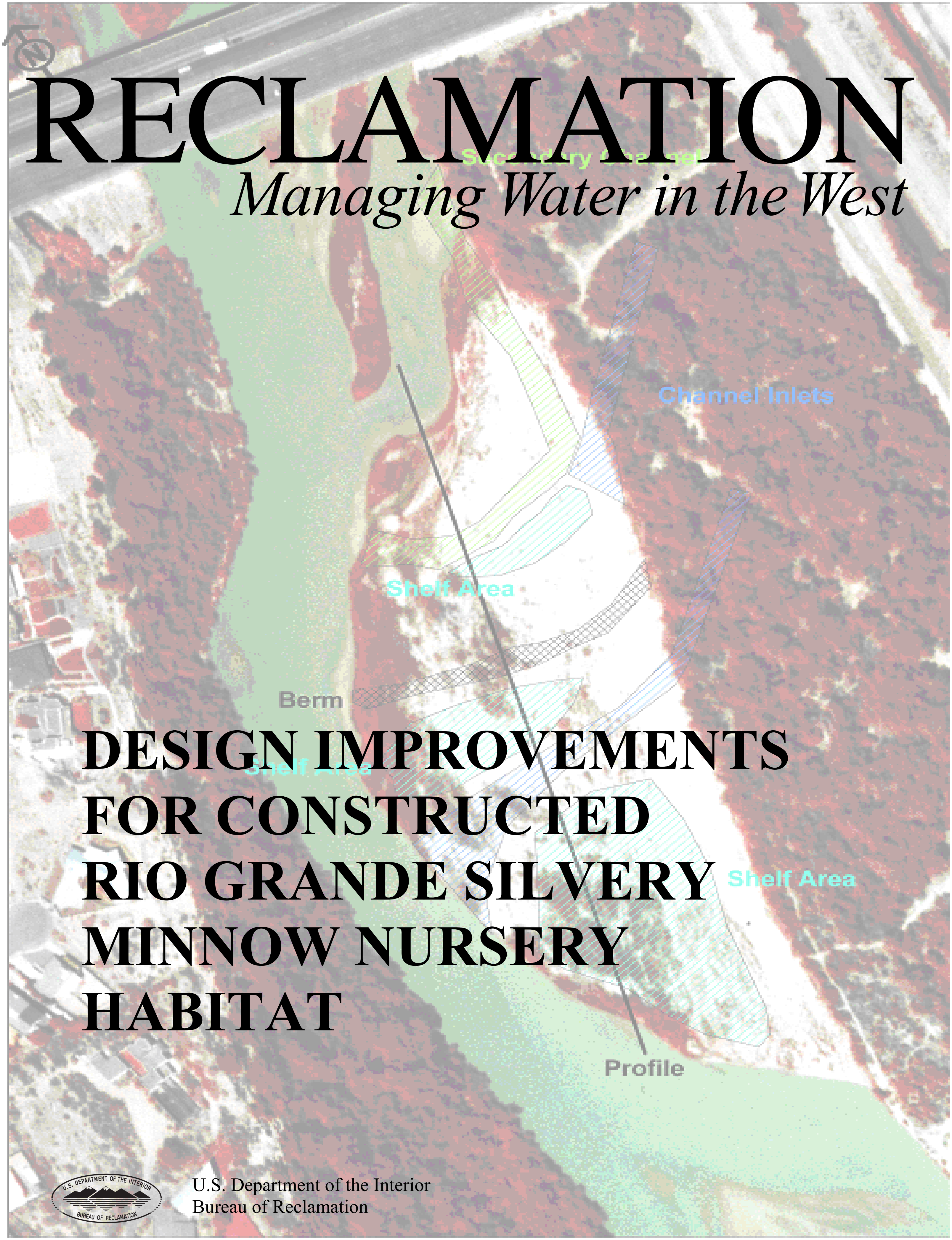
RECLAMATION

Managing Water in the West



DESIGN IMPROVEMENTS FOR CONSTRUCTED RIO GRANDE SILVERY MINNOW NURSERY HABITAT

U.S. Department of the Interior
Bureau of Reclamation

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INTRODUCTION

For the last two years, the Albuquerque Area Office of the Bureau of Reclamation has lead several efforts to restore habitat along the Rio Grande in New Mexico for the endangered Rio Grande silvery minnow (*Hybognathus amarus*) (silvery minnow). This species was federally listed as endangered in 1994 (U.S. Department of the Interior 1994). Critical habitat was designated for the species along with portions of the Rio Grande in New Mexico in 2003 (U.S. Fish and Wildlife Service 2003). Loss of suitable habitat is thought to be the main contributing factor in the decline of the silvery minnow in the Rio Grande (Bestgen and Platania 1991). A main goal of this project is to increase Reclamation's understanding of silvery minnow habitat needs and to improve our ability to construct suitable habitat, especially habitat for the egg/larval lifestage (nursery habitat). This report summarizes potential design improvements for constructing nursery habitat.

This research uses a landscape ecology approach (Forman 1995) to evaluate habitat and life history needs for the silvery minnow. Channel incision resulting from upstream dams has isolated floodplain habitat during years with reduced runoff discharge (Porter and Massong 2005). The importance of edge habitat along the river bank for fulfilling critical life history components of the silvery minnow has not received much attention. In previous studies, we documented that constructed inlets adjacent to the main flow in the channel retained silvery minnow eggs and attracted a variety of free-swimming fish. The primary features in successful inlets for egg retention appeared to be both the formation of a 'drift zone' within the inlet, but also substantial inflow and outflow at the inlet mouth (Figure 1). The drift zone is defined as the inundated area with an un-measurable low water velocity that occurs farther back in the inlet.

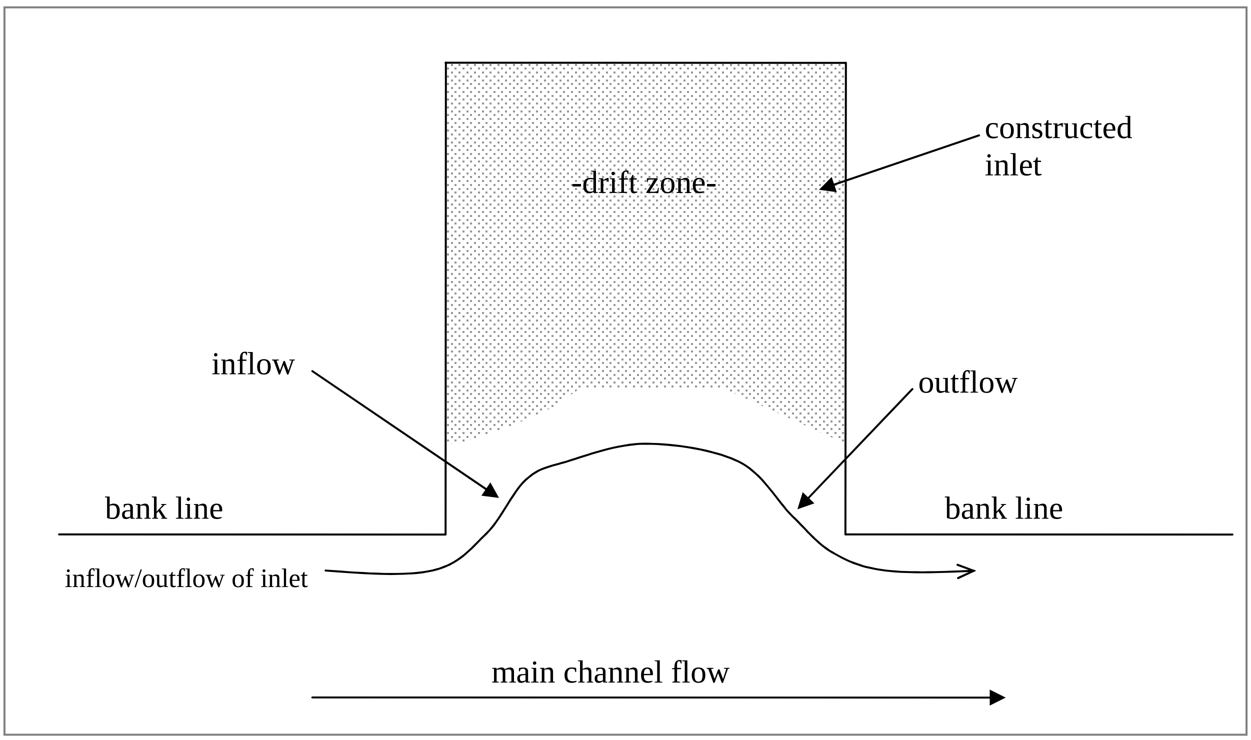


Figure 1. Generalized plan view of the constructed inlets in 2003 at the Channel Widening Restoration Project at Bosque del Apache National Wildlife Refuge (BDA) on the Rio Grande.

