APPENDIX D

ALTERNATIVES ANALYSIS REPORT

Alternatives Analysis - Prescreen

Reach	1	2	3	4	5	6	7
Description	D/S of Longmont (confluence with Boulder Creek to E. corp limits of Longmont)	Longmont Proper (E. corp limits of Longmont to Airport Rd)	Longmont to Lyons (Airport Rd to just downstream of CEMEX)	Lyons Area (CEMEX to choke in S. St. Vrain Canyon and through Apple Valley along N. St. Vrain)	N. St. Vrain (Apple Valley to Button Rock Reservoir)	S. St. Vrain (choke in canyon to confluence with Middle St. Vrain)	Middle St. Vrain (confluence with S. St. Vrain through Raymond/ Riverside)
"Status Quo" Maintain Existing Configuration	Not an option. Leaving the channel in the existing alignment could result in accelerated erosion to adjacent properties and potentially threaten the stability of upstream projects. Many vertical and lateral instabilities are present.	Not an option due to flood risk.	Large split flow path cascading through old gravel pit ponds, issues with connectivity to historical channel. One split resulted in flooding outside the 100-year floodplain affecting neighborhoods downstream in Longmont.	Not an option due to flood risk.	Not an option due to flood risk.	Limited options due to constraints of canyon geometry and SH7.	Not an option due to flood risk.
Stream Restoration - NCD, Habitat	Stream restoration as necessary to achieve biological connectivity and restore natural beneficial function of stream.	Natural Channel Design could be implemented for biological enhancements.	Stream restoration as necessary to achieve biological connectivity and restore natural beneficial function of stream.	Stream restoration as necessary to achieve biological connectivity and restore natural beneficial function of stream.	Stream restoration necessary to achieve biological connectivity and restore natural beneficial function of stream.	Stream restoration as necessary to achieve biological connectivity and restore natural beneficial function of stream.	Stream restoration necessary to achieve biological connectivity and restore natural beneficial function of stream.
Structural Improvements and Additions	Better candidate for NCD due to natural setting and lack of infrastructure along reach.	City has conceptual design for 100-year channel.	Evaluate functions of gravel pit ponds within reach.	Potential for mix of NCD and hard structures to protect life and property.	Better candidate for NCD due to natural setting and lack of infrastructure along reach.	Better candidate for NCD due to natural setting and lack of infrastructure along reach.	Potential for mix of NCD and hard structures to protect life and property.
Conveyance Improvements	Existing flood hazard does not warrant additional improvements.	City has conceptual design for 100-year channel.	Minimal aggradation in channel due to split flow. Most sediment deposited in gravel pits at upstream portion of reach. Downstream portion of reach did experience some aggradation upstream of Airport Road.	Should be evaluated due to large flood risk and sediment deposition. May be an option in vicinity of CEMEX plant.	Potential for mitigating aggradation downstream of Button Rock and Longmont Dams.	Potential for mitigating aggradation downstream of choke in canyon.	Unlikely candidate since it's in the upper reaches of the watershed.
Roadway Crossings, Underground Conduits	Weld County Road 1/East County Line Road in process of being replaced. One rec path bridge affected. Bridge appears to have survived while path was severely damaged by relocated flow path.	Numerous road and rec path crossings to be evaluated.	Several road crossings within reach need to be analyzed for capacity.	Several road crossings within reach need to be analyzed for capacity.	Several road crossings within reach need to be analyzed for capacity.	N/A	Two road crossing within reach need to be analyzed for capacity.

Alternatives Analysis - Prescreen

Detention/Retention	Existing flood hazard does not warrant additional improvements.	Ponds downstream of Airport Road for flood storage likely won't provide much benefit since they are so far downstream in the watershed and don't have much storage capacity.	Evaluate functions of gravel pit ponds within reach.	Button Rock/Longmont Reservoirs increase capacity to allow for some flood control?	Button Rock/Longmont Reservoirs increase capacity to allow for some flood control?	Potential for detention downstream of choke in canyon?	Unlikely due to property constraints and relatively low flows.
Agricultural Diversions	None in this reach (based on aerial inspection)	TBD	98 diversions in this area?	Several major diversions but safety and fish passage concerns.	TBD	TBD	TBD
Recreation Improvements	Native and Game Fish Habitat	Rec Path all along St. Vrain Creek and Denkins Park Tubing. Trails should consider and minimize environmental impacts to the creek.	Native and Game Fish Habitat	Large interest in fish-friendly whitewater parks in Lyons city limits. Need for fish habitat and fishing access. Consider regional trail connectivity. Trails and parks should consider and minimize environmental impacts to the creek.	Governor mandate for rec path along N. St. Vrain/36 from Lyons to Estes Park. Large interest in whitewater parks in vicinity of existing winery and need for fish habitat. Trails and parks should consider and minimize environmental impacts to the creek.	Native and Game Fish habitat	Native and Game Fish habitat
Acquisition of Floodprone Properties	N/A	Potential as some residential structures in floodplain.	Potential as some residential structures in floodplain.	Large FEMA buyout implications.	Potential as some residential and commercial structures in floodplain.	Potential as some residential structures in floodplain.	Potential as some residential structures in floodplain.
Non-structural Measures	Continue to promote floodplain management activities.	Continue to promote floodplain management activities. More restrictive ordinances possible?	Continue to promote floodplain management activities. Updated flood hazard analysis would provide a better management tool.	Continue to promote floodplain management activities. More restrictive ordinances possible?	Continue to promote floodplain management activities. Updated flood hazard analysis would provide a better management tool.	Continue to promote floodplain management activities. Updated flood hazard analysis would provide a better management tool.	Continue to promote floodplain management activities. Updated flood hazard analysis would provide a better management tool.

Probable Alternative
Requires Additional Evaluation
Not Applicable / Limited Potential

1. REACH 1

1.1 Overview

Reach 1 begins at the confluence of St. Vrain Creek with Boulder Creek and ends at the eastern corporate limits of Longmont. This portion of the creek has been realigned over time through numerous sand and gravel mining sites. During the September 2013 flood, the St. Vrain Creek left its channel and entered old gravel mining sites. Sediment was deposited along the southern bank of the Creek. Although the new flowpath does not adversely affect infrastructure, the stream is unstable and the connectivity is largely nonexistent.

1.2 Assessment

The ecological assessment did not encompass the segment of St. Vrain Creek downstream of County Road 1 because it was inaccessible at the time. However, based on observation during field work, this reach would likely be classified as being in Poor or Fair condition because of channel instability, eroding banks, barriers to movement of fish and aquatic organisms, and disconnected riparian areas. The primary recommendation from the ecological assessment is to ensure that all future bridges and/or culverts that are placed within the creek corridor span the active (low-flow) channel to encourage ecological connectivity.

