RECLAMATION

2007 Geomorphic Summary of the Middle Rio Grande
Velarde to Caballo

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INTRODUCTION

The repeated, extreme-high flows of the 1800s coupled with a larger than normal supply of sand from adjacent lands due to poor land-management practices resulted in rapid aggradation, large-scale flooding, and general unrest within the Rio Grande valley (Scurlock 1998). These events prompted the Middle Rio Grande Project which created a series of large dams on the Rio Grande and its major tributaries (1950s-1970s) to control flooding and sedimentation (Lagasse 1980). Much of the Middle Rio Grande (MRG) today is no longer flooding and aggrading, but rather is evolving at a rapid rate in the opposite direction. The historical floodplain is in many places abandoned from bed degradation/incision (Massong et al., 2006), with the formation of vegetated bars constituting the majority of the regularly flooded surfaces (Tashjian and Massong, 2006). The river's width, which was widest in the 1930s, rapidly decreased in the 1960s and 1970s, corresponding closely with activities from the MRG Project, but has continued narrowing even after decades without channelization (Makar et al., 2006).

In recent times (late 1990s to 2004), the Rio Grande watershed has been in the middle of a regional drought cycle. This major reduction in water supply and peak flows caused the river to 'shrink' in size, mostly through the loss of active bars via vegetation encroachment. In 2005, the snows and rains returned, but found a river with stable bars and banklines. The Rio has reacted in a variety of ways; in those sections that had extensive island growth during the drought, the river has narrowed, deepened and abandoned all but a single dominant channel. In areas where a single channel already existed, but bank attached bars had stabilized with vegetation, the channel has begun to migrate. These changes and others display the speed at which change occurs in the MRG and at least partially explains the rapid increase of river maintenance sites of concern throughout the management area.

Much of the 270 river miles of Reclamation-managed Rio Grande channel (Velarde-Caballo) is either incising resulting in abandonment of its historical floodplain or rapidly changing its planform pattern resulting in narrowing and channel migration. A simple planfrom model is presented in Appendix C. Along with these highly visible changes, gravel is becoming more abundant throughout the watershed which is changing the governing processes for sediment transport and other in-channel processes. Together, incision, migration, planform conversion and gravel emergence is rapidly changing the Rio Grande channel and forcing us to evolve in what we think about the Rio Grande, but also about appropriate management strategies.

The purpose of this report is to generally describe current conditions of the Rio Grande from a geomorphic view point, synthesizing as much of the available information as possible on a reach by reach basis. After synthesis, these trends are then extrapolated to discuss future riverine processes, changes to aquatic and riparian habitats, and potential management concerns.

Findings from many reports prepared within Reclamation will be presented in this report, and rather than citing each fact individually, a list of reports will be presented in the Reference section as background information used in preparation of this summary. On some facts, the report is either not a Reclamation report or has been more officially published, in these cases, an attempt is made to individually reference this information.

GENERAL RIVERINE DESCRIPTION

Although many processes control changes on the Rio Grande, three major features have been changing throughout the MRG: floodplain conversion to terraces, lose of active channel area and conversion from sand to gravel on the channel bed. Channel incision is widespread throughout the MRG creating tall banks that confine the Rio Grande which prevents overbank flooding (Massong et al., 2006). Although recently developed islands and bars flood during high flows, the loss of the large historical floodplain system indicates a major change in governing processes for the watershed.

Adapted from Tashjian and Massong, 2006
The majority of the historic floodplain within the MRG is disconnected from the MRG at flows below 5,000 cfs. Though often referred to as the "floodplain", this surface functions as a terrace and has been abandoned by river incision through flood and sediment control measures. Even when overbanking occurs, the flows generally do not contain the energy to disrupt the flooded surface. From Bernalillo, NM to Bernardo, NM (~75 river mile), jetty jack lines were placed in the mid 20th century to stabilize bank locations. These structures, coupled with ensuing non-native vegetation, have 'frozen' the banklines creating a ~600 foot wide active channel corridor within the ~1800 foot wide "floodway". Within this corridor, active river processes are limited by upstream sediment supply and the hydrograph. The most vital modern habitat occurs in two parts of this Section; 1) south of Bernalillo in the transition from a multi to a single threaded channel, 2) from Isleta Diversion south where a floodplain-like surface has recently developed within the 600 foot wide river corridor.

Vegetation encroachment has been rampant during this latest drought cycle; temporarily stabilized, sand dunes and bars quickly became colonization by a variety of plant species which now are resistant to being re-worked by the river. Vegetation encroachment is widespread through the watershed, but has been most obvious in the Los Lunas and Belen, NM areas where the stabilization of the mid-channel bars has resulted in massive planform change. Once established, vegetation anchors deposited sediments, restricting lateral movement by the river. During this planform shift, the thalweg deepens, creating a core of water that is more effective at eroding bank sediments. In locations where the banks are tall due to incision and the root mass of the riparian vegetation is above the high water level, this condensed thalweg is able to undermine bank material, allowing the river to migrate. Migration is of particular concern in the San Acacia, NM area, as several bends have begun rapidly migrating in the last couple of years.

Several locations have been coarsening recently, all of which appear to have different forcing processes. Although upstream from White Rock Canyon was traditional gravel bedded, the Rio Grande downstream from the canyon was sand bedded until recently. Conversion to gravel occurred within in just a few years immediately downstream from Cochiti Dam after operations began in 1973. Within 20 years, much of the Cochiti Reach had coarsened to gravel sized bed material. This coarsening of bed material associated with dam operations has slowly progressed downstream into the Albuquerque Area. At present (2006), the area transitioning to gravel extends throughout the Rio Grande in the Albuquerque Metro (Massong et al. 2007). Probably unrelated to Cochiti Dam, beginning in the 1990s, gravel was found in measurable amounts by the USGS at the Rio Grande stream gage at San Acacia, NM. By 2000, large portions of the river downstream from the San Acacia diversion dam were covered in gravel; the Rio Salado was acknowledged as the source for this coarse sediment (Reclamation 2003). Since that discovery, many arroyo confluences in the San Acacia area have been inspected and acknowledged as sources of coarse sediment material. At present, gravel patches have been mapped within the Belen Reach, which appear to be systematically deposited by the river. Although the Belen Reach does not have many tributary sources of coarse sediment, it is believed that it will also convert in the future as gravel is transported into the reach from upstream.

Rio Grande Canyon to White Rock Canyon

This Reach of the Rio Grande lies within the Española Basin, which is the northern-most basin in the Rio Grande Rift valley. This area has probably been managed for thousands of years, as it was used by the Native Americans long before the Spanish settlements of the 1500s (Scurlock 1998). Unlike downstream of Cochiti Dam, this section of the Rio Grande was probably never a true sand bedded river, as the gravel supply is high and the historical records on the Rio Chama do not indicate an overwhelming supply of sand. Numerous east-side tributaries deliver cobble, gravel and sand-sized sediment to the Rio and have built large, coarse-grained, alluvial fan complexes. The banks are usually composed of sandy material with layers of gravel while the water is relatively clear. Although the floodplain was active into the 1950s, it is essentially abandoned now by a modest amount of bed incision (3-5 feet).

Large channelization projects occurred throughout this reach 1930s-1960s which mainly straightened and narrowed the channel. Specifically, the channelization by Reclamation in the 1950's attempted to confine the river to a very narrow right-of-way. This channel rectification was to provide a stabilized channel having a nominal capacity of 5,000 cubic-feet-per-second (cfs) upstream from the Chama and 7,860 cfs downstream from the confluence. However, the constructed alignment has not remained stable as the river has begun to meander and erode adjacent lands.

Bank erosion is a concern because private property and Pueblo lands are located directly adjacent to the river. Farm lands and orchards were placed along the riverbanks and in many locations, houses and buildings have also been built very close to the river.

Velarde Reach (Rio Grande Canyon to Rio Chama Confluence)

The Velarde Reach extends upstream from the Rio Chama confluence, approximately 13 river miles to Velarde, NM. A major feature of this reach is the lack of a well-formed or extensive Rio Grande floodplain and riparian zones. The numerous east-side tributaries 'push' the Rio Grande towards the west valley wall in this reach, which is composed of large landslide deposits. Prior to sliding, the west valley wall contained thick deposits of ancient Rio Grande sediments (cobble, gravel and sand layers) capped by a lava flow of basalt. The large mass-wasting events created a mixture of the ancient fluvial deposits and basalt boulders, which effectively prevents river migration. As a consequence, the formation of a significant Rio Grande floodplain is absent in this reach. The channel has a slightly sinuous, single channel pattern (Stage 4 Planform). The bed is composed of gravel and small cobbles with a pool-riffle morphology, however, the pools tend to be small in size compared to the riffles (glides). This channel morphology has not changed significantly in the recent past and appears relatively stable.

The majority of the maintenance work in this reach is related to irrigation; seven diversion dams supply water to local irrigation canals and acequias. Many of the dams have been updated in the past ten years but a few are either in need of repair or have stability concerns. Most of the dams are a sheet-pile/concrete structure protected by a riprap apron. At some of the dams the riprap aprons have seen excessive movement suggesting that the riprap is too small or was incorrectly placed. At present, there are no priority sites in this reach, however, there are 9 monitored sites (2 of the 9 are completed priority site projects). Other than improving the diversion dam facilities, the most likely future maintenance comes from close proximity of irrigation canals to the river bankline.

Changes to in-channel habitats are rare, but usually it is the continued abandonment of wetted channel to vegetated bars. As the channel pattern is stable, in-channel changes are expected to be limited. Also the lack of a floodplain limits the amount of off channel habitat. Side channels are rare. The riparian zone in this reach is often very small or absent; small patches have recently formed in isolated locations which provide small sections of young vegetation.

Rio Chama to Otowi Bridge Reach (Rio Chama Confluence to White Rock Canyon)

Management of peak flows on the Rio Chama (Abiquiu Dam) has dramatically reduced the peak flow hydrology of this reach for flood control at Española, NM. Although the dams on the Rio Chama have also reduced the supply of sand-sized sediment, the reduction does not appear vast as the channel bed material appears to have always been coarse (gravel). Gravel mining has occurred at several locations within this reach, but appears to be lessening; several ‘headcuts’ and bed lowering events have been verbally linked with gravel mining activities in this area; a moderate amount of incision exists (4-5 feet). Unlike the Velarde Reach, the western valley wall is composed of relatively undisturbed ancient Rio Grande sediments and there is a relatively, large floodplain throughout most of this reach while. The channel planform is a combination of slightly sinuous single channel (Stage 4 Planform) with sections with migrating bends (Stage 5 Planform) and double channels (Stage 6-7 Planforms). Other than the sections with active bends, the bankline throughout this reach appear stable. The active bends will likely evolve into double channels and stop migrating.

At present there is one priority site in this reach and 9 monitored sites. The most likely future maintenance comes from the formation and migration of meander bends. The channel dimensions are relatively stable with only a slight amount of narrowing in recent times. As the active bends migrate, sediment deposits on the inside of the bend, creating a point bar; these point bars provide new habitat areas for both riparian and aquatic species. Older sections of the point bars are becoming vegetated, creating a mosaic of different vegetation age classes. The active areas of the point bars are providing areas of shallow flow at nearly all discharges. During high flows, these point bars as well as the islands associated with the channels with a double channel become inundated creating small, isolated patches of floodplain habitat.

Cochiti Dam to Angostura Diversion Dam

After operations began at Cochiti Dam in 1973, the channel bed immediately began to erode and coarsen (Lagasse 1980), as the Dam is the perfect sediment sink. This set of processes has continued to the present (Massong 2004). The large grain size that emerged quickly after 1973 is suspected in retarding incision, such that the floodplain although quickly abandoned, is not more than 6 ft. higher than the current channel elevation. Several large tributaries deliver the coarse grain sizes to the Rio Grande here, such as the Galisteo River and the Arroyo Toñque.

Data indicate that the grain size is continuing to increase, such that in some sections, small cobbles line the river channel. Additional incision is not likely.

Similar to the upstream reaches, the Rio Grande is slightly confined on the west by geologic features (volcanic vents and bedrock) and by the pro-grading sedimentary fans/deposits on the east side that 'push' the river towards the west valley wall. As a consequence, the Rio Grande valley is relatively narrow in this section of the MRG. The current channel planform is varied as in the Otowi Reach, with sections that are mostly straight to slightly sinuous channels interspersed with meanders, double channels and abandoned channels (Stages 4-9 Planforms). The point bars that formed in association with the meander bends vegetated quickly but still inundate during high flows. Most of these planforms are surprisingly stable, even the migrating bends which are moving very slowly. This trend is expected to continue creating a more stable channel.

The banklines are typically densely vegetated and mostly stable (not eroding). Historically the channel was wide (1500+ feet), but has narrowed to an apparently stable size of < 400 feet. As found upstream, the channel morphology is that of a pool-riffle, however the pools are infrequent and poorly formed while the riffles are wide spread and well formed.

At present, there are 15 priority sites and 10 monitored River Maintenance Sites; two of the monitored sites are completed priority sites. This reach of 23 river miles is almost entirely Pueblo owned; as in the Velarde Reach, the infrastructure is close to the river, including drains, irrigation canals and roads. Peak flows have been greatly reduced in this reach from dam operations, and historical photography indicates at least two episodes of large channelization projects. Evolution of habitat is similar to that in the Otowi Reach, however, this reach appears just a little more stable, which translates into smaller more isolated patches of evolving habitats.

Angostura Diversion Dam to Isleta Diversion Dam

The gravel/planform transition that started after Cochiti Dam began operations in 1973 is now located within this Reach. In the early 1990s, the transition zone appeared to be located near the City of Bernalillo, NM (R. Ortiz, 2004 MS Thesis). Since that time, the transition has moved downstream and is currently located within the City of Albuquerque limits. As a consequence to this transition zone, this reach is sub-divided into three smaller reaches based on the location of the gravel conversion: Post-Transition Reach (Angostura to Corrales), Transition Reach (Corrales to Bridge Street Bridge), and Pre-Transition (Bridge Street Bridge to Isleta Diversion Dam).

From Angostura diversion dam to the Isleta diversion dam, there are 8 sites that the River Maintenance team monitors. One site (Santa Ana Restoration site) is a completed maintenance site which is still monitored with adaptive management activities ongoing. Two sites (Bernalillo and Sandia Priority Sites) are in the long-term solution construction and planting phases. These sites will become monitoring sites before the 2007 spring runoff. Corrales Siphon Priority Site is in the long-term solution development phase and will go to construction after the 2007 spring runoff. The other 4 sites are monitoring sites.

Post-Transition Reach (Angostura Diversion Dam to Corrales)

Historically, these 10 miles of river was a sand bedded section of the Rio Grande, which was rapidly aggrading before Cochiti Dam began operations. As a result of the aggradation, the floodplain within the levees became higher than the floodplain outside the levee system. This super-elevated floodplain/channel is most noticeable near the HWY 550 bridge crossing in Bernalillo, NM. Part of the reason for the rapid aggradation was sediment from the Jemez River, the largest tributary in this reach which is located just downstream from Angostura diversion dam. This tributary was once a large supplier of coarse and fine grained sediments; the flood control dam that was built on the Jemez River in the 1960s which only withheld peak flows, was modified for water storage and sediment retention in 1979. This change in management on the Jemez River further reduced the sediment supply to the Rio Grande, and in particularly to this reach. Bank heights through most of this reach are higher than those found upstream; unlike upstream in the Cochiti Reach, bed degradation occurred prior to the channel bed coarsening, thus allowing more degradation to occur.

A major feature of this reach is a much larger/broader historical floodplain than that found upstream. Also, an extensive series of mid-channel bars emerged in the 1990s which now act as high-flow floodplain surfaces.

