APPENDIX B – GEOMORPHOLOGICAL ANALYSIS

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1.1 INTRODUCTION

In the Geomorphic Reconnaissance and GIS Development, Yellowstone River, Montana report (Applied Geomorphology 2004), the river reach through Laurel (designated A17 in the report) is classified as “unconfined anabranching”. Unconfined anabranching is further defined in the report by the following characteristics: low natural confinement, moderate gravel bar frequency, high side channel frequency, and a high relative rate of change. Numerous other studies have been conducted on the Yellowstone river and they all agree with this general assessment.

1.2 HISTORICAL AERIAL PHOTO INVESTIGATION

Historical aerial photographs were analyzed to gain a long-term perspective of the geomorphological trends in this reach of the Yellowstone. Photographs were analyzed from the following years: 1950, 1976, 2001, 2004, 2005, 2009, and 2011. Exhibits of the aerial photographs are included following this section. A discussion of the findings from the aerial photography is included below.

The Yellowstone River upstream from the railroad and highway bridges has changed its course significantly between 1950 and 2011. The channel has migrated toward the left bank (looking downstream) approximately 400 to 450 feet over this time period. The angle of flow has changed from approximately 17 degrees from the south in 1950 to approximately 11 degrees from the north in 2011. That nearly 30-degree change has moved the thalweg (point of highest flow volume), in such a way, that shear stress and scour has changed significantly since 1950.

1950

The channel is moving into the bridge at an angle of about 17 degrees south of perpendicular. It maintains a multi-thread channel that cuts through a fairly large sediment slug. The “main” channel upstream is difficult to identify, and there may not be one.

1976

The channel has eroded a large portion of the right bank just upstream of the bridge and formed an anabranch that turns 90 degrees at the railroad grade. But most of the flow is now on the left side of the sediment slug, which by that time has developed what appears to be a cottonwood riparian community.

1996

The main flow is still on the left side of the belt width zone. However, the thalweg is moving toward the right side of the bridges and takes a sharp left turn prior to passing beneath the bridges.

2001

The sediment slug has essentially been abandoned on the right side of flow. There is some evidence of erosion on the left bank, with the most significant change taking place just upstream of the bridge. Flow through the bridge is bifurcate, with one channel on the right side of the bridge and a smaller one on the left. The presence of the multiple channels implies the presence of aggradation upstream of the bridges. The anabranch on the right side that formed prior to 1976 is still present, but appears to be serving more as an overflow channel.

2004

The channel appears to have continuing aggradation upstream, but there is no clear main channel. The backwater on the right side at the railroad grade may be a major point of flow. The left side of the channel appears to have wider, shallower flow.

2005

The aerial photo from 2005 was taken during what appears to be a relatively high discharge. No clear indicators in the photograph allow for determining the locations of bars or areas of aggradation. Flow encompasses the entire width of the bridge span. There are no indicators of significant erosion on the left bank upstream of the bridges.

2009

The 2009 photo was taken at somewhat lower flow than the 2005 photo. A bar on the left side of the channel upstream of the bridge is partially exposed. The thalweg, however, appears to be more directly aimed at the right side of the channel beneath the bridges.

2011

The bridges introduce an obvious constriction to the natural floodplain. During high flows, the bridges create a backwater effect upstream. This backwater effect slows the velocity of the water and deposits sediment. The deposition of sediment has resulted in an abnormally steep gradient immediately upstream of the bridges. The 2011 photo shows significant erosion on the left bank upstream of the bridges (approximately 160 feet since 2009). The channel has adjusted to this steep gradient by meandering and adding length in order to lessen the gradient. The channel will likely continue to meander to the north (immediately upstream of the bridges) until it has added enough length to reach a stable gradient. That change in configuration has not only reinforced the change of flow to the right side of the channel beneath the bridges, but has also changed the angle at which the thalweg crosses beneath the structures. This change is likely responsible for the erosion on the right side of the channel downstream of the crossing. That side of the river appears to be receiving a more direct flow, which increases the shear stress.

Implications

The growth of a bar immediately upstream of the north side of the bridges, when combined with the migration of the channel upstream of that point, leads to the conclusion that the channel is attempting to form a meander system in the vicinity of the bridge. The buildup of sediment beneath and upstream of the bridges on the left side is indicative of point bar formation. Point bars develop on the insides of meanders. However, the river cannot form the lower part of the meander, nor can it develop what should be a corresponding meander downstream because of the existing infrastructure.

If the channel, upstream of the bridges, continues to meander to the north, the right side of the channel beneath the bridges will likely continue to host the thalweg, and it will continue to cause the channel to move to the south side of the bridges and deposit sediment on the north side of the channel. As the channel upstream of the bridges meanders farther to the north, the bank along Riverside Park will continue to experience substantial shear stress as the channel tries to meander to the south along the length of the park. The armoring of the bank and reestablishment of its original alignment are crucial to preventing the channel from meandering further to the south in this area.

1.3 RIVER TRAINING DISCUSSION

It is apparent, based on the above analysis, that the river is prone to lateral migration in this reach. Therefore, if the intake is to remain in its current location, river training must be incorporated to ensure that the river does not migrate further and that the water surface is at an adequate level at low flows. River training has been discussed and recommended by several regulatory agencies and studies.

In the 2000 study by the U.S. Army Corps of Engineers (COE), they state that "moving the intake structure either upstream of downstream from the bridge would not completely solve the sedimentation problems that currently plague the existing structure. Some river-training structures would most likely be needed at the alternate locations." Furthermore, the recommended alternative of the study was bendway weirs.

A geomorphic analysis completed by Womack and Associates, Inc. in 2000 gives the following recommendations: "Channel armoring and training should be consistent with river morphology, maintaining channel geometry, meander radius, etc…Long riprap lengths are not recommended. Weirs and spurs are preferable to riprap."

R. Mark Wilson, Field Supervisor for the U.S. Fish and Wildlife Service (USFWS), states in a February 2002 letter to HKM Engineering, Inc. regarding the intake,

> "the Service additionally recommended that the Corps examine the applicability of constructing a modified low profile 'W' weir in conjunction with, or in place of, Alternative Three [new intake alternative in 2002 HKM study]. We regret that this recommendation was not considered in the new feasibility study."

Toney Ott, Environmental Scientist for Region 8 of the U.S. Environmental Protection Agency (EPA), states in a February 2012 public comment letter to the COE,

> "The Corps did prepare a planning study for the City of Laurel to assist in the management of the intake structure and river. The city did not utilize river management techniques such [as] weirs or wing dams to manage river lateral movement suggested in the Corps planning study."