Field studies were conducted to quantify potential nursery habitat at seven sites. The experimental methods are described in more detail in Porter and Massong (2003, 2004). Yellow gellan beads were released in the current as surrogate silvery minnow eggs to track their drift and settling into potential nursery habitat area. After documenting requirements for egg retention within an inlet, our focus has been to document the inlet shape that optimizes egg capture. A variety of inlet shapes have been constructed, and their effectiveness of capturing artificial eggs has been assessed. In addition to the constructed inlets, several naturally formed inlets have been evaluated for egg capture effectiveness. Beyond inlet shape, both orientation to the main flow, and inlet elevation compared to channel bed elevation have been evaluated. Quality nursery habitat for the silvery minnow has 1) a drift zone for retaining eggs and larvae out of the current; 2) sufficient depth and area for rearing silvery minnow larvae; 3) the appropriate elevation to be inundated at minimal flows during spring runoff; and 4) the capacity to remain inundated for one to six weeks to support larval growth prior to returning to the river.

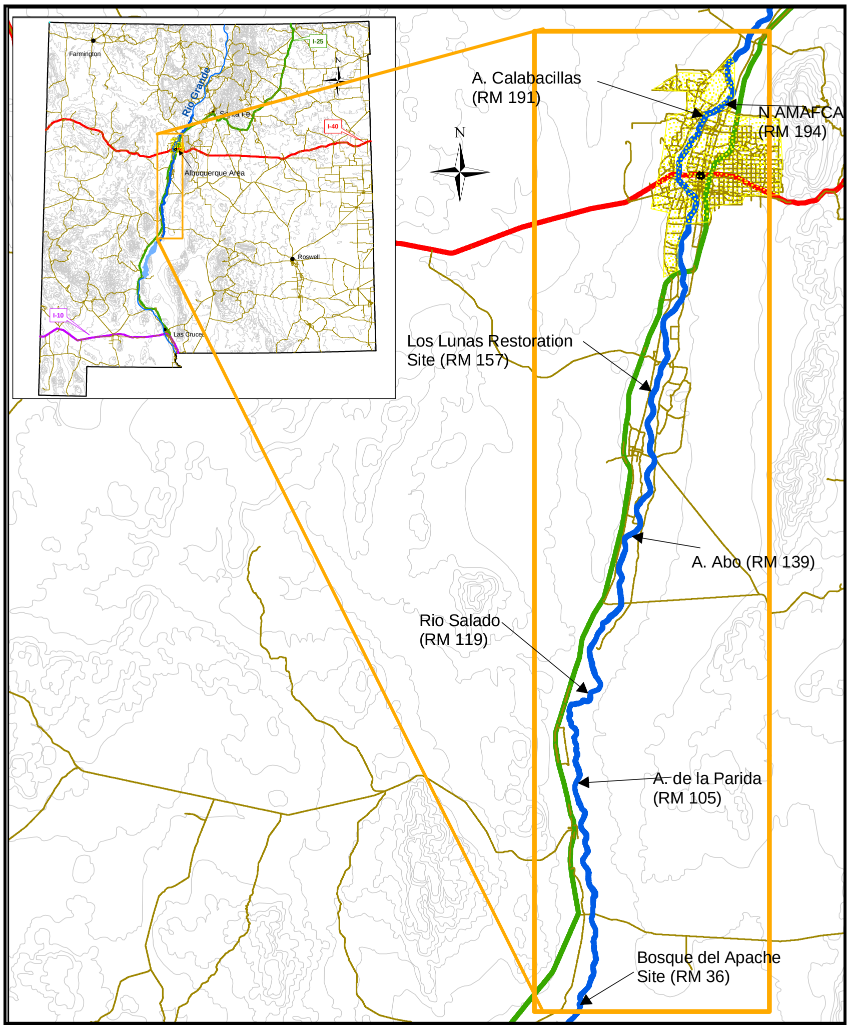


Figure 2. Location map showing locations along the Rio Grande where inlet shape has been assessed to improve egg capture.

INLET DESCRIPTIONS

The shape and flow interactions have been assessed at seven inlets along the Rio Grande. Constructed inlets at Albuquerque's North Diversion Channel (North Albuquerque Metropolitan Arroyo Flood Control Authority - N AMAFCA), Los Lunas Restoration Site, and Channel Widening Restoration Project at Bosque del Apache (BDA) were assessed for egg retention (Figure 2). Along with the constructed habitat, four natural habitats, all of which were located at arroyo confluences, were included in the field data collection for 2004. The natural habitat sites included the confluences of Arroyo Calabacillas, Arroyo Abo, Rio Salado, and Arroyo de la Parida (Figure 2).

North Diversion Channel (created habitat)

The inlet formed at the North Diversion Channel (N AMAFCA) is located at approximately river mile 194 on the east side of the Rio Grande just north of Albuquerque, New Mexico (Figure 2). The habitat feature at this confluence is a well-connected, back-water inlet with inflow from the Rio Grande year-round (Figure 3). During the summer months, surface runoff from thunderstorm activities is routed via this canal to the Rio Grande from the city of Albuquerque. Subsequently, these summer events scour sediment and debris from the canal bed, transporting the material into the Rio Grande. When the diversion channel is not routing storm water to the Rio Grande, field observations indicate that large and small fish species use this location (Propst 1995; Porter and Massong 2003).

Figure 3. N AMAFCA confluence (May 2004) with the Rio Grande forming an inlet that remains wet year round. The Rio Grande in the foreground is flowing from left to right; north is to the left of the picture.

A set of bars and islands partially blocked the inlet mouth during both the 2003 and 2004 field studies (Figures 3 and 4). In 2003, a wide, shallow inflow channel formed on the upstream side of the confluence with the deeper outflow channel on the downstream side of the inlet. The bar formation appears to change continually and depends upon the specific interactions between the Rio Grande and the canal. A significant flow in April 2004 from the N AMAFCA canal removed the complex set of bars that were formed during the summer of 2003 (Figure 4), leaving one central bar separating the drift zone within the canal from the Rio Grande (Figure 4).

The inlet is oriented at approximately 45º with the Rio Grande. In the Rio Grande, a stable, vegetated island splits the river's flow, with the dominant channel flowing to the left of the island. The dominant channel provides inflow to the inlet. The width of the inlet is approximately 75 meters (from bank to bank). The distance from the Rio Grande to the drift zone was approximately 50 meters in both 2003 and 2004 indicating an apparent stability in the drift zone location, regardless of inlet bar formation. The length of the entire inlet is approximately 500 meters.

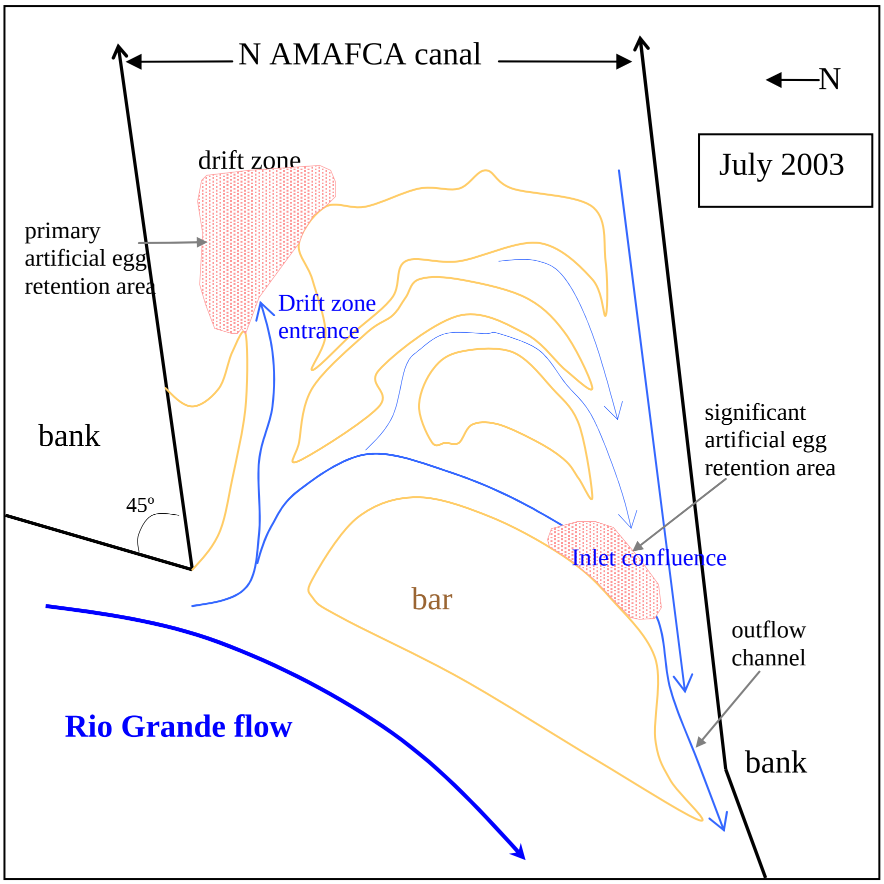


Figure 4. Schematic of the flow characteristics and bar development at the N AMAFCA inlet/confluence with the Rio Grande in July 2003.

Artificial egg collection data indicates that two dominant areas within the 2003 inlet retained artificial eggs (Figure 4): one at the entrance of the drift zone, and the second at the confluence of the split inlet channel with the outlet channel. At these two locations, the water velocity approached zero while the flow direction became indistinguishable. In 2004, a low number of yellow beads and larvae were collected with a moderate number of eggs over six days of sampling (Porter and Massong 2004). The N AMAFCA channel is a large site with a well-developed drift zone illustrated by the presence of yellow beads and eggs in the sampling area.

