U.S. FOREST SERVICE
NATIONAL STREAM AND AQUATIC ECOLOGY CENTER

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RIO SAN ANTONIO: STREAM CONDITION and RESTORATION POTENTIAL

Client: Carson National Forest, Tres Piedras Ranger District

Location: Rio San Antonio watershed, Rio Arriba County, New Mexico

Date of Visit: 8/15/2017

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Summary: At the request of the Carson National Forest, three segments of the Rio San Antonio and tributary streams were assessed for deficient conditions and the need for restoration. Current and historic conditions were evaluated and restoration alternatives were developed. Flow frequency relationships are provided at key points, for use in restoration planning and design. Recommendations for action and data needs are presented.

Generally, Canada Tio Grande has intermittent deficiencies, with insufficient riparian cover in places and a few short reaches where restoration may be advisable to address incision. Management changes and vegetation plantings, as well as possibly isolated channel and floodplain restoration and beaver dam analogs, should be considered.

The lower visited reach of Rio San Antonio is generally in fair to good condition, with active beaver activity and relatively dense riparian vegetation in many areas. Prior incision and, in 1962, braided conditions has generally stabilized at a lower grade with stands of riparian vegetation. Some reaches of overly-widened channel and bank instability were noted. Portions of this reach have extensive beaver activity, which can slowly recover the incision with dam building and beaver meadow development. Management changes as well as isolated channel and floodplain restoration (and beaver dam analogs) should be considered for this reach.

The upper reach of the Rio San Antonio is generally in fair condition, with many portions of the reach incised. Braided reaches evident in 1962 have since stabilized but woody vegetation is highly impaired from browsing and grazing activities. The continuation of current management will likely result in continued impairment, with poor cover and elevated water temperatures. Management changes and riparian plantings, combined with structural headcut arrest, is at least needed. Beaver dam analogs can also be considered. Full restoration of the channel at the former grade, reestablishing pre-disturbance groundwater table elevations and providing the best conditions for riparian vegetation, can be done with reasonable effort at this stage and should also be considered. To meet objectives, fish barrier construction and non-native fish elimination will likely be needed before fully restoring this reach.

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INTRODUCTION

Three segments of the Rio San Antonio and tributary streams were assessed for deficient conditions and the need for restoration. The preliminary objectives of restoring ecological and geomorphological functions and, for at least one reach (Rio San Antonio, upper) restoring Rio Grande cutthroat trout habitat, were utilized as a context for providing additional points for consideration. Excessive summertime stream temperatures were considered in this assessment. Restoration alternatives and recommendations were made for each of the three reaches.

The Rio San Antonio watershed has average annual precipitation that varies from 22 to 43 inches (PRISM, Daly et al. 2008). Watershed areas are 21.2 mi^2 at the downstream limit of the upper Rio San Antonio reach, 27.4 mi^2 at the downstream limit of the lower Rio San Antonio reach, and 11.0 mi^2 at the downstream limit of the Canada Tio Grande reach. The elevations of the watershed ranges from 10,900 to 8840 feet. This watershed is considered "functioning at risk" within the Forest Service Watershed Condition Framework (Potyondy 2011).

A watershed assessment and report was completed by Rocky Mountain Ecology, LLC and the Chimayo Conservation Corps (Knox 2016). This Forest Service report dovetails this previous work, supplementing provided information with additional needed information and recommendations in support of future restoration actions.

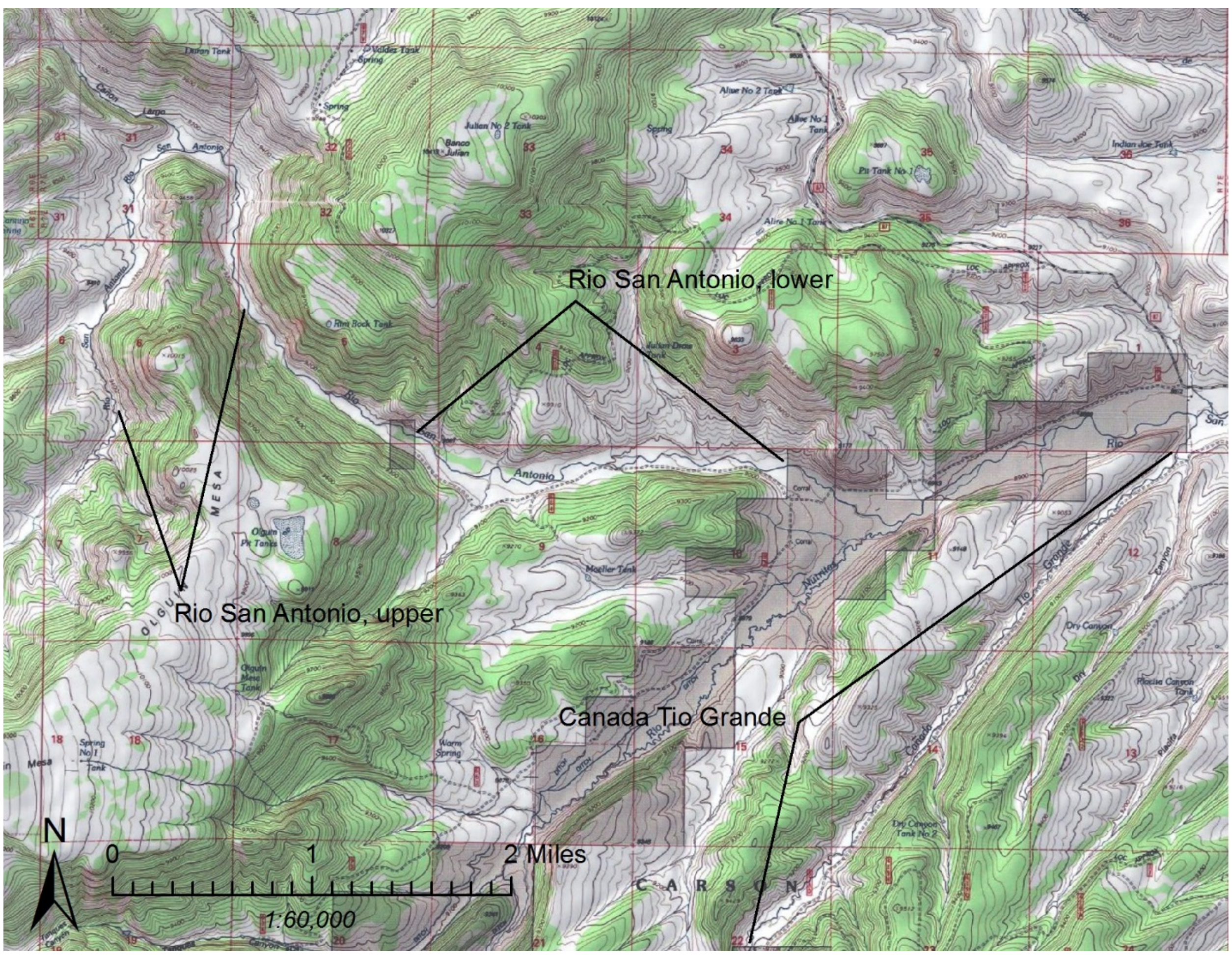

Figure 1: Proposed restoration reaches visited on August 15, 2017, in the Rio San Antonio watershed.

CONDITION of PROPOSED PROJECT REACHES

Canada Tio Grande

The Canada Tio Grande is a small stream that has variable shade and incision present. Incision appears to be typically low (0 to ~1 ft) – generally the stream was observed to be relatively well-connected to its floodplain, though some reaches are incised or are eroding adjacent terraces and creating relatively high raw banks. Some reaches had relatively little riparian canopy present (Figure 2; Figure 4), while other reaches had much more substantial amounts of vegetation and stream cover (Figure 3; Figure 6). Tall, mature willows were observed in some locations, though are frequently limited to one bank (reducing stream cover and shading). Some larger willows are decadent (Figure 5) and may benefit from disturbance. Sedges were commonly observed. Narrowleaf cottonwood was infrequently present.