The above studies and correspondence give substantive evidence that if the intake is to remain in its current location, river training measures should be incorporated into a final solution to mitigate the City of Laurel's water supply problem. These reports and other correspondence are included in Appendices G-J. However, as documented in recent meetings and correspondence with regulatory agencies (i.e. FWP, DEQ, and COE), river training measures, especially river spanning structures, are extremely undesirable from an environmental perspective and would be difficult, if not impossible, to permit. Therefore, the geographical scope of the project was broadened in order to seek a more stable reach of the river.

1.4 IDENTIFICATION OF STABLE REACHES OF THE RIVER

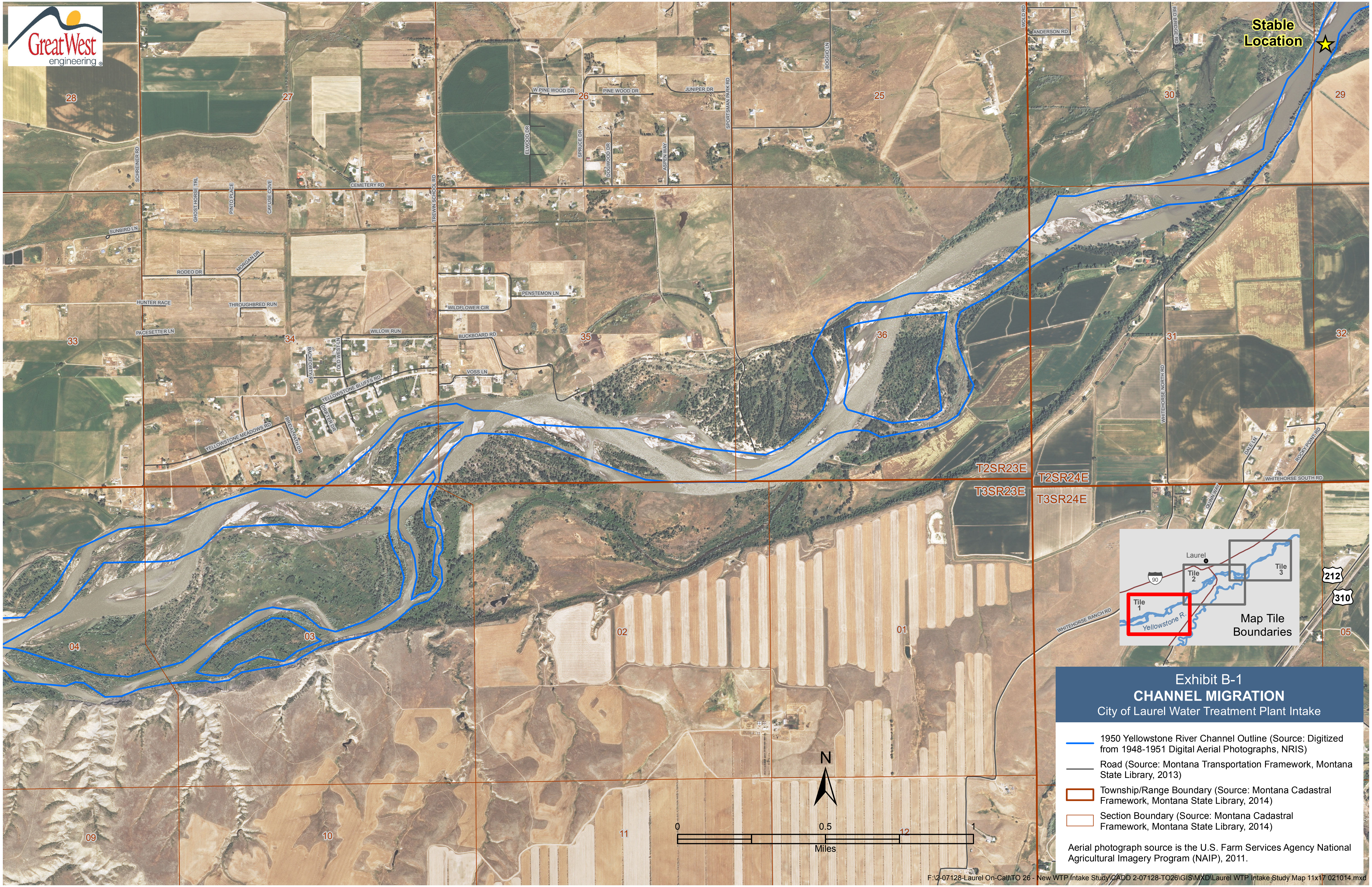
Aerial photographs, as previously described, were used to identify the location of the main channel of the river and its tendency to migrate. The 1950 photographs were compared against the 2011 photographs for approximately six miles upstream and six miles downstream of the highway and railroad bridges. Over this twelve-plus mile reach, only three stable locations were identified:

1. 2.5 miles upstream of the highway/railroad bridges, adjacent to the Canyon Creek Ditch point of diversion
2. 1600 feet downstream of the highway/railroad bridges, near the BBWA point of diversion
3. 2.8 miles downstream of the highway/railroad bridges or 1.1 miles downstream of the confluence with the Clarks Fork of the Yellowstone, where the river meanders to the north and parallels the BBWA ditch

Each of these locations has remained relatively stable over a period of 60 years, while other portions of the river in this stretch have migrated thousands of feet. These locations are shown on aerial exhibits included in this appendix.

Of these locations, only 1) and 2) should be considered further for the possibility of siting a new intake. Location 3) has several disadvantages. The primary disadvantage is that it is downstream of the Clarks Fork of the Yellowstone, which introduces large amounts of sediment and other contaminants into the Yellowstone. The water treatment plant would have to be modified in order to accommodate the change in water chemistry. In addition, this site is down-gradient from the water treatment plant, and water would have to be pumped, which would add cost and complexities to the system.

Locations 1) and 2) should be further evaluated as potential sites for a new surface water intake.