Yellow beads were collected in the same areas in July 2003 (389 cfs) and May 2004 (2650-2900 cfs).

Arroyo Calabacillas (natural habitat)

Arroyo Calabacillas drains the West Mesa area near Albuquerque, NM, joining the Rio Grande at approximately river mile 191 (Figure 2). As with most arroyos in New Mexico, the channel predominantly routes thunderstorm runoff from the uplands to the Rio Grande. At present, one dominant and four secondary channels dissect the arroyo fan deposit; the dominant and secondary channels are easily identified by the lack of vegetation growth (Figure 5). The dominant channel is located on the downstream side of the fan, and conveys the Corrales riverside drain water to the Rio Grande (Figure 5). A small 'shelf' along the river's edge of the fan became inundated during the modest 2004 spring runoff which peaked at 3,000 cfs for this area. This lightly vegetated, silty shelf area formed high quality fish habitat as demonstrated by abundant fish in the area (Figures 5 and 6). In the Rio Grande, a stable, vegetated island splits the river's flow upstream of the arroyo confluence such that the dominant Rio Grande channel flows to the left of the island while the right channel functions more as a side channel. Flow from these two channels re-combines immediately upstream of the arroyo fan deposit. Since the early 1970s, the Arroyo Calabacillas deposits in the Rio Grande channel have continued to 'push' the Rio Grande eastward.

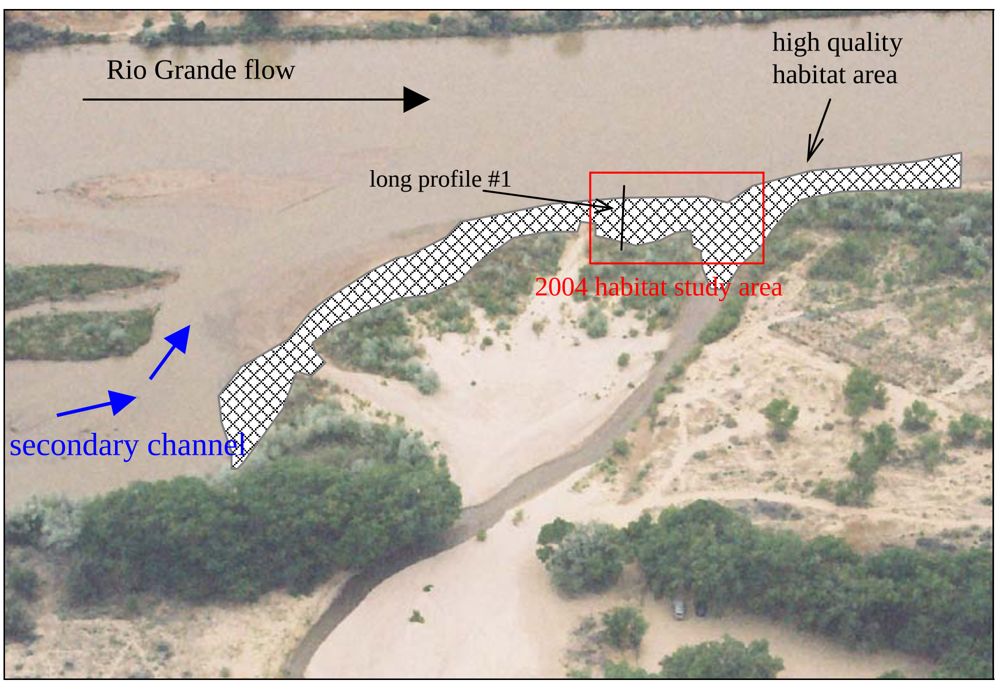


Figure 5. Several inlets have formed on the Arroyo Calabacillas fan (May 2004) as denoted by vegetation growth between the inlets. The Rio Grande flows from left to right; north is to the left of the picture.

Two distinct habitats were present at this confluence: a shallow, vegetated shelf on the fan edge, and the deeper, vegetation-free inlet in the main arroyo channel. The arroyo is oriented at almost 90º with the Rio Grande; however the edge of the fan (the shelf area) interacts with the

Rio Grande at every angle. At high water (3,000 cfs), the fan edge/shelf was approximately 15 meters in width. Velocity within this area was predominately un-measurable except right at the edges where the water was inflowing or outflowing from the shelf. The water depth was <0.75 meters across the shelf area and contained young woody vegetation (cottonwoods and willow) plus several perennial grass/rush species. The vegetation became denser inland from the main Rio Grande channel (Figure 6); the tallest/oldest vegetation was just at the edge of the spring runoff water level. Most of the retained artificial eggs at this site were collected and observed to linger at the water's edge.

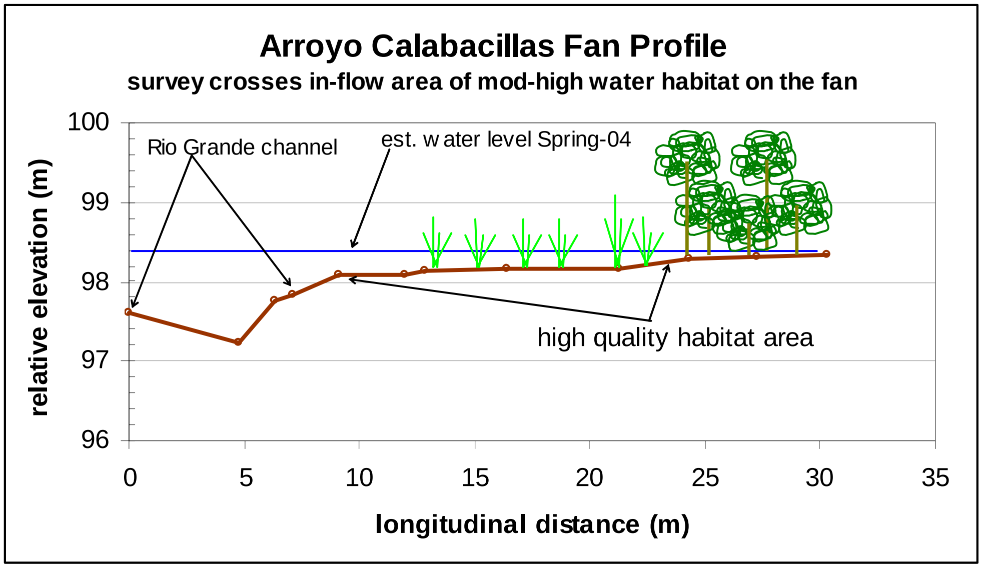


Figure 6. Long profile #1 through the high quality habitat area at the Arroyo Calabacillas confluence/fan. Data collected in June 2004.

The main arroyo channel formed a conventional inlet connected to the Rio Grande. The inlet is approximately 14 meters across with an up-arroyo drift zone that extended more than 20 meters. Due to water flowing out of the arroyo, the drift zone location changed dramatically throughout the day. When drain flow was low, nearly all the arroyo inlet became drift zone. In every release of artificial eggs, the eggs were observed entering the arroyo inlet area from the adjacent shelf area. Few eggs were observed entering the inlet directly from the Rio Grande channel.

Observations during the field study indicated that artificial eggs were retained in the shelf habitat outlined by the red box on Figure 5. Outflow from this high retention area drained into the drift zone of the arroyo inlet. Laboratory identification of several larval fish collected from the shelf habitat indicated white suckers, fathead minnows, longnose dace larvae present. This site had high retention of yellow beads and larvae, and a moderate number of eggs over four days of sampling (Porter and Massong 2004).

Los Lunas (restoration-constructed habitat)

The Los Lunas Restoration Project area is located at approximately river mile 157, near Los Lunas, NM (Figure 2). The restoration project consists of several riverside inlets sculpted out of the Rio Grande bank (a.k.a., Los Lunas inlets) at the upstream end of the project area (Figure 7). The upstream end of the project also includes a high flow channel constructed within the lowered floodplain. Additional backwater areas were created within the lowered floodplain beyond the high flow side channel, and a network of side channels with islands were constructed at the downstream end of the project. The egg retention study has focused on collecting real and artificial eggs at two riverside inlets in this restoration project area: inlet #3 (Figure 7) and inlet #1 (Figure 8). Physical monitoring of the entire project area is ongoing to document development of topography over time from flow interactions on the site.

Figure 7. Los Lunas Habitat Restoration Site in January 2003. Red square denotes the inlet #3 studied in May 2003. Photo by AAO-River Analysis Team.

Figure 8. Los Lunas Habitat Restoration Site in May 2004. Blue square denotes the inlet #1 studied in May 2004.

Inlet #1 was considered too small/unsuitable in 2003 to retain eggs as no-drift zone had established at 500 cfs. However with higher flows in 2004, the wetted area within the inlet extended nearly to the constructed high flow channel. This larger wetted area in the inlet created a drift zone. However, egg retention data indicated only minimal effectiveness. This inlet is approximately 35 meters wide with a length into the floodplain of 25 meters. Drift zone water depth in 2003 was typically less than 0.5 meters. A moderate number of beads and larvae were collected at this site in six days of sampling (Porter and Massong 2004).

