix

ID	Sub Reach	Tile #	Conservation Unit	Type	Target Discharge (cfs)	Silvery Minnow Habitat Target	Flycatcher Habitat Target	Treatment description	Project_Site
SRU-1	1	7	SRU	Bankline Benches	2500	Intermediate flow recruitment habitat		Create bankline benches to develop recruitment habitat at channel margins	
PR1-1	1	8	RCU-1	Bankline Benches	2500	Intermediate flow recruitment habitat		Create bankline benches to develop recruitment habitat at channel margins	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-2	1	8	RCU-1	Hard Structure/Bendway Wiers	<1500	Residential habitat		Stabilize bank using bendway weirs or similar structure to push river to the west bank and create low flow residential habitat	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-3	1	9	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of floodplain inundation channel	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-4	1	9	RCU-1	Backwater/Embayment	1500 - 2500	Low flow recruitment habitat	Establish Gooddings willow and coyote willow	Create backwater at downstream end of floodplain inundation channel	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-5	1	9	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat	Establish Gooddings willow stand	Create overbank inundation channel to connect with wetland feature proposed by the Corps Bosque Feasibility Study (BFS)	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-6	1	9	RCU-1	Hard Structure/Bendway Wiers	1500	Residential habitat		Stabilize bank using bendway weirs or similar structure to push river to the west bank and create low flow residential habitat	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-7	1	9	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of floodplain inundation channel	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-8	1	9	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create backwater at downstream end of floodplain inundation channel	# 1 - N. Diversion Channel Active River Channel Improvements
PR1-9	1	9	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat	Establish Gooddings willow and coyote willow	Create floodplain inundation channel to connect with willow swales proposed by the Corps BFS	# 1 - N. Diversion Channel Active River Channel Improvements
PR2-1	2	10	RCU-1	Arroyo Connectivity	2500	Residential habitat		De-stabilize through vegetation removal	# 2 - PDN High Flow Side Channels
PR2-2	2	10	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-3	2	10	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create backwater at downstream end of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-4	2	10	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat		Create floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-5	2	10	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-6	2	10	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat		Create floodplain inundation channel to connect with channel braid	# 2 - PDN High Flow Side Channels
PR2-7	2	11	RCU-1	Floodplain Coupling/Bankline Lowering	2500	Intermediate flow recruitment habitat	Establish Gooddings willow adjacent to Corps BSF water feature; Establish coyote willow along bankline bench	Create embayment into bankline to connect to Corps BFS water feature, provide stepdown to river channel.	# 2 - PDN High Flow Side Channels

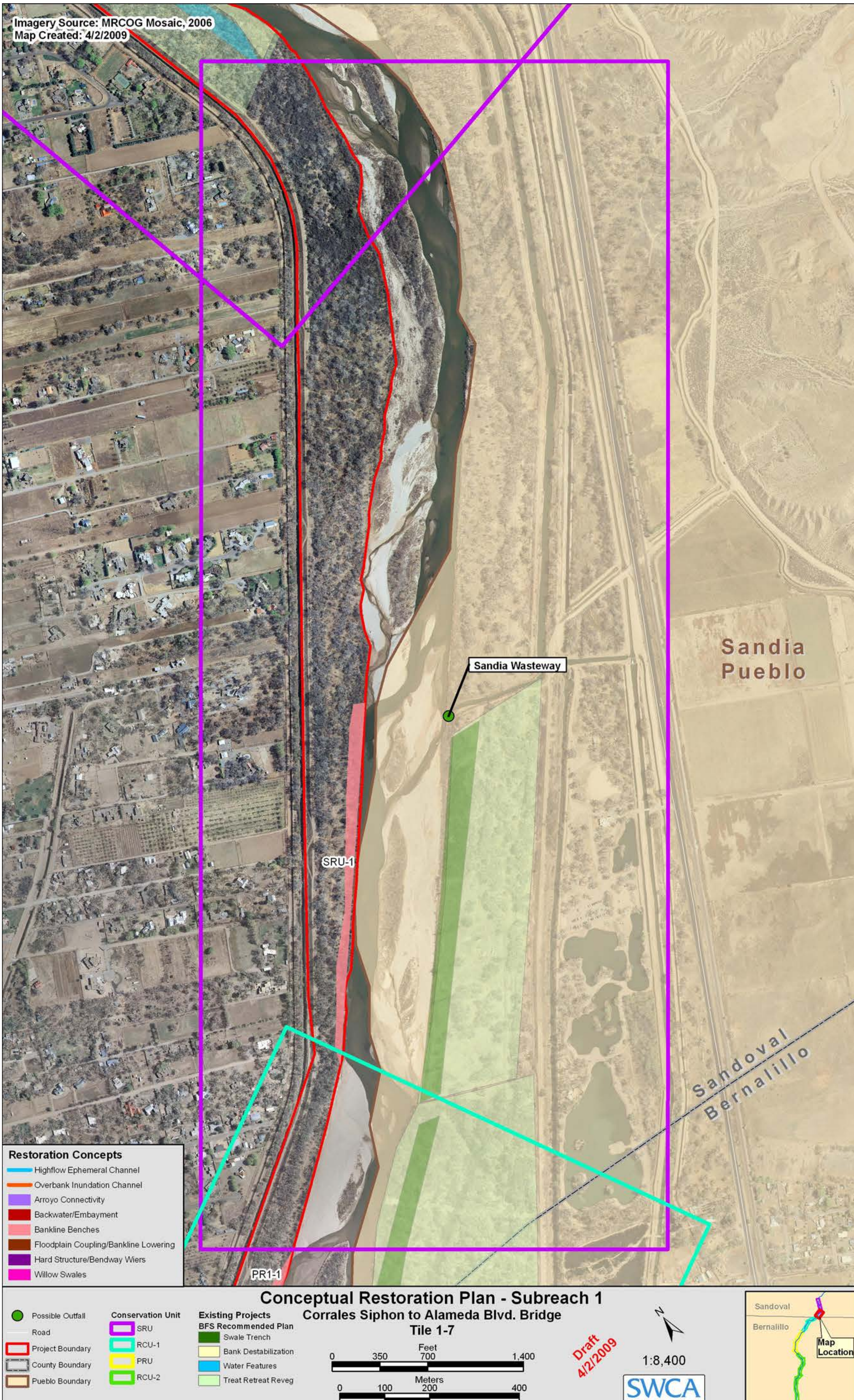
ID	Sub Reach	Tile #	Conservation Unit	Type	Target Discharge (cfs)	Silvery Minnow Habitat Target	Flycatcher Habitat Target	Treatment description	Project_Site
PR2-8	2	11	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-9	2	11	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create backwater at downstream end of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-10	2	11	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat		Create floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR2-11	2	11	RCU-1	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat		Create floodplain inundation channel, connect to NMISC feature	# 2 - PDN High Flow Side Channels
PR2-12	2	11	RCU-1	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create backwater at downstream end of floodplain inundation channel	# 2 - PDN High Flow Side Channels
PR3-1	2	12	PRU	Backwater/Embayment	1500	Low flow recruitment habitat		Create embayment at mouth of La Orilla Drain	# 3 - Montano Bridge Wetlands Creation
PR3-2	2	12	PRU	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat	Establish large Gooddings willow stands within inundated floodplain	Construct large floodplain inundation feature, connected to the La Orilla Drain with backwater outlets. Use a hydraulice control (e.g. gated weir) in the drain to control water diversion into the floodplain. Construct downstream hydraulic control to control water levels in the created wetland	# 3 - Montano Bridge Wetlands Creation
PR3-3	2	12	PRU	Hard Structure/Bendway Wiers	1500	Residential habitat		Stabilize bank using bendway weirs or similar structure to push river to the west bank and create low flow residential habitat. Would provide protection for adjacent levee	# 3 - Montano Bridge Wetlands Creation
PR3-4	2	12	PRU	Jetty Jack Removal		Residential habitat		Remove jetty jack lines found upstream and downstream of La Orilla Drain	
PR4-1	3	13	PRU	Floodplain Coupling/Bankline Lowering	3500	High flow recruitment habitat		Construct upstream inlet channel that would connect to the existing drain and the oxbow meander.	# 4 - Oxbow Wetland Enhancements
PR4-2	3	13	PRU	Flycatcher Habitat			Establish large Gooddings willow/coyote willow stands adjacent to the Montano oxbow	Vegetation management to control non-native phreatophytes and active planting	# 4 - Oxbow Wetland Enhancements
PR4-3	3	13	PRU	Flycatcher Habitat			Establish coyote willow and/or Gooddings willow stands adjacent to the Corps BSF wetland feature and the silvery minnow refugia channel	Vegetation management to control non-native phreatophytes and active planting	# 4 - Oxbow Wetland Enhancements
PR4-4	3	13	PRU	Floodplain Coupling/Bankline Lowering	3500	High flow recruitment habitat		Construct oultet channel that would connect to the oxbow meander. Install hydraulic control to manage wetland water levels.	# 4 - Oxbow Wetland Enhancements