GreatWest engineering
Stable Location
T2SR23E
T2SR24E
T3SR23E
T3SR24E
Laurel
Tile 1
Tile 2
Tile 3
Yellowstone R.
Map Tile Boundaries
N
0
0.5
1
Miles
Exhibit B-1
CHANNEL MIGRATION
City of Laurel Water Treatment Plant Intake
1950 Yellowstone River Channel Outline (Source: Digitized from 1948-1951 Digital Aerial Photographs, NRIS)
Road (Source: Montana Transportation Framework, Montana State Library, 2013)
Township/Range Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Section Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Aerial photograph source is the U.S. Farm Services Agency National Agricultural Imagery Program (NAIP), 2011.
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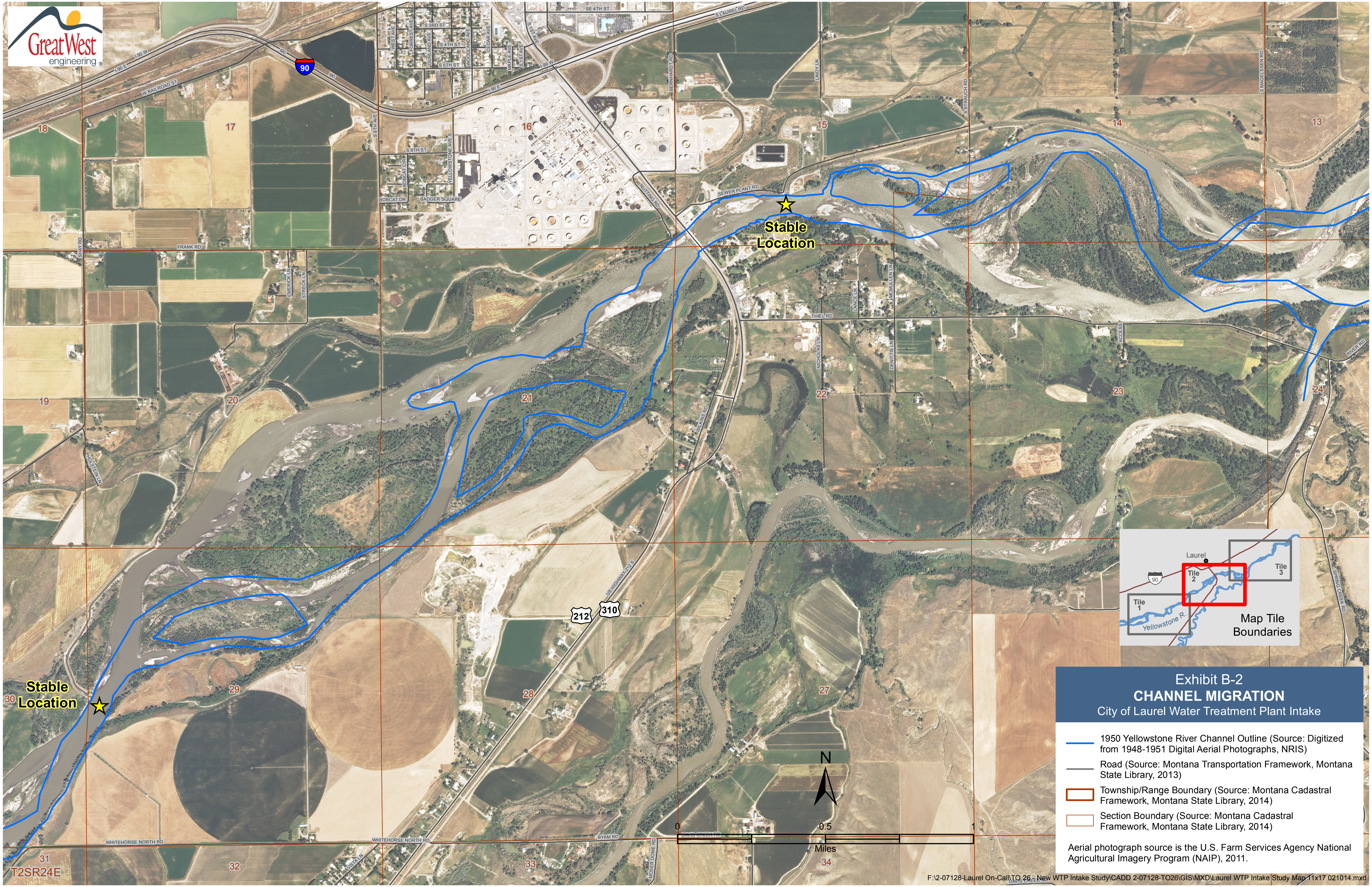
GreatWest engineering
Stable Location
Stable Location
Exhibit B-2
CHANNEL MIGRATION
City of Laurel Water Treatment Plant Intake
1950 Yellowstone River Channel Outline (Source: Digitized from 1948-1951 Digital Aerial Photographs, NRIS)
Road (Source: Montana Transportation Framework, Montana State Library, 2013)
Township/Range Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Section Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Aerial photograph source is the U.S. Farm Services Agency National Agricultural Imagery Program (NAIP), 2011.
Map Tile Boundaries
Laurel
Tile 1
Tile 2
Tile 3
Yellowstone R.
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0
0.5
1
Miles
T2SR24E
90
212
310
SEWER PLANT RD
THIEL RD
FRANK RD
WHITEHORSE NORTH RD
BYAM RD
RIVER RD
S 3RD ST
S 4TH ST
S 5TH ST
S 9TH ST
SE 4TH ST
S LAUREL RD
W RAILROAD ST
BOBCAT DR
BADGER SQUARE
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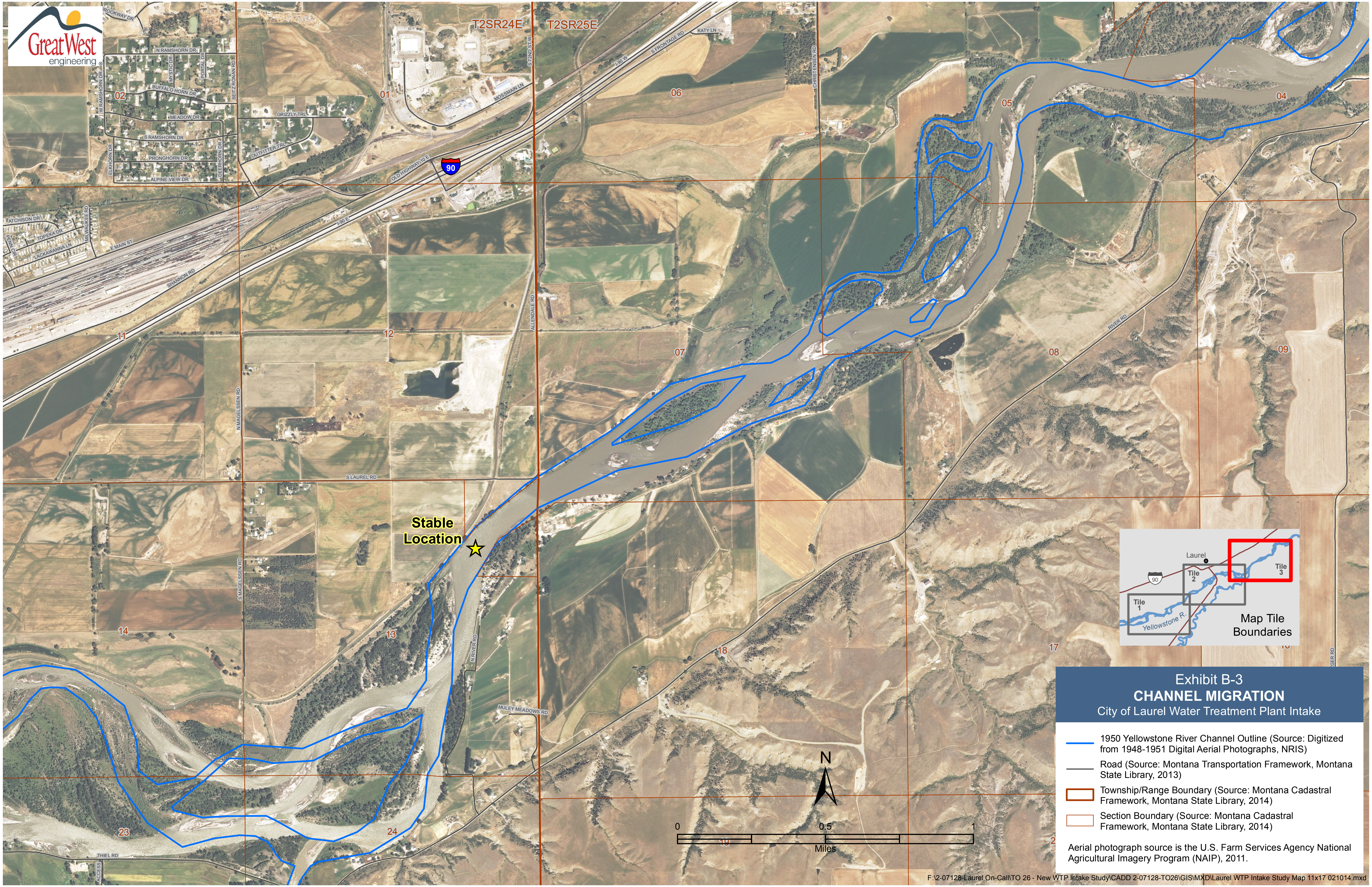