Inlet #2, located between inlet #1 and #3 has not been sampled for its effectiveness for egg retention. In 2003, limited field resources prevented data collection at the inlet. By 2004, a substantial bar had filled in the drift zone area at the back of this inlet (Figure 8), making the inlet unsuitable egg-retention habitat. This inlet is approximately 55 meters wide with a length into the floodplain of 25 meters. There was moderate capture success of artificial eggs in inlet #2.

Inlet #3 was chosen in 2003 for the egg retention study, as it had a well defined inflow, outflow and drift zone. During the 2003 study, 57 beads were retained, along with one silvery minnow egg. The real egg was found on quadrats within a slightly vegetated area. During field reconnaissance in spring 2004, a large mid-channel bar was discovered in inlet #3, dominantly filling the inlet (Figure 8). With the higher spring flows in 2004, the inlet routed Rio Grande flow around the bar, essentially creating a side channel and reducing the drift zone area. This inlet is approximately 75 meters wide and 20 meters in length.

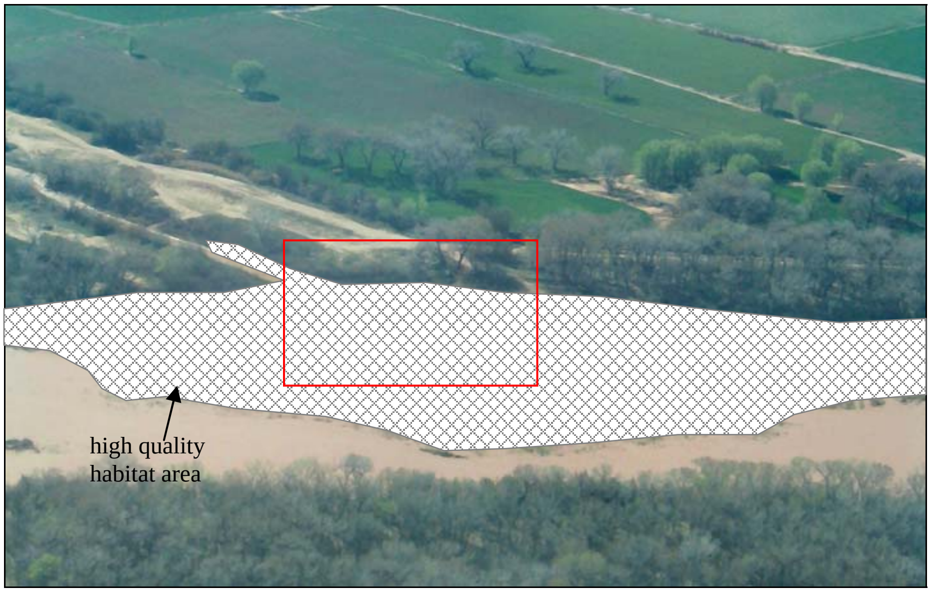
Inlet #4, the inlet located downstream of inlet #3 was sampled for only a short time in 2003. Sampling ceased when slightly increased flows created an outflow channel at the back of the inlet, draining into the constructed high flow channel in the floodplain. This flow scenario created a flow-through channel eliminating the drift zone that had originally formed. Monitoring data collected in 2004 revealed that a distinct channel formed between the Rio Grande and the high flow channel, and that the remainder of the inlet filled with sediment (Figure 8).

Arroyo Abo (natural habitat)

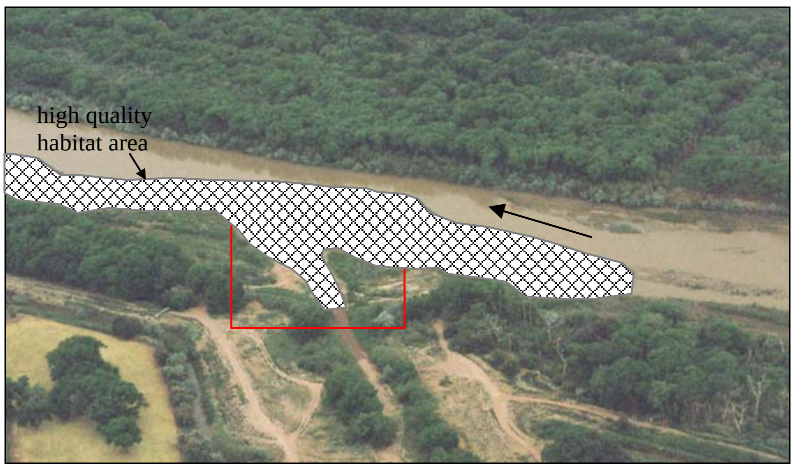
Arroyo Abo drains the northern edge of the Joyita Uplift, south of Bosque, NM joining the Rio Grande at approximately river mile 139 (Figure 2). As with most arroyos in New Mexico, the channel predominantly routes thunderstorm runoff from the eastern uplands to the Rio Grande. At present, one dominant channel conveys the arroyo flows across the fan, (Figure 9). Two small Rio Grande side channels cut across the right-side fan deposits, isolating the upstream half of the fan during moderate to high Rio Grande flows. During the moderately high spring flows in May 2004, about 2,000 cfs, the Rio Grande flowed over the fan deposits, and the dominant arroyo channel formed a well defined inlet with drift zone (Figure 9). The inlet was approximately 30 meters wide and extended more than 40 meters up the arroyo.

Unlike Arroyo Calabacillas, the Arroyo Abo fan is closer in elevation to the low flow Rio Grande active channel bed. As observed in May 2004, a large portion of the fan was submerged with a modest flow of 2000 cfs in the Rio Grande. These submerged fan deposits supported a variety of vegetation, similar to those found at Arroyo Calabacillas. The inundated fan appeared to contain high quality habitat for larval fish, as this area contained a relatively high density of the fish.

The capture success of yellow beads was moderate in the arroyo formed inlet. Secondary currents from the Rio Grande side channels appeared to dominate the current direction, which carried the yellow beads away from the formed drift zone. A low number of larvae were collected in two days of sampling (Porter and Massong 2004).



(a)



(b)

Figure 9. Arroyo Abo confluence with the Rio Grande in April 2004 (a) and May 2004 (b). The April 2004 photo (a) is taken from the west side of the Rio Grande towards Arroyo Abo, while the May 2004 photo was taken from the east side of the Rio Grande looking down Arroyo Abo towards the Rio Grande. Red square on (b) denotes the section of the confluence studied in May 2004.

Rio Salado

The Rio Salado confluence is at approximately RM 119 (Figure 2), just upstream of the San Acacia diversion dam. The Rio Salado watershed drains the Magdelena Mountains and surrounding mountains that lie west of the Rio Grande near Socorro, NM. Data collected from historic aerial photography in this area indicates that the Rio Salado fan has expanded since 1949 'pushing' the main Rio Grande channel eastward (Figure 10) into the valley wall. At present, two main channels convey flows in the Rio Salado across its fan to the Rio Grande (Figure 11). Located between the two main channels, several recently abandoned channels exist. Three of these have formed inlets connected to the Rio Grande at moderate flows. The three inlets and the two main channels meet the Rio Grande at near perpendicular angles.

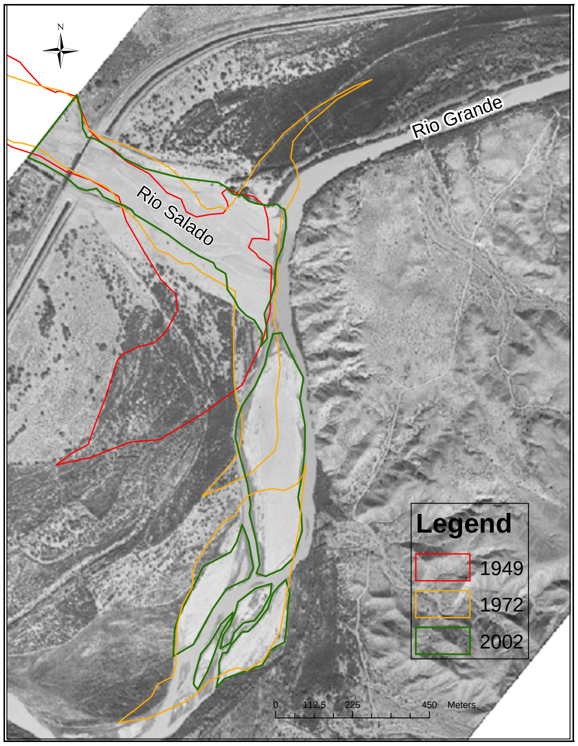


Figure 10. History of the Rio Salado confluence with the Rio Grande from 1949-2002. The arroyo fan outlines are overlain on the 2002 aerial photography.