Between the Angostura diversion dam and Arroyo de las Montoyas/Harvey Jones Channel in Corrales, NM, the channel bed has already degraded and coarsened, but at different times. Near Angostura diversion dam, the incision and conversion occurred first, probably back in the late 1980s-early 1990s, while the changes just recently occurred near Corrales (2000-2005). The transition included:

- Although channel bed incision began in the 1980s, the bed continued to degrade through the 1990s as part of the transition. Channel incision has abandoned the historical floodplain.
- A coarsening of the bed material or armouring from sand bed to gravel bed began in the 1990s. Currently the grain size is coarse gravel to cobble in the upstream half of the reach, then grades down to medium gravel near Corrales.
- Planform conversion appeared to be a late feature to change in the transition, as it converted in the late 1990s. The current planform is that of a single, deep thalweg, especially during low flows, with high flow channels inundating only when river flows near the 2-year return event or greater.
- Medial bars (islands) were transitory prior to the late 1990s/transition period; post-transition, the bars are relatively stable and now partially vegetated. Some of these surfaces inundate during high flows.

The major river maintenance concern in this section is that the river's planform is within Stage 4 – slightly sinuous planform which now has a few sections with eroding bends forming, tending towards a Stage 5 planform-migrating bends. The thalweg is alternating between the banklines and is developing a series of migrating bends. At present, the bank height is tall enough for the river's thalweg to intersect the bankline beneath the root zone of the riparian vegetation and be easily eroded.

During the 1990s, numerous bars began vegetating; these surfaces are both islands and bank attached bars. These features provide small patches of young vegetation and small patches of floodplain, which adds to both riparian habitat and in-channel habitat. The migrating bends are also creating small point bars, which will evolve in the same manner as the islands, vegetating and acting as small floodplains. Although these small habitat 'gems' exist in this section, in general, the channel is getting more coarse, narrower and deeper, while the historical floodplain is growing in height above the active channel with an aging cottonwood gallery. Neither the main channel nor the historical floodplain are providing quality habitat. If channel migration continues, both the riparian and channel habitat will likely improve. The migrating planform exchanges the tall, relatively undesired terrace habitat for new point bar habitat that is better connected to the river channel.

Transition Reach (Corrales to Bridge Street Bridge)

This portion of the Angostura-Isleta reach is transitioning from the traditional sand bedded channel with a braided planform to gravel bed with a single dominant channel. The amount of transitioning gradually lessens downstream toward Bridge Street. Common features throughout this sub-reach include: channel bed incision, such that the historical floodplain is abandoned (began 1980s-1990s); gravel deposition within the active channel; and some level of planform shift which initially includes the growth of islands, abandonment of side channels, and then the formation of a single, relatively deep channel.

At present the channel bed has incised 3-5 feet and has caused the historical floodplain to become disconnected from high river flows, even 2-year events. Gravel deposition decreases in the downstream direction, but its initial presence is systematic, such that it begins by lining the islands and bar edges then expands into the main channel and eventually forms riffles. The planform is currently between Stage 2 and 4 (island braided to single, slightly sinuous channel). This change in planform causes a rapid decrease in wetted width and a deep thalweg. Migration is absent thus far. Islands and bank-attached bars are now vegetating and still mostly connected to the river channel but due to surface deposits during the last high flows in spring 2005, are requiring higher runoff events to inundate; due to the dense vegetation anchoring these features, they are highly resistant to river erosion often forcing the river to flow around them even during high flows which inundate their surfaces. All of this reach will eventually convert to a single channel with few exceptions.

The major feature of the fully transitioned channel is that the full-channel has a gravel bed, with or without coarse grained riffles. Sand dunes may temporarily covering the gravel but is transient in nature. At present, this reach is still dominantly a sand bedded river, however, gravel is systematically depositing within the active channel, indicating the transition is in progress. Gravel deposits were first sampled near I-40 in 2004, and observed at Bridge Street in 2004:

- The first location where gravel is often found during transition is at the head of islands, and along the sides of the islands.
- Next, these patches along the islands grow upstream, which creates small 'riffle-like' features that remain sand-free.
- The 'riffle-like' deposits continue to grow, until they reach another 'riffle-like' deposit, an island bankline, or the channel's bankline. At that time, these gravel deposits become more like a traditional riffle.

- After the riffles have formed, with a coarsened channel bed, then the channel between the riffles coarsens until the channel bed is fully gravel bedded.
- In this section and throughout the Rio Grande, sand dunes are often present and are transported over the more competent gravel layer.

Full conversion of this reach could happen as quickly as the next large spring runoff. More likely though, is that the upstream half of the reach, which is closer to full conversion, would switch sooner than the downstream half. The most likely river maintenance concern in this section of the Rio Grande is additional channel bed incision and the formation of migrating meander bends. At present, the in-channel features are widely variable are have been considered good habitat. The continued evolution would likely decrease this habitat value. The riparian habitat is similar to the upstream section that is already past this transition; the historical floodplain is already abandoned with a mature vegetation complex. The only locations with new or young vegetation growth are on the islands and bank attached bars. These areas are relatively small, but have the potential for high quality riparian habitat.

Pre-Transition Reach (Bridge Street Bridge to Isleta Diversion Dam)

The Rio Grande downstream from Bridge Street is similar to the historical Rio Grande descriptions: it still has a sand bed with migrating macro-dunes and dune fields; during low flows, the dunes become inactive, but do not vegetate as they become re-active when flows increase; gravel deposition is not present in measurable amounts; the floodplain is active during high flows; and the channel planform and width are relatively stable in Stage 1. The planform is low-flow braided with a relatively shallow thalweg that changes to a single fairly uniform channel during high flows. Islands and bank-attached bars are mostly absent. The bed elevation is mostly stable to slightly decreasing (slightly incising). Banklines are relatively stable, with no priority sites within this sub-reach.

River maintenance concerns are low in this area with no monitoring or priority sites present. As the channel still exhibits historical river conditions, the channel habitat has good channel bed complexity within the braided planform and an active floodplain. The riparian habitat may not be considered as good as the in-channel habitat, as the floodplain contains mostly mature habitat. Areas with new riparian growth are rare and isolated. Eventually, the transitioning Rio Grande will impact this reach, as it continues to migrate downstream. As a consequence, this reach will evolve as that discussed above.

Isleta Diversion Dam to Arroyo Abo Confluence (a.k.a., Belen Reach)

The Belen Reach is typically described as one of the most stable reaches on the Rio Grande. It remains sand bedded with a connected floodplain and a mostly braided morphology. The channel width varies little throughout the reach; channelization and bank stabilization efforts in the 1950s resulted in an initial large-scale reduction in width between 1949 and 1962 but with long-term width stabilization until 2002. A significant amount of narrowing occurred between 2001 and 2002 which coincides with field data which found the formation of numerous islands, vegetated sand bars. Since 2002, the channel has begun shifting towards a single-thread planform, with the islands becoming bank attached. The unvegetated portion of the channel has decreased significantly and a more sinuous low flow channel is forming. Despite relatively stable bed elevations, the reach has seen significant amounts of vegetation growth on bars and islands in the past few years which has stabilized these features.

Although has often considered stable, several changes have been occurring that may indicate that this reach is rapidly becoming unstable.

- Planform
  - Starting in 2002 with an abnormally low water year, macro-dunes in the Belen reach became less active and woody vegetation started growing on them. This bar stabilization process created numerous islands that effectively reduced the channel width and concentrated the low and moderate flows into only two or three small channels.
  - In 2004, a moderate spring runoff year, channel filling was evident some of the side channels, which began the process of changing their function from low-flow channels to moderate or even high flow channels.
  - Through the 2005 runoff cycle, the islands continued to be stable and resisted overbank erosion.
  - A dominant thalweg developed during the 2005 spring runoff event. In addition, the continuation of side channel filling produced numerous high flow channels.
  - After 2005, field observations indicate that the side channels are starting to vegetate.
  - The current planform is best described as a single-treaded channel at low flows, but becoming an anastomosing or island-braided planform at higher flows (when the side channels become active).
- Floodplain
  - In 2005, much of the historical floodplain was significantly inundated during the spring runoff event. Also inundated were the islands and bars.
  - After runoff ended, field observations indicate significant aggradation which occurred on the bars, islands and floodplains (near the bankline) which has increased bank heights, such that higher flows are now required to cause overbanking on these surfaces.
- Sediment Composition
  - Prior to 2005, only minor amounts of gravel were observed in this reach, and the locations appeared random.
  - After the 2005 runoff, gravel deposits have been found systematically at the head of islands/side channels and in long patches within the high-flow side channels, and at the side channel outlets between islands.

Right now the banklines in this reach are stable as they are near the high water mark and are densely vegetated. Numerous jetty jack lines also add to bankline protection. At present, there are no monitored sites or priority sites. In the future, channel capacity may decrease, as the side channels continue to fill and become vegetated. The planform will likely continue to evolve into a slightly sinuous, single channel (Stage 4 Planform).

For in-channel habitat, this reach is expected to continue to narrow through the abandonment of side channels, and the main channel is expected to incise eventually containing the larger flows and abandoning the current floodplain. All of these changes reduce space for aquatic habitat. However, as these riverine features evolve, new vegetation will emerge, thus providing new riparian and new floodplain features, which may provide new bird and other riparian habitats.

Uplift Reach (Arroyo Abo to North Socorro Diversion Channel)

The major feature of this geomorphic reach is that it is all being uplifted by the Socorro Magma Body. As a result of the uplift, a series of terraces and abandoned floodplains line the Rio Grande from about Arroyo Abo confluence to the North Socorro diversion channel outfall. Smaller, inset floodplains appear to be continuously developed as the river abandons older surfaces creating a classically entrenched river system. Presumably due to a basin-wide reduction in sand supply, gravel has become a large component of the bed material in this reach, especially downstream from the Rio Salado confluence. From the Rio Salado to almost the Escondida Bridge crossing, the channel bed is dominated by gravel, even though sand dunes often cover the gravel layer. At nearly all of the tributary junctions, gravel fans have developed which partially cover the Rio Grande's bed with gravel sized sediment and sometimes create temporary breaks in the channel's slope. This reach can be subdivided into two smaller reaches: upstream from the center of uplift; and downstream from the center of uplift.

Upstream from Uplift Center (Arroyo Abo to Rio Salado Confluences)

Upstream from the Rio Salado, the channel is single threaded with what appears to be continually encroaching vegetation onto the sediment deposits. Although islands are present, most of the new sediment deposits are bank attached or are islands that are in the process of attaching to the banks. This process results into an ever decreasing channel width, but with very stable banklines. The channel slope is slightly lower than downstream from the Rio Salado, as it is upstream from the main uplifted area; channel incision is also less than that measured downstream. Deposits of gravel are mostly isolated around the arroyo confluences and appear to be scoured and scattered by high flows.

River maintenance concerns are low in this reach, as there are no priority sites and only two monitored sites. This channel appears to be caught in the slightly sinuous, single channel planform (Stage 4), which appears stable. However, as the banks are tall, the slightly sinuous pattern that currently exists could cause some bank erosion sites, but large migrating bends are unlikely as the channel slope is relatively low. As this is within the uplifted area, the floodplains are continually, and naturally becoming abandoned, however, new floodplains are forming and quickly becoming vegetated. Riverine habitat is naturally shrinking as the channel incises, narrows, and the bars become vegetated and stable. However, the new floodplains provide small isolated pockets of good habitat for both riparian and in-channel species.

Downstream from Uplift Center (Rio Salado Confluence to North Socorro Diversion Channel)

Downstream from the Rio Salado, the channel planform is also single threaded, but the channel is more incised (especially downstream from the San Acacia diversion dam) and several meander bends have begun to migrate. The alternating thalweg that began forming in the late 1990s has become the dominant morphology, creating numerous migrating bends. Several series of "mega-bends" have formed throughout this reach; some are migrating towards riverside facilities (i.e., levees, canals). Channel incision has been rapid with up to 15 feet in the past 60 years. As the terraces are quite tall, the high water mark is often well below the root zone of the riparian vegetation, coupled with the dominantly sandy bank composition, the bank material is particularly susceptible to riverine erosion.

Most of this reach is gravel bedded, with the coarsest bed material located at the Rio Salado confluence and grading downstream towards Escondida bridge area where it is still dominantly sand-sized bed material. Planforms range from Stage 4 which is the single, slightly sinuous channel to Stage 8, which is an advanced bend with a well developed cutoff channel that has captured the main flow.

River maintenance concerns are high in this reach, as there were 17 sites of active bank erosion in 2005, 2 priority sites (Drain Unit 7 and RM 111) and 6 monitored sites, 3 of which are completed priority sites. Additional concern sites are likely to develop as high flows occur.

As this is within the uplifted area, the floodplains are continually, and naturally becoming abandoned, however, point bar growth is rampant as the banklines migrate. These point bars act as new floodplain surfaces and create shallow, wetted surfaces at nearly all flows. The older sections of the point bars are becoming vegetated creating new riparian vegetation. Old riparian zones that are located on top of the abandoned floodplains (terraces) are being eroded by the migrating bends. Although the channel location is moving, channel area and width appear to be remaining fairly constant.

Stable Transition Zone (North Socorro Diversion Channel to Brown Arroyo)

Unlike the transition zone in Albuquerque, which is transitory, this transition zone (8 river miles) represents a relatively stable stretch of river which is located between significant degradation upstream and aggradation downstream. In the last 10 years, channel width has decreased slightly, which can be attributed to island and bar growth/vegetation during the recent drought cycle. Planform characteristics within this reach are relatively stable, however with the development/stabilization of the bars and islands, the remaining active channel area is concentrating the river flows, a similar process of that found in the Belen Reach but at a smaller scale. The channel’s grain size and bed elevation remain stable. The location of greatest bed stability appears to be near river mile 100, just upstream from Arroyo de la Presilla, near agg/deg line #1355. The floodplain throughout this reach is active and begins to inundate at moderate sized flows.

Right now the banklines and bed in this reach are mostly stable, however, a slightly meandering thalweg pattern is beginning to form. At present, there is one priority site (Arroyo de las Cañas PS). Since the levee is close to the river channel in several locations in this reach, additional concern sites are likely to form as this single channel forms. Although individual migrating bends may form in this reach, numerous migrating bends are unlikely since bank height is low.

For in-channel habitat, this reach may continue to narrow and possibly incise as the thalweg becomes more concentrated into an ever smaller active channel, reducing space for aquatic habitat. However, new riparian areas will develop, which may provide new bird and other riparian habitats.

Brown Arroyo to the Tiffany Plug Area

From Brown Arroyo to the Tiffany Plug area (~9 river miles) is and has been gradually aggrading since the 1930s; bank heights are low and the floodplain along with newly formed islands are flood prone at relatively low flows (3,000 cfs). The amount of aggradation increases in the downstream direction. Although all of the Rio Grande has been narrowing since historical times (1918), this section of river has always been the widest; it has maintained its wide, braided, shallow planform with a sand bed better than any other section on the Rio Grande. Several possibilities give insight into this reach's resistance to significant change:

- Much of the reach is within the Bosque del Apache National Wildlife Refuge, which has protected this section from extensive channelization activities that began in the 1930s and extended into the 1980s.
- This reach is slightly aggradational, and been since first surveyed in the 1930s, and perhaps before. This aggradation has persisted beyond that of all the other reaches in the Middle Rio Grande.
- Channel slope lessens slightly in this reach.
- The valley width is very wide in this reach.
- This reach receives water and sediment from numerous tributaries that are not controlled for flood or sediment production, allowing for a more natural hydrograph and sediment supply than found in the upstream reaches.

During the recent drought cycle, mid-channel bars have formed and become vegetated. In 2005, many of the side channels filled-in, became vegetated and are now attaching the islands to the banks. High flows in both 2005 and 2006 have not been able to erode these features; in fact, the main channel rapidly decreased in width and now 'snakes' around these stable features, similar to that seen in the Belen Reach.

In locations where the channel was straightened by cutting pilot channels through the floodplains, the channel width is significantly narrower. The bank material in these locations is likely more resistant to erosion than elsewhere due to a higher clay content more consistent with the floodplain depositional environment prior to the channelization activities.