ID	Sub Reach	Tile #	Conservation Unit	Type	Target Discharge (cfs)	Silvery Minnow Habitat Target	Flycatcher Habitat Target	Treatment description	Project_Site
PR5-1	3	14	PRU	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at entry of ephemeral channel	# 5 - I-40 High Flow Side Channel
PR5-2	3	14	PRU	Highflow Ephemeral Channel	2500	Residential habitat		Create backwater at downstream end of ephemeral channel	# 5 - I-40 High Flow Side Channel
PR5-3	3	14	PRU	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create ephemeral channels on the bank-attached bar	# 5 - I-40 High Flow Side Channel
PR5-4	3	14	PRU	Willow Swales			Establish coyote willow along transition to the bluff		# 5 - I-40 High Flow Side Channel
PR5-5	3	14	PRU	Backwater/Embayment	1500	Low flow recruitment habitat		Create backwater on "Mickey's Bar" to remove sediment blockage and minimize silvery minnow entrapment	# 5 - I-40 High Flow Side Channel
PR6-1	4	16	RCU-2	Floodplain Coupling/Bankline Lowering	3000	High flow recruitment habitat		Remove natural levee along bankline to permit more frequent floodplain inundation	# 6 - Bridge Street Floodplain Coupling
PR6-2	4	17	RCU-2	Floodplain Coupling/Bankline Lowering	3000	High flow recruitment habitat		Remove natural levee along bankline to permit more frequent floodplain inundation	# 6 - Bridge Street Floodplain Coupling
PR6-3	4	17	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat		Create embayment into bankline at wasteway drain	# 6 - Bridge Street Floodplain Coupling
PR6-4	4	17	RCU-2	Floodplain Coupling/Bankline Lowering	3000	High flow recruitment habitat		Remove natural levee along bankline to permit more frequent floodplain inundation	# 6 - Bridge Street Floodplain Coupling
PR6-5	4	17	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat		Create embayment into bankline at wasteway drain	# 6 - Bridge Street Floodplain Coupling
PR6-6	4	17	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat	Establish Gooddings willow habitat adjacent to Corps BSF water feature and embayment feature	Create embayment into bankline at wasteway drain	# 6 - Bridge Street Floodplain Coupling
PR6-7	4	17	RCU-2	Floodplain Coupling/Bankline Lowering	3000	High flow recruitment habitat		Remove natural levee along bankline to permit more frequent floodplain inundation	# 6 - Bridge Street Floodplain Coupling
PR6-8	4	18	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat	Establish Gooddings willow habitat within embayment feature	Create embayment into bankline at wasteway drain	# 6 - Bridge Street Floodplain Coupling
PR7-1	4	18	RCU-2	Floodplain Coupling/Bankline Lowering	3000	High flow recruitment habitat	Establish coyote willow along bankline feature	Remove natural levee along bankline to permit more frequent floodplain inundation	# 7 - Rio Bravo Floodplain Coupling
PR8-1	4	19	RCU-2	Backwater/Embayment	2500	Residential habitat		Create embayment at inlet to ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-2	4	19	RCU-2	Highflow Ephemeral Channel	2500	Residential habitat		Create ephemeral channels on the bank-attached bar	# 8 - S. Diversion Channel River Channel Improvements
PR8-3	4	20	RCU-2	Backwater/Embayment	1500	Residential habitat		Create backwater at outlet of ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-4	4	20	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat		Create backwater at outlet of ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements

ID	Sub Reach	Tile #	Conservation Unit	Type	Target Discharge (cfs)	Silvery Minnow Habitat Target	Flycatcher Habitat Target	Treatment description	Project_Site
PR8-5	4	20	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet to floodplain inundation channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-6	5	20	RCU-2	Highflow Ephemeral Channel	2500 - 3000	Intermediate flow recruitment habitat		Create ephemeral channel on the bank-attached bar and floodplain inundation channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-7	4	20	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet to floodplain inundation channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-8	4	20	RCU-2	Backwater/Embayment	2500 - 3000	Intermediate flow recruitment habitat	Establish large Gooddings willow stands along floodplain inundation channel, embayment, and Corps BSF willow swale. Establish coyote willow stands adjacent to river channel	Create large embayment into bankline, connected to floodplain inundation channel. Embayment to grade from 3000 cfs to inundation discharge along adjacent linguoid bar. Embayment would connect with Corps BFS willow swale	# 8 - S. Diversion Channel River Channel Improvements
PR8-9	4	20	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet to ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-10	5	20	RCU-2	Highflow Ephemeral Channel	2500	Residential habitat		Create ephemeral channels on the bank-attached bar	# 8 - S. Diversion Channel River Channel Improvements
PR8-11	4	20	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat		Create backwater at outlet of ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-12	5	20	RCU-2	Highflow Ephemeral Channel	1500	Residential habitat		Create ephemeral channels on the bank-attached bar	# 8 - S. Diversion Channel River Channel Improvements
PR8-13	4	20	RCU-2	Backwater/Embayment	1500	Low flow recruitment habitat		Create backwater at outlet of ephemeral channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-14	4	20	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet to floodplain inundation channel	# 8 - S. Diversion Channel River Channel Improvements
PR8-15	5	20	RCU-2	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat	Establish Gooddings willow or coyote willow in Corps BFS	Create floodplain inundation channel, connect with Corps BFS willow swales	# 8 - S. Diversion Channel River Channel Improvements
PR8-16	5	21	RCU-2	Highflow Ephemeral Channel	1500	Residential habitat		Create ephemeral channel, connect to NMISC features	# 8 - S. Diversion Channel River Channel Improvements
PR8-17	5	21	RCU-2	Backwater/Embayment	1500 - 2500	Low flow recruitment habitat	Establish coyote willow within backwater	Create large backwater to drain floodplain inundation channel, connect to bank-attached bar	# 8 - S. Diversion Channel River Channel Improvements
PR8-17	5	22	RCU-2	Flycatcher Habitat			Establish large Gooddings willow stands along Corps BSF water feature	Vegetation management to establish willow habitat	# 8 - S. Diversion Channel River Channel Improvements
PR9-1	5	22	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet of floodplain inundation channel	# 9 - I-25 High Flow Side Channels
PR9-2	5	22	RCU-2	Floodplain Coupling/Floodplain Inundation Channel	3000	High flow recruitment habitat	Establish Gooddings willow and coyote willow	Create floodplain inundation channel following existing contours; connect with Corps BFS willow swales	# 9 - I-25 High Flow Side Channels
PR9-3	5	23	RCU-2	Floodplain Coupling/Floodplain Inundation Channel	3000			Create floodplain inundation channel following existing contours into depression in floodplain	# 9 - I-25 High Flow Side Channels

ID	Sub Reach	Tile #	Conservation Unit	Type	Target Discharge (cfs)	Silvery Minnow Habitat Target	Flycatcher Habitat Target	Treatment description	Project_Site
PR9-4	5	22	RCU-2	Flycatcher Habitat	3000 - 3500		Establish Gooddings willow within inundated area in floodplain connected to floodplain inundation channel	Vegetation management to control non-native phreatophytes and active planting	# 9 - I-25 High Flow Side Channels
PR9-5	5	22	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-6	5	22	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-7	5	22	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-8	5	23	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-9	5	23	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayment at inlet of floodplain inundation channel	# 9 - I-25 High Flow Side Channels
PR9-10	5	22	RCU-2	Overbank inundation channel	3000	High flow recruitment habitat		Create floodplain inundation channel following existing contours into depression in floodplain	# 9 - I-25 High Flow Side Channels
PR9-11	5	23	RCU-2	Flycatcher Habitat	3000 - 3500		Establish Gooddings willow within inundated area in floodplain connected to floodplain inundation channel	Vegetation management to control non-native phreatophytes and active planting	# 9 - I-25 High Flow Side Channels
PR9-12	5	23	RCU-2	Backwater/Embayment	2500 - 3000	Intermediate flow recruitment habitat	Establish Gooddings willow along floodplain inundation channel; establish coyote willow within backwater	Create backwater cut into bankline to drain floodplain inundation channel	# 9 - I-25 High Flow Side Channels
PR9-13	5	23	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-14	5	23	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels
PR9-15	5	23	RCU-2	Backwater/Embayment	2500	Intermediate flow recruitment habitat		Create embayments cut into the bank under openings in the canopy	# 9 - I-25 High Flow Side Channels

Appendix D
Conceptual Restoration Projects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Map Created: 4/2/2009
Sandia Wasteway
Sandia Pueblo
SRU-1
PR1-1
Sandoval
Bernalillo
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Possible Outfall
Road
Project Boundary
County Boundary
Pueblo Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 1
Corrales Siphon to Alameda Blvd. Bridge
Tile 1-7
Feet
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Meters
0 100 200 400
Draft 4/2/2009
N
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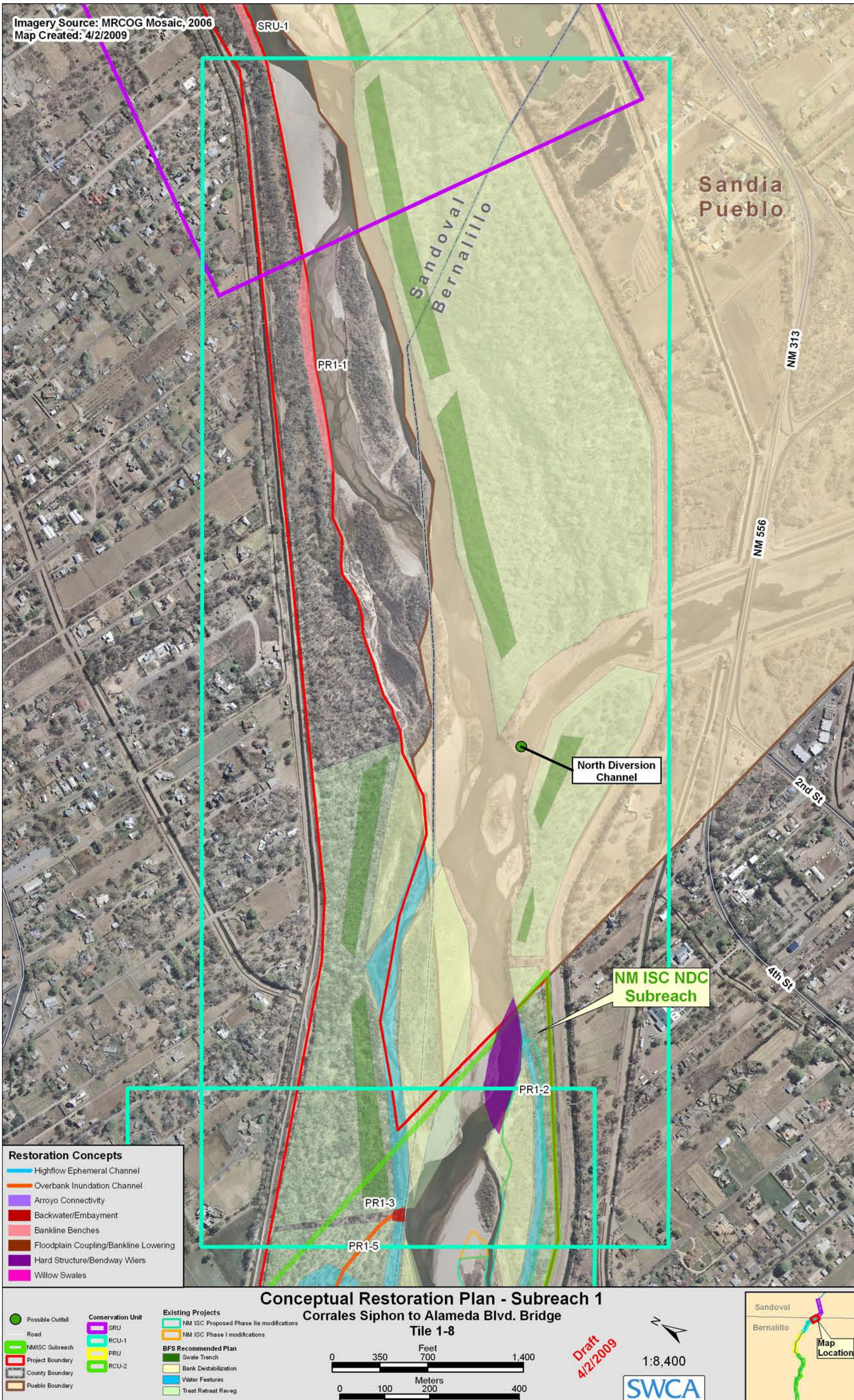
SWCA
Sandoval
Bernalillo
Map Location