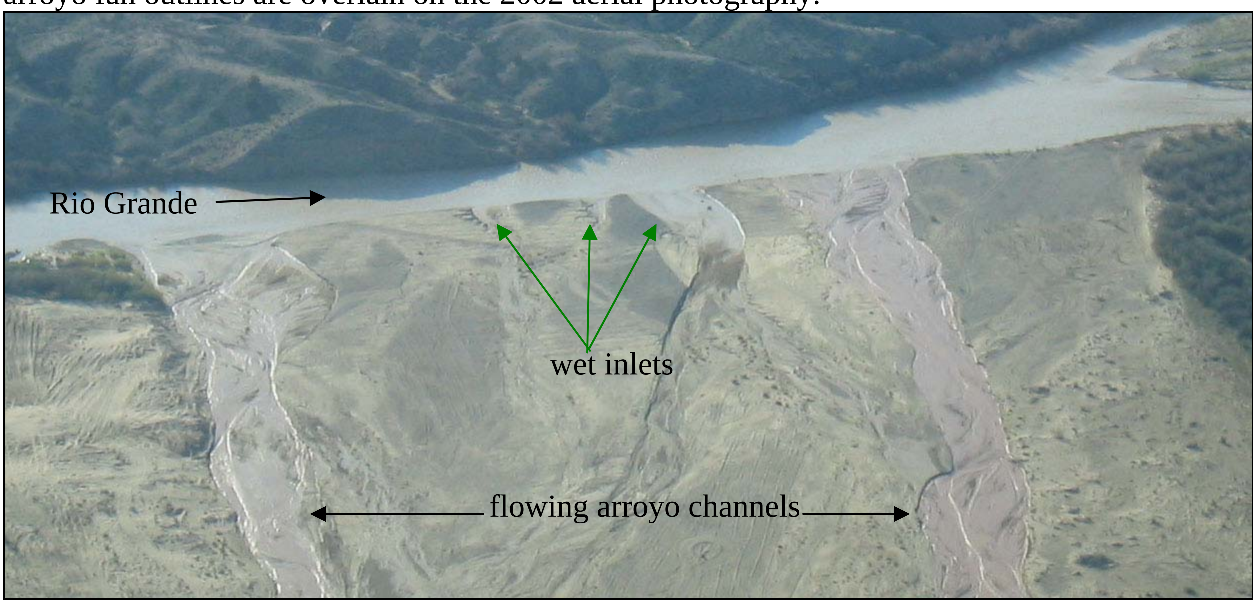


Figure 11. The confluence of the Rio Salado with the Rio Grande on April 7, 2004, Rio Grande flow of 2,650 cfs. The Rio Grande is flowing from left to right in the lower portion of the photograph; photo taken by Reclamation's AAO-River Analysis Team. The three small inlets in the middle are inundated by Rio Grande water.

Unlike the other arroyos studied, this arroyo fan is more complex, since the arroyo deposits are down stream (Figure 10) and forms a dominantly riffle planform. The narrow river channel through these deposits indicates lower availability of edge habitat than found at Arroyo

Abo or Arroyo Calabacillas. The formation of inlet or shelf appears dependant on Rio Grande water surface elevation when the sediment is deposited. The Rio Salado last flowed on April 7th, 2004, when the Rio Grande had flows peaking at 3,000 cfs. As a consequence, Rio Salado deposited material/sediment at or above that water surface elevation. Therefore, these inlets require higher flows to become inundated.

The spring runoff discharge in May 2004 peaked at approximately 2,000 cfs at this location. This discharge was too low to inundate these naturally formed inlets, therefore, no egg monitoring or artificial egg retention experiments were attempted.

Arroyo de la Parida

Arroyo de la Parida watershed drains the Joyita Uplift to the east of the Rio Grande; this arroyo currently joins the Rio Grande at approximately River Mile 105 (Figure 2). In the 1950s, the Rio Grande channel was straightened and moved west in this reach of the valley (Figure 12; Reclamation 2003). As a result of the channelization work, the Arroyo de la Parida confluence was abandoned in the old Rio Grande channel (Figure 12). After abandonment, Arroyo de la Parida began filling the old Rio Grande channel with coarse and fine sediment. In approximately 2000, the coarse sediment supply transported by Arroyo de la Parida reached the current Rio Grande channel. These arroyo deposits are creating a pro-grading (expanding) fan at the current

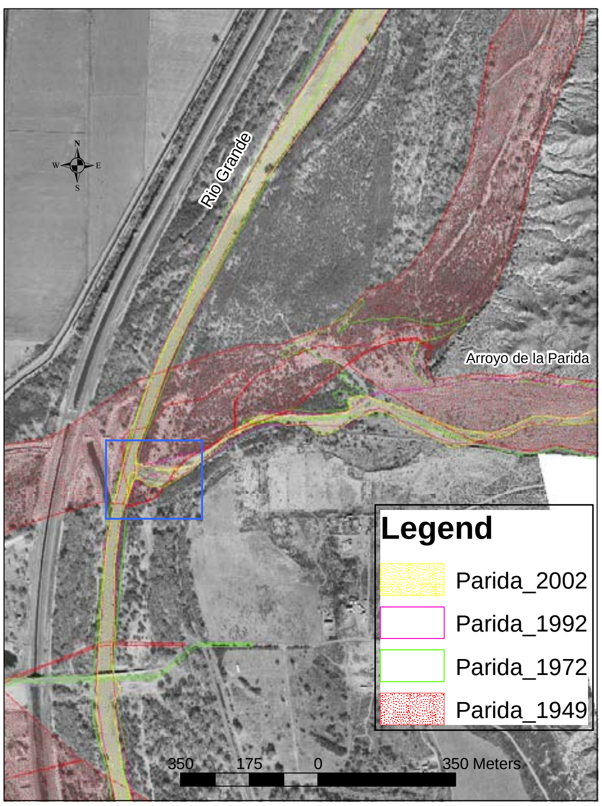


Figure 12. Historical confluences of Arroyo de la Parida with the Rio Grande (1949-2002). The Rio Grande is flowing from top of figure to bottom, with Arroyo de la Parida joining from the east. The blue square denotes the 2004 study area; the underlying aerial photography was taken in 2002.

confluence, which has just begun to 'push' the Rio Grande westward toward the Low Flow Conveyance Channel outfall.

At present one main Arroyo de la Parida channel meets the Rio Grande. This channel was inundated at a 2,000 cfs Rio Grande flow and stayed wet until flows decreased to less than 1,500 cfs (Figure 13). The confluence angle is rotated downstream 5-10 degrees. The width of the confluence is approximately 25 meters. Although the sediment fan is just beginning to form downstream of the confluence, it doesn't appear to be forming quality habitat. A moderate number of beads, and low number of fish larvae were collected in seven days of sampling (Porter and Massong 2004).

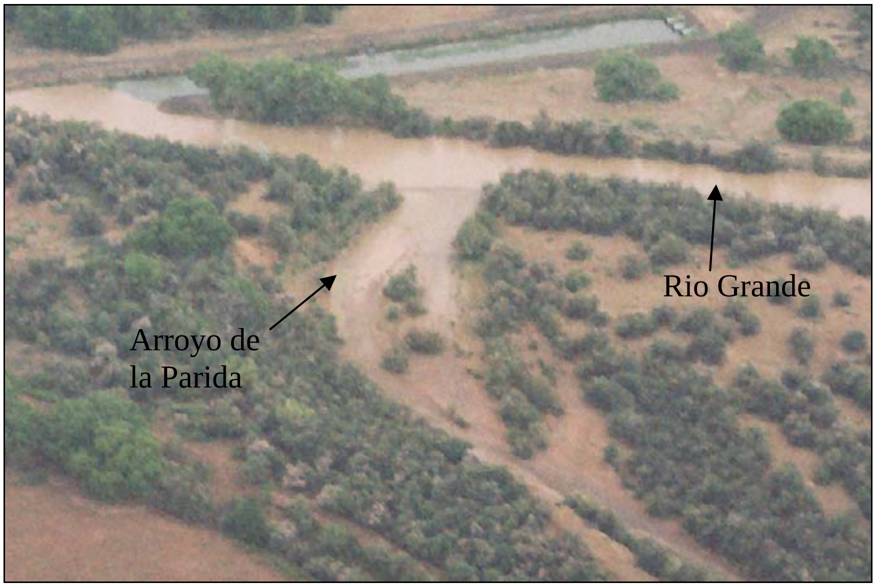


Figure 13. The confluence of Arroyo de la Parida with the Rio Grande on May 26, 2004 (1,150 cfs in the Rio Grande). The Rio Grande is flowing from right to left in the upper portion of the photograph; Low Flow Conveyance Channel Outfall at top of photo.

Channel Widening at Bosque del Apache National Wildlife Refuge (constructed habitat)

The BDA nursery habitat site is located at RM 36 and is the most southern site in this study. Nursery habitat inlets were created to facilitate widening of the Rio Grande at this restoration site, therefore their lifespan as nursery habitat were designed to be temporary. The created inlets were approximately 40 m wide with a length of 45 m and were perpendicular to the constructed Rio Grande channel. The inflow from the Rio Grande traveled approximately 12 m into the inlet in 2003, while the remaining 33 m of inlet was driftzone. At the time of construction, the inlet mouth was level with the pilot channel bed. In 2003, a moderate number of silvery minnow eggs and beads were collected within the constructed inlet (inlet #1) during three two-hour sampling periods (Figure 14).