The levee along the west side of the river is considered a Priority Site, as levee raising is an ongoing process to prevent flooding outside the floodway. One monitored site (Bosquecito), is located within this reach. Although meandering is not extensive in this reach, several banklines (5 new sites in 2005) started eroding in the last two years, and are expected to continue to erode. Luckily, these locations are not too close to the riverside facilities present in the reach.

With the extensive formation of vegetated islands and bars, less wetted channel area is available for aquatic species; the island growth trend is likely to continue in this reach. These islands/bars are very stable and force the main channel to flow around them forming a deeper more concentrated main channel to convey the in-channel flows. The likely evolution of this reach is that a single dominant channel will emerge, with the rest of the current active channel becoming vegetated floodplain. Although these newly formed surfaces easily flood, so does the historical floodplain, therefore, these features only add to the abundant floodplain habitat already available in this reach. These new riparian areas provide young vegetation that is close to the river's edge and may improve avian habitats.

One additional concern for this reach is the upstream migration of the Elephant Butte Reservoir headcut. At present, the headcut appears to be in the Tiffany Plug area. Although that zone of temporary degradation appears to be stalled, it could migrate into this reach. The effects of the headcut would be temporary bed degradation, probably less than 3 vertical feet of scour. The most important change in bed elevation would require higher river flows to inundate the floodplain. After the degradation ended, aggradation would likely ensue, and the channel bed would re-fill.

San Marcial Reach (Tiffany area to ~RM 60)

Prior to 2005, this reach was rapidly aggrading, with about 15 ft in the last 65 years. In 2003, a large headcut (>10 feet in vertical elevation) was identified within the upper section of Elephant Butte Reservoir. In 2005, the headcut migrated upstream with the spring runoff event, passing though this reach. The headcut divided into several smaller headcuts that are now located throughout the reach. The most upstream portion of the headcut migrated to approximately the Tiffany Sediment Plug area. It is unknown whether the smaller headcuts will all continue to migrate upstream and possibly re-form one larger headcut. Another unknown is whether the upstream portion of the headcut will continue to migrate upstream from the Tiffany Plug area and if so, how far upstream it will move.

Subsequent bed scour in 2005 from the headcut caused significant bed elevation lowering (degradation) throughout this reach. This degradation varies, with the greatest amount at the downstream end of the reach (>10 feet) to 3-4 feet at the upstream end of the reach. Regardless of the exact amount, degradation has abandoned most of the floodplain in this reach. Due to rapid base level lowering and subsequent water table elevation lowering, especially at the downstream end of the reach, riparian vegetation is being stressed with some mortality.

Along with the rapid bed degradation, several bends within this reach have begun to migrate. The two most notable locations are at RM 60 and at the Ft. Craig pumping station; in both locations, river flows intersect the bank material below the root zone and is causing erosion. Also at both locations, the erosion began at pre-existing bends in the river but is now evolving to create new bends. On the inside of each of the migrating bends, large point bars have developed. The acknowledgement of this sediment deposition is important, as it indicates that the channel has formed a prominent thalweg which is located at or near the eroding bankline (across from the sediment deposition). This thalweg development indicates a shift from a uniform bed depth to that of varying depths.

Although this reach has changed significantly within the last few years, the channel location at a broad scale remains stable. This reach was always the narrowest and least variable based on historical photo reviews. Much of this reach was relocated when the river channel was moved to the east side of the valley during Low Flow Conveyance Channel construction. Although a major threat just a couple of years ago, channel avulsion is not likely until the channel bed aggrades back to elevations similar to that measured in 2003; right now the river is the lowest valley elevation in most of this reach. Grain size continues to be fine sand.

The initial bed incision has cause massive abandonment of the floodplain which adversely affects aquatic and riparian species alike. As this reach is normally rapidly aggrading, the incision is presumed to be temporary; based on recent historical aggradation rates, once sedimentation processes return, the channel bed could fill to 2003 elevations within 10-15 years. However, any additional headcuts migrating into this reach from the Reservoir will extend this timeframe.

River maintenance concerns are broad in this reach including: channel migration; maintenance of the levee system and roads; and management of sediment plugs. Channel migration is a recent process and is associated with the lowered bed elevation. The incised channel bed allows bank erosion to occur under the riparian root mass. This type of erosion is expected as long as the bed elevation continues to be lower than the vegetation roots. Westward migration of the river channel threatens the levee, access roads and the Low Flow Conveyance Channel.

Normally, overflowing of the levee system is the most important maintenance need in this reach. As the channel re-fills, this will once again become the main issue. While the channel bed is incised, another issue arises: a lowered water table allows the sediments composing the levee and under the levee to dry which will cause local areas of settling/subsidence and could impact the existing levees and roads.

Another major issue is sediment plugs that occur in this reach, particularly during years of extended high flows. Simply speaking, a sediment plug is the first stage in the avulsion process. Large amounts of sediment deposit in the channel forcing all flows to go overbank. If not managed, a new prominent channel would develop on one side of the old channel, thus becoming the new main channel. Repeated sediment plugs have formed in the Tiffany area, just upstream from the San Marcial Railroad Bridge crossing. The most recent plug formed during the 2005 runoff. For sediment plugs forming in this location, river flows have been re-established by partially excavating the filled channel and re-directing water to flow into the pilot channel. As these plug sediments are loose and often still wet, the water flowing through the pilot channel easily erodes the deposits and re-establishes a channel similar to channel prior to the plug formation.

The incision and lowered water table are two important changes in this reach that affect habitat conditions. The incision and deepening thalweg has obvious consequences for aquatic species, as the channel area has decreased, but more importantly the shallow flow areas are disappearing. Also, the once well connected floodplain is not abandoned. The lowered water table is already affecting the riparian vegetation; stress and mortality of the riparian vegetation has obvious negative implications for flycatcher habitat. These conditions are expected to exist until the reach resumes its aggradational processes and aggrades to a level at which the floodplain becomes active again.

Temporary Channel in Elephant Butte Reservoir Pool

As this reach is within the Elephant Butte Reservoir pool area, it has experienced periods of substantial and rapid aggradation. At the upstream end of the narrows (upper portion of the reservoir), the bed elevation has risen about 40 feet since 1915. The most sustained period of near maximum reservoir storage occurred in 1980s through the mid-1990s. The reservoir pool elevation started decreasing in 1999, moving the head of the reservoir pool downstream of the Narrows in 2002.This rapid lake recession disconnected the river from the lake, such that a channel had to be excavated through the reservoir sediments. The capacity and stability of the constructed channel has been and remains a key issue for the Albuquerque Area Office. Over 20 miles of channel was constructed between the late 1990s and 2005.

Once the constructed channel had at least partially stabilized in 2003, a headcut formed upstream from Silver canyon and began progressing upstream. By 2004 the headcut had moved upstream to the location of the 1992 temporary channel where it temporarily stalled in a thick clay deposit. In August of that year, the main headcut drop was estimated at 10 feet high. In 2005, the headcut moved upstream and appeared to stall at the downstream end of the Tiffany sediment plug.

Over 20 miles of channel have been constructed since the late 1990s.

- End of the 1990s - 1.9 miles
- 2000 – 0.9 miles
- 2001 – 2.2 miles
- 2002 – 2.2 miles
- 2003 – 4.9 miles
- 2004 – 6.8 miles
- 2005 – 1.0 mile

The main portion of the temporary channel (upstream of the Narrows) has started to evolve since it was first constructed in 2001-2004; in 2006, silvery minnow were found throughout this part of the channel. As long as the reservoir pool does not fill over this channel, it will continue to evolve. A slight meander pattern is beginning to set up and is likely to progress as the reservoir sediments are soft and easily eroded, however, vegetation growth along the channel could stifle this planform development. The meandering pattern adds complexity to the channel bed through the development of with inset point bar growth (shallow surfaces within the main channel) and deeper thalweg which alternates between banklines.

The longer the Reservoir pool stays low, the more likelihood that additional headcuts will form and migrate upstream. These headcuts will increase channel capacity within the constructed channel, while lowering the water table. As discussed in the San Marcial Reach, a lower water table may negatively impact the riparian vegetation and reduces the potential for overbank flooding for aquatic species.

Caballo Reach (Elephant Butte dam to Caballo Reservoir)

The Rio Grande between Elephant Butte dam and Caballo Reservoir is extensively controlled in terms regulated river flows and sections of the river bed elevation. All of the upstream sediment supply for this reach is stored in Elephant Butte Reservoir, such that released water is clear and cold; local tributaries (Arroyo Cuchillo Arroyo Negro, Mescal Arroyo, and Arroyo Hondo) which contribute to this reach flow infrequently but can deliver copious amounts of coarse and fine sediments. As an apparent result of the low sediment supply, the channel appears to be slightly incised.

Water releases to this reach are maximized for water delivery to downstream irrigators. Reclamation's main authority for this reach is to maintain a channel capacity of 5,000 cfs. As part of this authority, in 1985, Reclamation channelized this reach which included lowering the bed elevation. This work decreased natural flows to local hot springs along the river, so yearly Reclamation constructs a temporary dike during the winter (when releases are stopped) to artificially raise the stage in the river, which increases hot spring flows. The bankline is very stable throughout the reach; only some of the banks are lined with riprap.

As this reach is so controlled and has been since 1917 when Elephant Butte Dam began operations, it is not likely to evolve significantly in the future. The current availability and type of habitat is likely stable unless manipulated by humans.

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Appendix A - List of Sites (Monitoring and Priority Sites)

Velarde to Chama Maintenance Sites

– Los Chicos	Monitored
– La Canova	Completed
– South Velarde	Monitored
– Salazar Pit	Completed
– Canada Ancha	Monitored
– El Guique	Monitored
– Palacio Arroyo	Monitored
– La Villita	Monitored
– Alcalde	Monitored

Chama to Otowi Maintenance Sites

– Vigil Ditch Heading	Monitored
– San Jose	Monitored
– San Juan Ponds	Monitored
– Santa Cruz	Monitored
– Santa Clara	Monitored
– Arroyo Madrid	Monitored
– Rio Arriba County Line	Monitored
– Black Mesa	Monitored
– San Ildefonso Pond	Priority
– Otowi	Monitored

Cochiti dam to Angostura Maintenance Sites

– Priority sites	
– Cochiti RM 231.1	Priority
– Cochiti RM 230.9	Monitored
– Santa Fe River Confluence	Completed
– Peralta Canyon	Monitored
– Cochiti RM 228.9	Priority
– Sile	Monitored
– Ca±on Santo Domingo	Monitored
– Santo Domingo RM 225.1	Priority
– Galisteo Creek	Priority
– Santo Domingo Stockpile	Priority
– Santo Domingo Curve #4	Completed
– Borrego Canyon	Monitored
– La Mesita	Monitored
– Tonque Arroyo	Monitored
– San Felipe RM 215.5	Priority
– San Felipe RM 214.4	Priority
– San Felipe RM 213.7	Priority

– San Felipe RM 213.4	Priority
– San Felipe RM 212.8	Priority
– San Felipe RM 212.0	Priority
– San Felipe RM 211.6	Priority
– San Felipe RM 211.3	Monitored
– San Felipe RM 210.3	Priority
– San Felipe RM 210.1	Priority
– San Felipe RM 210.0	Priority

Angostura to Isleta Maintenance Sites

– Santa Ana Restoration	Completed
– Santa Ana Corps Project	Monitored
– Highway 550 Bridge	Monitored
– Bernalillo	Priority
– Sandia	Priority
– Corrales Siphon	Priority
– Albuquerque Wastewater Outfall	Monitored
– Isleta Railroad Bridge	Monitored

Isleta Diversion Dam to Rio Puerco Confluence Maintenance Sites

– Highway 309 Bridge	Monitored
– Los Trujillos	Monitored
– Rio Puerco RM 127.9	Monitored
– Rio Puerco RM 127.5	Monitored
– Rio Puerco RM 127.0	Monitored

Rio Puerco to San Acacia Maintenance Sites

– La Joya	Monitored
– Bernardo Arroyo	Monitored
– Drain unit 7	Priority

San Acacia to Arroyo de las Cañas Maintenance Sites

– San Acacia RM 115	Monitored
– San Acacia RM 114	Completed
– San Acacia RM 113	Completed
– San Acacia RM 111	Priority
– San Acacia RM 110	Monitored
– San Acacia RM 107	Monitored
– Arroyo de la Parida	Completed
– Arroyo de las Cañas	Priority

Stable Transition Maintenance Sites

– none

Brown Arroyo to the Tiffany Plug Area Maintenance Sites (Bosque del Apache area)

– Bosque Levee	Priority Site
– Bosquecito	Monitored

San Marcial Maintenance Sites

– Tiffany Levee	Priority
– San Marcial Levee	Priority
– Fort Craig Bend	Monitored
– River Mile 60	Priority

Temporary Channel Maintenance Sites

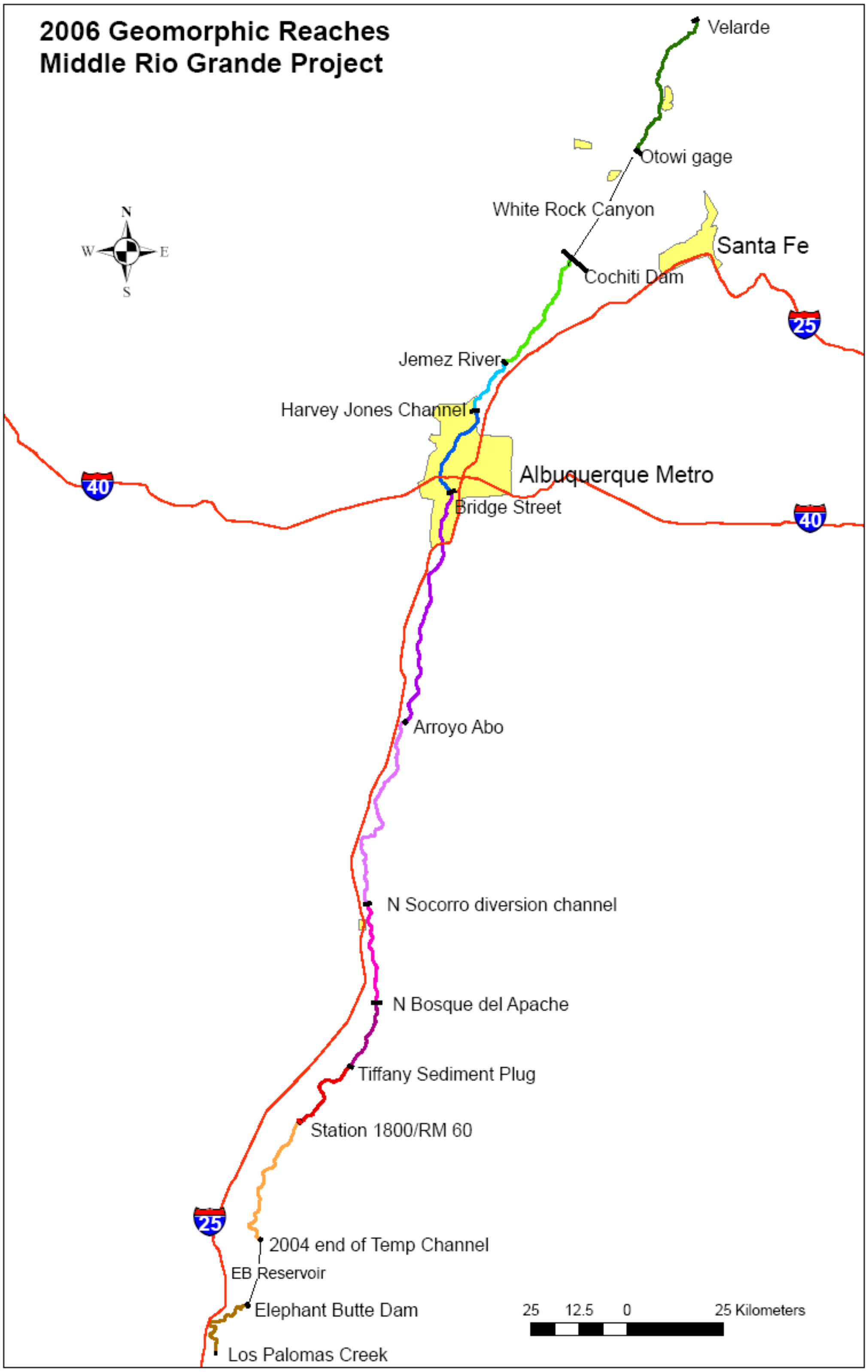
– Ongoing maintenance occurs to keep the water flowing inside the temporary channel.