The planform for this reach of St. Vrain Creek has been relatively stable over the past 60 years, however, there has been some natural lateral migration across the floodplain during this time period. The results of the geomorphic assessment show that the alignment of the channel changed drastically between pre- and post-flood conditions as a result of an avulsion through the reclaimed gravel mining sites. As a result, the planform geometry for this reach is less sinuous and steeper when compared to pre-flood conditions. The primary recommendation from the geomorphic assessment is to return the channel to the pre-flood alignment. However, it is noted that this recommendation may be cost prohibitive.

Infrastructure damage from flooding occurred to the East Countyline Road Bridge, and the pedestrian bridge adjacent to Sandstone Ranch Community Park. There are a few private residences that are at risk for future flooding during larger flood events.

1.3 Alternatives and Evaluation

The Baker Team met with Coalition members in order to define restoration objectives for this reach. In addition to the benefits outlined in Table D.1.2, the following restoration objectives were discussed:

- Restore roadway and pedestrian crossings
- Preserve trees in the pre-flood channel
- Restore the natural channel where it is feasible and not cost prohibitive
- Consider preserving both the pre- and post-flood channel alignments
- Avoid making improvements where risk is not a concern

Other restoration opportunities that were identified consist of:

- Transitioning reclaimed gravel mines into riparian corridors
- Creating a pilot/showcase project for floodplain preservation
- Repair St. Vrain Creek breach below Spring Gulch #2 confluence to return Spring Gulch flows to St. Vrain Creek pre-flood channel

Constraints for this reach are as follows:

- Channel improvements need to be compatible with projects currently underway at East Countyline Road and in Reach 2 (proposed flood control channel underway in Longmont)
- Channel alignment options are restricted near the confluence with Boulder Creek

A total of four alternatives were discussed for this reach. Two of the four alternatives consisted of the channel and floodplain restoration options for both the pre- and post-flood channel alignment. However, based on conversations during the Reach 1 meeting held on August 13, 2014 it was decided that these alternatives would be too cost prohibitive and were not carried forward for further evaluation. As a result, two of the alternatives were developed based on the objectives, opportunities, and constraints outlined above:

Alternative 1 – Split Channel (Reach 1 Alternative 1 Maps 1 - 4)

The purpose of this alternative is to preserve the pre-flood channel alignment and add a primary natural channel to the south of the pre-flood channel. Flow will be delivered to the pre-flood channel with a baseflow diversion, which will help sustain the existing riparian vegetation throughout this corridor. The new channel alignment to the south will convey a majority of the flow in this reach. Flood conveyance is improved with this alternative by eliminating constrictions in the floodplain and implementing floodplain culverts to help convey flood flows through embankments. It is important to note that a significant amount of fill will be required to eliminate the risk of a future avulsion through the reclaimed gravel mining sites and to allow for the construction of the confluence of the parallel channels near the downstream end of the reach.

Alternative 2 – Minor Stabilization (Reach 1 Alternative 2 Maps 1 - 4)

This purpose of this alternative is to implement only the improvements required to protect infrastructure and property that are at risk of being damaged and to implement site-specific projects to protect against major modes of failure. Major modes of failure in this reach consist of headcutting through the reclaimed gravel mining sites and a potential avulsion through the pre-flood channel alignment. Most of the channel will generally remain in the post-flood alignment and continue to cascade through the reclaimed gravel mining sites. It is important to note that the channel will continue to erode and migrate in the absence of any stabilization measures and continued erosion could eventually encroach upon Boulder Creek and adjacent private property.

Table D.1.1 Reach 1 Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Split Channel	Alternative 2 : Minor Stabilization
Earthwork	1	2
Bridges/Culverts	1	2
Hydraulic Structures	2	1
Re-vegetation	1	2
Land/Property Acquisition	1	1
Utilities	1	1
Maintenance	N/A	N/A
	7	9

Table D.1.2 Reach 1 Relative Benefit Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Split Channel**	**Alternative 2 : Minor Stabilization**
Addresses Other Reach Objectives	1	2
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	1	2
Flood Mitigation	2	1
Environmental Restoration	1	2
Public Safety	N/A	N/A
Transportation	N/A	N/A
Aesthetics	2	1
Permitting Requirements	1	2
Right of Way Acquisition / Easements	N/A	N/A
Operations and Maintenance	2	1
Agricultural / Irrigation	N/A	N/A
Consistency with Local Policies and Plans	2	1
	18	15

1.4 Planning Recommendations

The results of the benefit cost analysis show that both of the alternatives have a similar cost and benefit score. The results of this analysis were presented to the SVCC attendees at the meeting on August 13, 2014. Alternative 2 is the recommended alternative because it is the most cost effective solution and there is no infrastructure at risk downstream of the pedestrian trial crossing that needs to be mitigated. Furthermore, preserving the channel in the post-flood alignment will allow denuded areas to be re-vegetated with native plant species.

2. REACH 2

2.1 Overview

Reach 2 begins at the eastern corporate limits of the City of Longmont and ends at Airport Road. This reach includes Longmont proper and is the most heavily populated portion of the St. Vrain. The City of Longmont was among the hardest hit communities during the catastrophic flooding event in September 2013. Damages to City infrastructure, in excess of $148 million, included significant damages to parks and trails along the St. Vrain corridor. A number of homes were flooded at the eastern edge of the reach and numerous bridges and culverts were damaged by floodwaters and debris.

2.2 Assessment

The results of the ecological assessment show that this reach is mostly in "Fair" condition with overall scores ranging between 5-7 out of 10. The lowest scoring elements from the ecological assessment are the degree of hydrologic alteration and factors impacting fish and aquatic habitat. The channel is somewhat unstable and the channel banks are eroding in some locations. The streamflow in this reach has been significantly altered due to upstream hydrologic controls such as diversions, gravel pits, and reservoirs. Hydrologic alteration also has adverse impacts on habitat and riparian ecosystems. The primary recommendations from the ecological assessment are to rebuild floodplain benches, incorporate a low flow channel, and improve in-stream habitat by incorporating pools and planform complexity.

The planform for this reach of St. Vrain Creek has been relatively consistent through the river corridor over the past 60 years. The results of the geomorphic assessment show that the alignment of the channel did not change significantly between pre- and post-flood conditions with the exception of at Dickens Farm Park, where the pond was breached during the flood. The primary recommendation from the geomorphic assessment is to return the channel to the pre-flood alignment.

Substantial infrastructure damage from flooding occurred throughout this reach and several homes were flooded. Numerous businesses and private residences continue to be at risk for future flooding during a 100-year event if no improvements are made.