Alluvial fans from side drainages are present, influencing the fluvial geomorphology of the stream (Figure 6). In some locations these fans are pushing the channel to the far side of the valley bottom. Abandoned relic channels were noted in places, which could be utilized in restoration activities. Beaver activity was noted in at least one location, where a dam had failed prior to the field visit and had not yet been reconstructed. A maintained beaver dam and impoundment was noted in the September 2016 imagery (Appendix A).

Figure 2: Reach of Canada Tio Grande with less vegetation cover.

Figure 3: Reach of Canada Tio Grande with more vegetation cover.

Figure 4: Canada Tio Grande example reach with less riparian vegetation present (10/4/2016). An alluvial fan is also present (red circle).

Figure 5: Decadent willows on Canada Tio Grande.

Historic aerial imagery from 1962 was obtained and compared to 2016 conditions (Appendix A). Generally, in 1962 the channel had a similar form as in 2016, though meander migration has occurred over the 54 years. As is currently the case, numerous alluvial fans were present in 1962, contributing sediment to the valley bottom and channel. Few willows or other woody vegetation were present in 1962. Additionally, no beaver activity within this reach is clearly present in the 1962 imagery.

The relatively narrow and stable condition of the channel in 1962, despite the lack of willows or other woody vegetation, indicates that sedges were plentiful for maintaining channel form. However the lack of shade likely resulted in warmer temperatures than present.

Knox (2016) did not collect temperature data on the Tio Grande. Temperature data may be available from the Carson National Forest, but has not been provided.

Figure 6: Canada Tio Grande (10/4/2016), example reach with more riparian vegetation present. A tributary alluvial fan (red circle) is also present.

Rio San Antonio (Lower)

The proposed lower Rio San Antonio restoration reach is located between two private inholdings (Figure 1), between a large tract downstream and small tract upstream. The downstream portion of this reach is a beaver pond dominated meadow (Figure 7), while beaver activity is less prevalent upstream (Figure 8). The upstream portion of this reach was not visited during this trip.

The areas with active beaver pond construction activities appear to be well connected with the floodplain surface, creating a beaver meadow. The recently inundated areas where dams have not been recently maintained (Figure 9) have a prevalence of dead willows and alders present (presumably due to inundation), though alder and willow recruitment was observed in these areas. Generally, in disturbed reaches substantial vegetation recovery was noted (Figure 10).

Primary riparian vegetation in this reach was observed to be sedges, willows, alders and cottonwood. Both younger and more mature alder were observed. The cottonwood population appears to be composed of primarily younger individuals.

Figure 7: Lower Rio San Antonio proposed restoration reach (2016-10-4), downstream (just above private lands). Beaver activity is evident, with numerous currently-maintained ponds. Temperature monitoring at noted point (ID 10352943) in 2013.

Figure 8: Lower Rio San Antonio proposed restoration reach (2016-10-4), upstream.

Figure 9: Beaver dam-impacted reach on lower Rio San Antonio.

Figure 10: Vegetation recovery on lower Rio San Antonio.

Figure 11: Well vegetated incised reach on lower Rio San Antonio.

Figure 12: Unstable streambanks on lower Rio San Antonio.

In some areas the channel appears to be incised, with up to 18 inches or so of incision and resulting disconnections from its former floodplain. However, these reaches have generally recovered with a narrower but well vegetated floodplain (Figure 11) that provides cover for fish and solar radiation (reducing temperature increases). This vegetation at the incised grade is also providing substantial amounts of bank stabilization and fine sediment load reduction (compared to unvegetated surfaces).

At some locations, more substantial erosion-induced disturbance was observed (Figure 12). Such reaches are overwidened and are receiving excessive solar radiation, potentially leading to increased water temperatures.

The bed material size appears to be dominated by cobbles.

Periodic alluvial fans were noted in the aerial imagery. These alluvial fans can lead to terrace erosion features that appear to be high, unstable streambanks.

Historic aerial imagery from 1962 was obtained and compared to 2016 conditions (Appendix A). Generally, in 1962 the channel was frequently braided within this reach, with a frequent lack of channel stabilizing vegetation (sedges, willows, alders, cottonwoods) that have since populated this riparian zone. Additionally, much less beaver activity was present in 1962 compared to 2016, though some activity was noted. The braided conditions of 1962 indicate that much of this reach lacked vegetative bank stabilization, including sedges, and that the riparian condition was quite poor. The lack of shade from woody vegetation indicates that warmer stream temperatures were likely present in 1962 compared to 2016.

Temperature data for this lower reach of Rio San Antonio was collected in 2013 by Knox (2016), at the location illustrated in Figure 7. However, these probes were removed in mid July and may have missed the maximum stream temperatures for the year. During the warmest period in the record (July 1 through July 7), the mean temperature was 18.4 C, with a maximum of 24.1 C and minimum of 11.4 C. With only one data point available it is unknown how much temperature is increasing within this specific reach.

Generally, this reach appears to have features that are beneficial to fish and other aquatic life.

Rio San Antonio (Upper)

The upper Rio San Antonio Reach (Figure 13, Figure 14, Reaches 4-upper, 5 and 6 in Knox 2016) was not directly assessed on 8/15/2017, but was evaluated from an overlook (Figure 15) and was visited in 8/2017 by Michael Gatlin. A number of photographs documenting conditions were collected, which were utilized in this condition assessment.

This reach is incised at a number of locations (Figure 16), with developed and vegetated bankfull benches frequently established at a lower grade (Figure 17). The riparian vegetation is impaired, with very heavy browsing of willows that is minimizing abundance and condition. Sedges appear to be prevalent on the bankfull benches. Cottonwood are present to a limited extent and frequently appear to be stunted due to heavy browsing. Upstream reaches have a more extensive cottonwood presence. Due to the generally poor woody vegetation condition, most of this reach lacks channel vegetative cover and is highly susceptible to heating due to solar radiation, resulting in elevated temperatures of the cold water fishery.

Abandoned or lesser-utilized secondary channels were observed within this reach. Wetlands were also observed. At least one channel headcut was present; incision is still occurring at some locations.

Figure 13: Upper Rio San Antonio proposed restoration reach (2016-10-4), downstream.

Figure 14: Upper Rio San Antonio proposed restoration reach (2016-10-4), upstream.

Figure 15: Downstream portion of the Upper Rio San Antonio proposed restoration reach.

Numerous small alluvial fans are present along this reach (Figure 13), from small and a moderate-sized tributary (Canon Largo). Erosion of the terraces that are former floodplain surfaces that were abandoned with incision are evident, as is erosion of higher terrace surfaces, including portions of alluvial fans.

Historic aerial imagery from 1962 was obtained and compared to 2016 conditions (Appendix A). Generally, in 1962 the channel was frequently braided within this reach, with a lack of channel stabilizing vegetation (sedges, willows, alders, cottonwoods). After the intervening 54 years sedges appear to be much more common in 2016, though, unlike the lower Rio San Antonio reach, woody vegetation has yet to recover through most of this reach. No beaver activity is evident in 1962. The braided conditions of 1962 indicate that much of this reach lacked vegetative bank stabilization, including sedges, and that the riparian condition was quite poor. The lack of shade from woody vegetation indicates that, aside from warmer temperatures from climate change, warm stream temperatures were likely present in 1962 at similar levels as contemporary conditions.

Knox (2016) documents two temperature monitoring stations within this reach (Figure 13, Figure 14), in addition to the monitoring station in the lower Rio San Antonio reach (Figure 7). Mean and peak temperatures for July 1 through July 7, 2013 are provided in Table 1, with a plot of the data for the three stations illustrated in Figure 18.

Table 1: Rio San Antonio temperature monitoring results from Knox (2016), for July 1 through July 7, 2013.