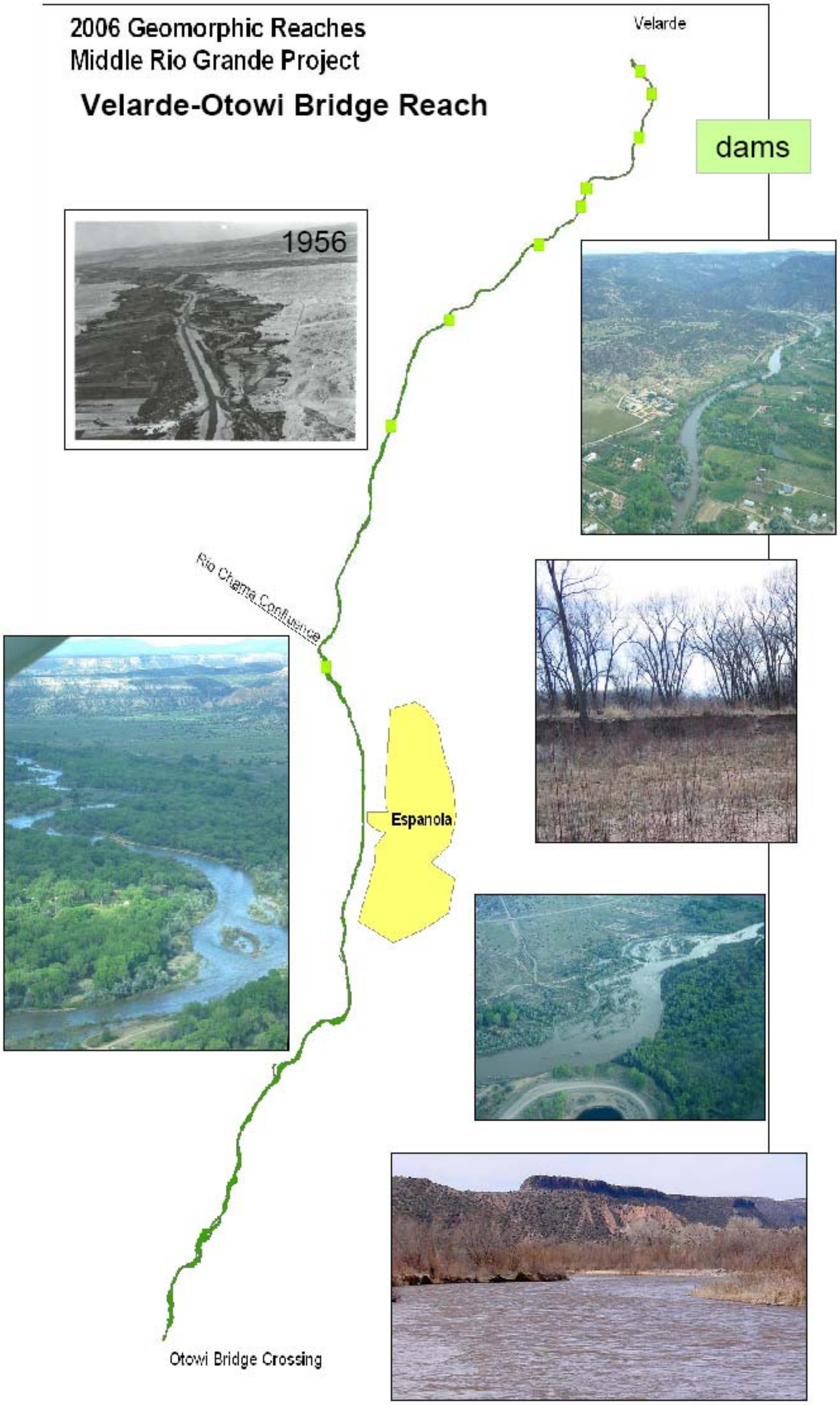
– As reservoir fills, the temporary channel is expected fill and become part of the reservoir pool.

Caballo Reach Maintenance Sites

– T or C Channel Capacity Priority Site
  - Annual excavation of sediment deposited by arroyos
  - Construct and remove temporary dike each year
  - Install riprap revetment as necessary to protect property developed before 1985

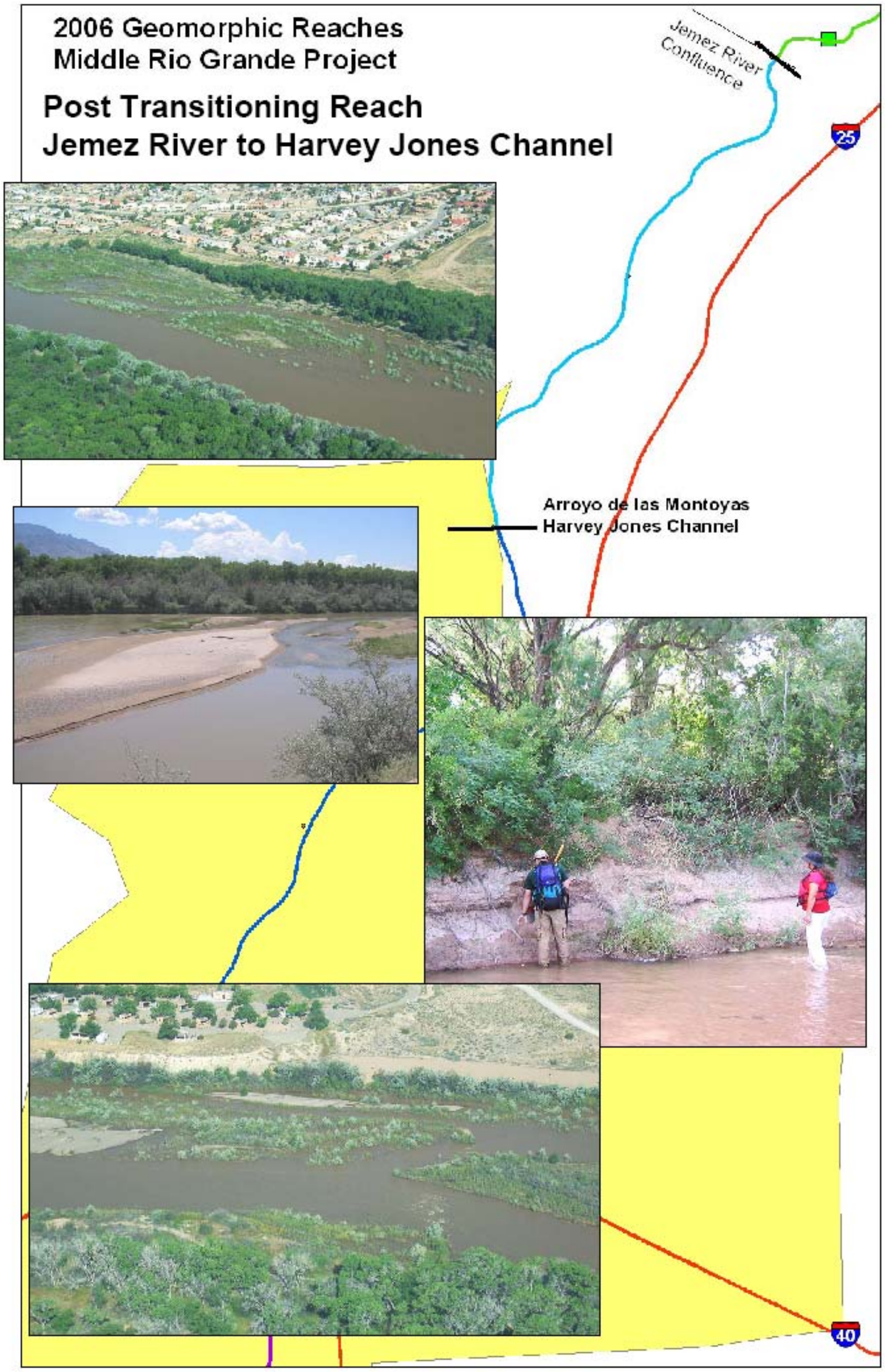
Appendix B - Reach Figures

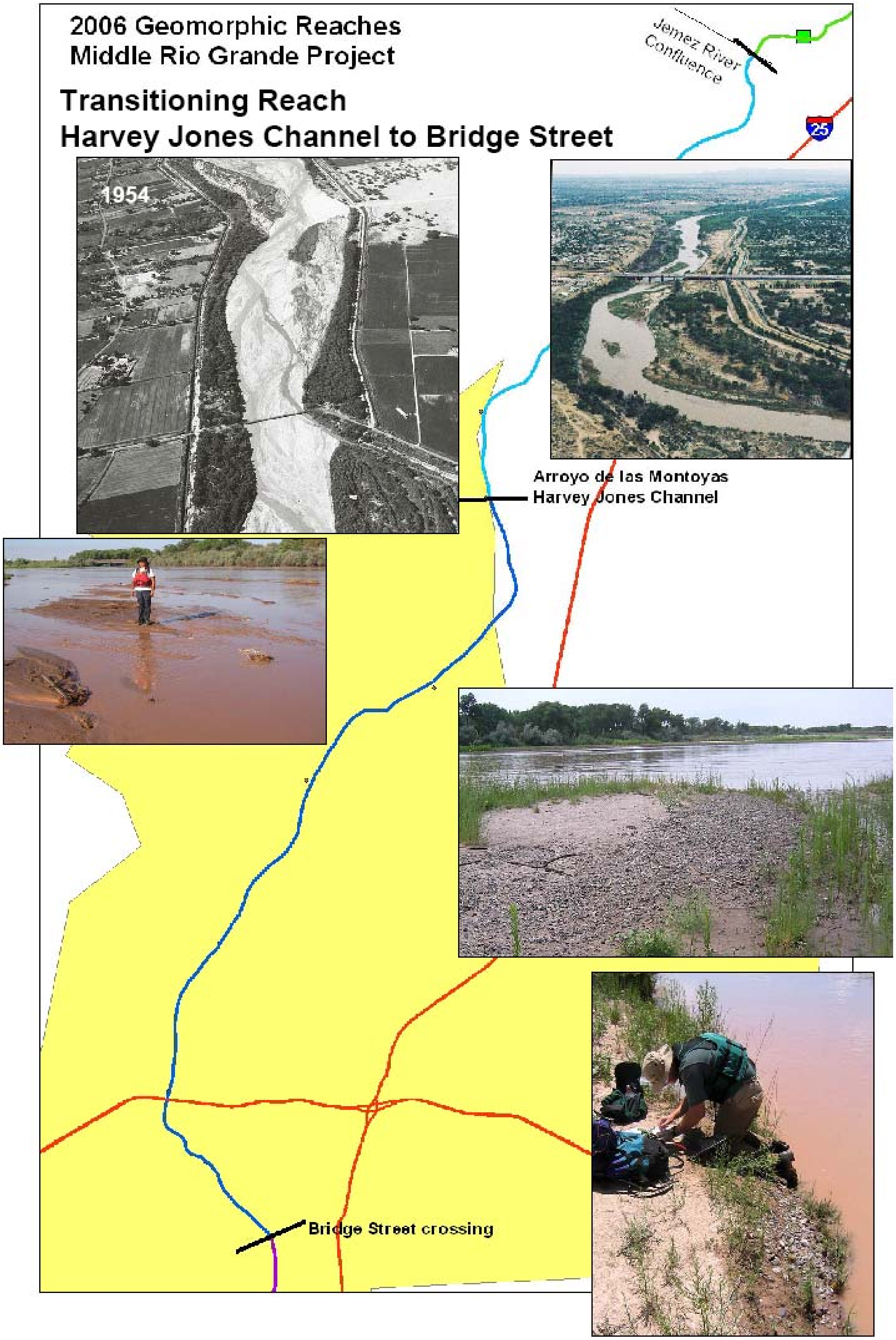


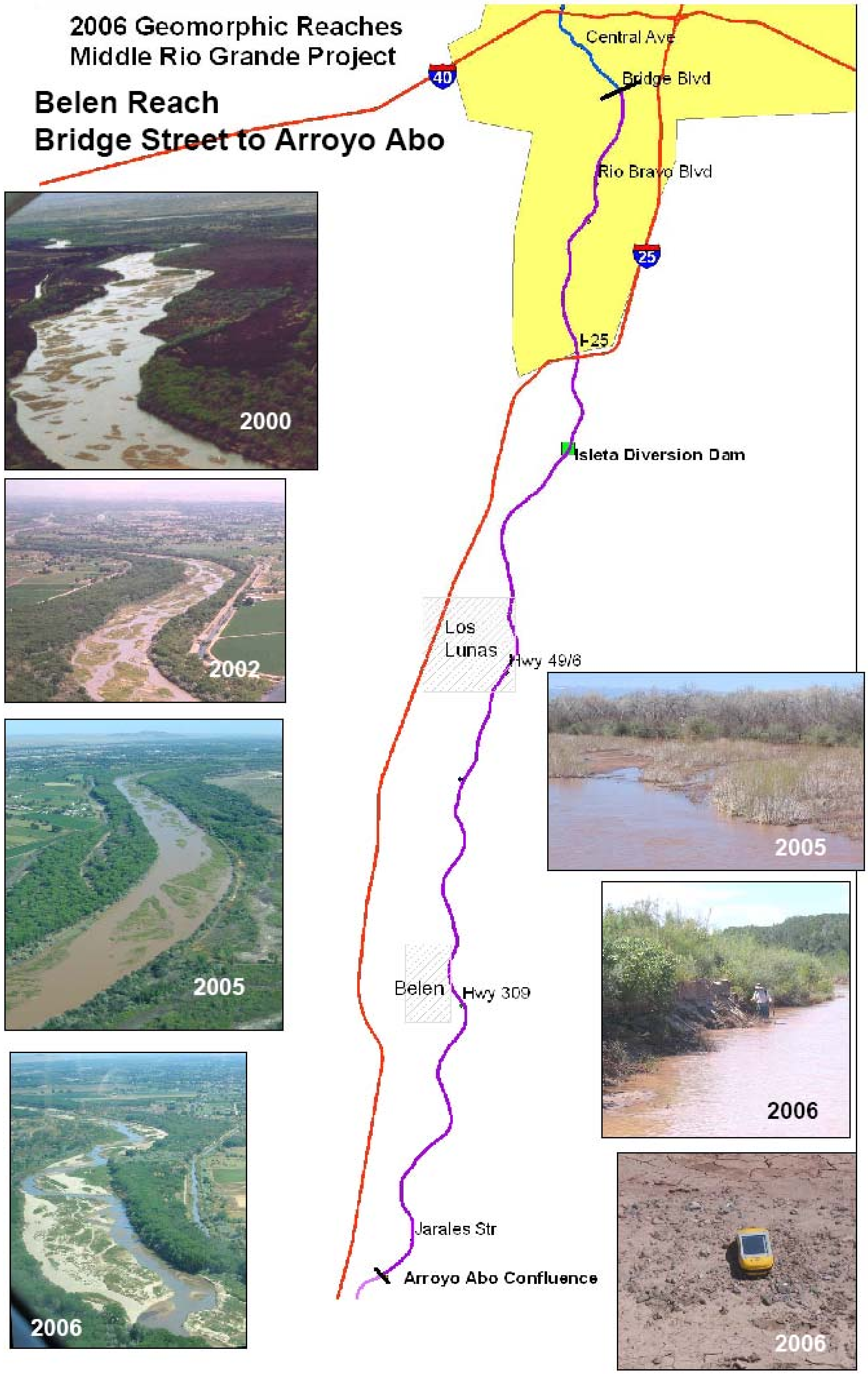

2006 Geomorphic Reaches
Middle Rio Grande Project
Velarde-Otowi Bridge Reach
Velarde
dams
1956
Rio Chama Confluence
Espanola
Otowi Bridge Crossing