2.3 Alternatives and Evaluation

A formal alternatives analysis was not completed for this reach. The alternatives and planning recommendations are being determined by ongoing planning and design efforts being completed by Longmont. Longmont hired CH2M Hill to completed a conceptual analysis and design for a 100-year flood conveyance channel between the Golden Ponds and just downstream of Martin Street. There are two alternatives identified in the report titled "Saint Vrain Creek through Longmont: 100-Year Conceptual Design". Both alternatives provide a means of conveying the 100-year peak flow, but differ in total channel width. The wider of the two channel alternatives is depicted in the figures for this reach.

Objectives for this reach consist of:

- Providing 100-year flood conveyance
- Adding in-stream water recreation at Dickens Farm Park
- Implementing a trail along the entire creek alignment
- Improve and/or restore damaged pond embankments
- Recreation enhancements at key locations on the St. Vrain Blueprint

There are limited restoration opportunities within this reach due to the degree of lateral confinement from adjacent development. However, the implementation of a low flow channel within the 100-year flood conveyance channel could help assist in meeting some of the ecological objectives and also improve overall stream health by efficiently moving sediment through the system without aggradation or degradation.

The constraints within this reach are mostly structural. Channel improvements need to be compatible with ongoing projects and other existing constraints identified below:

- Main Street Bridge improvements
- Sunset Boulevard Bridge improvements
- Multiple roadway crossings
- Multiple recreational crossings
- Need for improving the Airport Road Bridge to reduce the potential for debris jams.

Two alternatives were considered for this reach:

- **Alternative 1 - 100-Year Flood Control Channel w/ Low Flow Channel (Reach 2 Alternative 1 Maps 1 - 5)**
- **Alternative 2 - 100-Year Flood Control Channel**

Figures were not developed for Alternative 2 because the only difference in the plans would be the lack of a low flow channel.

Table D.2.2 Reach 2 Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1 : Flood Control w/ Low Flow Channel	Alternative 2: Flood Control
Earthwork	1	2
Bridges/Culverts	1	1
Hydraulic Structures	1	1
Re-vegetation	2	1
Land/Property Acquisition	1	1
Utilities	1	1
Maintenance	2	1
	9	8

Table D.2.2 Reach 2 Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1 : Flood Control w/ Low Flow Channel	Alternative 2 : Flood Control
Addresses Other Reach Objectives	2	2
Natural Channel Restoration	2	1
Recreation	2	2
Fish Habitat	N/A	N/A
Flood Conveyance	2	2
Flood Mitigation	2	2
Environmental Restoration	2	1
Public Safety	2	1
Transportation	2	2
Aesthetics	2	1
Permitting Requirements	2	2

Table D.2.2 Reach 2 Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1 : Flood Control w/ Low Flow Channel	Alternative 2 : Flood Control
Right of Way Acquisition / Easements	2	2
Operations & Maintenance	2	1
Agricultural / Irrigation	N/A	N/A
Consistency with Local Policies and Plans	N/A	N/A
	24	19

2.4 Planning Recommendations

The results of the benefit cost analysis show that both of the alternatives have a similar cost; however, the relative benefit provided by Alternative 1 is much greater. Alternative 1 is the recommended alternative because it provides the same amount of flood control as Alternative 2, but also provides the additional benefits of enhanced environmental restoration opportunities, increased public safety, improved aesthetic value, and require less operations and maintenance.

3. REACH 3

3.1 Overview

Reach 3 begins at Airport Road and ends at Highway 36 near Lyons. This reach is primarily rural, although the St. Vrain Creek interacts with the existing sand/gravel mining sites and irrigation ponds. The St. Vrain Creek corridor is an important corridor for wildlife diversity, water quality, and includes habitat for three federally threatened species. Currently, large areas of intact riparian habitat exist in Reach 3. Additionally, Reach 3 is home to a high number of native fisheries. It is critical that these areas are preserved to ensure long-term ecological health of the creek.

During the September 2013 flood, large split flow paths left the main channel and cascaded through the reclaimed gravel mining sites in the overbanks. The majority of the flood impacts suffered at Lakes 3 and 4 and to the South Branch ditch were caused by the split flow that occurred at Breach 1. One split flow (locally referred to as Breach 7) occurred upstream of Hygiene and resulted in flooding outside of the 500-year floodplain and affected residential downstream in the City of Longmont.

3.2 Assessment

The results of the ecological assessment show that this reach is in “Fair” to “Good” condition with overall scores ranging between 6-7 out of 10. The lowest scoring elements from the ecological assessment are the degree of hydrologic alteration and factors impacting fish and aquatic habitat. Additionally, the channel is somewhat unstable and the channel banks are eroding in some locations. The streamflow in this reach has been significantly altered due to upstream hydrologic controls such as diversions, gravel mining activities, and reservoirs. Hydrologic alteration also has adverse impacts on habitat and riparian ecosystems. The primary recommendations from the ecological assessment are to increase the capacity of Airport Road Bridge, improve and expand riparian zones, enhance and preserve floodplains, and incorporate a low flow channel.

The planform for this reach of St. Vrain Creek has been relatively consistent through the river corridor over the past 60 years, however, there has been some natural lateral migration across the floodplain during this time period. The results of the geomorphic assessment show that the alignment of the channel is similar between pre- and post-flood conditions. However, the post-flood channel alignment did change drastically as a result of an avulsion through the BCPOS ponds and Breach 7 in the ponds upstream of Hygiene Road. The planform geometry at these locations is less sinuous and steeper when compared to pre-flood conditions. The

primary recommendation from the geomorphic assessment was to return the channel to the pre-flood alignment. This work was completed in winter 2014.

Two notable areas of flooding occurred during last September in this reach. The first was upstream of the Cemex plant where flood flows overtopped the channel banks and the road entrance to the plant (locally referred to as Breach 1). Flood flows continued downstream and entered the BCPOS ponds, which ultimately resulted in an avulsion and drastic change in channel alignment. The second area is the overtopping of a pond just upstream of Hygiene Road (Breach 7), which eventually resulted in additional pond flooding and breaches downstream. Flood flows eventually overtopped the adjacent railroad and flooded many homes outside of the effective 500-year floodplain. No roadway crossings were completely destroyed, but some of them experienced minor damage. The Airport Road Bridge did become clogged with debris and caused flooding on adjacent landowners' properties.

It should be noted that many of the breaches in this reach have emergency repairs implemented at this time, and the majority of hazardous debris in the channel was removed. A large amount of work has gone into minimizing flood risk in anticipation of the 2014 spring run-off season and the potential of another flood prior to permanent repairs. In most cases, these efforts performed by BCPOS, City of Longmont, and private property owners, have returned the stream flows to the pre-flood channel. The proposed site-specific projects in this chapter may be permanent repairs to emergency measures that were undertaken by others.