Imagery Source: MRCOG Mosaic, 2006
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SRU-1
Sandia Pueblo
Sandoval
Bernalillo
PR1-1
NM 313
NM 556
North Diversion Channel
2nd St
4th St
NM ISC NDC Subreach
PR1-2
PR1-3
PR1-5
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Conceptual Restoration Plan - Subreach 1
Corrales Siphon to Alameda Blvd. Bridge
Tile 1-8
Possible Outfall
Road
NMISC Subreach
Project Boundary
County Boundary
Pueblo Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase I modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Feet
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Meters
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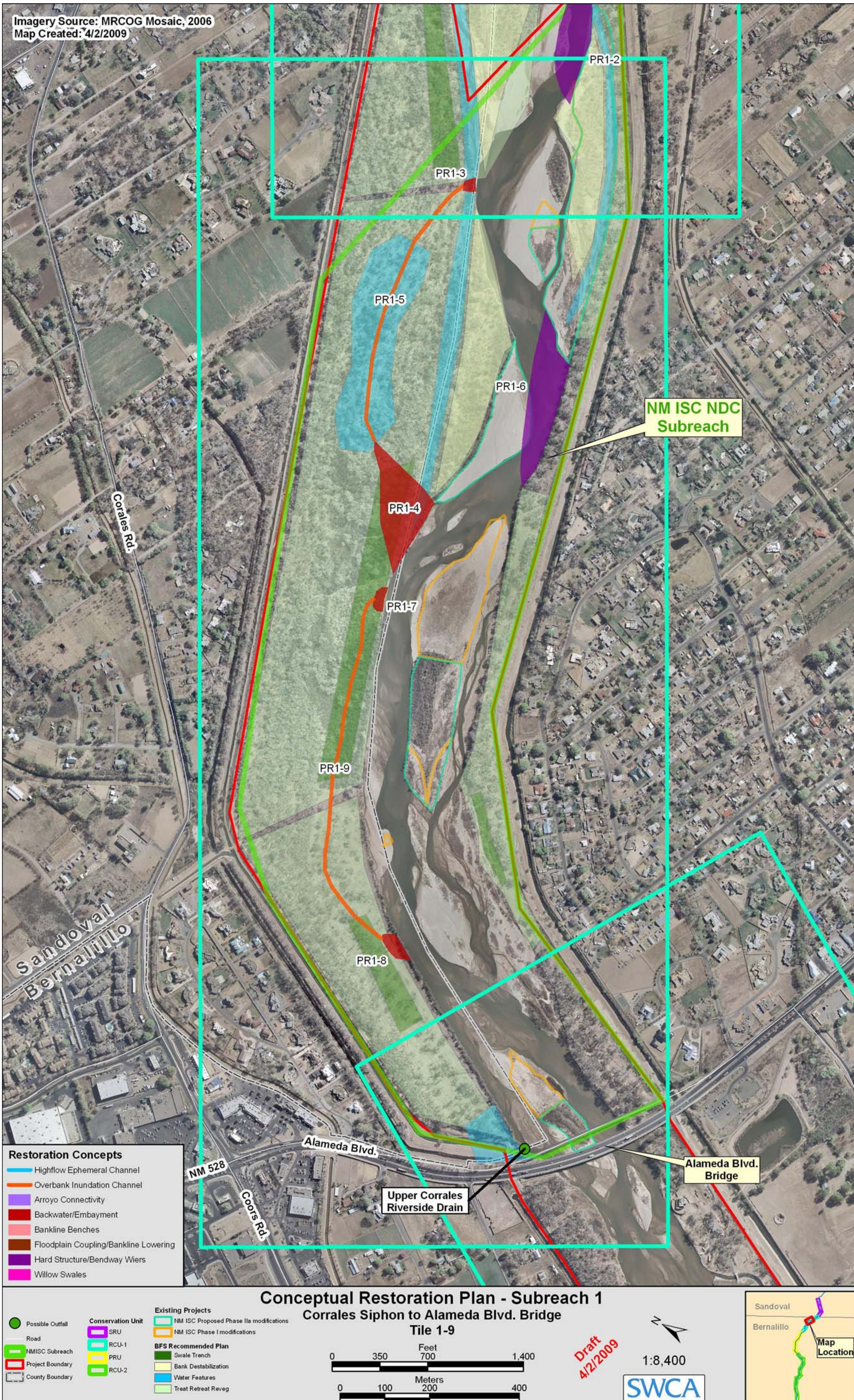
Draft 4/2/2009
1:8,400
SWCA ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location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PR1-2
PR1-3
PR1-5
PR1-6
NM ISC NDC Subreach
PR1-4
PR1-7
PR1-9
PR1-8
Corrales Rd.
Sandoval
Bernalillo
Alameda Blvd.
NM 528
Coors Rd.
Upper Corrales Riverside Drain
Alameda Blvd. Bridge
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Conceptual Restoration Plan - Subreach 1
Corrales Siphon to Alameda Blvd. Bridge
Tile 1-9
Possible Outfall
Road
NMISC Subreach
Project Boundary
County Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase I modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Feet
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Meters
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Draft 4/2/2009
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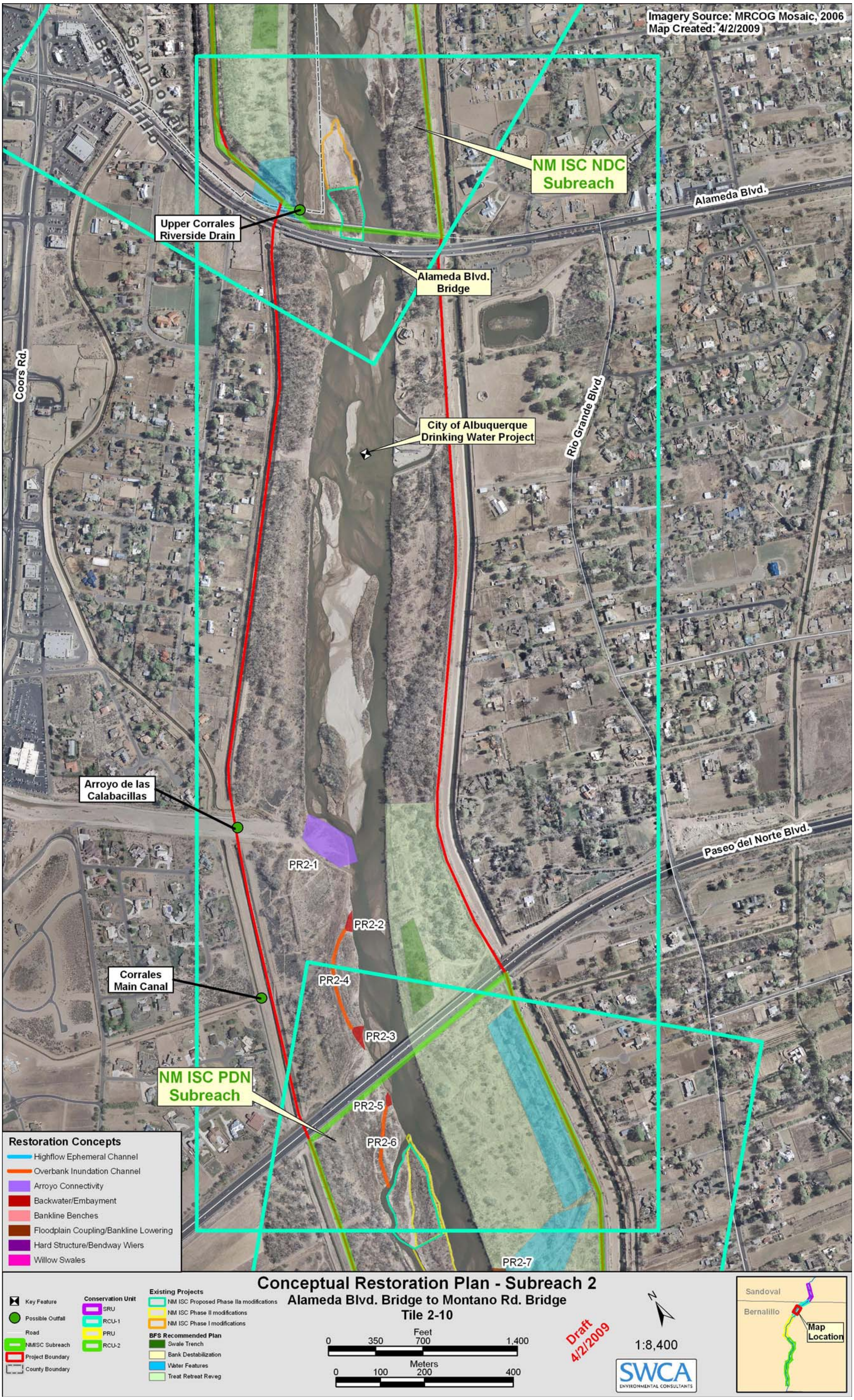
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location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NM ISC NDC Subreach