Temp ID and Location	Temperature (degrees C) Average	Maximum	Minimum
10352945 - upstream	15.9	26.5	7.4
10352944 - mid	16.4	27.3	7.0
10352943 - downstream	18.4	24.1	11.4

Figure 16: Incised stream channel, with limited riparian vegetation due to browsing (photo by Michael Gatlin).

Figure 17: Inset floodplain development, with bankfull bench (photo by Michael Gatlin).

The upstream stations have lower averages but increased diurnal variations, while the downstream station has higher average temperatures but lower maximum temperatures. This may likely be the result of the poor shading and riparian vegetation conditions upstream, forcing higher high temperatures (from solar radiation) and lower low temperatures (from a lack of microclimate zones to moderate temperature). Beaver ponds and associated increased hyporheic exchange immediately upstream of the downstream monitoring site is likely also contributing to the lesser diurnal temperature variability.

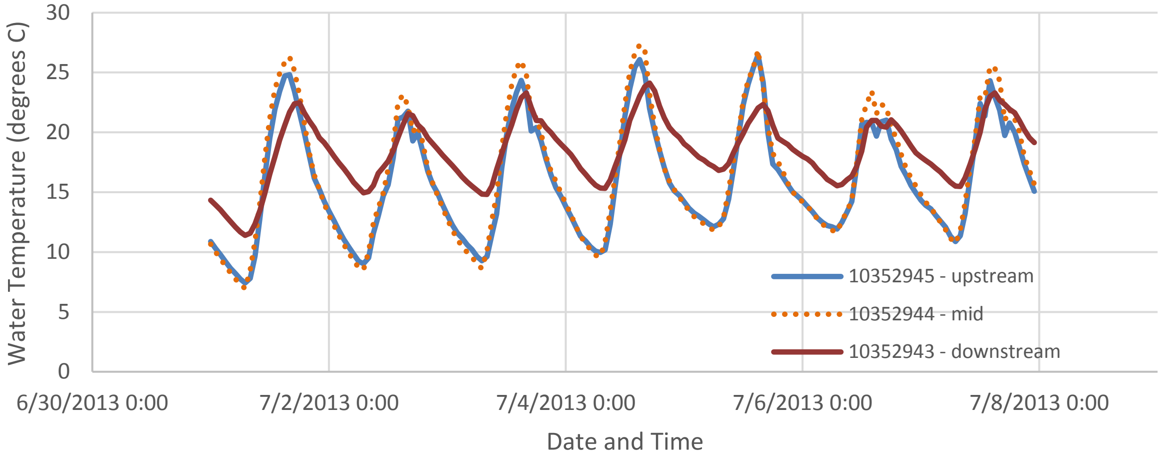

Figure 18: Plot of Rio San Antonio temperature monitoring results from Knox (2016), for July 1 through July 7, 2013.

FLOW FREQUENCY

Flow frequency estimation for the potential restorations were computed as a part of this assessment. At key locations (Figure 21), flow frequency was computed using Waltemeyer (2008) within the StreamStats platform (version 3). The accuracy of regional regressions for flow frequency predictions varies for each region. To check for systematic inaccuracies and biases flow frequency relationships at local streamgages were computed using the standard logPearson protocol and compared to the regional regression results obtained through StreamStats.

Local Streamgages

Thirteen streamgages that are within 45 miles of the Rio San Antonio watershed were considered for assessing the accuracy of flow frequency predictions in this area. Four streamgages are most appropriate for comparison (Figure 19); these gages are most climatically relevant to the Rio San Antonio. Key watershed information are provided in Table 3, including analysis results for the 100-, 10- and 2-year events (1%, 10% and 50% chance of occurrence, respectively).

Peak annual flows for the four watersheds most typically occur in April and May (spring), but also occur (much less frequently) in March, June, July, August, and September.

A logPearson frequency analysis was performed for each of the streamgages, using Bulletin 17B procedures (IACWD 1982). These four datasets are systematic, though two of the gages had one low outlier. These values were disregarded. The implemented regional skew (-0.1) was selected from IACWD (1982). Waltemeyer (2008) used a regional skew of 0 throughout New Mexico.

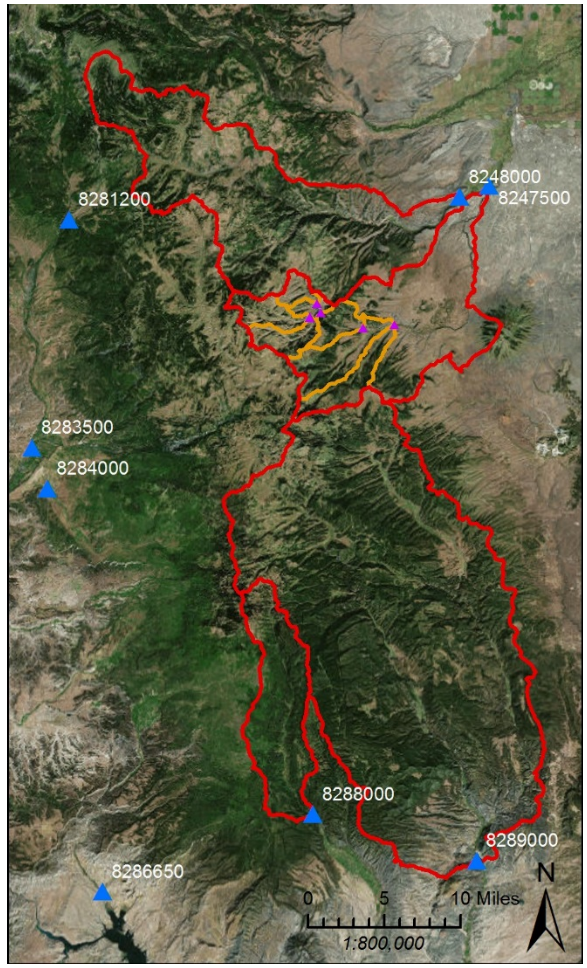

Figure 19: Local streamgages (blue triangles) to Rio San Antonio, with watershed delineations for gages used in comparison (red) and watersheds delineations (orange) of prediction locations (magenta triangles) within the proposed project areas. Numbers are USGS streamgage IDs.

Table 2: Streamgages utilized and flow frequency results for Rio San Antonio flow frequency relationship development. For comparison, Rio San Antonio at the downstream limit of the downstream reach (SA-3) has a watershed area of 27.5 mi² and mean annual precipitation of 32.5 inches.

Name	ID	Watershed Area (mi ²)	Record Length (years)	Mean Annual Precipitation (inches)	logPearson			StreamStats		
					Q_{100}	Q_{10}	Q_2	Q_{100}	Q_{10}	Q_2
Los Pinos River near Ortiz, CO	08248000	167	98	31.3	3060	2150	1210	3700	1750	700
San Antonio River at Ortiz, CO	08247500	110	93	25.8	1790	1030	440	2260	1020	400
El Rito near El Rito, NM	08288000	51	38	24.8	1240	580	220	1080	460	170
Rio Ojo Caliente at La Madera, NM	08289000	419	84	19.5	4350	2380	1070	4450	2000	790

Regional Regression Predictions

Flow frequency relationships for the Rio San Antonio watershed and the streamgaged locations were computed using the methods published in Waltemeyer (2008), through the StreamStats website. The regional regression predictions for the gaged locations were compared to the logPearson analysis results, to assess for systematic bias and a need for adjustment. A comparison of results for the 100-, 10- , and 2-year floods (1%, 10%, and 50% chance of occurrence in any given year) are shown in Figure 20. The 45 degree lines on these plots indicates perfect agreement between the regional regression results with the logPearson streamgage analyses, with points above the line indicating where the regional regressions are overpredicting and points below the line indicating where regional regressions are underpredicting.