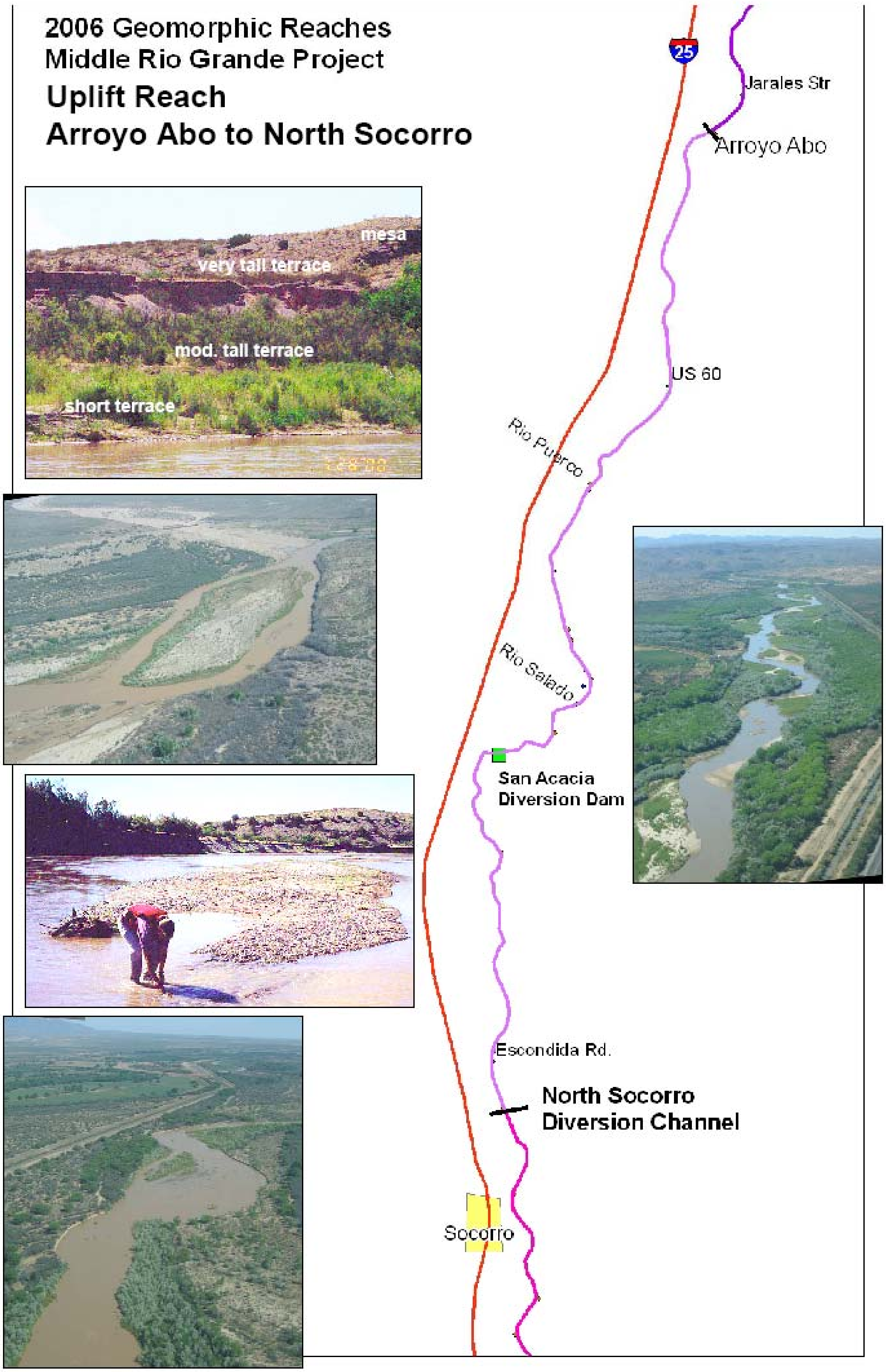
2006 Geomorphic Reaches
Middle Rio Grande Project

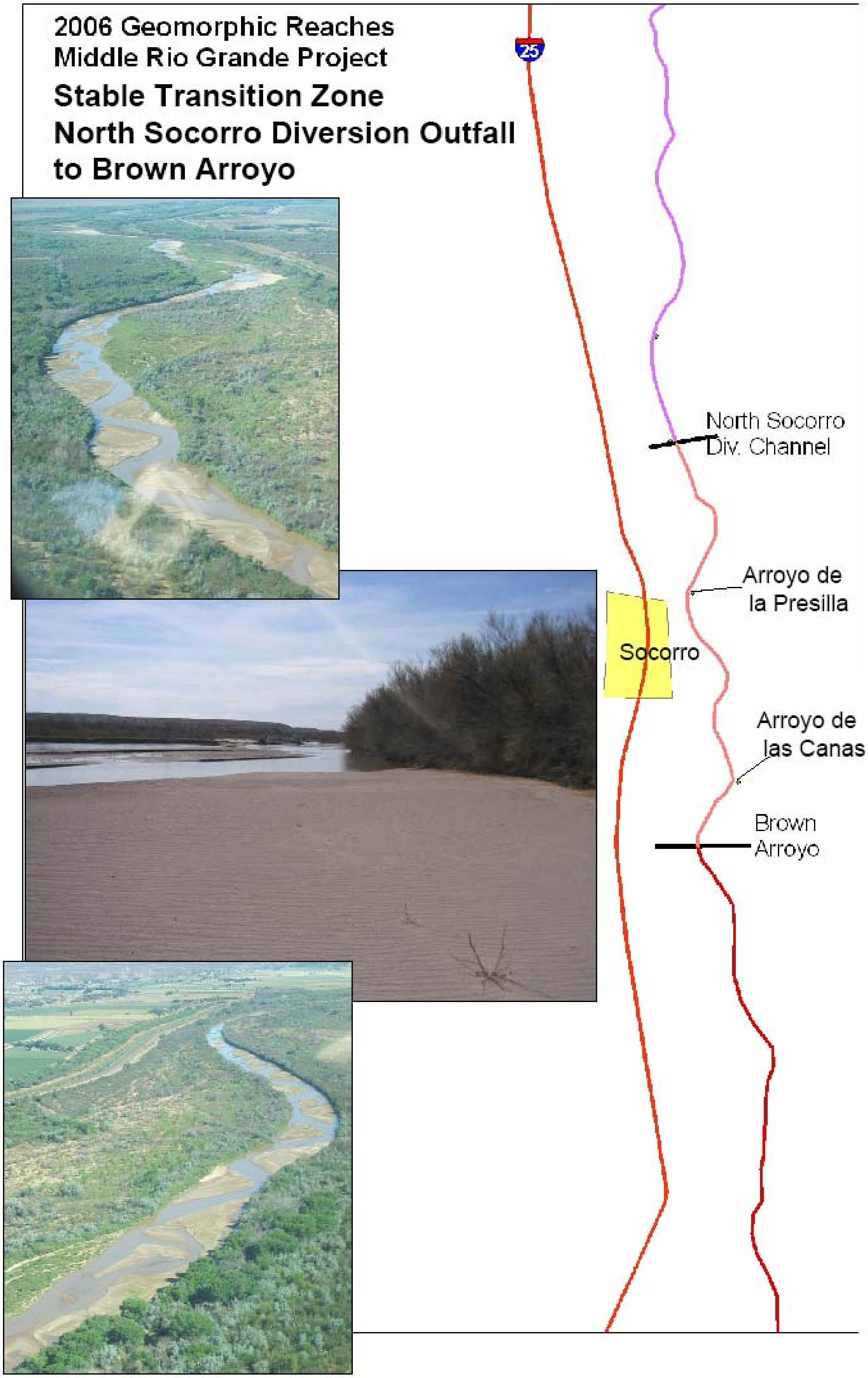
Cochiti – Jemez River Reach

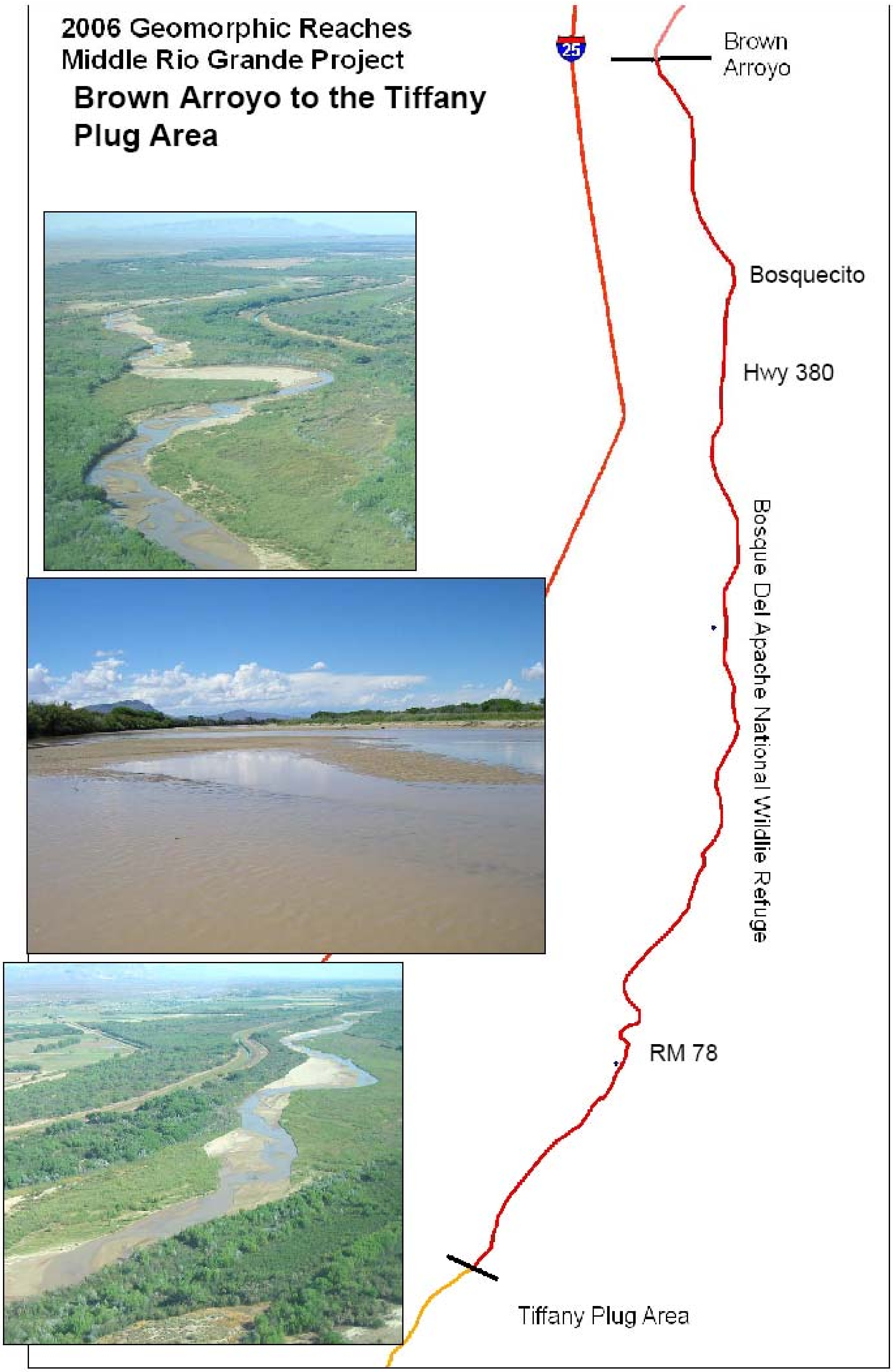

2006 Geomorphic Reaches
Middle Rio Grande Project
Post Transitioning Reach
Jemez River to Harvey Jones Channel
Jemez River Confluence
25
Arroyo de las Montoyas
Harvey Jones Channel
40


2006 Geomorphic Reaches
Middle Rio Grande Project
Transitioning Reach
Harvey Jones Channel to Bridge Street
Jemez River Confluence
25
1954
Arroyo de las Montoyas
Harvey Jones Channel
Bridge Street crossing

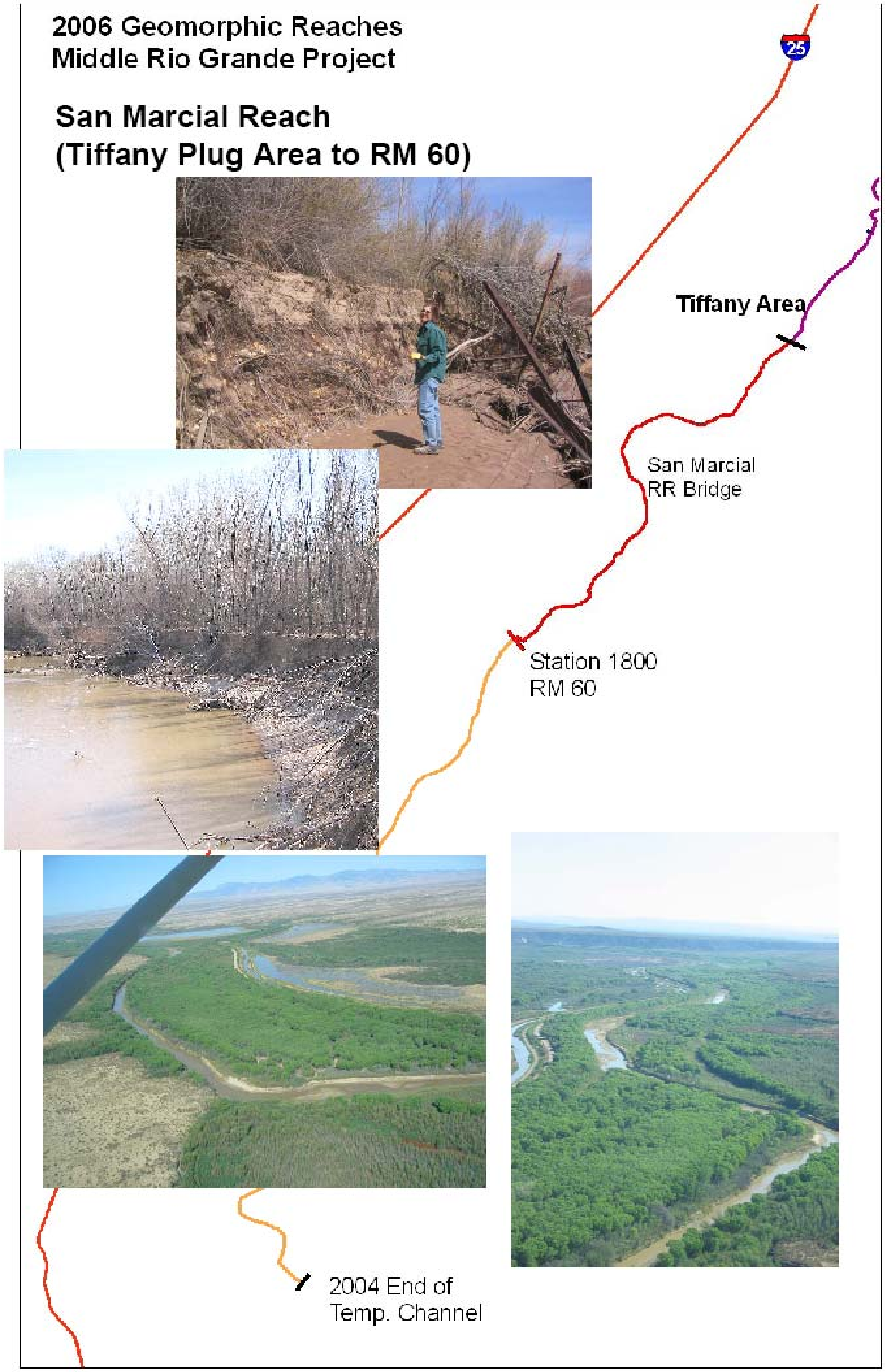

2006 Geomorphic Reaches
Middle Rio Grande Project
Belen Reach
Bridge Street to Arroyo Abo
40
Central Ave
Bridge Blvd
Rio Bravo Blvd
25
I-25
Isleta Diversion Dam
Los Lunas
Hwy 49/6
Belen
Hwy 309
Jarales Str
Arroyo Abo Confluence
2000
2002
2005
2006
2005
2006
2006