Alameda Blvd.
Upper Corrales Riverside Drain
Alameda Blvd. Bridge
Coors Rd.
City of Albuquerque Drinking Water Project
Rio Grande Blvd.
Arroyo de las Calabacillas
Paseo del Norte Blvd.
PR2-1
PR2-2
PR2-4
PR2-3
Corrales Main Canal
NM ISC PDN Subreach
PR2-5
PR2-6
PR2-7
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Key Feature
Possible Outfall
Road
NMISC Subreach
Project Boundary
County Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 2
Alameda Blvd. Bridge to Montano Rd. Bridge
Tile 2-10
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Meters
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Draft 4/2/2009
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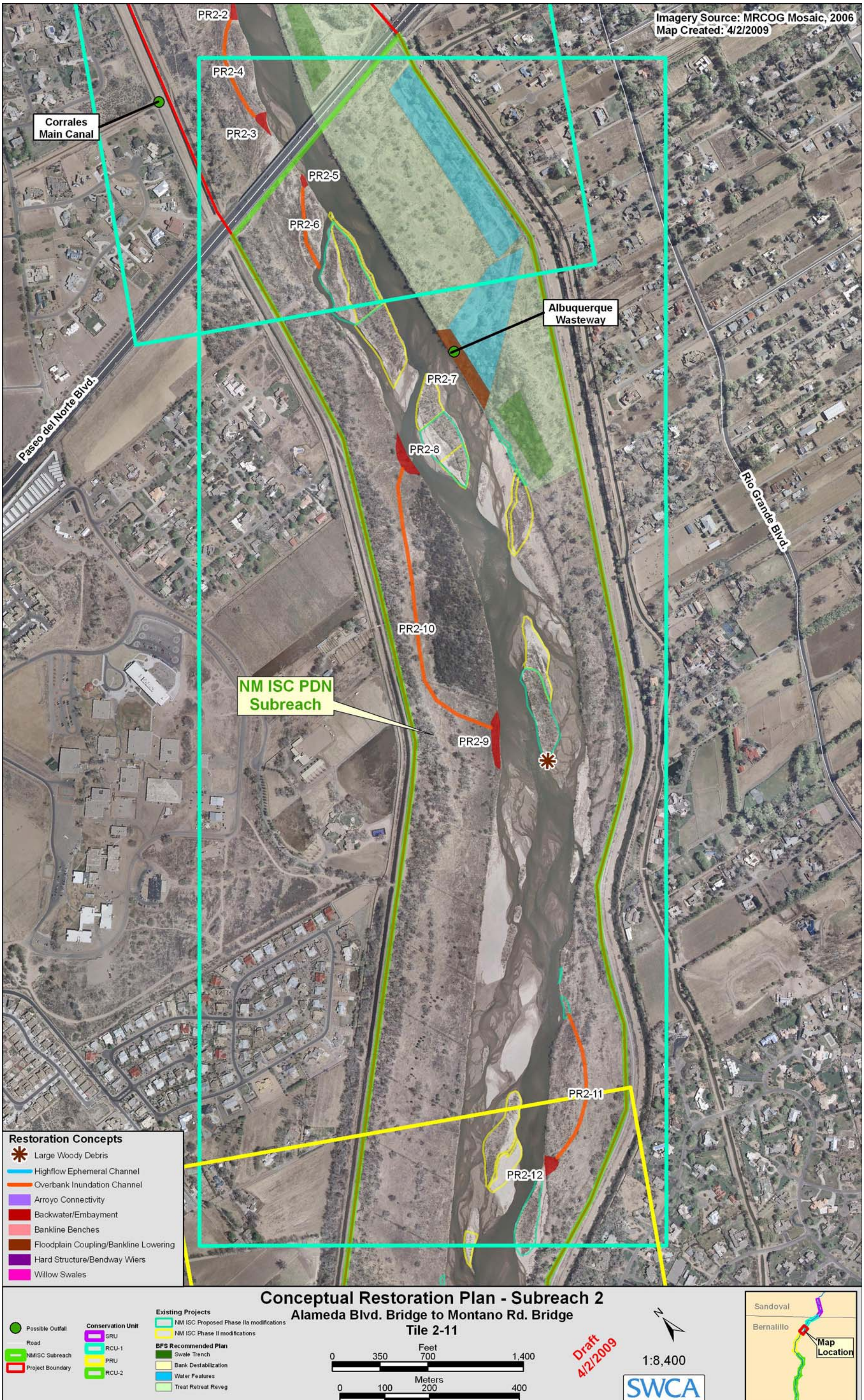
SWCA
Sandoval
Bernalillo
Map Location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PR2-4
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PR2-6
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PR2-8
PR2-9
PR2-10
PR2-11
PR2-12
Corrales Main Canal
Albuquerque Wasteway
Paseo del Norte Blvd.
Rio Grande Blvd.
NM ISC PDN Subreach
Restoration Concepts
Large Woody Debris
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Conceptual Restoration Plan - Subreach 2
Alameda Blvd. Bridge to Montano Rd. Bridge
Tile 2-11
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Feet
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Meters
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Draft 4/2/2009
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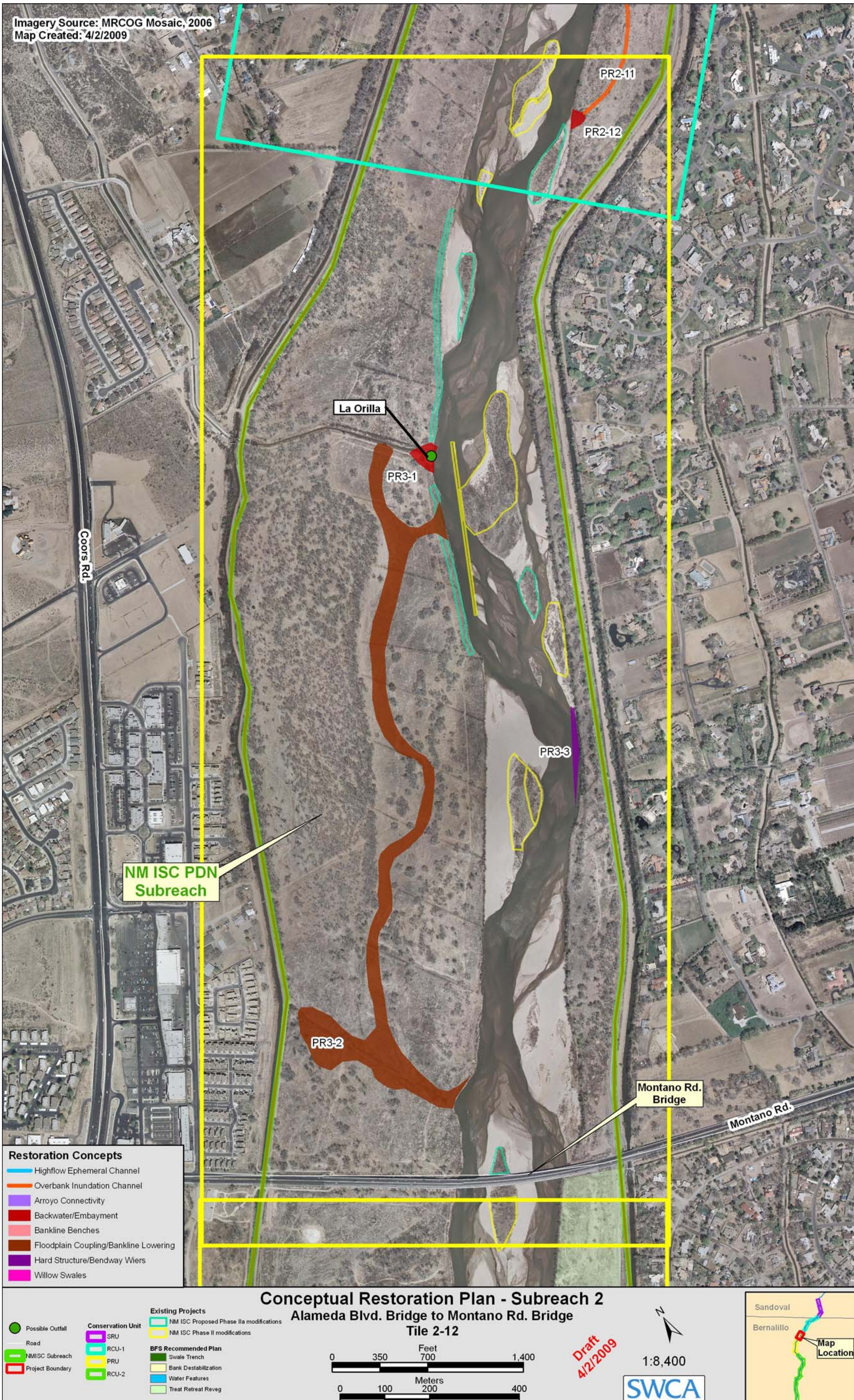
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location