3.3 Alternatives and Evaluation

In addition to the benefits outlined in Table D.3.2, the following restoration objectives were discussed:

- Incorporate ongoing planned projects for BCPOS ponds (prepared by BCPOS)
- Fix the split flow and breach at Breach 7
- Evaluate and improve roadway crossing capacity where necessary
- Restore the natural channel where it is feasible
- Permanent repairs of breaches
- Preserve existing habitats
- Protect native species
- Remain compliant with existing planning documents and management plans

There are many channel segments within this reach that are stable and functioning well in the post-flood condition. Therefore, the opportunity exists to recommend site-specific restoration projects as opposed to wholesale channel restoration. This method will not only save cost, but also reduce interim impacts to the channel as a result of construction.

The primary constraint within this reach exists at Airport Road. It is crucial that a solution be developed to prevent the overtopping of Airport Road. Overtopping at this location could reduce or eliminate the potential benefit provided by the 100-year flood control channel in Reach 2 because flood flows upstream of Airport Road would not have a concentrated point of conveyance towards the downstream channel improvements. Channel improvements within this reach need to correspond with potential improvements Airport Road.

Although some reclaimed gravel ponds still interact with the creek (e.g. just upstream of Hygiene Road), others have been temporarily repaired and are no longer connected to the creek (specifically, Breaches 1, 2, and 7). It is important to note that there are negative ecological impacts where the creek and reclaimed gravel ponds are still connected. These impacts include damage to native fisheries and aquatic insects through the introduction of invasive predators and long-term water-quality impacts. Immediately after the 2013 flood, emergency work was completed to repair Breaches 1, 2, and 7. Temporary berms were constructed; however, permanent repairs to Breaches 1, 2, and 7 are essential to the long-term resilience of St. Vrain Creek. In addition, it is critical that Breaches 3 - 6 and Breaches 8 and 9 are incorporated into the long-term recovery strategy for the creek. Breach repairs and habitat preservation are a priority for local stakeholders in the creek corridor. Colorado Parks and Wildlife, which designated the Foothills region of the St. Vrain watershed a"Wild Trout Water" in 2008, is an important partner in coordinating future restoration work in and around Reach 3.

Two alternatives were developed based on the objectives, opportunities, priorities and constraints outlined above:

Alternative 1 – 100-Year Flood Control Channel (Reach 3 Alternative 1 Maps 1 - 6)

The purpose of this alternative is to provide 100-year flood conveyance throughout the reach and also repair pond breaches, eliminate future avulsion risk, and evaluate and redesign undersized infrastructure. This alternative would correspond well with improvements at Airport Road and the downstream 100-year flood conveyance improvements in Reach 2.

Alternative 2 – Restoration w/ Site-Specific Projects (Reach 3 Alternative 2 Maps 1 - 6)

The purpose of this alternative is to restore the natural channel throughout the entire reach. As previously mentioned there are many channel segments within this reach that are stable and functioning well in the post-flood condition. As a result, many site-specific restoration projects are recommended as opposed to a wholesale channel restoration. Restoration and stabilization of the pre-flood channel alignment is generally recommended; however, there are a few locations where a slightly modified channel alignment is recommended. Restoring the channel to the pre-flood alignment provides many benefits such as the presence of established vegetation and an established floodplain bench and low-flow channel. This alternative also addresses the required repairs to pond breaches, eliminates future avulsion risk, and evaluates and redesigns undersized infrastructure.

Table D.3.1 Reach 3 Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Flood Control	Alternative 2: Restoration w/ Site Specific Projects
Earthwork	1	2
Bridges / Culverts	1	2
Hydraulic Structures	1	2
Re-vegetation	1	2
Land / Property Acquisition	1	2
Utilities	1	1
Maintenance	1	2
	7	13

Table D.3.2 Reach 3 Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Flood Control	Alternative 2: Restoration w/ Site Specific Projects
Addresses Other Reach Objectives	1	2
Natural Channel Restoration	1	2
Recreation	1	2
Fish Habitat	1	2
Flood Conveyance	2	1
Flood Mitigation	2	2
Environmental Restoration	1	2
Public Safety	2	1

Table D.3.2 Reach 3 Relative Benefit Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Flood Control**	**Alternative 2: Restoration w/ Site Specific Projects**
Transportation	N/A	N/A
Aesthetics	1	2
Permitting Requirements	1	2
Right of Way Acquisition / Easements	1	2
Operations & Maintenance	1	2
Agricultural / Irrigation	1	2
Consistency with Local Policies & Plans	N/A	N/A
	16	24

3.4 Planning Recommendations

The results of the benefit cost analysis show that Alternative 2 is the lowest cost alternative and provides the most overall benefit. Alternative 2 is the recommended alternative because it preserves stable sections of this reach that do not need to be restored and enhances the overall reach by restoring damaged sections to a stable condition by implementing natural restoration practices. The implementation of Alternative 2 will result in enhanced recreation, fish habitat, environmental restoration, and overall aesthetics when compared to Alternative 1. Additionally, Alternative 2 will likely be easier to permit and require less operations and maintenance.

4. REACH 4

4.1 Overview

Reach 4 begins at Highway 36, continuing upstream through Lyons along both South and North St. Vrain Creeks. North St. Vrain Creek from the upstream-most Apple Valley Bridge to the confluence, the South St. Vrain River from just upstream of the Andesite Quarry downstream to the confluence, and on the main stem of St. Vrain Creek from the confluence downstream through the Town of Lyons to Highway 36. The Town of Lyons was severely damaged during the September 2013 flood event. The flood destroyed critical segments of the Town's electrical, sewage, and potable water systems, as well as damaging or destroying nearly 30% of the Town's housing stock. The floodwaters breached the Town's wastewater treatment plant, contaminating Lyon's water supply. Multiple sections of the St. Vrain left the original channel and the flood permanently damaged many of the Town's roads, bridges, parks, trails, and stream channels. Floodwaters also destroyed Lyons Public Works facilities and equipment, and the Town Hall and Library building. The total amount of damage to the Town of Lyons is estimated at $50 million, including $5 million in temporary measures.

4.2 Assessment

The results of the ecological assessment show that this reach is generally in "Fair" condition with overall scores ranging between 5-6 out of 10. There is one section on South St. Vrain Creek that is in "Poor" condition. The lowest scoring elements from the ecological assessment are the degree of hydrologic alteration and factors impacting fish and aquatic habitat. Additionally, the channel is somewhat unstable and the channel banks are eroding in some locations. The streamflow in this reach has been altered due to upstream hydrologic controls such as diversions and reservoirs. Hydrologic alteration also has adverse impacts on in-stream habitat and riparian ecosystems. The primary recommendations from the ecological assessment are to incorporate planform complexity, improve and add in-stream habitat, preserve and expand floodplains, and design roadway crossings that promote the natural function of a channel.