In April 2004, a relatively large flow (about 2,800 cfs) inundated much of the project area (Figure 15), including the inlets. As a consequence, filling with fine sediments occurred in the inlets, with significant growth of a bar at the mouth of three inlets (Figure 16). Scouring at inlet #1 reduced the length about 50% from the former bankline. The runoff flows in May 2004 peaked at only 1,600 cfs, which were too low to flow over the bars at the mouth of the inlets. No sampling for egg retention occurred at this site in 2004.

Figure 14. Constructed inlets in the Bosque del Apache NWR Channel Widening Project area in 2003. Inlet #1 is circled in blue adjacent to the newly constructed Rio Grande Channel. The previous Rio Grande channel is to the left of the inlets. Photo by R. Doster.

Figure 15. The Bosque del Apache NWR Channel Widening Project area in April 2004 with 2,800 cfs flowing in the Rio Grande. Inlet #1 is circled in blue. Photo from River Analysis Archives.

Figure 16. Looking east across the Rio Grande toward ponded water in Inlet #2 downstream of inlet #1 (May 2004). The inlet filled with sediment during high flows in April 2004. Photo by M.D. Porter.

DISCUSSION

Natural Habitats

Investigation of natural habitats focused on arroyo confluences, and specifically arroyos delivering significant quantities of sediment such that they developed, at least in part, a fan-like deposit. Of the four arroyo confluences sampled, Arroyo Calabacillas was the confluence that retained the most eggs (both real and artificial). The physical features unique to this site were: 1) a semi-circular fan deposit (Figure 5), 2) 'shelf' surfaces at a variety of elevations (Figure 6), and 3) an inlet connected to the Rio Grande and the flooded shelf (Figure 17).

Of all the confluences observed, Arroyo Calabacillas was the only arroyo with a semi-circular fan deposit. An aerial view shows how these fan deposits 'push' the secondary Rio Grande channel east (Figure 5), into the main channel. Eggs drifting down the secondary channel appeared to drift straight into the fan deposit and up onto its flooded surfaces (the wetted shelf). Artificial eggs were found throughout the flooded shelf (Figure 17 and denoted as the high quality habitat area in Figure 5). The flow interactions of the secondary Rio Grande channel with the fan deposit created a variety of flow angles, including perpendicular flow onto the fan.

A major aspect of the fan deposit that appeared vital for egg retention was having a surface that acted as a floodplain during spring runoff in 2004. This fan deposit has sloped surfaces (shelfs) that provide a variety of depths through a range of discharges above 1500 cfs, creating floodplain nursery habitat for moderate to high flows in the Rio Grande. Low discharges (less than 1500 cfs) during the silvery minnow spawning period in recent years (2000, 2002, and 2003) would be insufficient for inundating nursery habitats similar to Arroyo Calabacillas, probably resulting in lower recruitment. The relatively low shelf inundated during the 2004 spring runoff (about 3,000 cfs) had emergent vegetation. Vegetation on the shelf appeared to aid egg retention by reducing flow velocities across the shelf. Many larval fishes were also observed in this shelf area.

Although the shelf area retained most of the beads, some beads/eggs were transported into the inlet. When the riverside drain was not flowing into the arroyo, a well developed drift zone formed within the inlet. Many larval and adult fishes were also present in the inlet, indicating the inlet was suitable habitat. Although several larval fish were collected for identification, none were silvery minnow larvae.

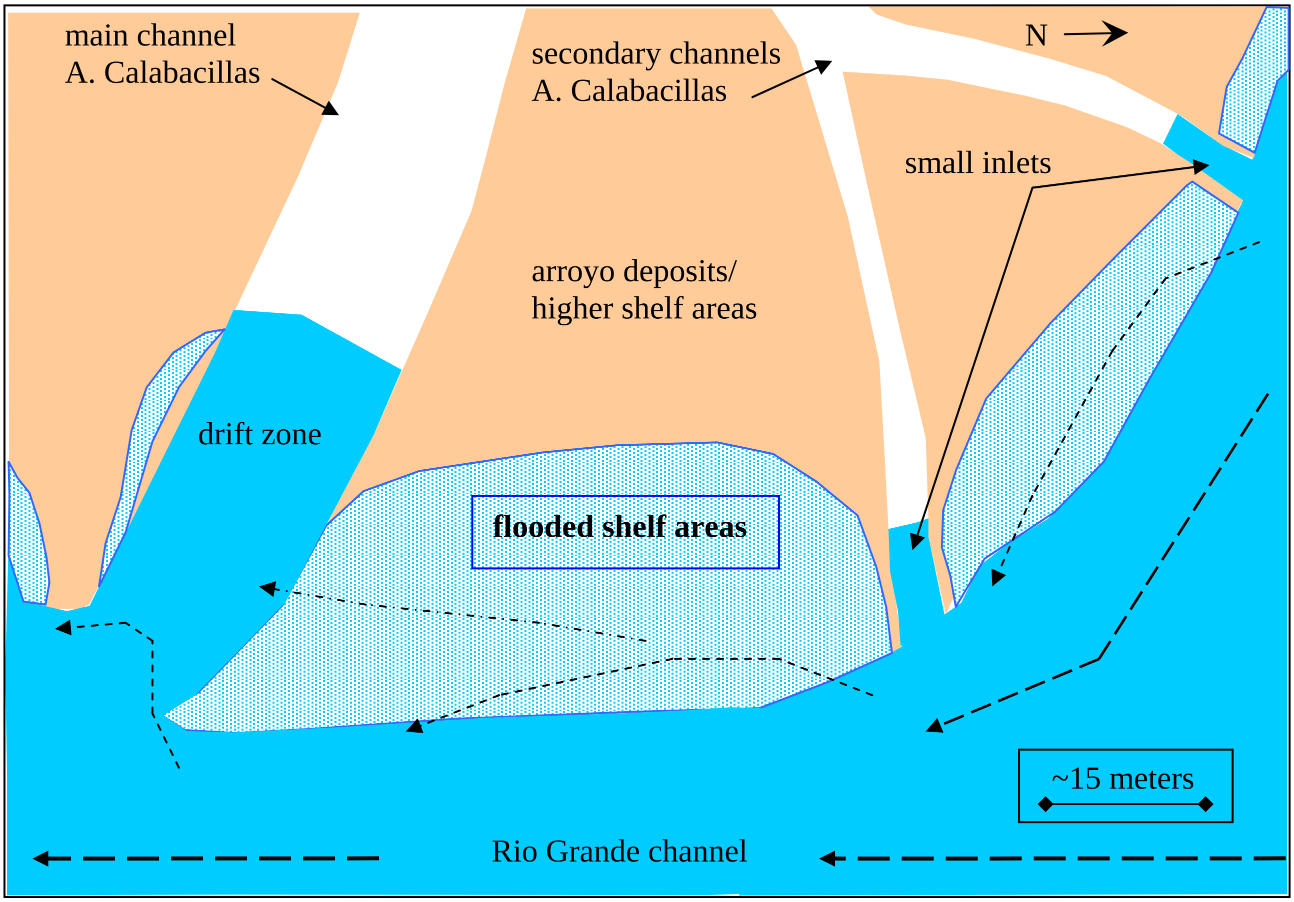


Figure 17. Sketch of Arroyo Calabacillas fan/confluence with the Rio Grande showing the flow paths and water height present during spring runoff in May 2004.

At Arroyo Abo, many larval fishes were observed within its submerged, partially vegetated shelf area, indicating the area was providing suitable fish habitat. The major difference at Arroyo Abo was that the Rio Grande had ‘cut’ a significant side channel through the upstream arroyo fan deposits (Figure 18). The shelf areas were connected to the side channel rather than the inlet. Far fewer eggs and beads were retained in the inlet area. Flow in the side channel was directed away from the inlet area. Connectivity between the Rio Grande, the side channel, and the inundated shelf areas will require additional study to understand how this system functions for egg retention and nursery habitat.