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PR2-11
PR2-12
La Orilla
PR3-1
Coors Rd.
PR3-3
NM ISC PDN Subreach
PR3-2
Montano Rd. Bridge
Montano Rd.
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Conceptual Restoration Plan - Subreach 2
Alameda Blvd. Bridge to Montano Rd. Bridge
Tile 2-12
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Feet
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350
700
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Meters
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Draft 4/2/2009
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1:8,400
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location


Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
NM ISC PDN Subreach
Coors Rd.
PR4-1
Corrales Riverside Drain Ext.
Montano Oxbow Complex
PR4-4
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Key Feature
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 3
Montano Rd. Bridge to Central Ave. Bridge
Tile 3-13
Feet
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Meters
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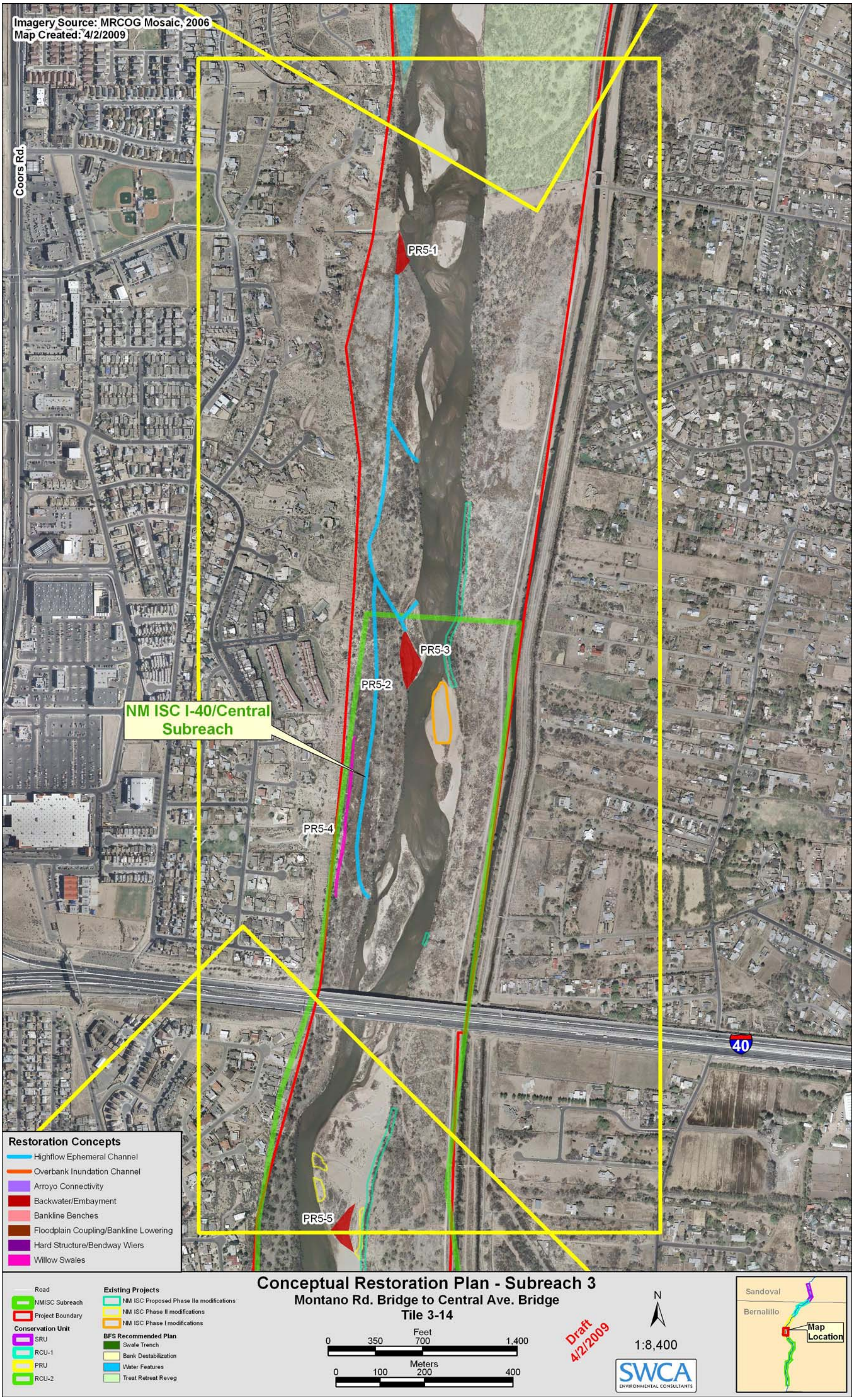
Draft 4/2/2009
1:8,400
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location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PR5-1
PR5-3
PR5-2
NM ISC I-40/Central Subreach
PR5-4
PR5-5
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Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 3
Montano Rd. Bridge to Central Ave. Bridge
Tile 3-14
Feet
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Meters
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Draft 4/2/2009
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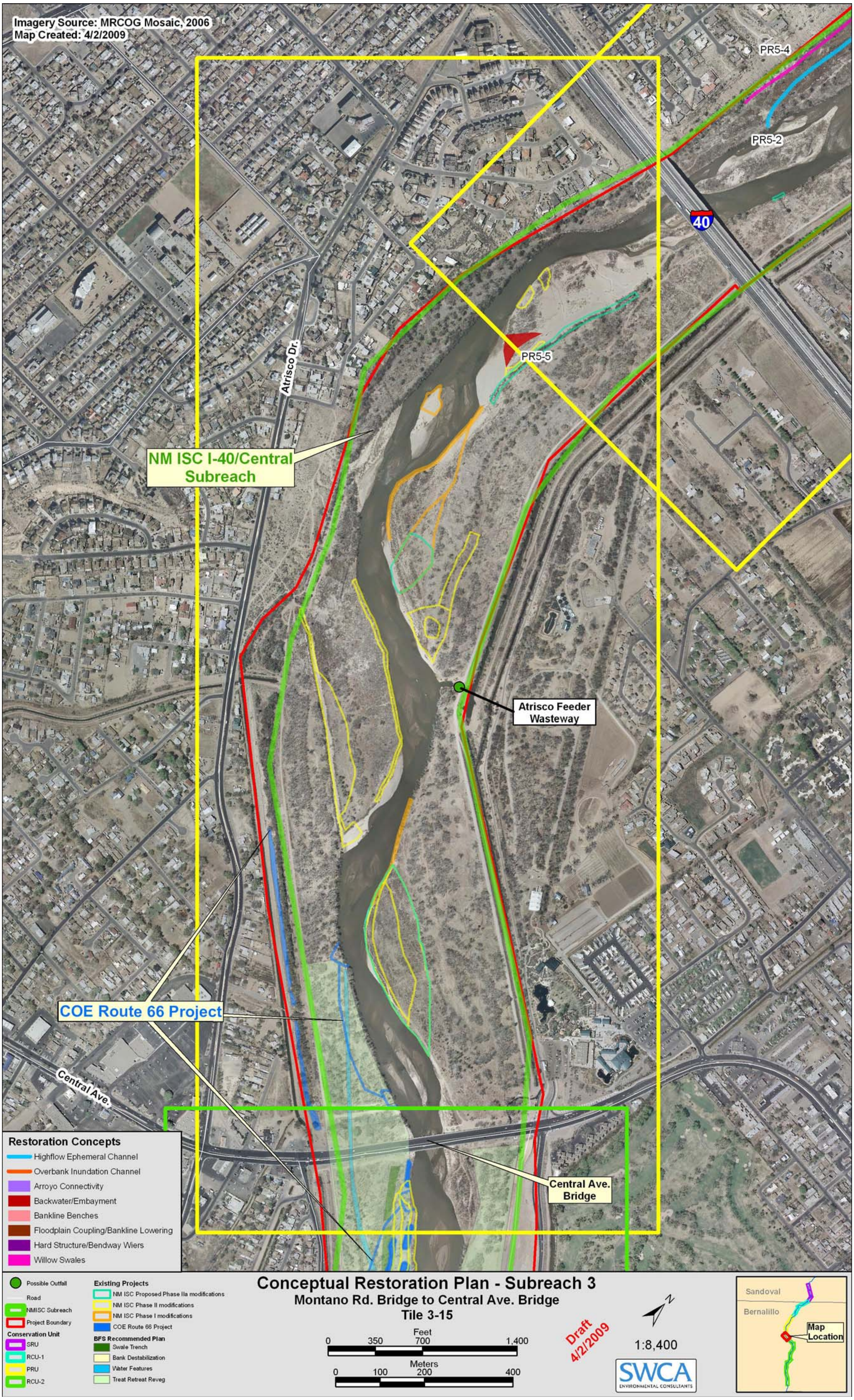
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location



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PR5-5
Atrisco Dr.
NM ISC I-40/Central Subreach
Atrisco Feeder Wasteway
COE Route 66 Project
Central Ave.
Central Ave. Bridge
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
COE Route 66 Project
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 3
Montano Rd. Bridge to Central Ave. Bridge
Tile 3-15
Feet
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Meters
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Draft 4/2/2009
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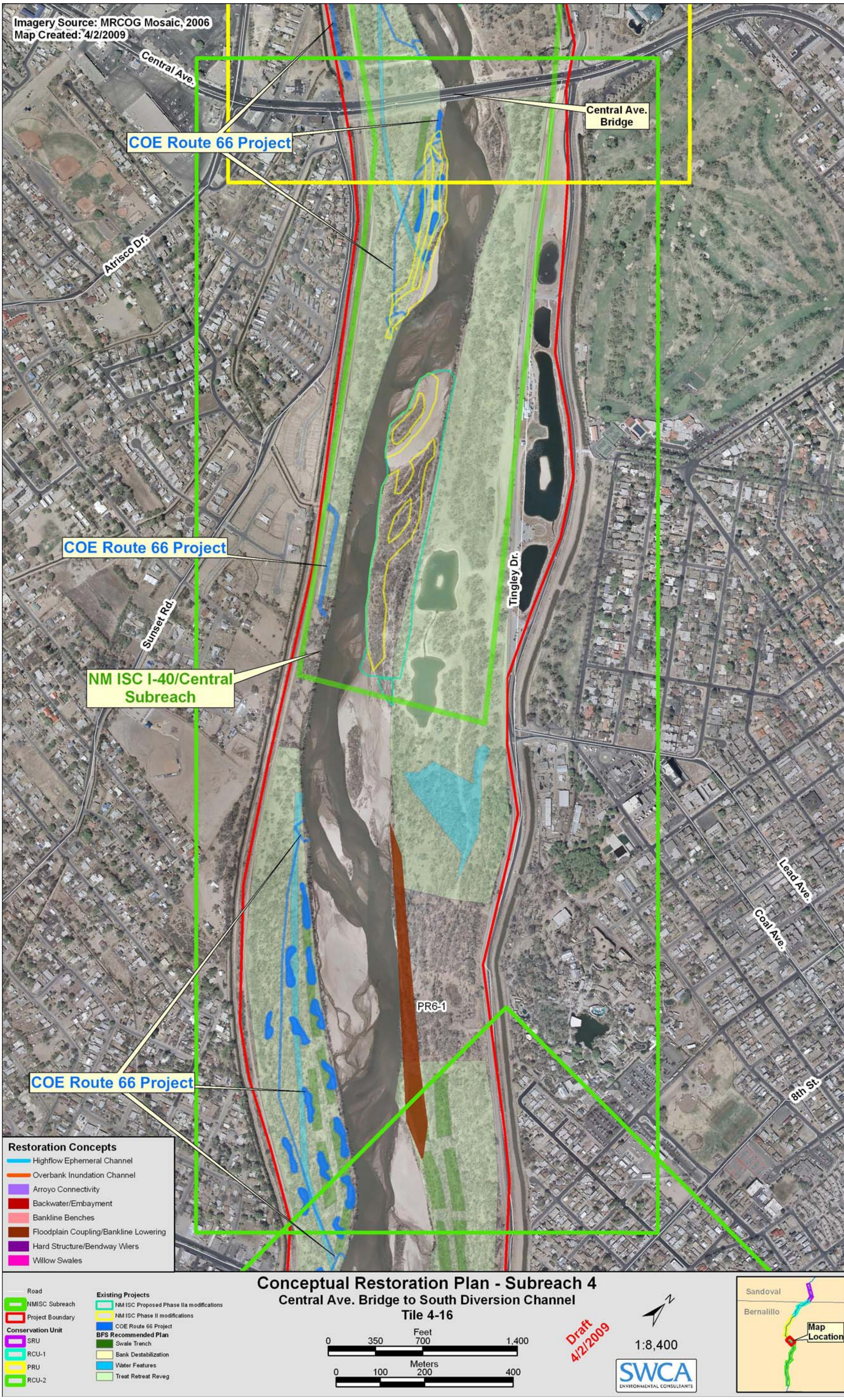
SWCA
Sandoval
Bernalillo
Map Location