GreatWest engineering
T2SR24E
T2SR25E
Stable Location
Map Tile Boundaries
Laurel
Tile 1
Tile 2
Tile 3
Yellowstone R.
Exhibit B-3
CHANNEL MIGRATION
City of Laurel Water Treatment Plant Intake
1950 Yellowstone River Channel Outline (Source: Digitized from 1948-1951 Digital Aerial Photographs, NRIS)
Road (Source: Montana Transportation Framework, Montana State Library, 2013)
Township/Range Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Section Boundary (Source: Montana Cadastral Framework, Montana State Library, 2014)
Aerial photograph source is the U.S. Farm Services Agency National Agricultural Imagery Program (NAIP), 2011.
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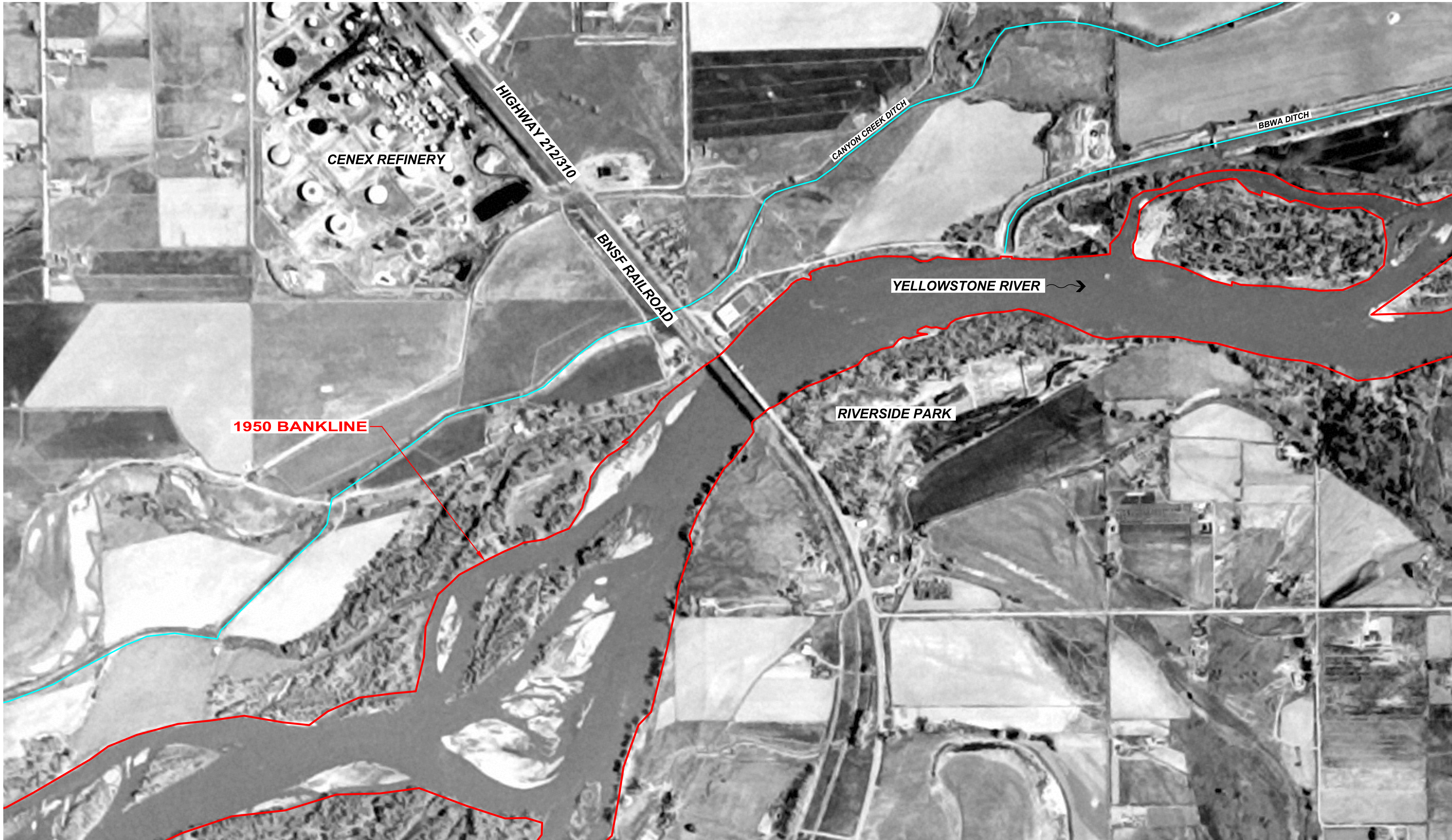