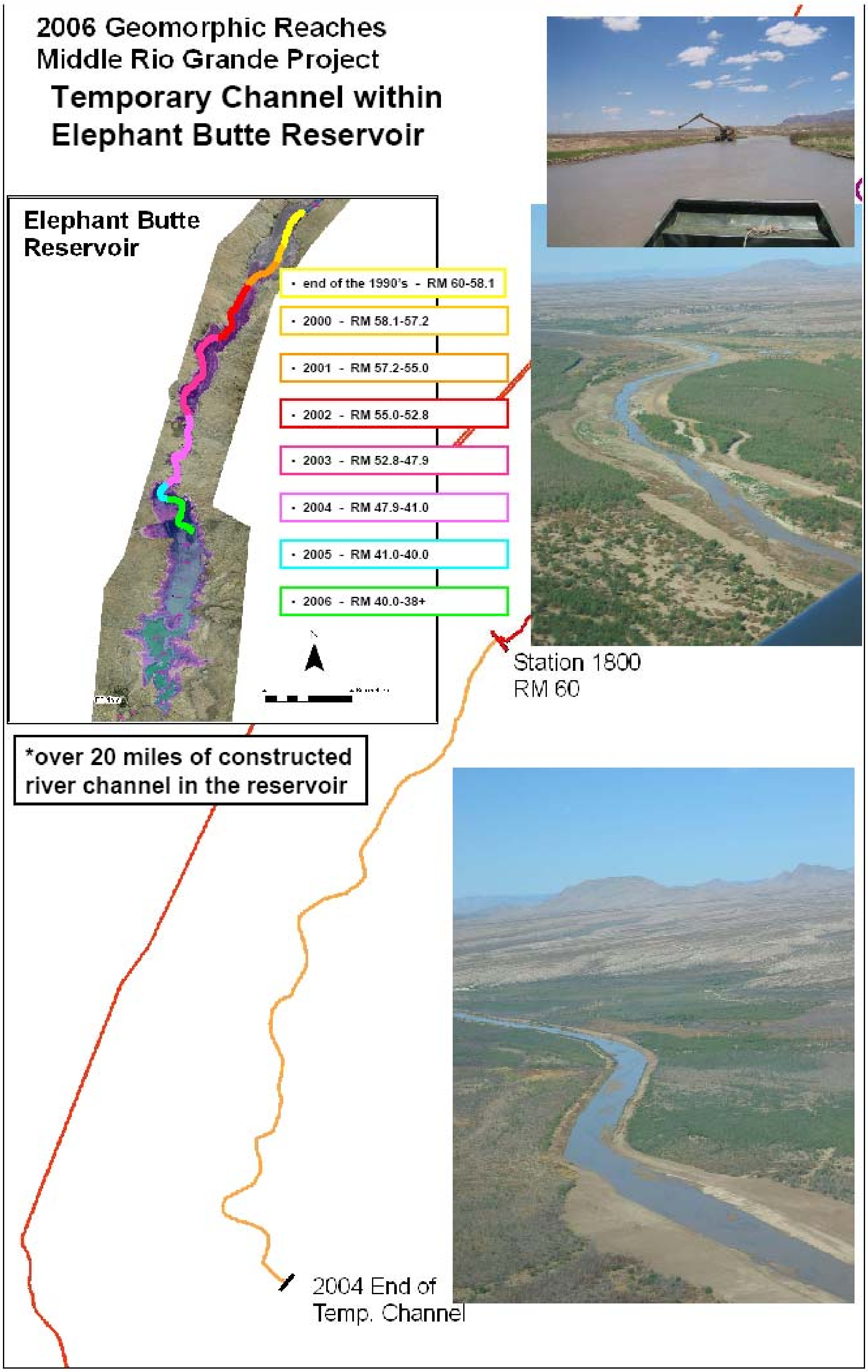

2006 Geomorphic Reaches
Middle Rio Grande Project
Uplift Reach
Arroyo Abo to North Socorro
mesa
very tall terrace
mod. tall terrace
short terrace
25
Jarales Str
Arroyo Abo
US 60
Rio Puerco
Rio Salado
San Acacia
Diversion Dam
Escondida Rd.
North Socorro
Diversion Channel
Socorro

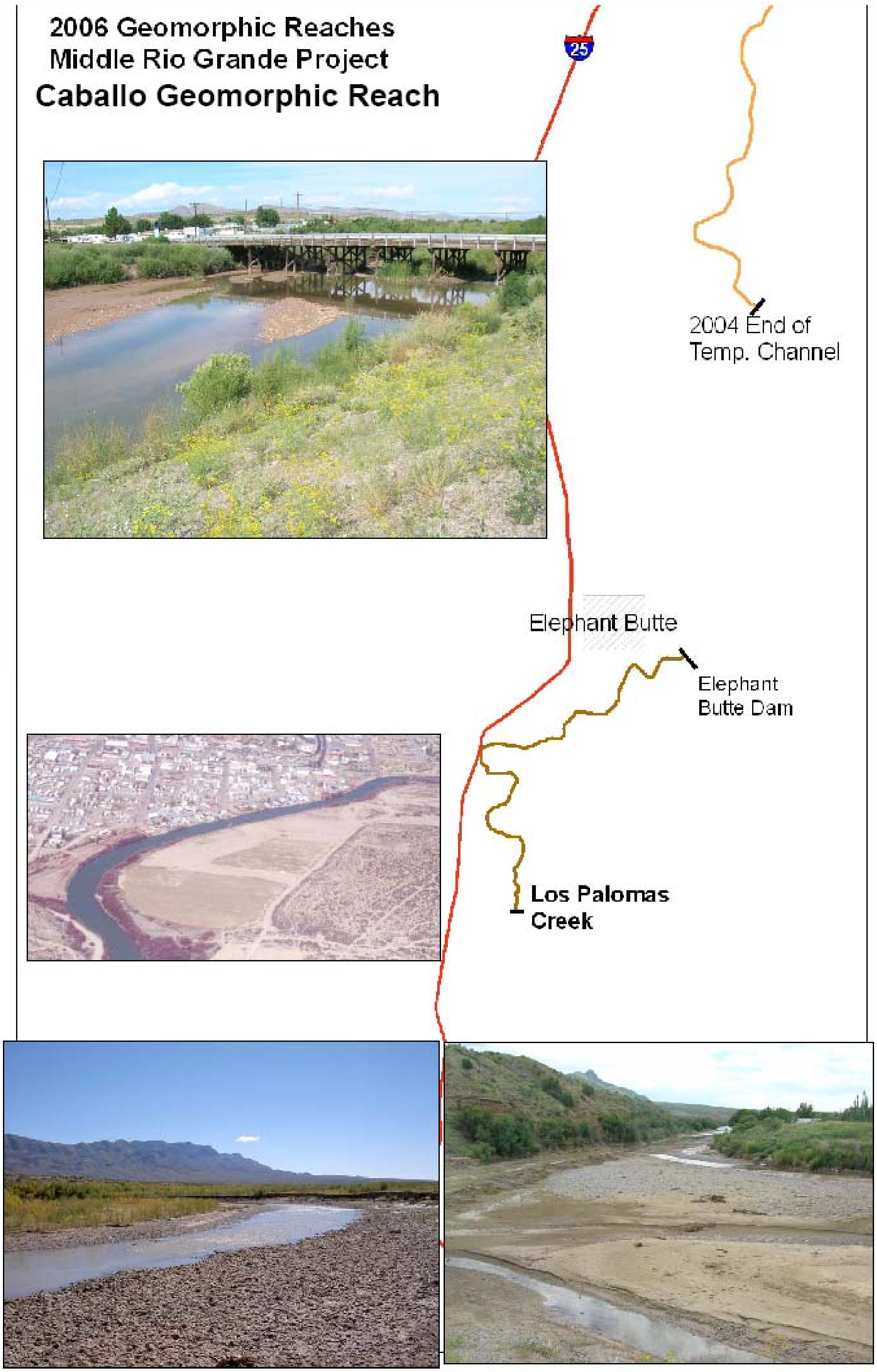

2006 Geomorphic Reaches
Middle Rio Grande Project
Stable Transition Zone
North Socorro Diversion Outfall
to Brown Arroyo
25
North Socorro
Div. Channel
Arroyo de
la Presilla
Socorro
Arroyo de
las Canas
Brown
Arroyo



2006 Geomorphic Reaches
Middle Rio Grande Project
Brown Arroyo to the Tiffany Plug Area
25
Brown Arroyo
Bosquecito
Hwy 380
Bosque Del Apache National Wildlie Refuge
RM 78
Tiffany Plug Area


2006 Geomorphic Reaches
Middle Rio Grande Project
San Marcial Reach
(Tiffany Plug Area to RM 60)
25
Tiffany Area
San Marcial
RR Bridge
Station 1800
RM 60
2004 End of
Temp. Channel

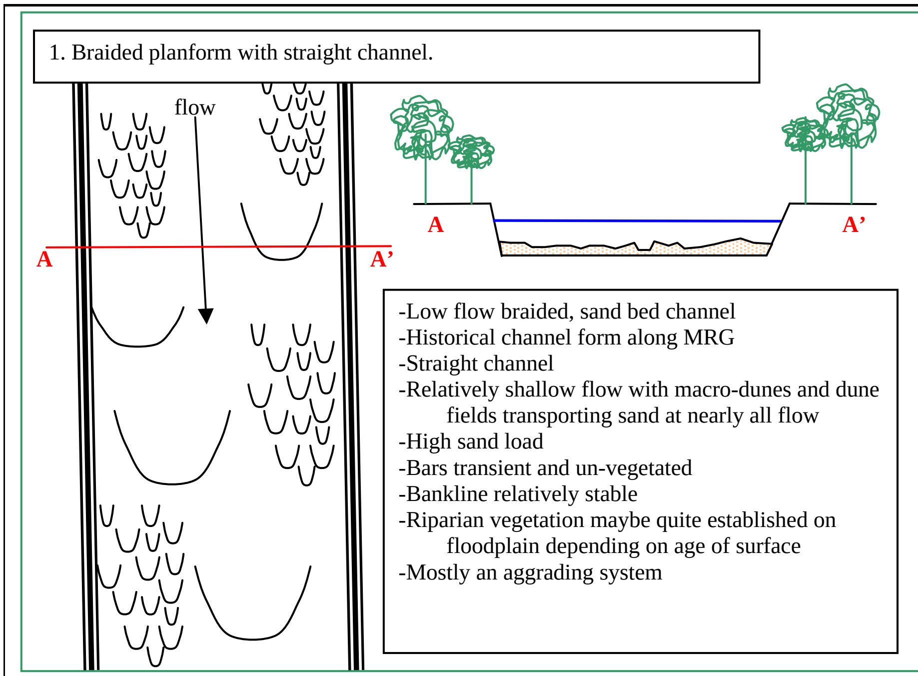

2006 Geomorphic Reaches
Middle Rio Grande Project
Temporary Channel within
Elephant Butte Reservoir
Elephant Butte
Reservoir
• end of the 1990's - RM 60-58.1
• 2000 - RM 58.1-57.2
• 2001 - RM 57.2-55.0
• 2002 - RM 55.0-52.8
• 2003 - RM 52.8-47.9
• 2004 - RM 47.9-41.0
• 2005 - RM 41.0-40.0
• 2006 - RM 40.0-38+
Station 1800
RM 60
*over 20 miles of constructed
river channel in the reservoir
2004 End of
Temp. Channel

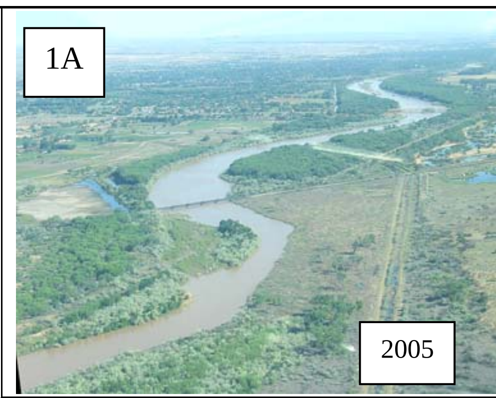

2006 Geomorphic Reaches
Middle Rio Grande Project
Caballo Geomorphic Reach
25
2004 End of
Temp. Channel
Elephant Butte
Elephant
Butte Dam
Los Palomas
Creek

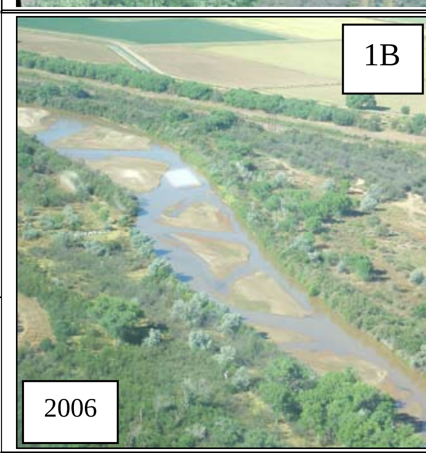
Appendix C – Planform Evolution Model
Stages1-9 of Planform Evolution on the Middle Rio Grande

Stage 1 is the classic form of the Rio Grande, where sand is abundant and is migrating downstream in the form of dunes and macro-dunes. The floodplain is active, the channel bed can be either stable or slightly aggrading. Sand and water are abundant which keeps the channel bed active and vegetation is only able to colonize the floodplain. At high flows, the sand bars are fully submerged as seen in 2005, just upstream of the Isleta diversion dam (Picture 1A). At low flows, the macro-dunes temporarily freeze until high flows return and reactivate the sediment, Picture 1B near Bosque del Apache NWR.

Typically this channel form has been described as preferred minnow habitat as it has lots of in-channel diversity and an active floodplain. As this channel does not necessarily create new riparian habitats, this in-channel morphology does not necessarily indicate quality of flycatcher habitat.