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Central Ave.
Central Ave. Bridge
COE Route 66 Project
Atrisco Dr.
COE Route 66 Project
Sunset Rd.
Tingley Dr.
NM ISC I-40/Central Subreach
Lead Ave.
Coal Ave.
PR6-1
8th St.
COE Route 66 Project
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
COE Route 66 Project
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 4
Central Ave. Bridge to South Diversion Channel
Tile 4-16
Feet
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Meters
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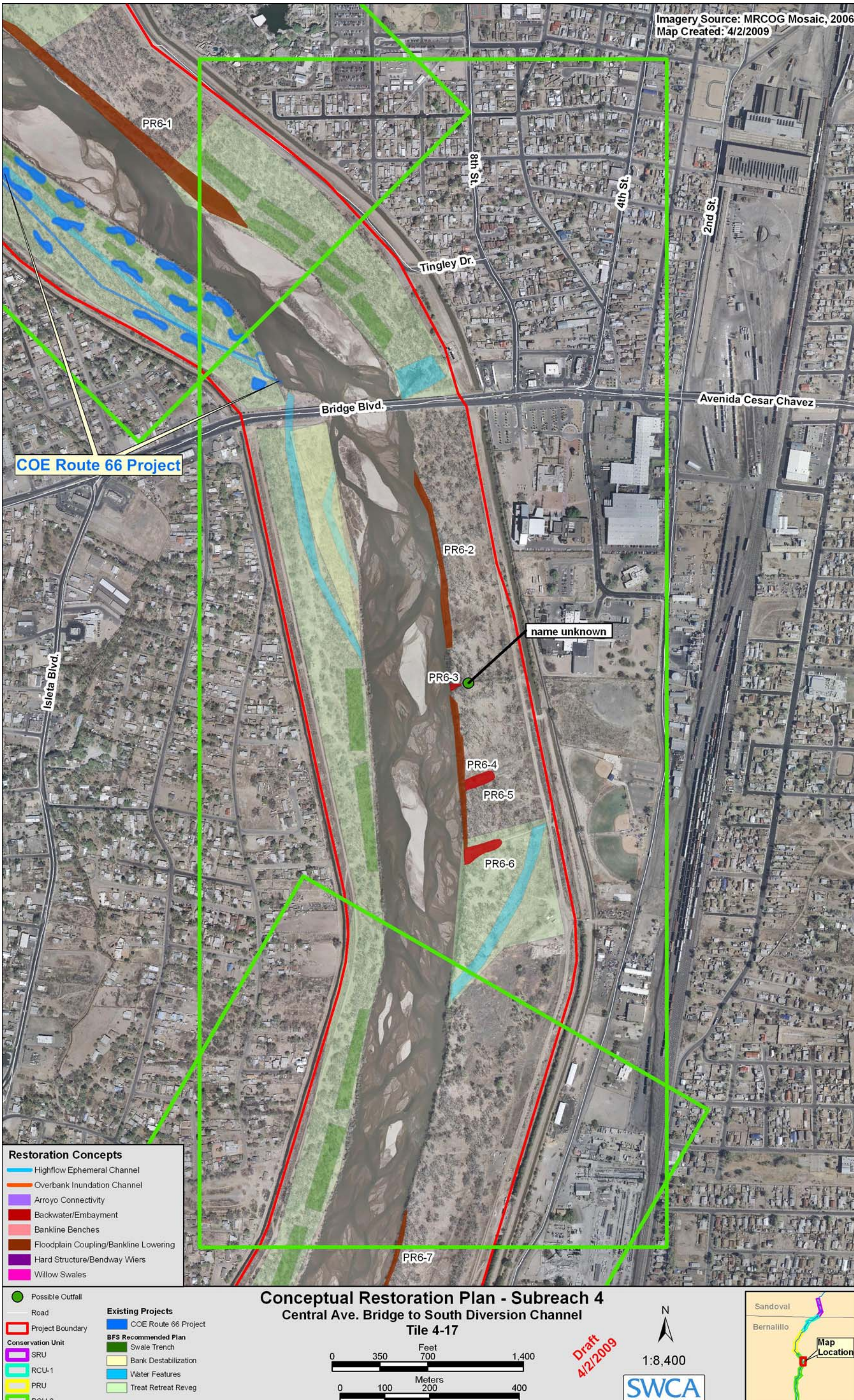
Draft 4/2/2009
1:8,400
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location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Map Created: 4/2/2009
PR6-1
8th St.
4th St.
2nd St.
Tingley Dr.
Bridge Blvd.
Avenida Cesar Chavez
COE Route 66 Project
PR6-2
name unknown
PR6-3
Isleta Blvd.
PR6-4
PR6-5
PR6-6
PR6-7
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Possible Outfall
Road
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
COE Route 66 Project
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 4
Central Ave. Bridge to South Diversion Channel
Tile 4-17
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Meters
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Draft 4/2/2009
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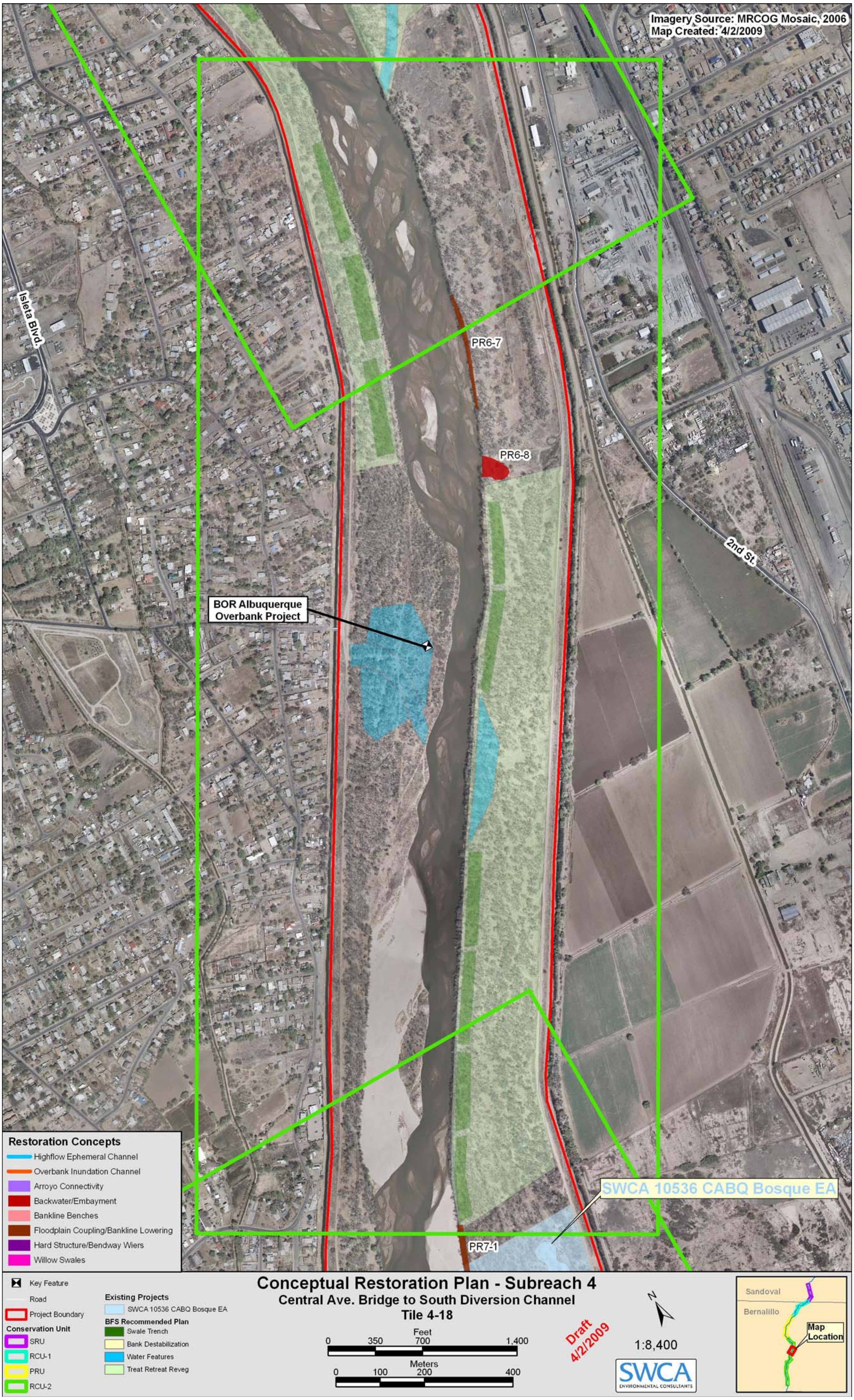
SWCA
Sandoval
Bernalillo
Map Location



Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
Isleta Blvd.
PR6-7
PR6-8
2nd St.
BOR Albuquerque Overbank Project
SWCA 10536 CABQ Bosque EA
PR7-1
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Key Feature
Road
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
SWCA 10536 CABQ Bosque EA
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 4
Central Ave. Bridge to South Diversion Channel
Tile 4-18
Feet
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Draft 4/2/2009
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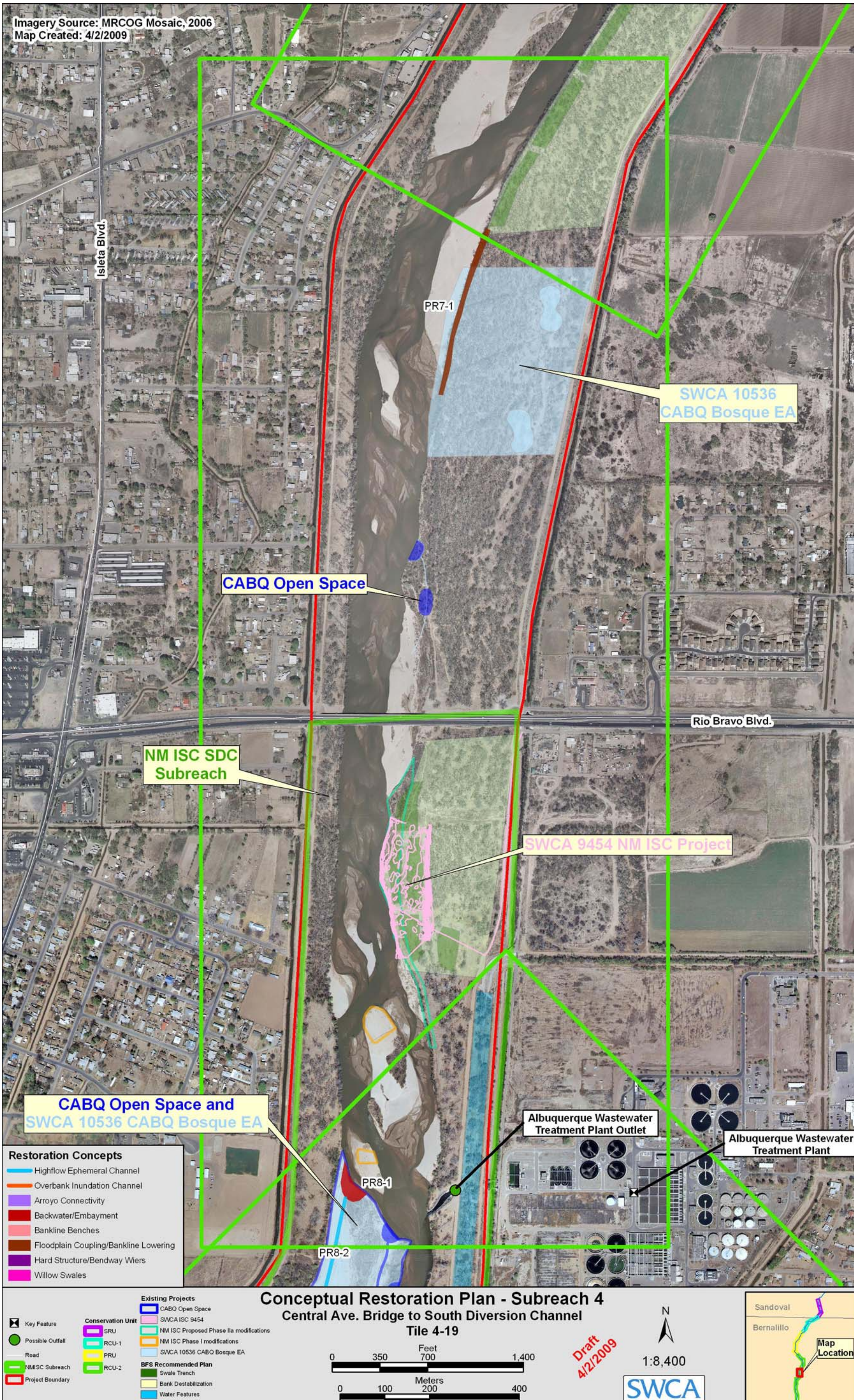
SWCA ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location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Map Created: 4/2/2009
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PR7-1
SWCA 10536 CABQ Bosque EA
CABQ Open Space
Rio Bravo Blvd.
NM ISC SDC Subreach
SWCA 9454 NM ISC Project
CABQ Open Space and SWCA 10536 CABQ Bosque EA
Albuquerque Wastewater Treatment Plant Outlet
Albuquerque Wastewater Treatment Plant
PR8-1
PR8-2
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Key Feature
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
CABQ Open Space
SWCA ISC 9454
NM ISC Proposed Phase IIa modifications
NM ISC Phase I modifications
SWCA 10536 CABQ Bosque EA
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 4
Central Ave. Bridge to South Diversion Channel
Tile 4-19
Feet
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Draft 4/2/2009
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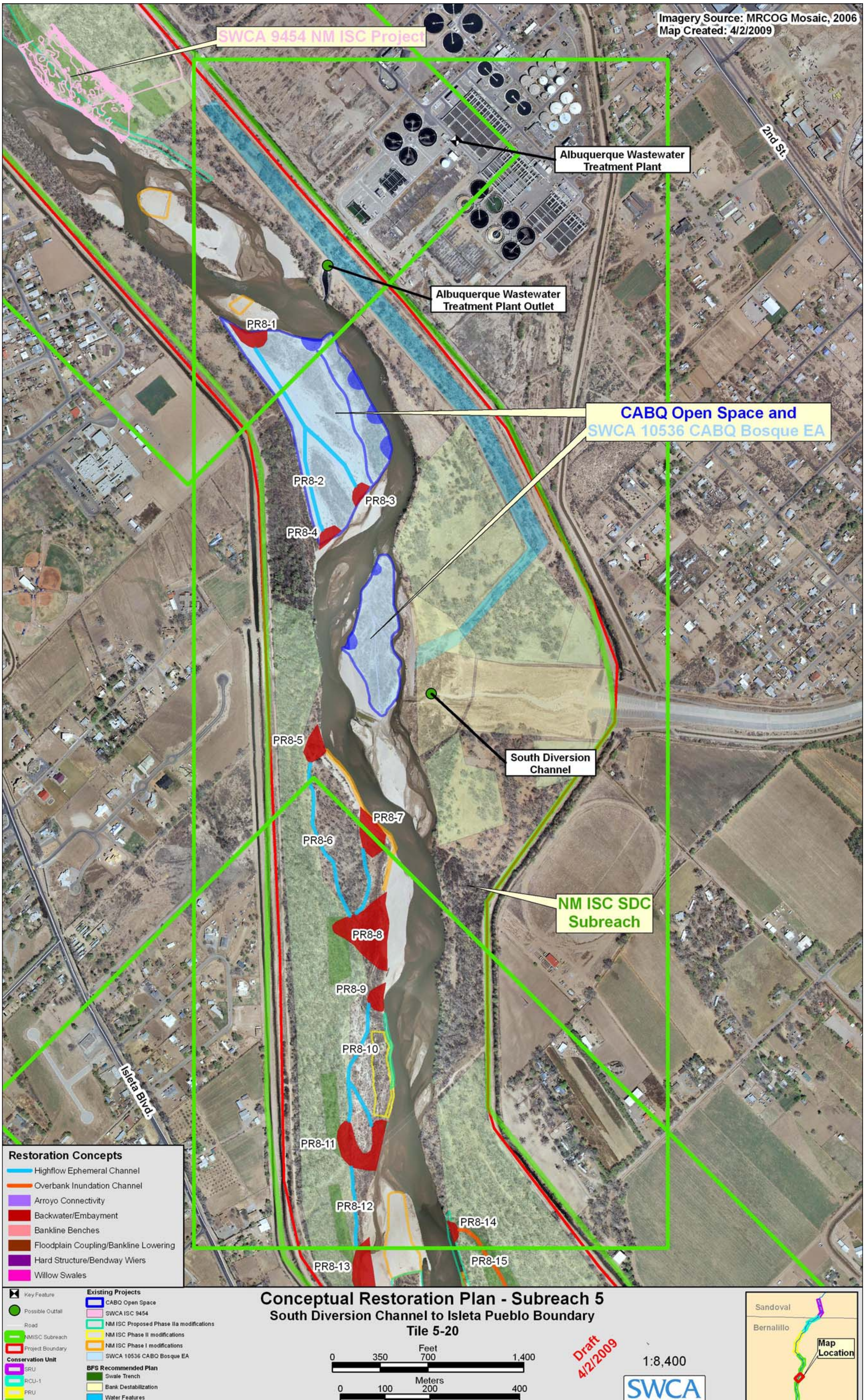
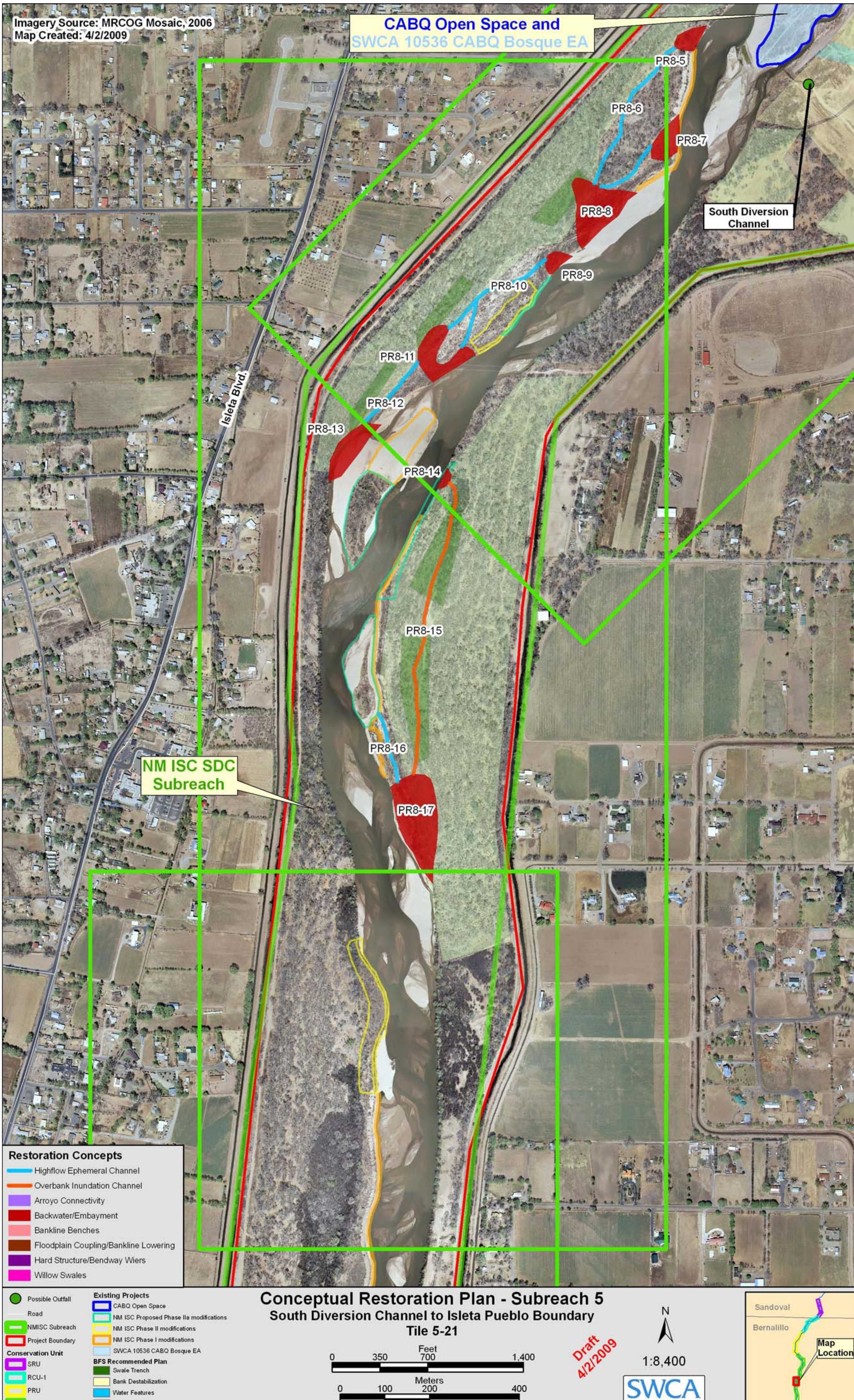
Sandoval
Bernalillo
Map Location



Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
SWCA 9454 NM ISC Project
Albuquerque Wastewater Treatment Plant
2nd St.
Albuquerque Wastewater Treatment Plant Outlet
CABQ Open Space and
SWCA 10536 CABQ Bosque EA
South Diversion Channel
NM ISC SDC Subreach
Isleta Blvd.
PR8-1
PR8-2
PR8-3
PR8-4
PR8-5
PR8-6
PR8-7
PR8-8
PR8-9
PR8-10
PR8-11
PR8-12
PR8-13
PR8-14
PR8-15
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
Willow Swales
Key Feature
Possible Outfall
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
CABQ Open Space
SWCA ISC 9454
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
SWCA 10536 CABQ Bosque EA
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 5
South Diversion Channel to Isleta Pueblo Boundary
Tile 5-20
Feet
0 350 700 1,400
Meters
0 100 200 400
Draft 4/2/2009
1:8,400
SWCA ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location


Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
CABQ Open Space and
SWCA 10536 CABQ Bosque EA
PR8-5
PR8-6
PR8-7
PR8-8
PR8-9
PR8-10
PR8-11
PR8-12
PR8-13
PR8-14
PR8-15
PR8-16
PR8-17
South Diversion Channel
Isleta Blvd.
NM ISC SDC Subreach
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
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PRU
RCU-2
Existing Projects
CABQ Open Space
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
SWCA 10536 CABQ Bosque EA
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 5
South Diversion Channel to Isleta Pueblo Boundary
Tile 5-21
Feet
0 350 700 1,400
Meters
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Draft 4/2/2009
N
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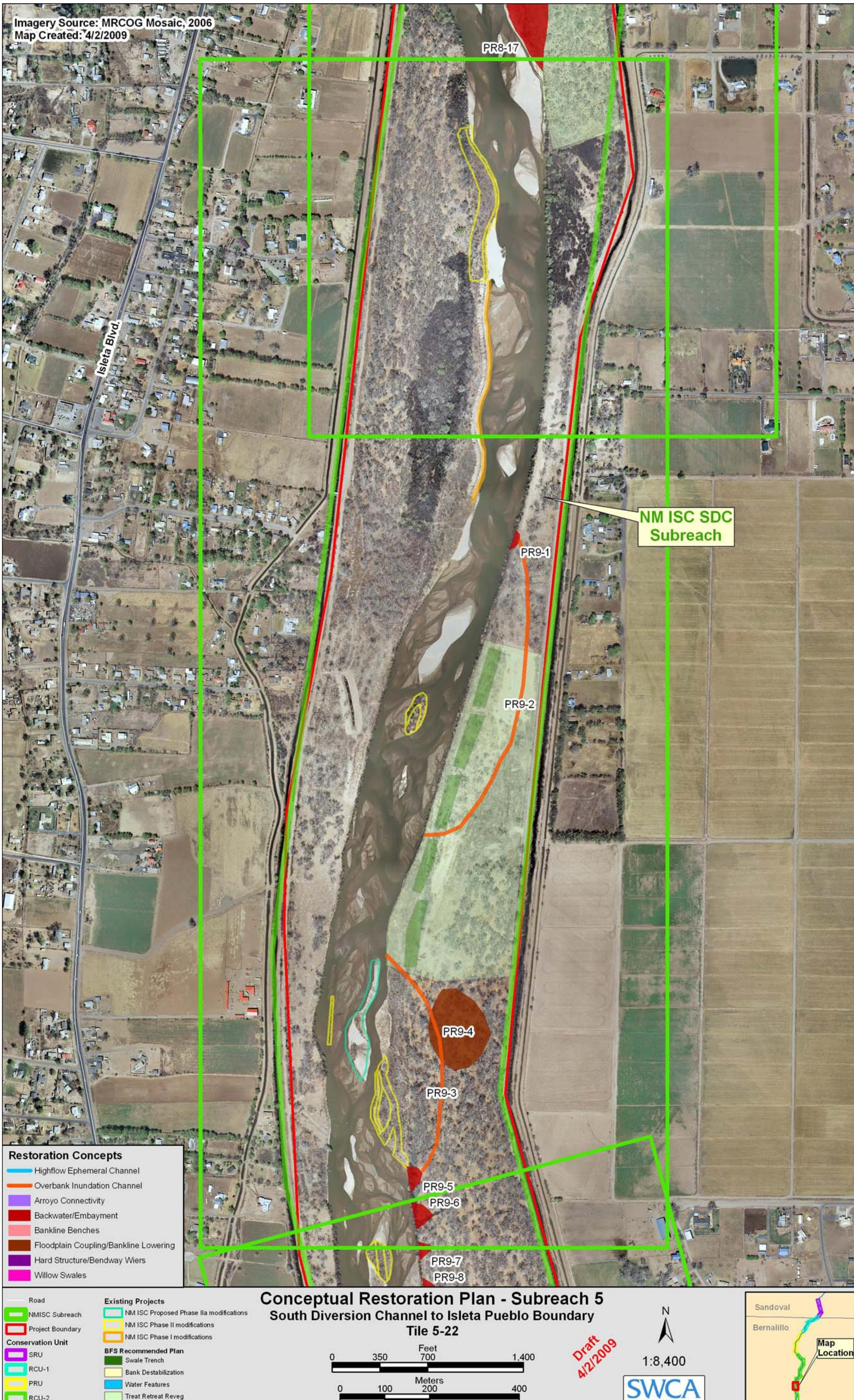
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location



Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
Isleta Blvd.
PR8-17
NM ISC SDC Subreach
PR9-1
PR9-2
PR9-4
PR9-3
PR9-5
PR9-6
PR9-7
PR9-8
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
Hard Structure/Bendway Wiers
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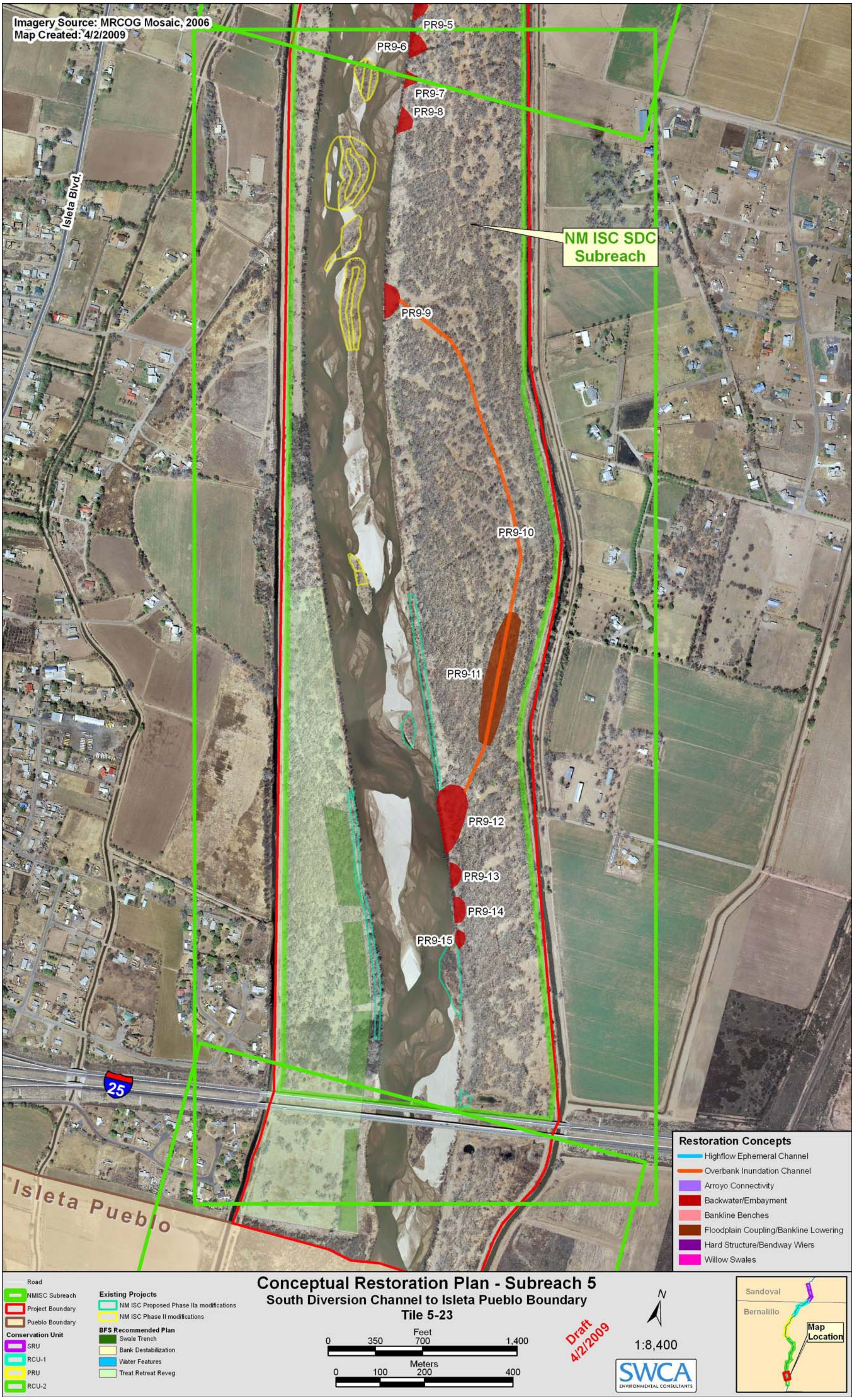
Road
NMISC Subreach
Project Boundary
Conservation Unit
SRU
RCU-1
PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
NM ISC Phase I modifications
BFS Recommended Plan
Swale Trench
Bank Destabilization
Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 5
South Diversion Channel to Isleta Pueblo Boundary
Tile 5-22
Feet
0 350 700 1,400
Meters
0 100 200 400
Draft 4/2/2009
N
1:8,400
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location



Imagery Source: MRCOG Mosaic, 2006
Map Created: 4/2/2009
PR9-5
PR9-6
PR9-7
PR9-8
PR9-9
PR9-10
PR9-11
PR9-12
PR9-13
PR9-14
PR9-15
Isleta Blvd.
NM ISC SDC Subreach
25
Isleta Pueblo
Restoration Concepts
Highflow Ephemeral Channel
Overbank Inundation Channel
Arroyo Connectivity
Backwater/Embayment
Bankline Benches
Floodplain Coupling/Bankline Lowering
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NMISC Subreach
Project Boundary
Pueblo Boundary
Conservation Unit
SRU
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PRU
RCU-2
Existing Projects
NM ISC Proposed Phase IIa modifications
NM ISC Phase II modifications
BFS Recommended Plan
Swale Trench
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Water Features
Treat Retreat Reveg
Conceptual Restoration Plan - Subreach 5
South Diversion Channel to Isleta Pueblo Boundary
Tile 5-23
Feet
0 350 700 1,400
Meters
0 100 200 400
Draft 4/2/2009
N
1:8,400
SWCA
ENVIRONMENTAL CONSULTANTS
Sandoval
Bernalillo
Map Location