The planform for this reach has been relatively consistent through the river corridor over the past 60 years; however, there has been some natural lateral migration across the floodplain during this time period. The results of the geomorphic assessment show that the alignment of the channel differs between pre- and post-flood conditions in areas with wider valley bottoms and flatter longitudinal slopes. The planform geometry at these locations is less sinuous and steeper when compared to pre-flood conditions. The primary recommendation from the geomorphic assessment is to return the channel to the pre-flood alignment.

Flooding in this area was most severe at the confluence of North and South St. Vrain Creeks. Many residences and business were flooded within Lyons and remain at risk for future flooding.

4.3 Alternatives and Evaluation

After the floods many groups have collaborated to develop Project Development Guides (PDGs) which were ranked in the Lyons Recovery Action Plan (LRAP) by the Board of Trustees, Planning and Community Development Commission and the Sustainable Futures Commission. These ranking were developed with heavy community and local government input.

The PDGs consist of a detailed questionnaire that facilitates collection and evaluation of information about goals, strategies and expected outcomes of proposed projects and programs. The PDG format assisted local government and stakeholders (i.e. business groups, schools, non-profit organizations, businesses, local association and community members) to create projects for the long-term community recovery process. The PDG, when used to identify and organize information, provides a number of benefits: streamlined data, ease of analysis, consistent formatting and sourcing of information, assist in fundraising efforts and can serve as a benchmark against which progress is measured.

The LRAP is a comprehensive plan that includes goals for arts, culture & historic preservation, economic & business, health & human services, housing, infrastructure, parks & recreation, and the stream. PDGs were developed to achieve the goals in the LRAP. The PDGs identified in the LRAP that are relevant to the river corridor include the stream specific PDGs (see Table D.4.1) and the Parks & Recreation PDGs.

Table D.4.1 Lyons Recovery Action Plan Stream PDGs
1. Re-vegetate the North, South, and combined Creek corridor in Lyons
2. Improve riparian habitats and bank stabilization from the confluence to McConnell Bridge
3. Restore and improve North, South and combined St. Vrain corridor in Lyons
4. Assess the ongoing water quality in the St. Vrain during flood response, recovery, and restoration
5. Restock the native fisheries in the St. Vrain River, and improve aquatic habitat for fish species
6. Design & implement the ponds and associated wetlands to promote increased natural areas, and provide a variety of recreational and hazard mitigation
7. Mitigate high water mark debris and sediment deposits
8. Mitigate Highway 36 CDOT bridges near the Planet Bluegrass property
9. Mitigate channelization of the North St. Vrain from 5th Ave to confluence
10. Develop detention and retention units on South St. Vrain Creek to Boulder County Open Space as a means of flood mitigation

The Lyons Flood Recovery Task Force identified six objectives for this area:

1. Flood Mitigation - The mitigation of flood impacts by addressing bridges, by creating detention and retention and by restoring the river in a way that maintains and improves existing flood boundaries.

2. Recreation - The creation of in-stream and bankside recreational opportunities that invite people to kayak, float, camp, cycle, walk, fish, tube, spectate, and otherwise enjoy the river and its bank.

3. Economic Impact - Connect the river to the downtown in a way that revitalizes the Lyons economy through increased opportunities to recreate along the river for locals and visitors alike.

4. Aquatic & Riparian Habitat - The creation and preservation of a showcase example corridor that features a continuous and connected riparian and in-stream habitat that is designed to optimize the natural habitat within the reach.

5. Infrastructure - Set a standard for infrastructure in the river corridors that is robust, aesthetically appropriate to the river corridor, and that contemplates recovery from the next major event.

6. Private Property - Definition of a process that encourages future property (Re)Development in a responsible way such that it fosters a healthy river and riparian system and respects flood impacts to neighboring properties.

Other restoration opportunities that were identified by the Baker Team consist of:

- Incorporate projects that address multiple objectives
- Develop and enforce new development standards
- Incorporate multi-purpose diversion structures

Constraints for this area are as follows:

- Significant amount of private property
- Significant amount of roadway crossings
- Uncertainty with potential buyout properties

A significant amount of planning, design, and construction has already taken place for the reaches in this area and somewhat constrain the ability to consider multiple alternatives. As a result, the alternatives analysis for this area focused on different options for channel alignment and includes recommendations for site-specific projects to work in concert with ongoing flood recovery efforts that address objectives for this area. This chapter will focus on specific areas that require input on long-term stream alignment and options that need to be vetted related to upcoming projects.

4.3A Reach 4A

Two alternatives were developed to work in concert with the ongoing post-flood restoration efforts being completed in this area.

Alternative 1 – Channel Realignment & Site-Specific Projects (Reach 4a Alternative 1 Maps 1 - 3)

The purpose of this alternative is to implement a channel alignment that will optimize the interaction with completed, ongoing, and funded projects while being sensitive to the constraints presented by the presence of numerous private residences throughout this river corridor. The implementation of this alternative will expedite the maturation of this reach by re-establishing a natural channel, repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks.

Alternative 2 – Leave As-Is w/ Infrastructure Improvements (Maps N/A)

The purpose of this alternative is to let the channel stabilize and vegetate naturally over time while ongoing infrastructure improvements continue to be implemented. Leaving this reach in the post-flood alignment and not implementing any additional channel improvements is a feasible solution according to the results of the geomorphic assessment. The post-flood channel alignment is mostly in a stable state, with only minor areas of instability and ongoing channel adjustment taking place. However, it is important to note the channel corridor will not look mature for many more years, as it will take time for vegetation to establish and allow for natural channel processes to form natural channel features such as the low-flow channel, pools, point bars, etc.