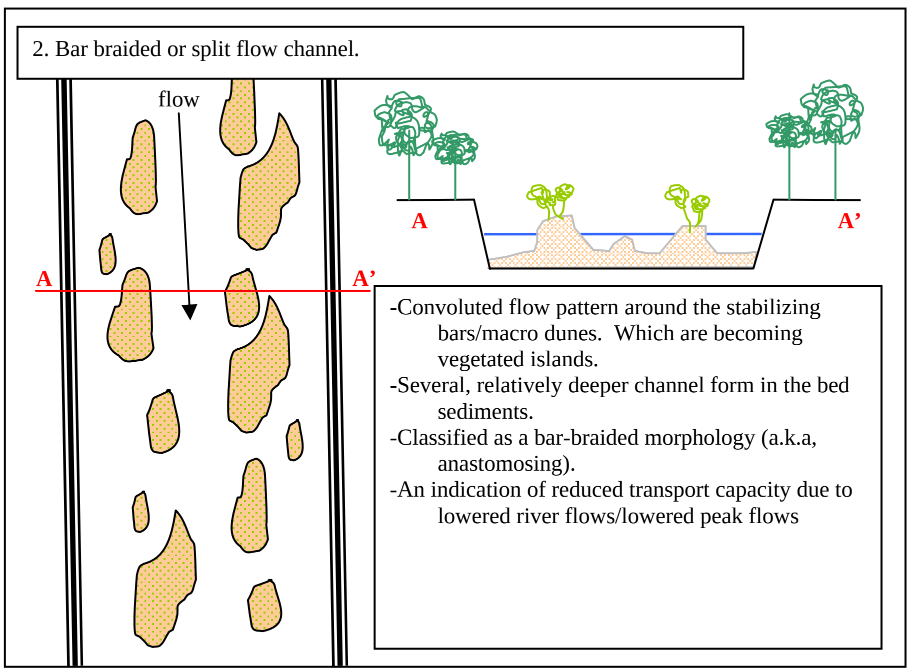


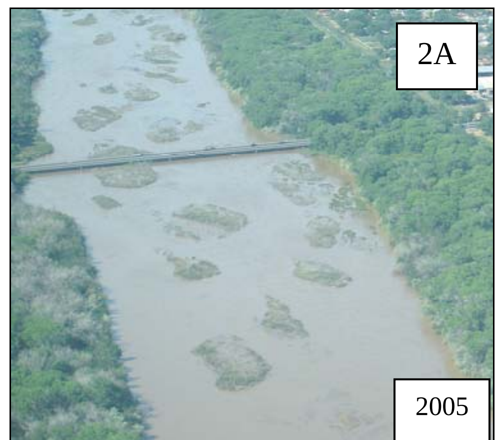


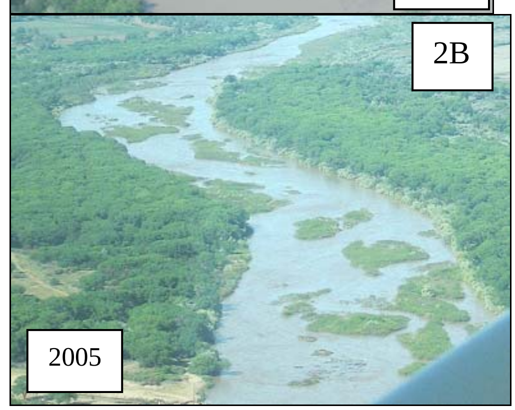


Stage 2 is the dominant planform morphology of the Rio Grande in the Albuquerque-Belen areas. In these areas the macro-dunes have started to stabilize and vegetation easily colonized the exposed dunes forming numerous islands within the active channel. The active channel bed narrows, as these islands are resistant to river erosion, even at high flows as seen in 2005 when an above 'normal' spring runoff occurred. In the Isleta to Belen area (Picture 2A), most of the stabilization occurred during the recent drought cycle when much of the river was dry during the summer months (2001-2004). All of these surfaces flooded in 2005, as well as the connected floodplain. In Albuquerque (Picture 2B), the islands formed in the late 1990s are appear more established than the Belen islands, as the vegetation is taller, but also the islands are taller. The floodplain is not active in the southern Albuquerque area, such that only the islands and bank-attached bars flooded.

The change from Stage 1 to Stage 2 appears to be due to the loss of peak flows that keep the dunes active and unvegetated. This channel form still appears good for minnow habitat, as lots of edge habitat is available and the vegetated bars still inundate during high flows. For the flycatcher, this morphology may slightly improve habitat descriptions as the new vegetation patches are small in size.

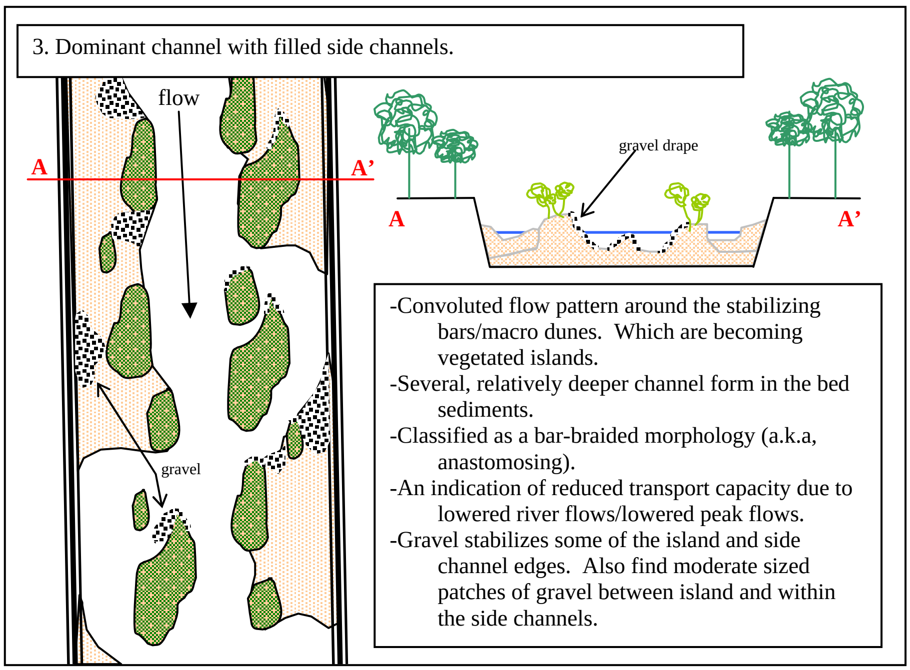


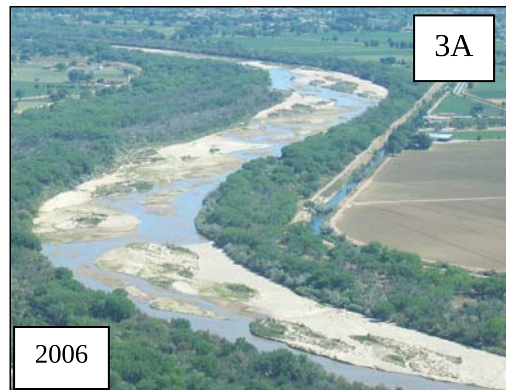


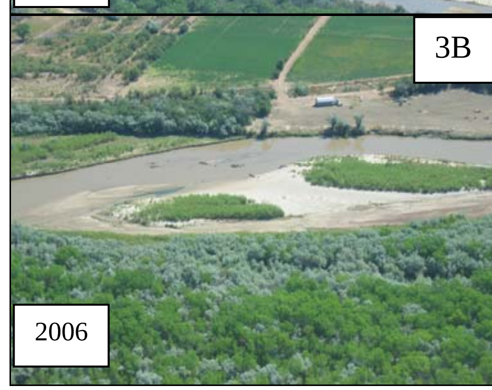


Stage3 is the large scale abandonment of active channel into high flow side channels between the vegetating islands, resulting in continued channel narrowing and the formation of a preferred river channel/path. The single channel that forms during low discharges, flows around the islands and filled side channels. The surfaces of the side channels and the islands aggrade during high flows as they become inundated. Patches of gravel begin to be found in predictable locations: lining the head of an island, at the entrance and outlet of the side channels, within the active channel between two closely spaced islands, and at coarse sediment sources (tributaries).

Both bird and fish habitats are good in this planform. In-channel species gain additional vegetated floodplain areas as the islands vegetate, but also gain side channel habitats during moderate to high flows. As the islands vegetate, new vegetation growth is rapid, however, these patches are small, but mostly isolated from the bankline, as they are surrounded by flowing water during most flows outside extreme low flows.

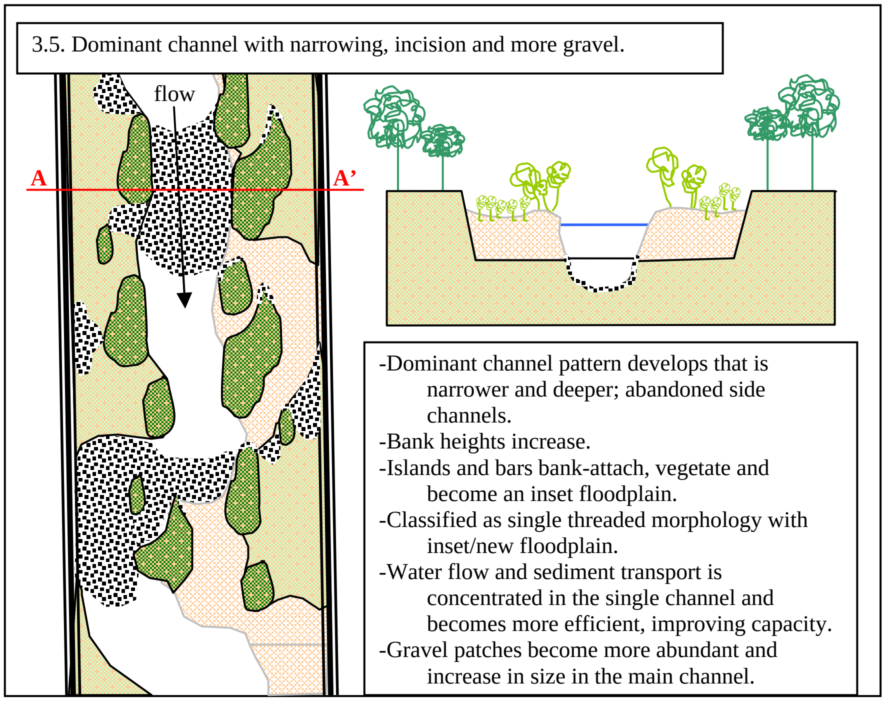


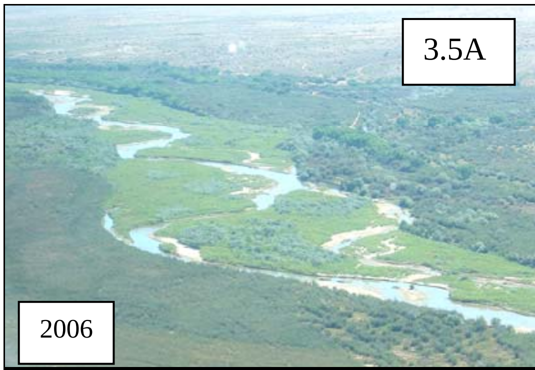




Stage 3.5 is similar to that of Stage 3, however, the main channel begins to incise. Additional narrowing of the single channel may occur. Gravel deposits are becoming wide spread within the main channel and side channels. Riffles or channel spanning gravel patches may exist. Stage 3 and 3.5 may occur at the same time.

Habitat value for in-channel species decreases in this stage, as the channel becomes more incised, higher flows are required to inundate the floodplain, bars, islands and side channels. During low flows, the water is contained within a single channel with a reduced area/perimeter as compared to previous stages. For riparian species, this phase is probably great, since the islands/bars/side channels rapidly vegetate and provide new riparian areas for wildlife.

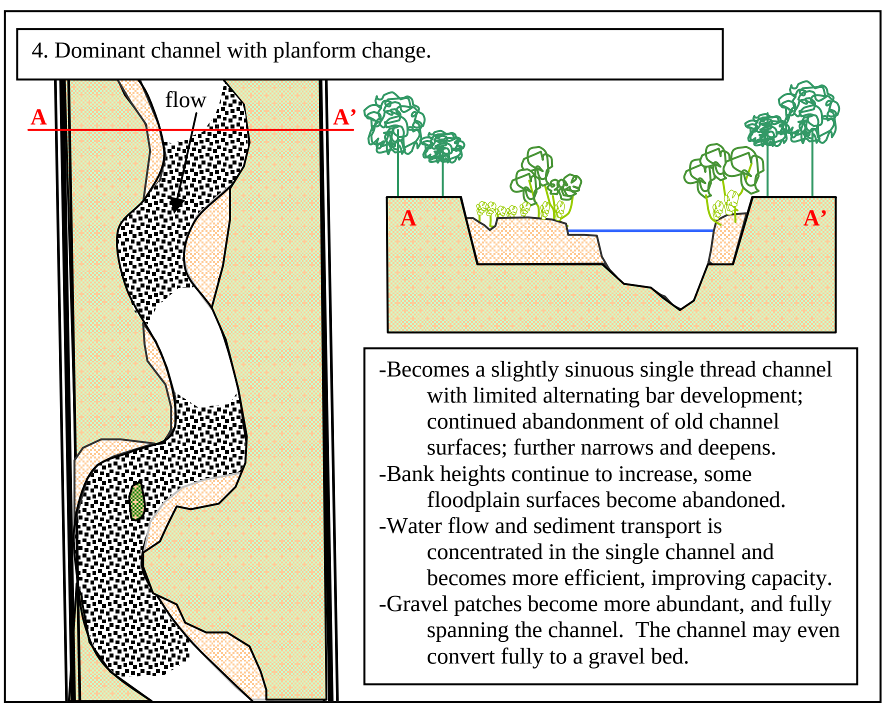




Stage 4 occurs after the channel has formed a stable single-threaded channel. A slightly sinuous pattern, alternating thalweg may form, however, the channel is still essentially straight (sinuosity is less than 1.5). The channel width may decrease in this stage as the floodplain vegetation encroaches on the active channel. The historical floodplain is mostly abandoned, except in very high flow events. . It appears to get a stable channel, a gravel bed is required, however, this is only observation and could be incorrect. Stages 3.5 and 4 could occur at the same time.

This stage may be the final stage for some sections of the Rio, as the banklines are heavily vegetated, peak flows are controlled and the river is not able to erode the historical floodplain. A good example of this type of channel is just downstream from Cochiti Dam (Figure 4A). Parts of the river channel within the San Acacia reach have evolved from Stages 1-3.5 to this Stage 4. But due to the high incision, these Stage 4 channel are expected to continue to evolve. The Belen reach could get stalled in this Stage, as the riparian vegetation is exceptionally dense, and incision will probably be limited

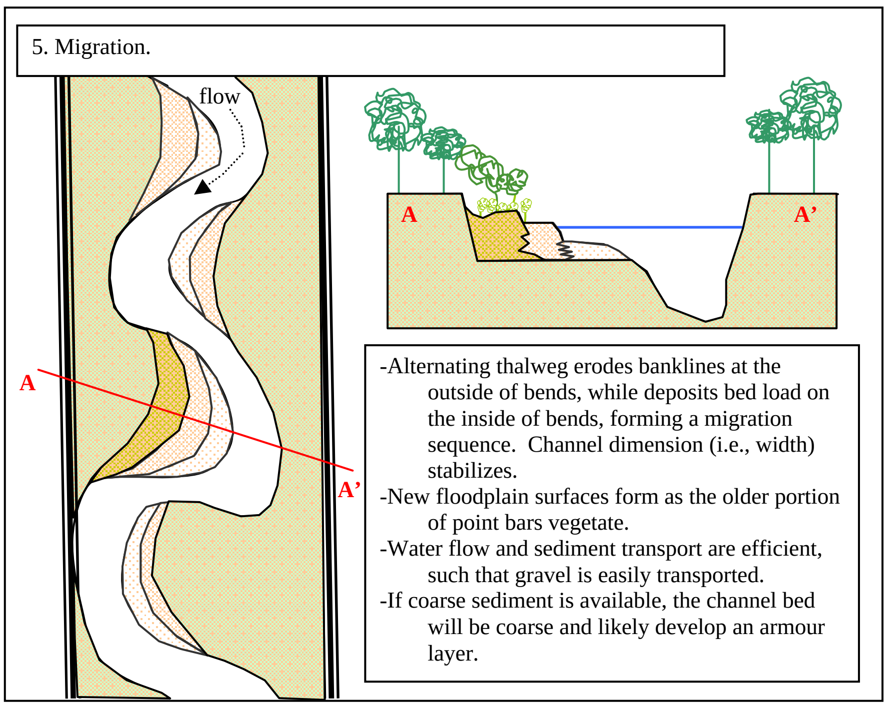
The in-channel habitat in this reach is similar to that in Stage 3.5. The river flows are mostly contained in the low-flow channel, and the banklines are stable. New sediment deposits do not occur, nor are the vegetated features re-shaped or eroded. The riparian in this stage matures, as the channel and floodplains are stable.