For streamgages in the vicinity of the Rio San Antonio, regional regression equations tend to predict the flow frequency relatively accurately for the 100-year event, though flow at two of the streamgages were over predicted a bit. For the 10- and 2-year events the regional regression equations predict relatively well for the smaller watersheds (with lesser flow estimates) and underpredict flood magnitudes for the larger watersheds, compared to the logPearson results. The limited available data indicate that the regional regression equations perform relatively well for smaller watersheds. However, it should be noted that the Rio San Antonio watersheds are substantially smaller than those assessed, resulting in additional unknown uncertainty.

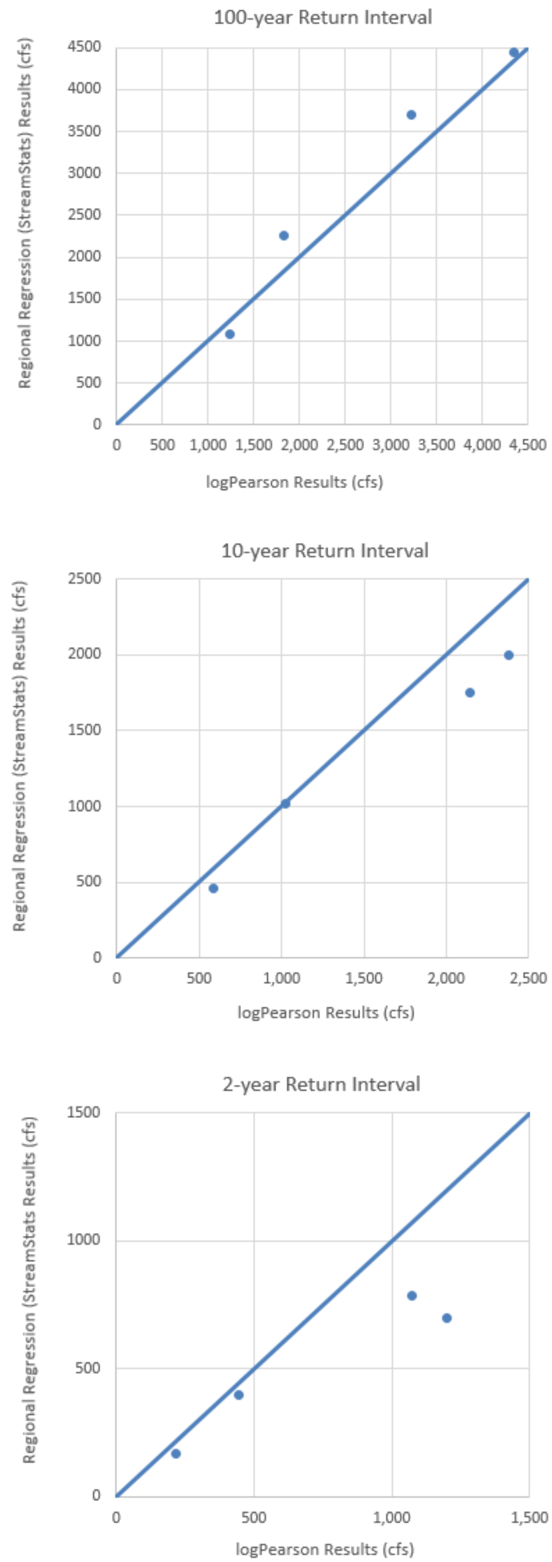

Figure 20: Comparison of results between regional regression equations and streamgage logPearson analyses.

Recommended Flow Frequency

Flow frequency predictions based on Waltemeyer (2008) provide reasonable results in the vicinity and within the Rio San Antonio watershed, without signs of consistent bias. Based on these regional regressions combined with (for events with return intervals more frequent than the 2-year event) computations based on a regression fit of unit discharge at the neighboring streamgages, recommended flow frequency relationships (Table 3) for key points in the Rio San Antonio (Figure 21) are provided.

Additionally, to provide additional understanding of the potential magnitude of floods that can be expected within this watershed, floods of record at streamgages within the same flood characteristics zone can be used to estimate peak floods that can be expected (given the historic record) at ungaged or insufficiently gaged locations. Specifically, expected flood potential and the maximum likely flood potential were computed using the watersheds' area and average annual precipitation. The results are also presented in Table 3. Being preliminary using a method not yet peer reviewed, these results should be used with caution.

Table 3: Flow frequency and flood potential estimates for the Rio San Antonio stream and riparian restoration projects.

Recurrance Interval (years)	Percent Chance of Occurance	Discharge (cfs)					
		LC-1	SA-1	CL-1	SA-2	SA-3	TG-1
1.25	80	25	23	13	57	70	33
2	50	66	56	32	140	160	67
5	20	140	120	70	270	320	140
10	10	200	170	100	390	460	200
25	4	290	250	160	570	660	300
50	2	380	330	210	730	850	390
100	1	480	420	270	920	1060	500
Expected Flood Potential		440	360	230	910	1100	440
Likely Maximum Flood Potential		800	660	410	1600	1900	800

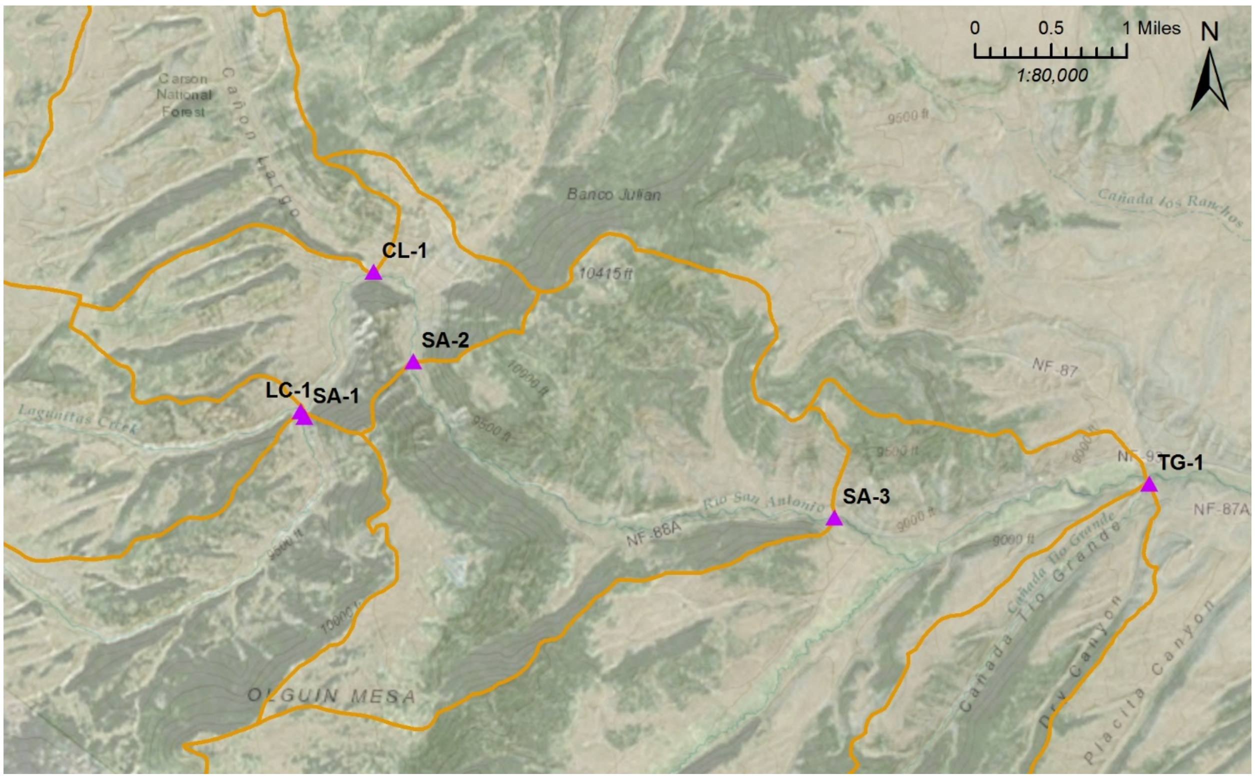

Figure 21: Flow prediction locations (magenta triangles) in the Rio San Antonio watershed. Orange lines are watershed delineations for the prediction nodes.