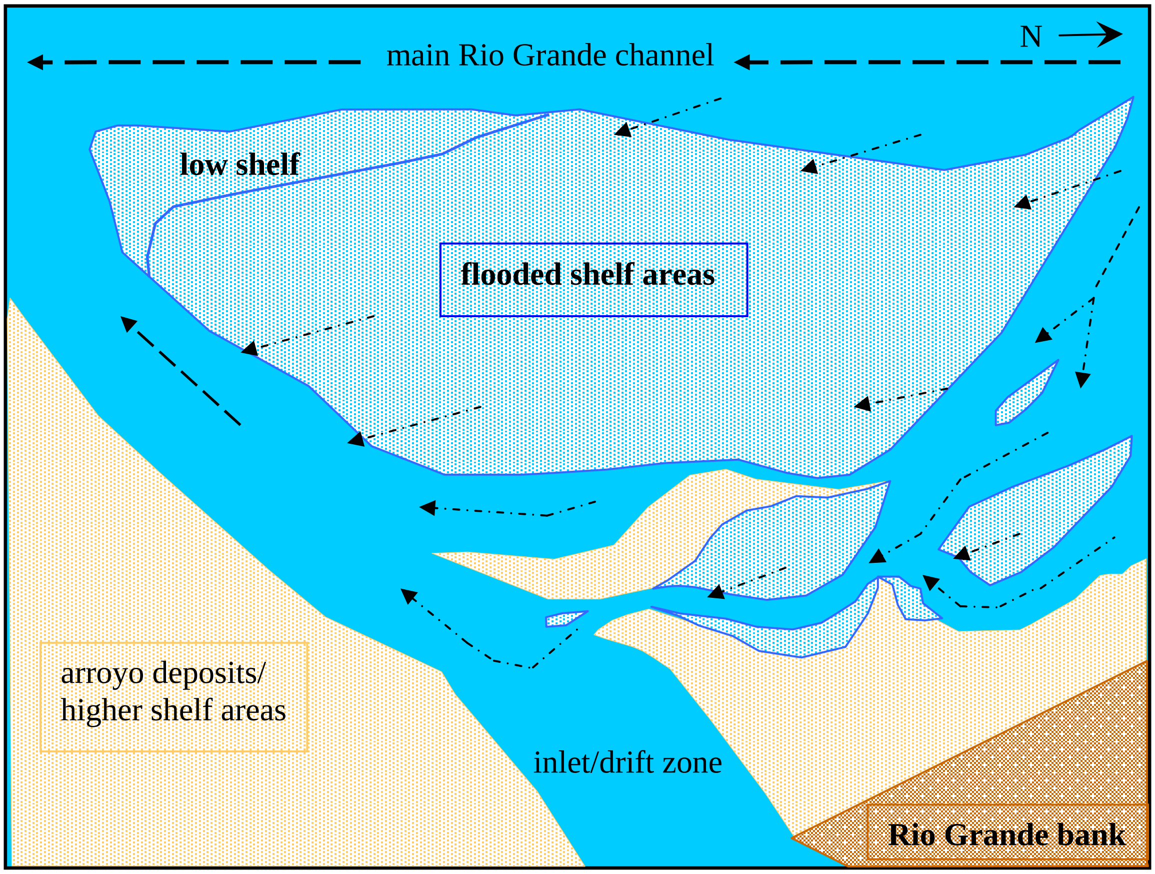


Figure 18. Sketch of Arroyo Abo fan/confluence with the Rio Grande showing the flow paths and water height present during spring runoff in May 2004.

Egg retention at Arroyo de la Parida was also poor. Although this arroyo-formed inlet continued to be flooded at much lower Rio Grande flows than the other natural inlets studied, the inlet was actually angled downstream (Figure 13). As a result, the amount of inflow from the Rio Grande was limited. Rio Grande current reached approximately 3 meters into the inlet. The lack of inflow appears to have limited the effectiveness of the inlet in retaining eggs.

Created Habitats

Egg retention was documented at both constructed habitats, the BDA site and the N AMAFCA site. At both these sites, the inlets were well connected to the river channel and had significant drift zone development. These two features, although both present in the Los Lunas Project were not well connected to each other.

The N AMAFCA inlet is by far the largest inlet sampled in this study. The inlet is essentially rectangular with a length of several hundred meters and a width of approximately 75 meters (Figure 3). Rio Grande currents flow into the inlet about 50 meters regardless of bar development. Although Rio Grande sediment and arroyo sediment partially fills this inlet as medial bars, the inflow channel appears to easily stay connected with the drift zone some 70 meters into the inlet. The inlet mouth stays connected to the Rio Grande at all flows. The BDA inlets are similar to the N AMAFCA inlet except they are much smaller (40 meters wide by 45 meters length). These inlets were also constructed to remain wetted in low flow conditions. The water in the drift zones are also relatively deep (more than 0.5 meters).

The Los Lunas inlets are also rectangular in shape, rotated 90º, such that the long axis is parallel to the flow of the river current. As a consequence to the wider inlet mouths, the river currents flow through most of the inlet, often over half the length. This increased inflow length significantly reduces the space required to create a drift zone. But the other major physical difference of the Los Lunas inlets is that these inlets are much shallower (less than 0.3 m) than those at BDA or N AMAFCA.

The rectangular shape appears to better direct the river currents into and out of the inlets. The currents appear to also turn at a steeper angle to exit the inlet; the steeper curvature of the flowing water may increase the likelihood that eggs will leave the current and be retained in the inlet.

The depth of the inlet drift zone also appears to contribute to the retention of eggs. The inlets that are connected to the river at lower elevations capture most of the water column, rather than just surface currents. As eggs actually drift within the water column, not at the surface, routing the entire water column into the inlet increases the likelihood of receiving drifting eggs.

Although the Los Lunas inlets have not proven to retain large numbers of silvery minnow eggs, the site does appear to be productive in retaining silvery minnow larvae. In conjunction with this project, larvae were sampled at the Los Lunas Project site (H. Magaña, pers. comm.). This study found that silvery minnow larvae were being retained within the project area along with other fish larvae. The study focused on the downstream section of the project area, the side channel/island area. Unfortunately, the inlets were not sampled for larvae retention in this study.

IMPROVED DESIGNS FOR NURSERY HABITAT

Out of this study, three ideas for constructing nursery habitat have formed: 1) reworking point bars or island sediments to create side channels and shelf areas that become flooded at moderate flows; 2) bank line modifications that include shelf areas draining into constructed inlets; and 3) modifying riverside drains, canals or surface runoff outfalls into larger inlet features.

Point Bar/Island Modifications

In their current configuration, most bars/islands do not appear to have the correct structure and surface topography to first retain eggs and then function as nursery habitat. However, the surfaces of these in-channel features could be modified to possess important nursery habitat features that have been identified in this study. Four habitat features could easily be added to these channel features (Figures 19 and 20): 1) lowered surfaces along the active river's edge to simulate connected shelf areas; 2) shelf areas within the point bar connected to the river via small side channels; 3) constructed inlets connected to the river either directly or via a side channel; and 4) constructed inlets that are connected to the river but also convey surface water runoff or riverside drain water to the Rio Grande. The key process for the constructed inlet conveying water, feature #4, is that the periodic flow of water through the entire inlet would 'flush' fine sediments that have accumulated. As sedimentation in constructed inlets is a concern, these flushing flows would better maintain the inlet structure.

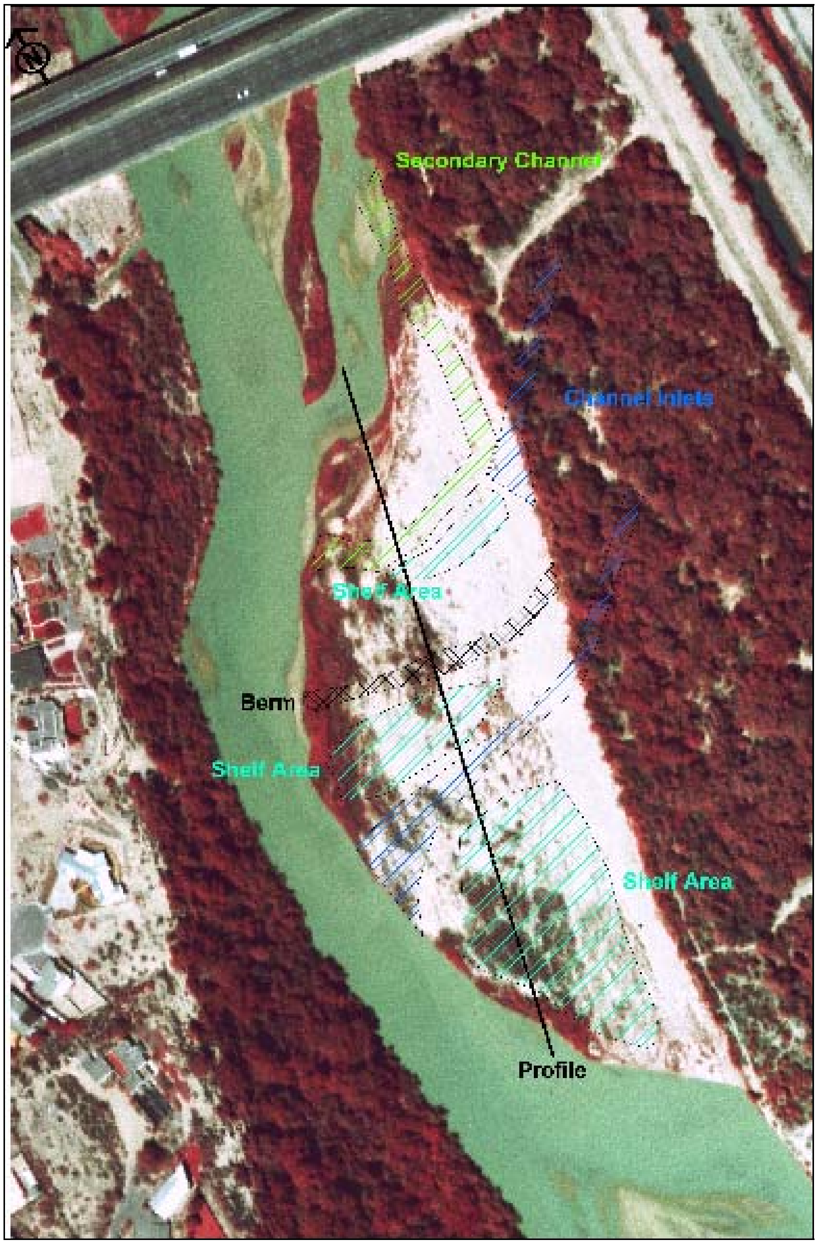


Figure 19. Sketched modifications to a point bar on the Rio Grande immediately downstream of Interstate-40 bridge crossing. The modifications shown include: 1) introduction of a side channel into the bar sediments with connected inlet and shelf area; 2) bar-spanning berm to hinder very high Rio Grande flows that overtop the bar; 3) inlets connected to surface runoff channels; and 4) lower bar elevation to create a directly connected shelf area on the downstream section of the bar.