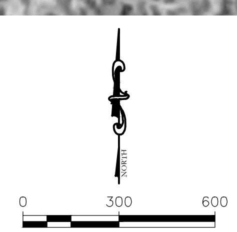

YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-4
PHOTO DATE - 1950

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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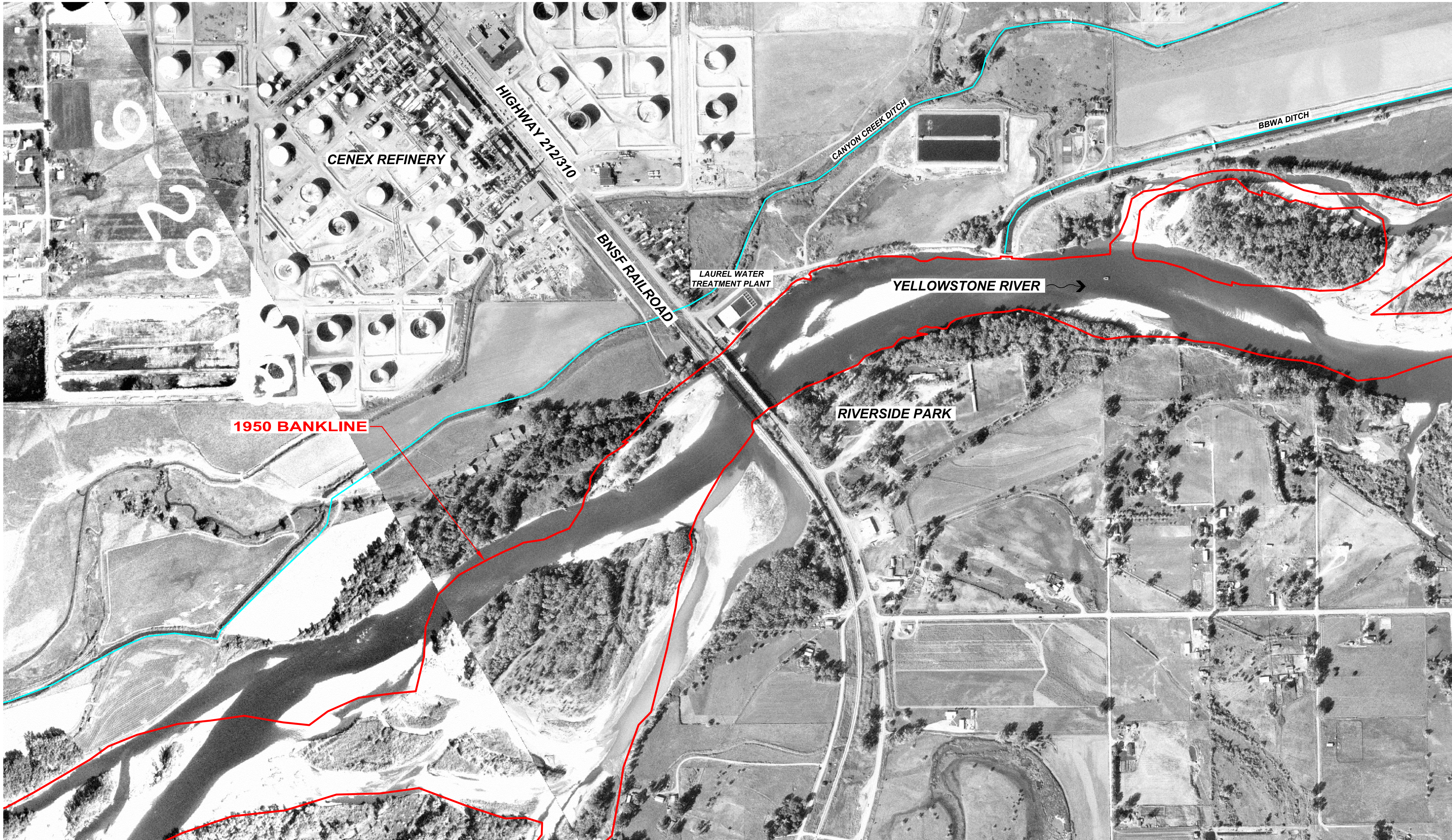