CONDITION and RESTORATION SUMMARY

The condition and restoration potential of the three assessed Rio San Antonio watershed stream reaches are summarized in this section, by reach. For overlap with the Knox (2016) report, Canada Tio Grande reach is reach 2b in Knox (2016), Rio San Antonio (lower) is Reach 4-lower, and Rio San Antonio (upper) is Reach 4-upper, Reach 5 and Reach 6.

This summary is based on observations made during a relatively brief field visit. More extensive observations may shift viewpoints on the condition and restoration potential of the stream reaches.

Helpful for understanding condition and restoration potential is the Channel Evolution Model and the fundamental principle of unit stream power. Before specific condition and restoration potentials are presented for each of the three reaches, these concepts are first presented.

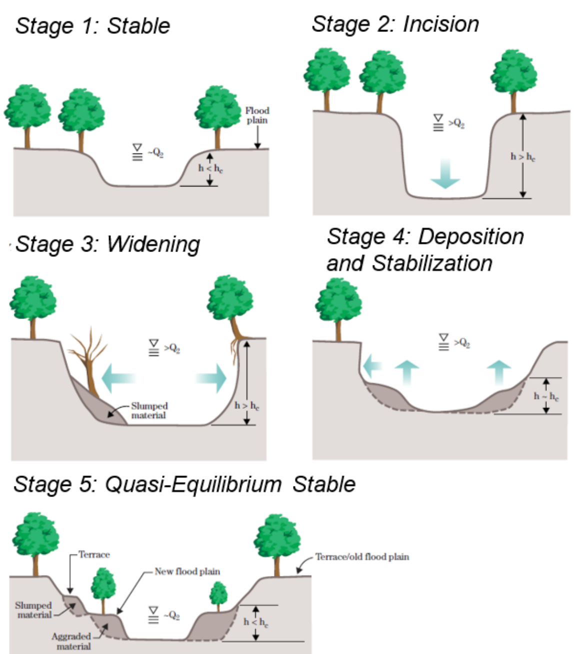

Figure 22: Channel evolution model, with channel cross sections illustrating the 5 channel stages (modified from NRCS 2007).

The Channel Evolution Model (Figure 22) is a valuable tool for understanding how channel form adjusts over space and time due to a disturbance that causes incision. At a specific location the channel evolves over time from an initial stable state (stage 1) through incision (stage 2), widening (stage 3), deposition and stabilization (stage 4), and once again stable (stage 5). Stages 2 and 3 are the most challenging stages of the evolution model for managers; this is the stage where instability and sediment supply is highest and restoration options are limited. Over time the incision moves upstream, forcing incision of the valley bottom on successive upstream reaches.

Unit stream power (ω; watts/m^2 or lb/ft-s) is the rate of energy expenditure against the channel bed and banks per unit flow width. Where there is an insignificant amount of flow acceleration, all the energy of streamflow must be used by friction against the bed and banks or work (erosion) on the bed and banks. Unit stream power is computed as:

$$\omega = \frac{\gamma Q S_f}{w}$$

where γ is the specific weight of water (9810 N/m^3), Q is the discharge (m^3/s or cfs), S_f is the friction slope (m/m, often assumed to be the average water surface or bed slope), and w is the flow width (m).

Unit stream power is valuable to consider when performing preliminary field assessments. For example, if a stream reach has incised or has been channelized and has little to no floodplain to expel energy across during a flood, the width is minimized and unit stream power will be elevated and can force erosion of the bed (further incision) or margins (accelerated streambank or terrace erosion). At higher discharges, unit stream power will also be elevated, with this increase counteracted by erosion or increased friction. Also, total and unit stream power are directly proportional to the sediment transport conveyance capacity; changes in total and unit stream power can feed insight into erosional or depositional tendencies of specific stream reaches.

Canada Tio Grande

Generally, the Canada Tio Grande reach has intermittent deficiencies, with insufficient riparian cover in places and a few potential shorter reaches where more complex restoration may be needed. An incision event appears to have occurred at some time but, where this has occurred, the stream has generally recovered. Where present, the riparian vegetation is reducing direct solar radiation to the stream, though changes in grazing and browsing management would likely increase its extent along most (if not all) of the Canada Tio Grande reach. Compared to conditions in 1962, by 2016 this stream has substantially increased the extent of woody vegetation and shading; conditions have improved over the intervening 54 years, though additional improvement opportunities exist.

This small stream has bankfull channel flow likely between 33 and 67 cfs (1.25 and 2-year flow, respectively). The small size of this stream (with low expected flood and unit stream power potential) provides conditions for a stable stream system.

Restoration efforts on this reach would likely best consist of riparian exclusion fences and plantings. Cottonwood plantings should be considered, which could eventually provide a gallery for establishing more continuous shade and reduced water temperatures. A few short reaches may merit instream structures, large wood augmentation, and channel and floodplain reconstruction to reconnect the stream to a wider floodplain and reduce the potential for future incision (reduce unit stream power and erosion potential). Relic channels that are still present within this reach could be valuable in locations where more substantial restoration activities are performed.

Rio San Antonio (Lower)

This reach of the Rio San Antonio is generally in fair to good condition, with active beaver activity and dense riparian vegetation in many areas. This stream has bankfull channel flow likely between 70 and 160 cfs (1.25 and 2-year flow, respectively). Prior incision has generally stabilized and is in Stage 5 (quasi-equilibrium stable) of the Channel Evolution Model. With these reaches having narrow floodplains, unit stream power is elevated during floods compared to pre-disturbance conditions (leading to enhanced sediment transport conveyance capacity and erosion potential) but the stream has stabilized with dense stands of streambank vegetation. In some locations within this reach beaver dam building activities are prevalent, creating a meadow surface that appears to inundate the pre-incision floodplain.

The unstable braided condition of the channel in 1962 indicates that substantial stabilization and recovery has occurred over the intervening 54 years. The 1962 imagery indicates that generally poor conditions that existed in the first half of the 20th century may have resulted in the incision currently noted, but recovery has since been occurring.

It is expected that continued beaver activity and sediment deposition will eventually recover additional portions of the reach to pre-incision grades as illustrated in Figure 23. This will create heterogeneous and resilient conditions that are beneficial to aquatic life.

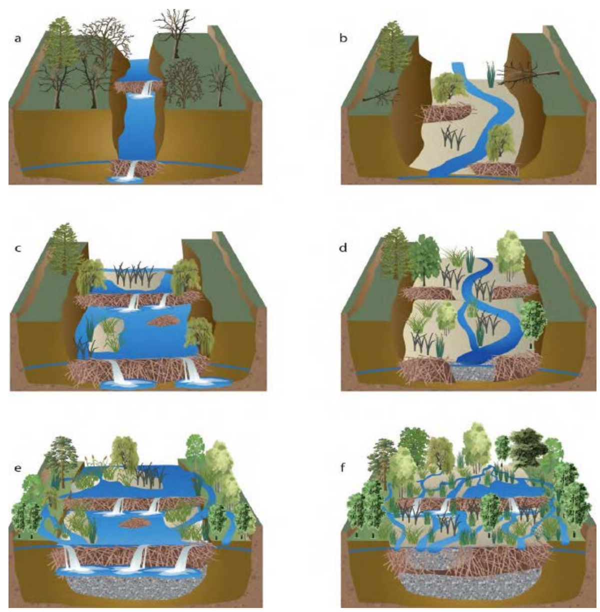

Figure 23: Conceptual model of beaver-induced recovery of incised streams (Pollock et al. 2017).