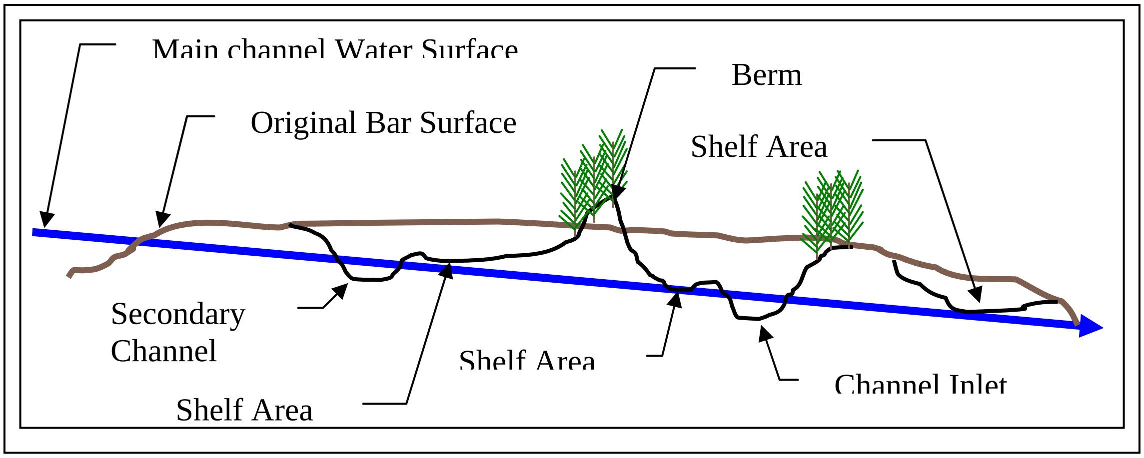


Figure 20. Example profile along the point bar in Figure 19 showing the secondary channel, gradual upslope to the berm, and the channel inlet downstream from the bar.

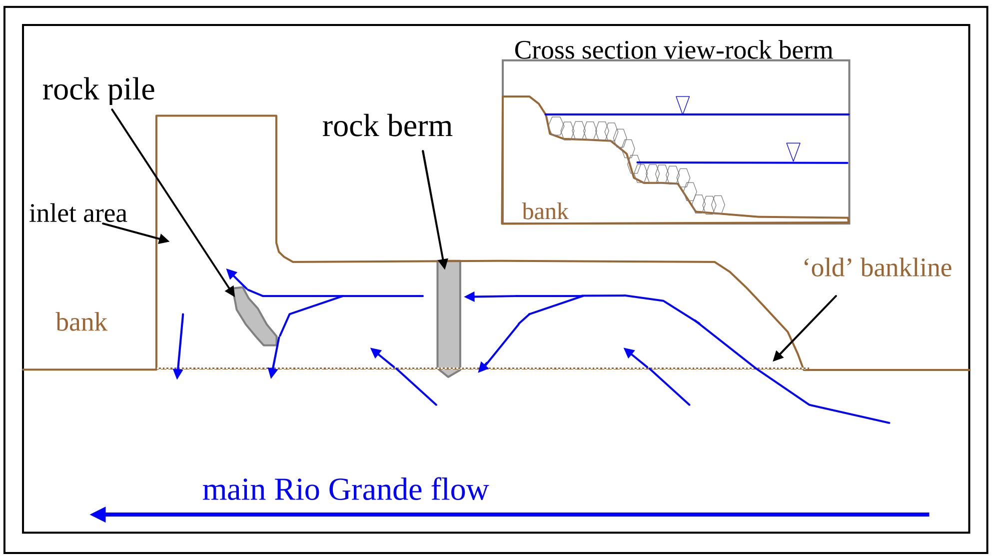


Figure 21. Planview sketch of initially constructed shelf/inlet area with initial flow patterns. Two shelf elevations are envisioned forming as indicated in the cross section view of the rock berm. The cross section view of the rock berm depicts a low water elevation and a high water elevation.

Bank Line Modifications

In the Rio Grande, and especially in the Albuquerque, NM area, the historic floodplain is abandoned for the 2-year flood flows. These banks tend to be composed of sandy-silty sediments that form vertical surfaces outlining the active Rio Grande channel. As a consequence, the bank line boundaries can easily be modified to include inlet and shelf features (Figures 21 and 22). In the past, the inlets constructed in the banks have been very simple (BDA and Los Lunas mimic the N AMAFCA site, a dug-out rectangle). Although this shape does function as nursery habitat, the Arroyo Calabacillas site highlighted the usefulness of flooded surfaces around the inlet. As a result, we propose adding complexity to the original inlet design by adding a variable height berm upstream of the constructed inlet. This feature would slow the flow of water directed at the inlet and instigate deposition of the sediment load upstream and downstream of the berm. This sediment deposition would create complex surfaces (shelves at varying elevations) over time.

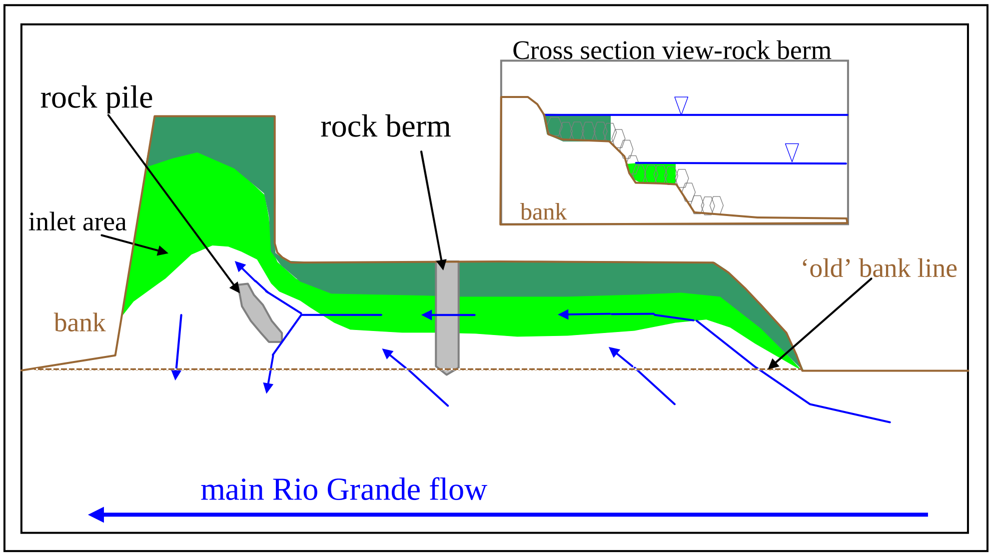


Figure 22. Planview sketch of constructed shelf/inlet area after several high flow and low flow events; shown is the estimated flow paths of low flow. The light green polygons represent sedimentation in the inlet at low flows, forming the lower shelf area. The dark green indicates the high flow/high shelf area. Note: the downstream bank line will be eroded over time and slowly moved downstream.

Riverside Drain Outfall Modifications

The last improvement idea is the modification of riverside drains, canals or surface runoff outfalls. As these features already create an inlet/channel that is connected to the Rio Grande at all flows, they would only require slight modification. As seen at BDA, sedimentation in the constructed inlet mouths is problematic during high flows. However, at all the arroyo confluences and N AMAFCA, where these inlets convey either storm water or riverside drain water to the Rio Grande, the inlet mouth remains open to the Rio Grande at all flows. This idea has two components: 1) connect new constructed inlets to outflow channels, such as riverside drains or surface runoff drains; and 2) modify the existing outfalls by widening the outfall area to promote shelf development and/or slow the outflow waters and create more of a slow water environment where Rio Grande water can partially flow into it.

SUMMARY OF DESIGN CONSIDERATIONS

- Orientation of the inlet, width of the mouth influences the distance river currents flow within the inlet and ultimately the quality of the drift zone. The quality of this connection between the inlet/drift zone and the river currents appears to be the key feature for eggs/larvae retention.
- Height of the inlet mouth controls the volume of water entering the inlet. For natural confluences, the height of the inlet/arroyo channel is determined by the last arroyo flow.
- Flooded shelf areas (floodplains) appear to not only retain beads and minnow eggs, but also influence the larvae retention.

- Elevation of inlets and flooded shelf areas relative to water surface during spawning determine the accessibility of habitat for eggs and larvae.
- Area of the drift zone is vital for retention.
- Sedimentation in the constructed inlets is problematic as the mouth area can fill in rapidly creating a disconnected drift zone within the inlet.
- Pro-grading fans with shelf areas and natural inlets appear to be ideal for egg retention and larval habitat as the river creates a variety of secondary flow characteristics, drift zones and flooded surfaces.

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