Table D.4.2 Reach 4a Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Channel Realignment & Site-Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Earthwork	1	2
Bridges / Culverts	1	1
Hydraulic Structures	1	2
Re-vegetation	1	2
Land / Property Acquisition	1	2
Utilities	2	1
Maintenance	2	1
	9	11

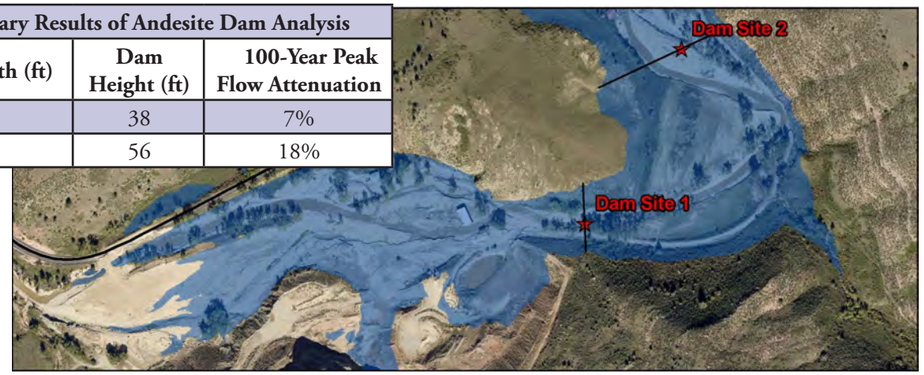
Table D.4.3 Reach 4a Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Channel Realignment & Site-Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Addresses Other Reach Objectives	2	1
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	2	2
Flood Mitigation	2	1
Envronmental Restoration	2	1
Public Safety	2	1
Transportation	2	1
Aesthetics	2	1
Permitting Requirements	1	1
Right of Way Acquisition / Easements	1	2
Operations & Maintenance	2	1
Agricultural / Irrigation	2	1
Consistency with Local Policies & Plans	2	1
	28	17

4.3B Reach 4B

Alternatives for this reach consist of both detention and channel alternatives. The potential for implementing a flood attenuation reservoir near the Andesite Quarry was discussed as a potential solution in the LRAP to alleviate flooding. The Baker Team evaluated two different potential dam locations (shown below in the figure) near the Andesite Quarry to provide flood storage and peak flow attenuation. For the purposes of this evaluation, the maximum dam height was set to an elevation such that Highway 7 would not be inundated during maximum storage conditions. Peak flow reduction benefit for the 100-year flood was calculated by comparing the maximum storage capacity of each dam alternative with the volume of the inflow hydrograph.

Table D.4.4 Preliminary Results of Andesite Dam Analysis			
Location	Dam Width (ft)	Dam Height (ft)	100-Year Peak Flow Attenuation
Site 1	320	38	7%
Site 2	680	56	18%



It was determined that neither detention alternative would be feasible to implement. Placing a dam at either location would inundate upstream infrastructure and would likely not provide enough peak flow attenuation to alleviate flooding within Lyons, although the 100-year flood flows from the South St. Vrain watershed would be somewhat attenuated; however, 100-year flood flows from the North St. Vrain Creek would not be attenuated and still likely result in flooding within Lyons.

Two channel alternatives were developed to work in concert with the ongoing post-flood restoration efforts being completed in this area.

Alternative 1 – Channel Realignment & Site-Specific Projects (Reach 4b Alternative 1 Maps 1 - 3)

The purpose of this alternative is to implement a channel alignment that will optimize the interaction with completed, ongoing, and funded projects while being sensitive to the constraints presented by the presence of numerous private residences throughout this river corridor. The implementation of this alternative will expedite the maturation of this reach by re-establishing a natural channel, repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks.

Alternative 2 – Leave As-Is w/ Infrastructure Improvements (Maps N/A)

The purpose of this alternative is to let the channel stabilize and vegetate naturally over time while ongoing infrastructure improvements continue to be implemented. Leaving this reach in the post-flood alignment and not implementing any additional channel improvements is a feasible solution according to the results of the geomorphic assessment, with the exception to the area. The post-flood channel alignment is mostly in a stable state, with only minor areas of instability and ongoing channel adjustment taking place. However, it is important to note the channel corridor will not look mature for many more years, as it will take time for vegetation to establish and allow for natural channel processes to form natural channel features such as the low-flow channel, pools, point bars, etc.

Table D.4.5 Reach 4b Relative Cost Analysis (1=less favorable; 2=more favorable)		
Item	Alternative 1: Channel Realignment & Site-Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Earthwork	1	2
Bridges / Culverts	1	1
Hydraulic Structures	1	2
Re-vegetation	1	2
Land / Property Acquisition	1	2
Utilities	2	1
Maintenance	2	1
	9	11

Table D.4.6 Reach 4b Relative Benefit Analysis (1=less favorable; 2=more favorable)		
Item	Alternative 1: Channel Realignment & Site-Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Addresses Other Reach Objectives	2	1
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	2	2
Flood Mitigation	2	1
Environmental Restoration	2	1
Public Safety	2	1
Transportation	2	1
Aesthetics	2	1
Permitting Requirements	1	1
Right of Way Acquisition / Easements	1	2
Operations & Maintenance	2	1
Agricultural / Irrigation	2	1
Consistency with Local Policies & Plans	2	1
	28	17

4.3c Reach 4c

The focus of the alternatives analysis for this reach is at the site of the McConnell ponds. The Baker Team understands that the reconstruction of these ponds is important to the community because of the social, recreational, and aesthetic benefit that they provided to the community. Since these ponds were destroyed during the flood last September, the opportunity now exists to reconstruct the ponds in the same or different location. There are ongoing discussions within the Lyons community about where the McConnell Ponds should be reconstructed. As of now, there are two locations being considered:

Alternative 1 – Restore McConnell Ponds on River Left (Reach 4c Alternative 1 Map 1)

Restoring the ponds on the left side of the river near Highway 36 could provide more of an aesthetic benefit, which could help draw additional tourism to the community. This alternative would likely be more expensive when compared to Alternative 2 and could result in additional permitting requirements.

Alternative 2 – Restore McConnell Ponds on River Right i.e. pre-flood location (Reach 4c Alternative1 Map 1)

Restoring the ponds in the pre-flood location is the more cost effective solution and would likely be easier to permit because the ponds once existed in the same location they would be reconstructed.

Table D.4.7 Reach 4c Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restore McConnell Ponds on Pre-Flood River Left	Alternative 2: Restore McConnell Ponds on Pre-Flood River Right
Earthwork		
Bridges / Culverts		
Hydraulic Structures		
Re-vegetation		
Land / Property Acquisition		
Utilities		
Maintenance		

Table D.4.8 Reach 4c Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restore McConnell Ponds on River Left	Alternative 2: Restore McConnell Ponds on River Right
Addresses Other Reach Objectives		
Natural Channel Restoration		
Recreation		
Fish Habitat		

Table D.4.8 Reach 4c Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restore McConnell Ponds on River Left	Alternative 2: Restore McConnell Ponds on River Right
Flood Conveyance		
Flood Mitigation		
Environmental Restoration		
Public Safety		
Transportation		
Aesthetics		
Permitting Requirements		
Right of Way Acquisition / Easements		
Operations & Maintenance		
Agricultural / Irrigation		
Consistency with Local Policies & Plans		

4.4 Planning Recommendations

For Reach 4a and 4b the results of the benefit cost analysis show that Alternative 1 is the higher cost alternative; however, it provides a higher overall benefit when compared to Alternative 2. Alternative 1 is the recommended alternative because it provides an immediate benefit for recreation, fish habitat, and overall aesthetic value. Additionally, Alternative 1 will likely result in improved public safety conditions and less operations and maintenance. It is important to note that Alternative 2 could eventually provide the same level of benefit; however, the level of benefit would not be recognized until many years from now when the stream corridor matures.