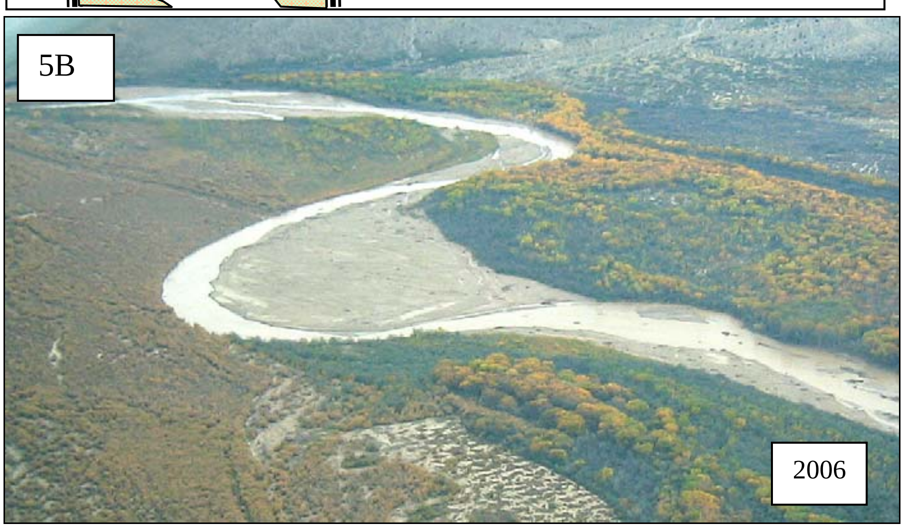


Stage 5 is the formation of an erosive alternating thalweg pattern, such that migrating bends form individually (Figure 5A) and in series (Figure 5B). Point bars are deposited on the inside of the bends, and as these sediments age, vegetation encroaches (Figure 5A). The thalweg is concentrated along the outside of the bend and is effective at transporting both water and sediment. Channel dimensions are stable unlike channel location.

Habitat for both riparian and in-channel species improves from Stage 4, as new riparian areas form on the older sections of the point bars. The point bars also provide shallow habitats for fish at nearly all flows. Also, the older point bar surfaces provide small floodplain habitat for all species.

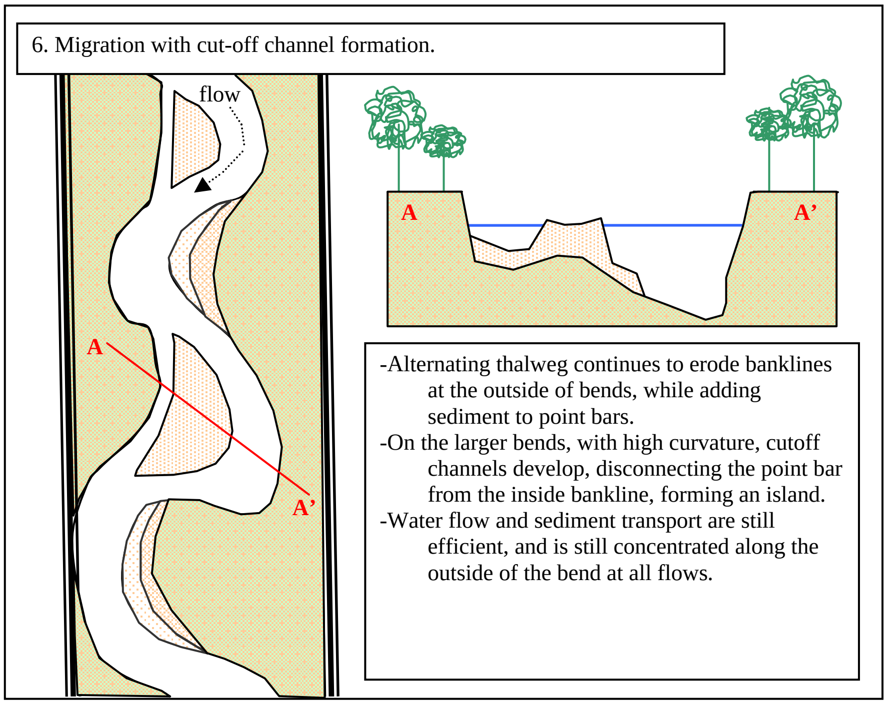
Both photos taken by C. Rolland; Figure 5A is located in the Cochiti Reach, while Figure 5B is located just upstream from San Acacia diversion dam.

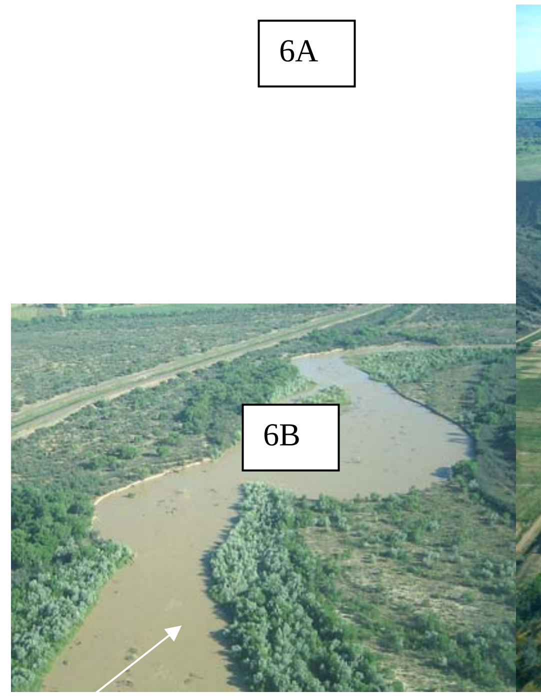




Stage 6 is similar to Stage 5, except the migrating bends have also formed a side channel through the point bar. These cutoff channels begin as small side channels (Figure 6A) but grow over time (Figure 6A). Migration along the outside bankline continues and appears unaffected by the cutoff channel formation.

Habitat for in-channel species is slightly improved with the side channel formation, as side channels have high habitat value. Probably no change for the riparian habitat, as long as the main point bar continues to vegetate.



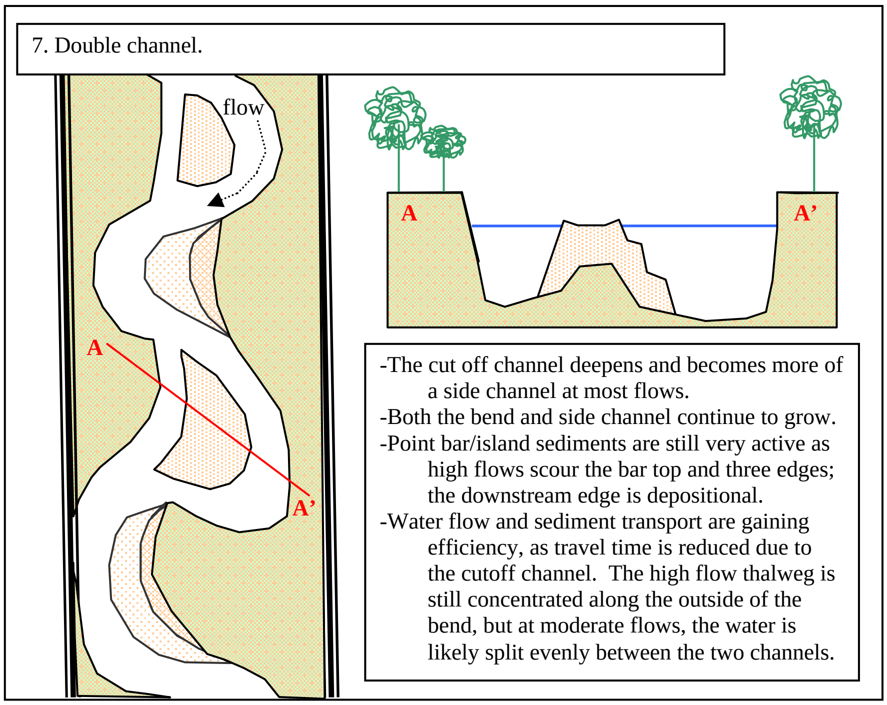


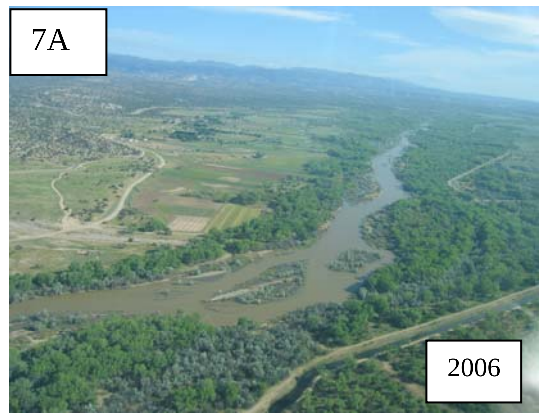
Thalweg

Stage 7, the double channel, forms as the cutoff channel grows and becomes more of an equal conduit for flows in the river (Figure 7A). Unlike in Stage 6, this new channel would be wet year-round, and about half the discharge would flow in it. Depending on length of time in this stage, the cutoff channel and the main channel would evolve to have similar channel dimensions (Figure 7A), i.e., width, depth, area. Bend migration along the outside bankline would probably still occur in this stage, however it would be significantly slower as the flows would be less than before.

Habitat would be similar to Stage 6.

Photo taken by C. Rolland; Figure 7A is located in the Cochiti Reach.

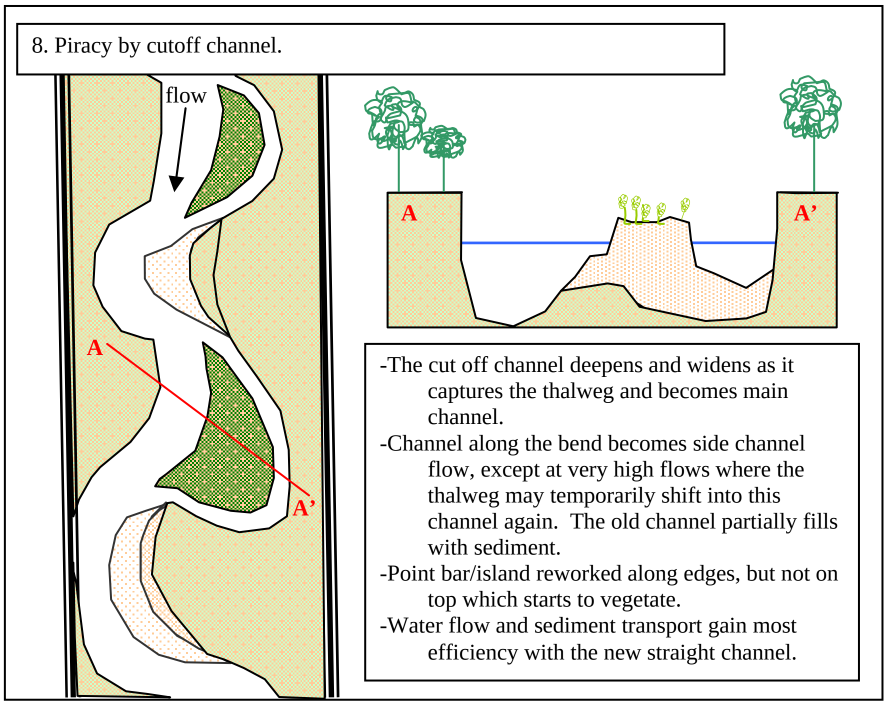


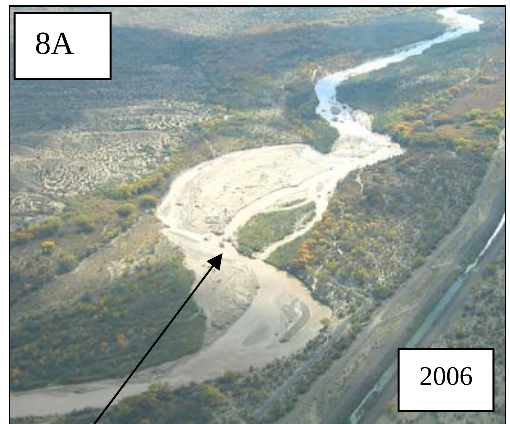


Stage 8 occurs when the cutoff channel becomes the dominant channel and the old migrating channel is demoted to a side channel. In some cases, additional cutoff channels form in this stage (Figure 8A). Also, evolution from Stage 5-8 could be an extended process as found in the Cochiti Reach, or quick as found in the San Acacia Reach (7 years at RM 111, Figure 8A).

When the process is quick, the cutoff channel is initially narrow and deep, like a pilot channel, but over time I will widen. However, it is not considered good in-channel habitat while it is narrow and deep. Vegetation growth would continue on the remainder of the point bar and within the old channel as it decreases in size promoting an improved riparian habitat.

Photo taken by C. Rolland; Figure 8A is RM 111 and RM 110 bends.

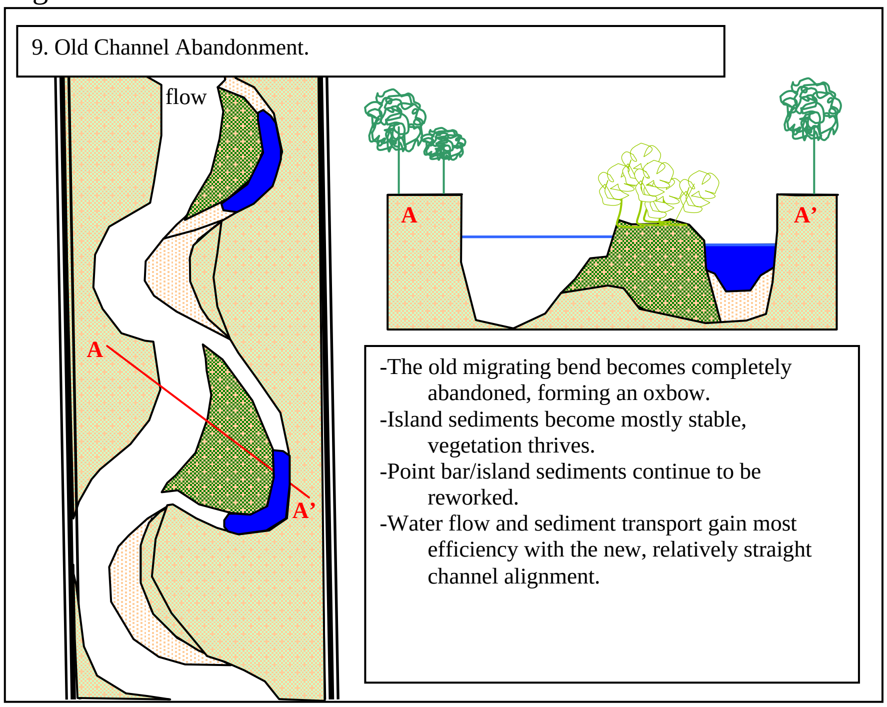




new cutoff channel formed in August 2006 which now captures almost all flow, channel along outside of bend is a side channel during low flows.

Stage 9, Abandonment of the old migrating channel is the final stage in planform evolution on the Rio Grande. The old channel would either form an oxbow or fill in completely creating a new 'floodplain-like surface'. The new straighter/cutoff channel would likely fall into one of the previous stages (4-5 most likely). The new channel would likely widen slightly over time and could begin migrating again.

Habitat would change as the old channel became floodplain and riparian habitat. Therefore in-channel habitat would decrease while riparian habitat may improve with the new area becoming vegetation.



abandoned bend filled with sediment..no oxbow

Stage 1 to Stage 3.5

- Sequence observed at the Belen Reach
- Classic example of a high sediment river with a reduced hydrology.

Stages 4-8

- Bend migration sequence observed within the San Acacia Reach at RM 110, bend on east side of the Rio Grande. Downstream is from left to right. The channel was slightly sinuous in the late 1990s, with this hook-shaped bend forming in about 1999.
- Relatively low sediment (Rio Puerco stopped delivering) with a relatively maintained hydrology regime. With more regular hydrology, these stages would likely evolve at a faster rate.
- As of yet, the channel along the outside of the bend has not been abandoned. However the cutoff channel captured the main flow in the summer of 2006.