However, some locations of more substantial erosion, less vegetation cover and bank stabilization, and overly-widened channels were observed (Figure 12). These reaches may be candidates for more extensive restoration practices, such as the installation of toe wood and bankfull benches, log bank vanes, and the introduction of additional large wood to the channel. Beaver dam analogs could also be considered in some locations. Additional on-the-ground inspection is necessary to further evaluate this potential need.

Rio San Antonio (Upper)

This reach of the Rio San Antonio is generally in fair condition, with many portions of the reach incised and in stage 4 of the Channel Evolution Model (Figure 22). This stream has bankfull channel flow likely between 57 and 140 cfs (1.25 and 2-year flow, respectively). The unstable braided condition of the channel in 1962 and subsequent limited recovery to stable single or multi-thread channel form, without woody vegetation for cover and shade from solar radiation, indicates that recovery within this reach is being curtailed by current management practices with grazing and browsing. Observed headcuts indicate that incision is actively ongoing and will continue until restorative measures are taken, with additional portions of this channel and riparian zone being impaired by additional local drops in water table elevations, shifts in vegetation type from hydric to mesic, and increased potential for accelerated geomorphic change due to increased unit stream power. The lack of shade from the poor abundance and condition of woody vegetation along this reach is a fundamental impairment, leading to unabated heating from solar radiation and elevated temperatures within this reach and in downstream reaches.

Due to the poor condition of woody vegetation within this reach, this reach is a strong candidate for reestablishing the channel grade to pre-incision elevations (a priority 1 restoration). This approach is dependent upon the availability of local borrow material and requires extensive use of heavy machinery. If this borrow material is available, channel gravels can be collected and installed on top of fill to reestablish the former channel grade and reestablish full floodplain connectivity and groundwater table elevations. Sedge mats can be removed and placed at higher grades, as can the few willows and cottonwoods that are present. The restored channel form could be either single thread or multi-thread. A multi-thread restoration could follow the concepts of Cluer and Thorne (2013), which presented a revised version of the Channel Evolution Model (the Stream Evolution Model, Figure 24) that includes multi-thread channels (Stage 0). This restoration approach can establish more complex aquatic habitat, with more shade and higher groundwater levels. With either a single or multi-thread restoration approach, abandoned channels at higher grades could be utilized as channels in the restored system.

In any case, an essential component of any restoration strategy is to reduce browsing of the woody vegetation, allowing shade and cover to develop. This would likely consist of both a cottonwood canopy as well as willows and alders. Exclusion fences will be required, with some of these enclosures likely needing to be greater than 0.1 acres.

To better understand the extent of incision and floodplain connectivity, 1-D hydraulic modeling of existing conditions is recommended using HEC-RAS. The results of this modeling should well illustrate where the stream would best be recovered to its previous grade.

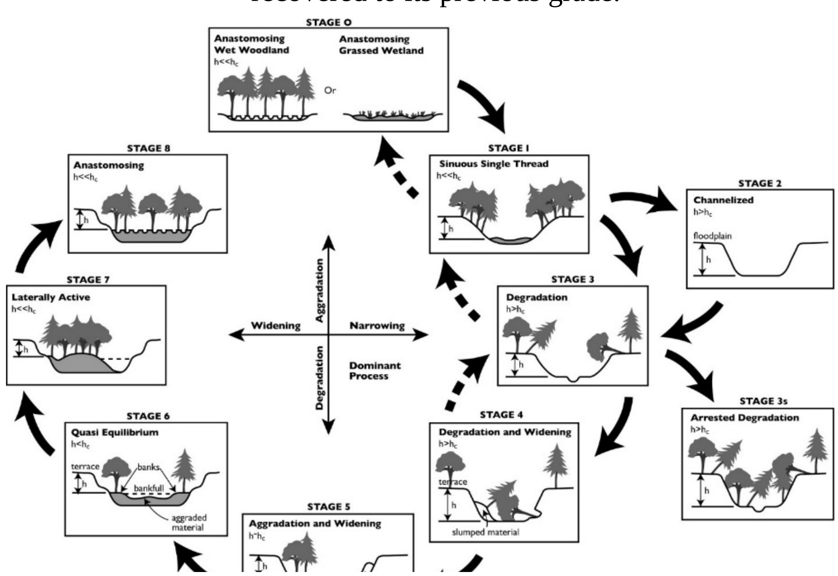

Figure 24: Stream evolution model (Cluer and Thorne 2013).

RESTORATION ALTERNATIVES and RECOMMENDATIONS

Canada Tio Grande

Alternative 1: No Action

The no action alternative (while maintaining current management actions) will likely result in continued slow improvements to riparian conditions.

Alternative 2: Management changes with vegetation plantings

This alternative would consist of fencing and vegetation plantings at strategic locations throughout this reach. Cottonwood plantings should be considered, which could eventually provide a gallery for establishing more continuous shade. Alder and willow plantings should also be considered. Exclusion fencing could be temporary and will likely be needed for 5 to 10 years.

Alternative 3: Management changes with vegetation plantings, plus isolated channel and floodplain restoration and/or beaver dam analogs

In addition to fencing and vegetation plantings, a few short reaches may merit more active restoration. This may consist of instream structures, large wood augmentation, and channel and floodplain reconstruction to reconnect the stream to a wider floodplain and reduce the potential for future incision. Reconnecting relic channels could be valuable with this alternative. Additionally, beaver dam analogs could be considered where ground water table elevations are depressed compared to relic floodplain elevations, to restore riparian conditions.

It is recommended that both alternatives 2 and 3 be considered for implementation, with further investigation performed to identify potential reaches for implementing Alternative 3's channel and floodplain restoration, and beaver dam analog options.

Rio San Antonio (Lower)

Alternative 1: No Action

The no action alternative (while maintaining current management actions) will likely result in continued slow improvements to riparian conditions, due to slowly recovering vegetation conditions (compared to 1962 imagery). Beaver dam activities and gradual beaver meadow creation can slowly address past incision, though this process would be expected to take numerous decades (or > century) for recovery.

Alternative 2: Management changes

This alternative would consist of fencing at strategic locations throughout this reach. Cottonwood, alder and willow plantings could also be considered, though may not be needed; further investigation of this is needed. Fencing may help increase food for beavers, to accelerate beaver activity and resulting recovery. Exclusion fencing could be temporary and will likely be needed for 5 to 10 years.

Alternative 3: Management changes plus isolated channel and floodplain restoration and/or beaver dam analogs

In addition to fencing, a few reaches may benefit from more active restoration. Such restoration may consist of the installation of toe wood and bankfull benches and log bank vanes (to narrow the channel for reduced solar radiation and heating), and the introduction of additional large wood to the channel. Additional on-the-ground inspection is necessary to further evaluate this potential need. Additionally, beaver dam analogs could be considered where ground water table elevations are depressed compared to relic floodplain elevations, to restore riparian conditions and encourage additional beaver activity.

It is recommended that both alternatives 2 and 3 be considered for implementation on this reach, with further investigation performed to identify potential reaches for implementing Alternative 3's channel stabilization and floodplain restoration, and beaver dam analog options.

Rio San Antonio (Upper)

Alternative 1: No Action

The no action alternative (while maintaining current management actions) will likely result in continued impaired conditions on this reach, without expectations for development of woody vegetation or substantial reductions in temperature on a multi-decadal time scale.

Alternative 2: Management changes and riparian vegetation plantings

This alternative would consist of fencing at strategic locations throughout this reach, to allow growth of currently stunted vegetation. A substantial amount of cottonwood, alder and willow plantings would also be needed. Exclusion fencing could be temporary and will likely be needed for at least 10 years. This approach would maintain the current incised form and allow existing headcuts to continue propagating upstream, leading to additional hydraulic impairments and groundwater table reductions that would have negative consequences to riparian conditions.