5. REACH 5

6.1 5.1 Overview

Reach 5 runs along the North St. Vrain Creek and begins at Apple Valley and ends at Buttonrock Reservoir. This reach is an important contributing area that affects flooding in the Town of Lyons. The September flooding event drastically disrupted the connectivity of the North St. Vrain Creek. Additionally, several road crossings within this reach were significantly damaged by floodwaters and debris.

5.2 Assessment

The results of the ecological assessment show that this reach is generally in "Fair" condition with overall scores ranging between 5-7 out of 10. The lowest scoring elements from the ecological assessment are related to factors impacting fish and aquatic habitat. Additionally, the channel banks are eroding in some locations. The primary recommendations from the ecological assessment are to implement pools and planform complexity into the reach, preserve and reestablish open space, evaluate the flood conveyance capacities of the many bridge crossings.

The planform for North St. Vrain Creek has been relatively consistent and stable through the river corridor over the past 60 years. The results of the geomorphic assessment show that the alignment of the channel is similar between pre- and post-flood conditions. This reach will tend to migrate and avulse for a range of hydrologic conditions. Absent of large flow events, the channel plan form for these reaches will likely remain reasonably stable once streambank vegetation has re-established. However, beyond some threshold discharge the channel plan form can be expected to change, and in some instances change significantly due to avulsion and migration. The primary recommendation from the geomorphic assessment is to keep the channel in the post-flood alignment.

Flood-related damages occurred mostly in the lower portions of this reach and consisted mostly of damage to Longmont Dam Road and multiple roadway crossings. Most of the residences adjacent to North St. Vrain Creek are not within the regulatory 100-year floodplain. However, many of these homes are still at risk for future flooding that could be triggered by modifications in channel configuration or debris jams.

5.3 Alternatives and Evaluation

In addition to the benefits outlined in Table D.5.2, the following restoration objectives were discussed:

- Implement a recreational path adjacent to the creek
- Implement whitewater recreation
- Restore and/or improve fish habitat
- Improve flood conveyance where possible
- Restore the natural channel where it is feasible

There are many channel segments within this reach that are stable and functioning well in the post-flood condition. Therefore, the opportunity exists to recommend site-specific restoration projects as opposed to wholesale channel restoration. This method will not only save cost, but also reduce interim impacts to the overall ecosystem as a result of construction.

The constraints within this reach are mostly structural. Channel improvements need to be compatible with the following ongoing projects:

- Improvements to Longmont Dam Road (ongoing coordination with Boulder County Transportation Dept.)
- Improvements to multiple public and private roadway crossings

Two alternatives were developed based on the objectives, opportunities, and constraints outlined above:

Alternative 1 – Restoration w/ Site-Specific Projects (Reach 1 Alternative 1 Maps 1 - 5)

The purpose of this alternative is to expedite the maturation of this reach by repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks in combination with implementing ongoing infrastructure improvements.

Alternative 2 – Leave As-Is w/ Infrastructure Improvements (figure is N/A)

The purpose of this alternative is to let the channel stabilize and vegetate naturally over time while ongoing infrastructure improvements continue to be implemented. Leaving this reach in the post-flood alignment and not implementing any additional channel improvements is a feasible solution according to the results of the geomorphic assessment. The post-flood channel alignment is mostly in a stable state, with only minor areas of instability and ongoing channel adjustment taking place. However, it is important to note the channel corridor will not look mature for many more years, as it will take time for vegetation to establish and allow for natural channel processes to form natural channel features such as the low-flow channel, pools, point bars, etc.

Table D.5.1 Reach 5 Relative Cost Analysis (1=less favorable; 2=more favorable)

Item	Alternative 1: Restoration w/ Site Specific Projects	Alternative 2 : Leave As Is w/ Infrastructure Improvements
Earthwork	1	2
Bridges / Culverts	1	1
Hydraulic Structures	1	2
Re-vegetation	2	1
Land / Property Acquisition	1	2
Utilities	1	1
Maintenance	1	2
	8	11

Table D.5.2 Reach 5 Relative Benefit Analysis (1=less favorable; 2=more favorable)

Item	Alternative 1: Restoration w/ Site Specific Projects	Alternative 2 : Leave As Is w/ Infrastructure Improvements
Addresses Other Reach Objectives	2	1
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	2	2
Flood Mitigation	2	2
Environmental Restoration	2	1
Public Safety	2	1

Table D.5.2 Reach 5 Relative Benefit Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Restoration w/ Site Specific Projects**	**Alternative 2 : Leave As Is w/ Infrastructure Improvements**
Transportation	2	1
Aesthetics	2	1
Permitting Requirements	1	1
Right of Way Acquisition / Easements	1	2
Operations & Maintenance	2	1
Agricultural / Irrigation	N/A	N/A
Consistency with Local Policies & Plans	N/A	N/A
	24	16

5.4 Planning Recommendations

The results of the benefit cost analysis show that Alternative 1 is the higher cost alternative; however, it provides a higher overall benefit when compared to Alternative 2. Alternative 1 is the recommended alternative because it provides an immediate benefit for recreation, fish habitat, and overall aesthetic value. Additionally, Alternative 1 will likely result in improved public safety conditions and less operations and maintenance. It is important to note that Alternative 2 could eventually provide the same level of benefit; however, the level of benefit would not be recognized until many years from now when the stream corridor matures.

6. REACH 6

6.1 Overview

Reach 6 along South St. Vrain Creek begins at the choke in the canyon (just upstream of the Andesite Quarry) and ends at the townsites of Raymond and Riverside. The stream channel is constrained along this reach due to canyon geometry and the highway and there are a number of issues along this reach related to embankments along State Highway 7. Aggradation occurred downstream of Reach 6 and opportunities exist to mitigate the accumulation of sediment at the choke in the canyon.

6.2 Assessment

The results of the ecological assessment show that this reach is generally in "Fair" condition with overall scores ranging between 5-7 out of 10. The lowest scoring elements from the ecological assessment are related to factors impacting fish and aquatic habitat. Additionally, the channel is somewhat unstable and the channel banks are eroding in some locations. The primary recommendations from the ecological assessment are to improve in-stream habitat and reconstruct floodplains in conjunction with State Highway 7 reconstruction.