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0 300 600
SCALE IN FEET

YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-5
PHOTO DATE - 1976

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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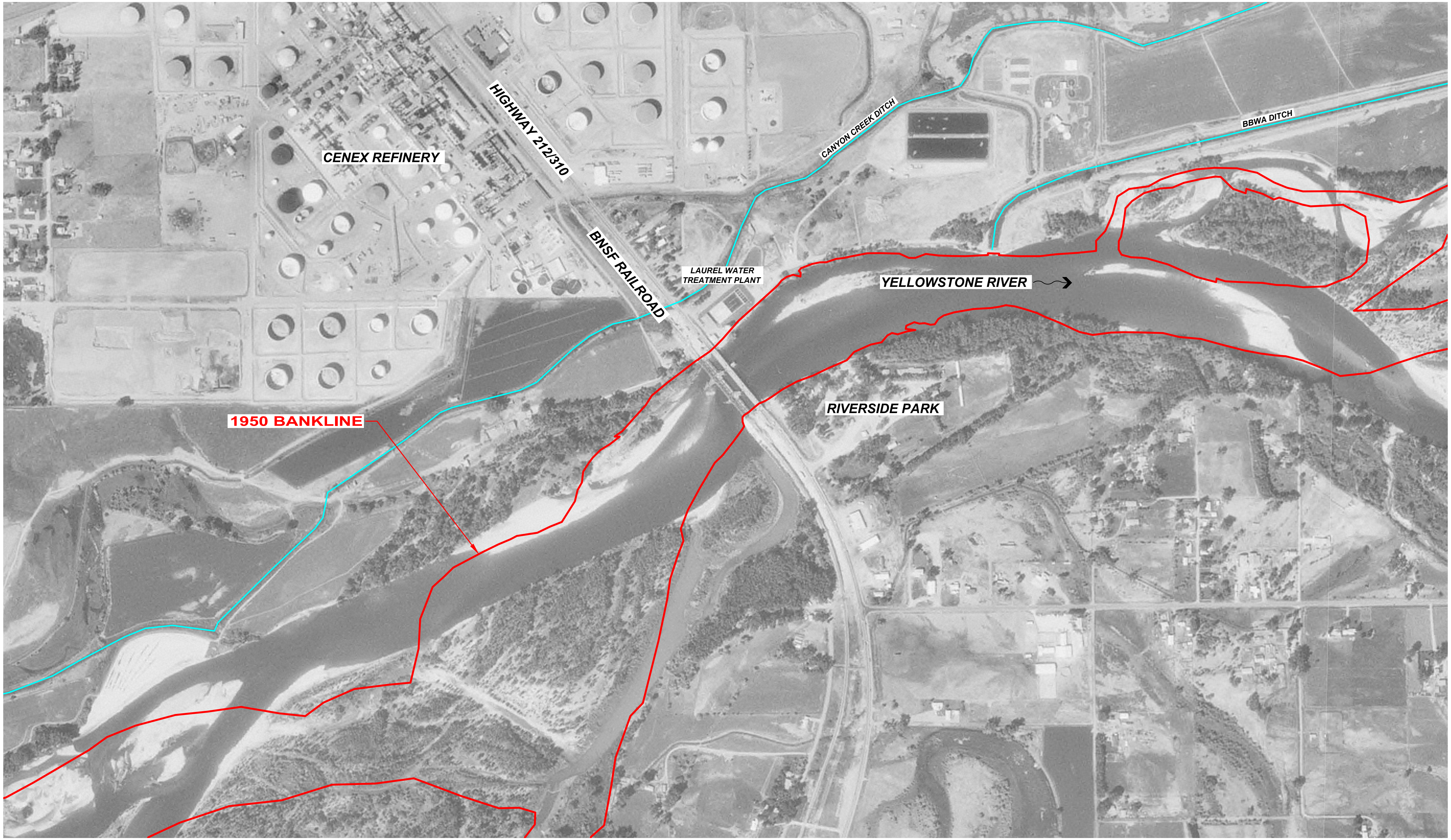

GreatWest engineering

0 300 600
SCALE IN FEET

YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-6
PHOTO DATE - 1996

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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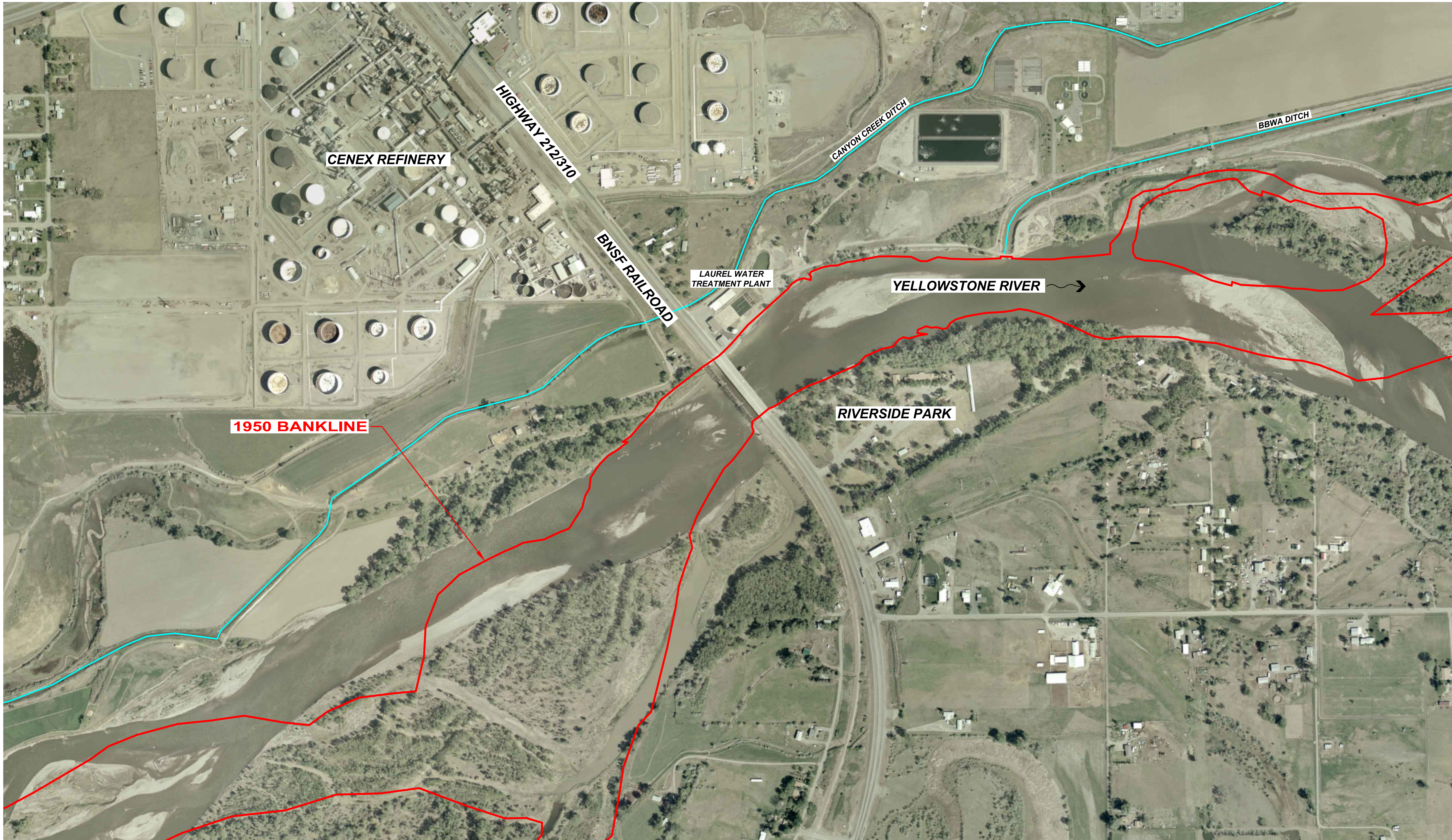
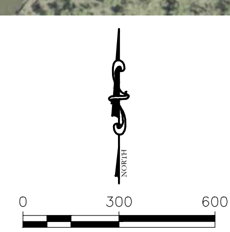
GreatWest engineering