Alternative 3: Management changes and riparian vegetation plantings plus headcut control and beaver dam analogs

In addition to fencing and plantings, control of the existing headcuts are needed to prevent future channel incision and preserve existing groundwater levels. Grade stabilization structures to arrest the headcuts can consist of either logs or rock. This approach would maintain the current incised form, retaining the current depressed groundwater table elevations and fixing in place conditions for elevated unit stream power, sediment transport conveyance capacity, and increased potential for geomorphic adjustment during large floods.

To address the incision and depressed groundwater levels, beaver dam analogs could also be considered. This action may be appropriate where ground water table elevations are depressed compared to relic floodplain elevations, to restore riparian conditions and encourage additional beaver activity. However, recovery using this approach will likely take decades. Additionally, installation of a fish passage barrier downstream and elimination of non-native fish may be needed before adding such complexity.

Alternative 4: Management changes and riparian vegetation plantings with channel reconstruction

The current highly impaired condition of the riparian vegetation within this reach, combined with frequent incision, provides an opportunity for full restoration of stream and riparian conditions with a reasonable amount of work and expense. Heavy equipment would be utilized to excavate local sediment material as borrow to be used to reestablish the channel and floodplain at the former grade, reconnecting former floodplain surfaces (that are now terraces), raising groundwater levels, and providing better conditions for establishing a robust riparian vegetation community. Sedge mats and the existing (stunted) woody vegetation would be raised in grade. Extensive fencing would be needed for at least 10 years. This alternative would provide the greatest amount of restoration, with the capability to fully mitigate the incision event and reestablish groundwater levels in the near term.

An important consideration with this level of restoration is that this work would add channel complexity that may make it difficult to eliminate non-native fish for reestablishment of a native cutthroat trout community. Prior to extensive restoration work on the upper Rio San Antonio, establishment of a fish passage barrier and elimination of non-native fish should be considered. This would be especially important if a multi-thread stream channel approach is selected as the preferred alternative.

It is recommended that both alternatives 3 and 4 be considered for implementation on this reach. Further investigation is needed to identify where grade stabilization is required and beaver dam analogs could be beneficial in Alternative 3, as well as the best reaches for implementing Alternative 4's channel and floodplain reconstruction option.

DATA NEEDS

It is recommended that all survey data be collected using methods that allow the data to be easily imported and viewed within GIS. To this end, laser and optical levels and total station surveying with assumed locations and elevations are not recommended. Instead, survey-grade GPS (RTK) and LiDAR-based surveys should be utilized.

Canada Tio Grande:

- Temperature monitoring (immediately upstream and downstream of proposed restoration reach)
- Longitudinal profiles (thalweg, high banks), including primary and relic channels
- Cross sections with bankfull indicators (to determine bankfull flow)
- Assessment of riparian vegetation condition, to determine the locations and sizes of exclusion fences
- Determination of (expected) short reaches where more extensive restoration may be needed
- Feature-based land surveying in areas where more active restoration may be deemed necessary (if Alternative 3 is selected)
- Riffle bed material gradation quantifications (pebble counts), if Alternative 3 is selected

Rio San Antonio (Lower):

- Additional temperature monitoring (immediately upstream and downstream of proposed restoration reach)
- Longitudinal profiles (thalweg, high banks), including primary and secondary channels, as well as relic channels
- Cross sections with bankfull indicators (to determine bankfull flow)
- Determination of reaches where more extensive restoration may be needed
- Feature-based land surveying in areas where more active restoration is deemed necessary (if Alternative 3 is selected)
- Riffle bed material gradation quantifications (pebble counts), if Alternative 3 is selected

Rio San Antonio (Upper):

- Additional temperature monitoring (immediately upstream and downstream of proposed restoration reach)
- LiDAR-based survey of stream, riparian zone, and adjacent hillslopes
- Using the same survey control as the LiDAR survey, longitudinal thalweg profiles and other below-water features to merge with the LiDAR survey
- Cross sections with bankfull indicators (to determine bankfull flows)
- Riffle bed material gradation quantifications (pebble counts, at several locations to show longitudinal change)