0 300 600
SCALE IN FEET

YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-7
PHOTO DATE - 2001

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY





YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-8
PHOTO DATE - 2004

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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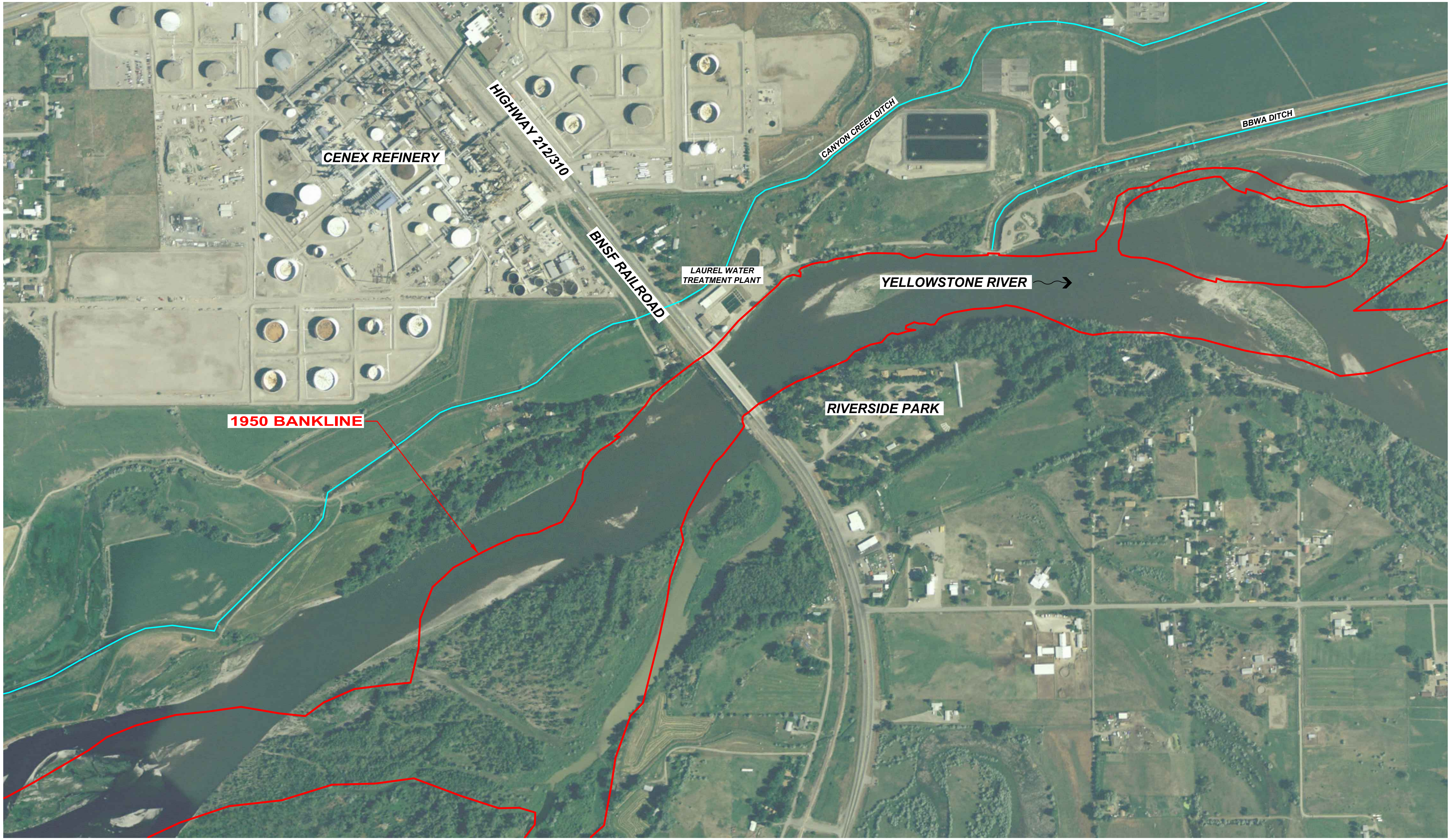

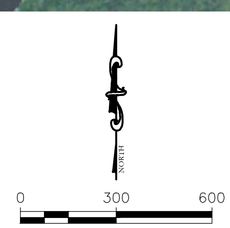

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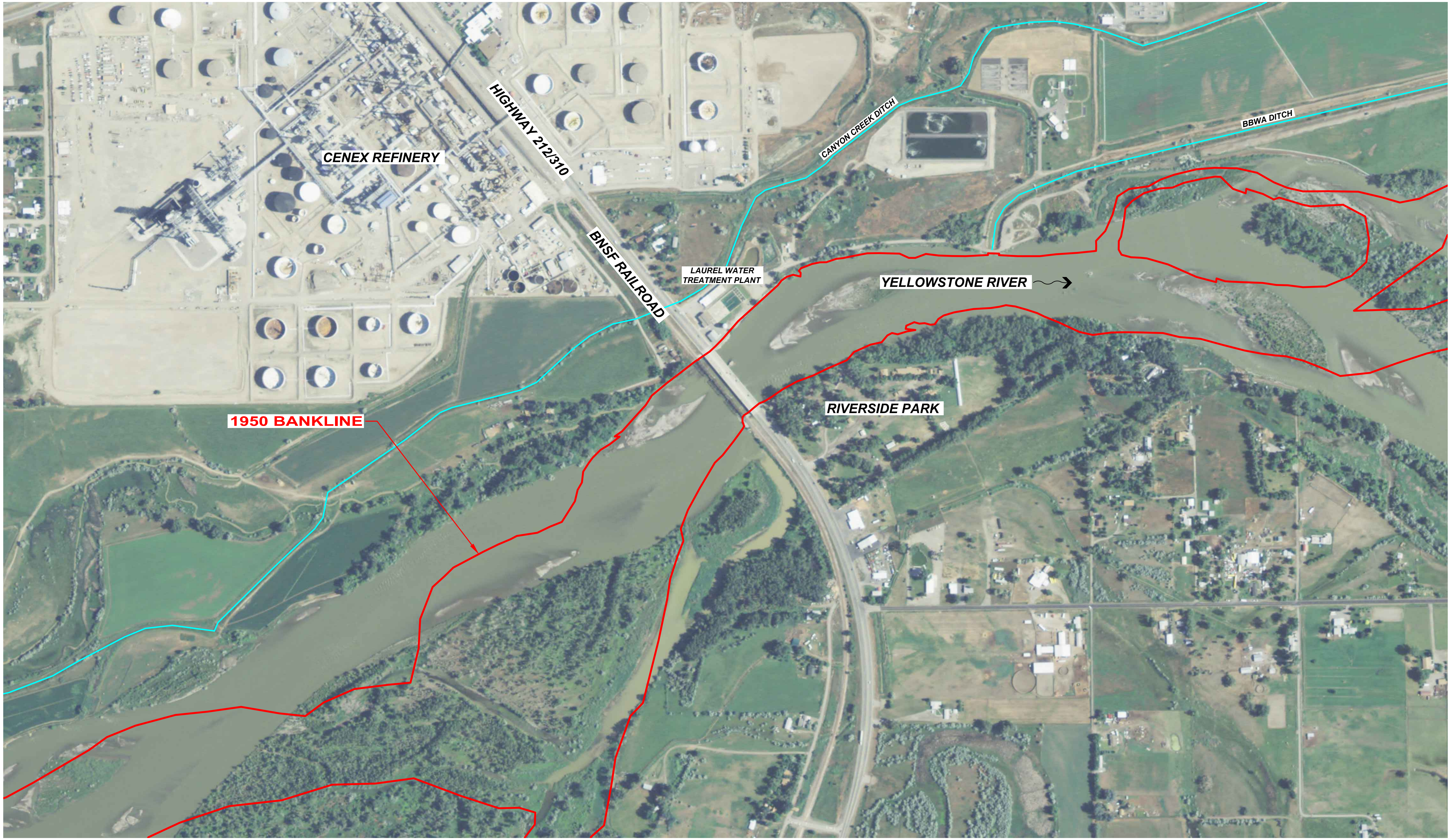
YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-9
PHOTO DATE - 2005

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY



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SCALE IN FEET

YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-10
PHOTO DATE - 2009

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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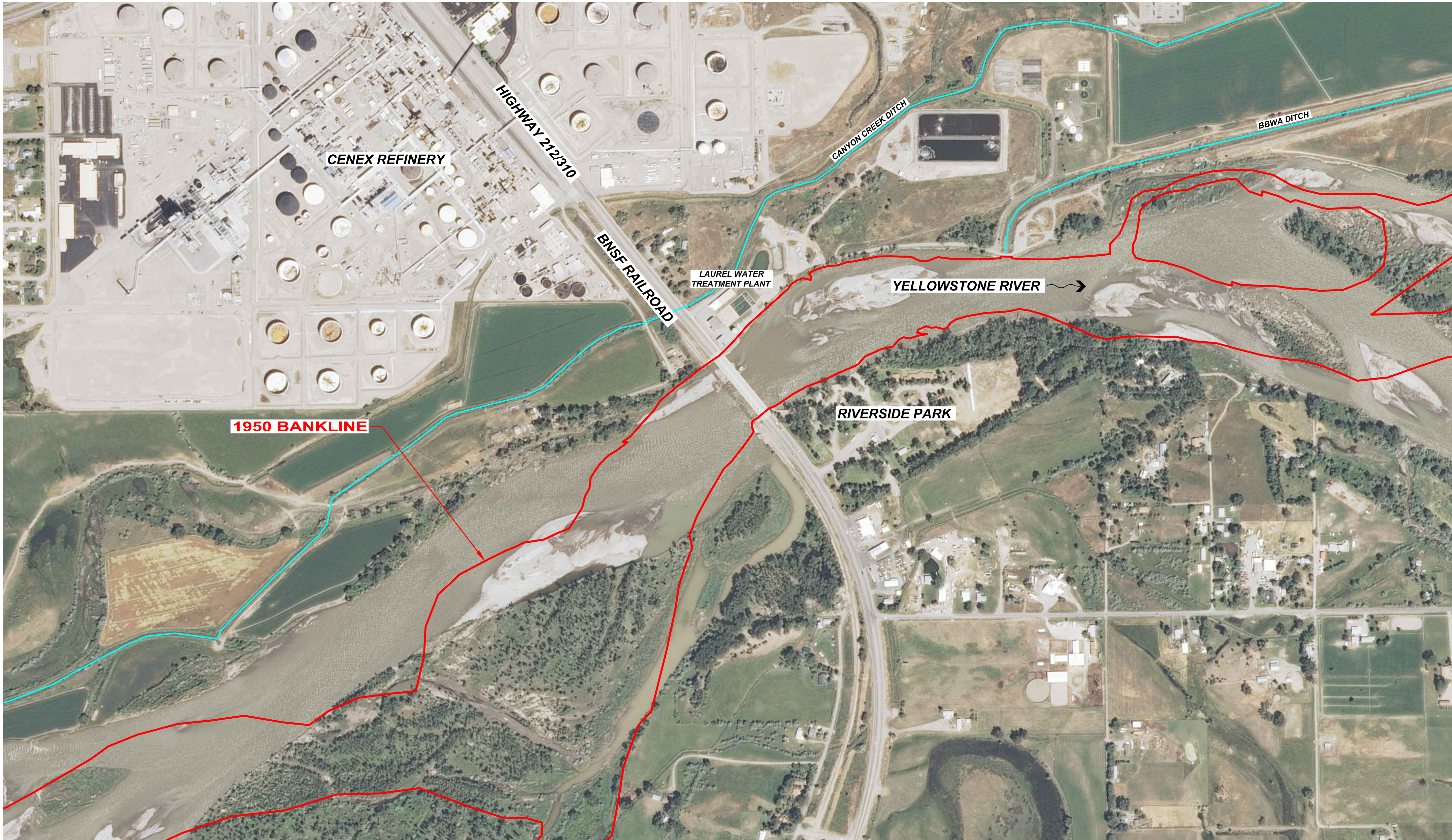

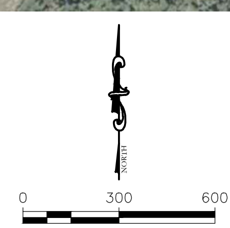

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YELLOWSTONE RIVER NEAR LAUREL
AERIAL PHOTO EXHIBIT B-11
PHOTO DATE - 2011

CITY OF LAUREL, MONTANA
WATER TREATMENT PLANT INTAKE FEASIBILITY STUDY

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