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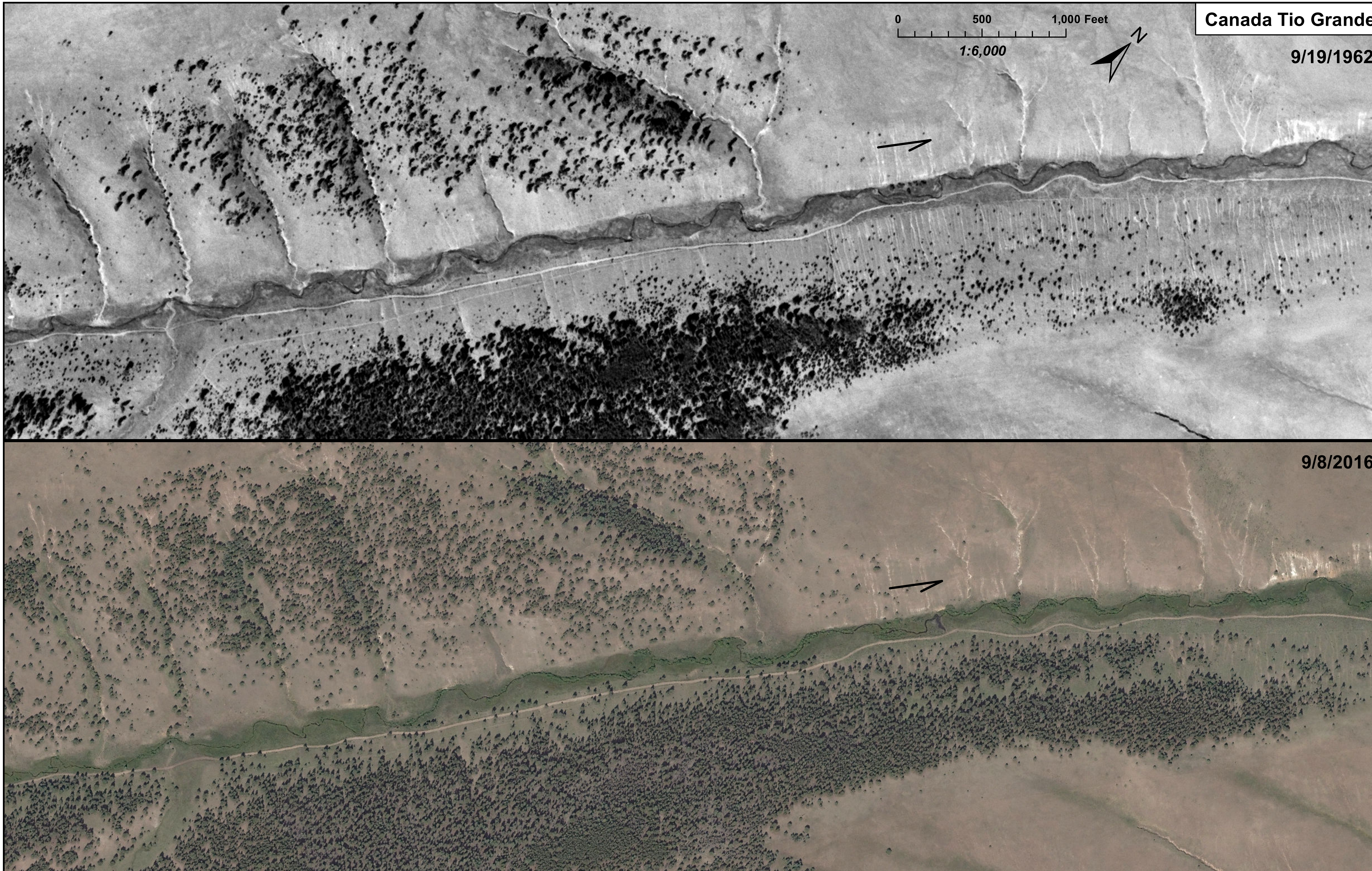
APPENDIX A: Historic Aerial Imagery Comparison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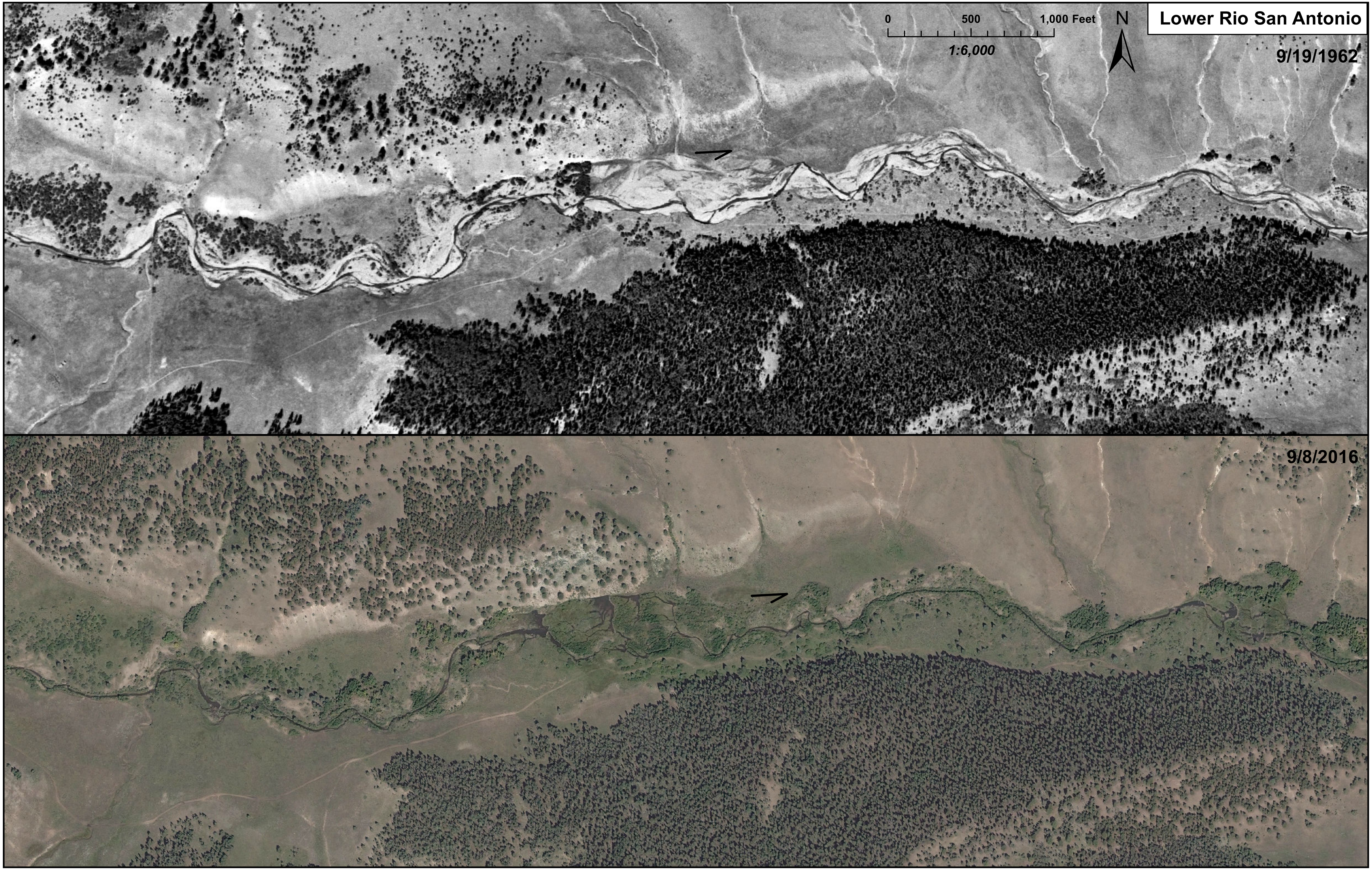
9/19/1962
9/8/2016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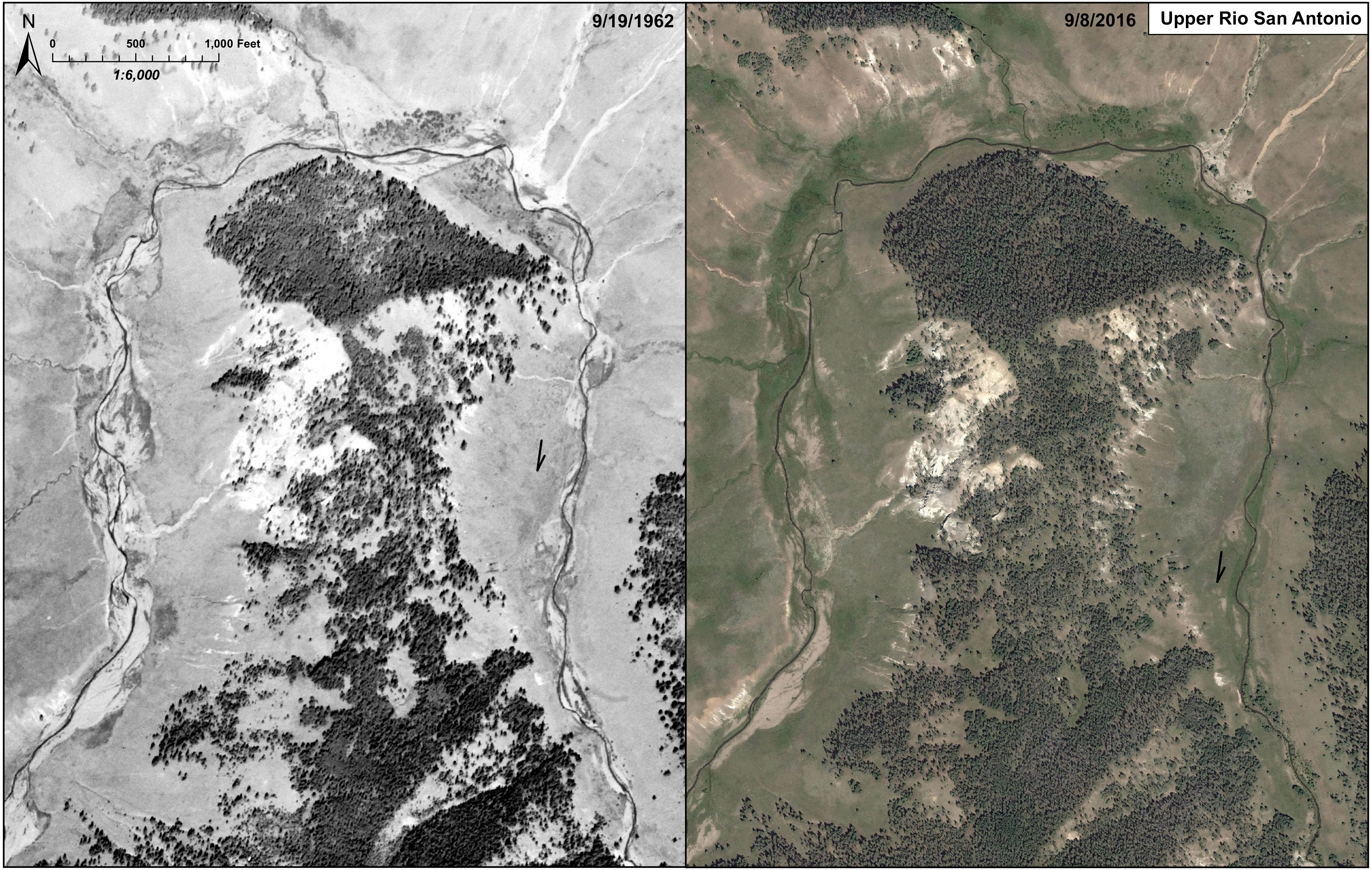
9/19/1962
9/8/2016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