The planform analysis did not encompass this portion of South St. Vrain Creek due to lack of historical aerials. However, based on visual observation and review of aerial photography, the alignment of the channel is similar between pre- and post-flood conditions. This reach will tend to migrate and avulse for a range of hydrologic conditions. Absent of large flow events, the channel plan form for these reaches will likely remain reasonably stable once streambank vegetation has re-established. However, beyond some threshold discharge the channel plan form can be expected to change, and in some instances change significantly due to avulsion and migration. The primary recommendation from the geomorphic assessment is to keep the channel in the post-flood alignment.

Flood-related damages occurred throughout this reach and consisted mostly of damage to State Highway 7 and multiple roadway crossings. There are not many residences adjacent to South St. Vrain Creek in this reach and only some were damaged by flooding. Many of these homes are still at risk for future flooding that could be triggered by modifications in channel configuration or debris jams.

6.3 Alternatives and Evaluation

In addition to the benefits outlined in Table D.6.2, the following restoration objectives were discussed:

- Restore and/or improve fish habitat
- Restore the natural channel where it is feasible
- Restoration of in-stream recreation features that were present pre-flood

There are many channel segments within this reach that are stable and functioning well in the post-flood condition. Therefore, the opportunity exists to recommend site-specific restoration projects as opposed to wholesale channel restoration. This method will not only save cost, but also reduce interim impacts to the channel as a result of construction.

The constraints within this reach are mostly structural. Channel improvements need to be compatible with the following ongoing projects:

- Improvements to Highway 7
- Public and private roadway crossings

Two alternatives were developed based on the objectives, opportunities, and constraints outlined above:

Alternative 1 – Restoration w/ Site-Specific Projects (Reach 6 Alternative 1 Maps 1 - 9)

The purpose of this alternative is to expedite the maturation of this reach by repairing erosion scars, optimizing low-flow channel capacity, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks in combination with implementing ongoing infrastructure improvements.

Alternative 2 – Leave As-Is w/ Infrastructure Improvements (figure is N/A)

The purpose of this alternative is to let the channel stabilize and vegetate naturally over time while ongoing infrastructure improvements continue to be implemented. Leaving this reach in the post-flood alignment and not implementing any additional channel improvements is a feasible solution according to the results of the geomorphic assessment. The post-flood channel alignment is mostly in a stable state, with only minor areas of instability and ongoing channel adjustment taking place. However, it is important to note the channel corridor will not look mature for many more years, as it will take time for vegetation to establish and allow for natural channel processes to form natural channel features such as the low-flow channel, pools, point bars, etc.

Table D.6.1 Reach 6 Relative Cost Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Restoration w/ Site Specific Projects**	**Alternative 2: Leave As Is w/ Infrastructure Improvements**
Earthwork	1	2
Bridges / Culverts	1	1
Hydraulic Structures	1	2
Re-vegetation	2	1
Land / Property Acquisition	2	2
Utilities	1	1

Table D.6.1 Reach 6 Relative Cost Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Restoration w/ Site Specific Projects**	**Alternative 2: Leave As Is w/ Infrastructure Improvements**
Maintenance	1	2
	9	11

Table D.6.2 Reach 6 Relative Benefit Analysis (1=less favorable; 2=more favorable)		
Item	**Alternative 1: Restoration w/ Site Specific Projects**	**Alternative 2: Leave As Is w/ Infrastructure Improvements**
Addresses Other Reach Objectives	2	1
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	2	2
Flood Mitigation	2	2
Environmental Restoration	2	1
Public Safety	2	1
Transportation	2	1
Aesthetics	2	1
Permitting Requirements	1	1
Right of Way Acquisition / Easements	1	2
Operations & Maintenance	2	1
Agricultural / Irrigation	N/A	N/A
Consistency with Local Policies & Plans	N/A	N/A
	24	16

6.4 Planning Recommendations

The results of the benefit cost analysis show that Alternative 1 is the higher cost alternative; however, it provides a higher overall benefit when compared to Alternative 2. Alternative 1 is the recommended alternative because it provides an immediate benefit for recreation, fish habitat, and overall aesthetic value. Additionally, Alternative 1 will likely result in improved public safety conditions and less operations and maintenance. It is important to note that Alternative 2 could eventually provide the same level of benefit; however, the level of benefit would not be recognized until many years from now when the stream corridor matures.

7. REACH 7

7.1 Overview

Reach 7 of South St. Vrain Creek begins at the Raymond and Riverside townsites and extends upstream to the upstream limit of the Planning Area. Reach 7 continues along the State Highway 7, south of the Highway 72 junction. Although the stream channel is constrained due to the canyon geometry, the flooding event disrupted the biological connectivity of the stream and damaged residential structures in the floodplain.

7.2 Assessment

The results of the ecological assessment show that this reach is generally in "Good" condition with overall scores ranging between 7-8 out of 10. The lowest scoring elements from the ecological assessment are related to the lack of pools and canopy cover, which are critical components to fish habitat. Additionally, the channel is somewhat unstable and the channel banks are eroding in some locations. The primary recommendations from the ecological assessment are replace roadway crossings with structures that convey the low-flow and improving in-stream habitat complexity by utilizing large woody debris.

The planform analysis did not encompass this portion of South St. Vrain. However, based on the assessment in North St. Vrain, visual observation, and review of aerial photography, the alignment of the channel is similar between pre- and post-flood conditions. This reach will tend to migrate and avulse for a range of hydrologic conditions. Absent of large flow events, the channel plan form for these reaches will likely remain reasonably stable once streambank vegetation has re-established. However, beyond some threshold discharge the channel plan form can be expected to change, and in some instances change significantly due to avulsion and migration. The primary recommendation from the geomorphic assessment is to keep the channel in the post-flood alignment.

Flood-related damages occurred throughout this reach and consisted mostly of damage to private residences and the privately-owned roadway crossings leading to the residences. Several of the residences adjacent to the South St. Vrain were damaged by flooding. Many of these homes are still at risk for future flooding that could be triggered by modifications in channel configuration or debris jams.

7.3 Alternatives and Evaluation

In addition to the benefits outlined in Table D.7.2, the following restoration objectives were discussed:

- Restore and/or improve fish habitat
- Restore the natural channel where it is feasible
- Analyze and size private roadway crossings to improve interaction with the channel

There are many channel segments within this reach that are stable and functioning well in the post-flood condition. Therefore, the opportunity exists to recommend site-specific restoration projects as opposed to wholesale channel restoration. This method will not only save cost, but also reduce interim impacts to the channel as a result of construction.

The constraints within this reach are mostly structural. Channel improvements need to be compatible with the following ongoing projects:

- Improvements to Highway 7
- Several private roadway crossings

Two alternatives were developed based on the objectives, opportunities, and constraints outlined above:

Alternative 1 – Restoration w/ Site-Specific Projects (Reach 7 Alternative 1 Maps 1 - 2)

The purpose of this alternative is to expedite the maturation of this reach by repairing erosion scars, re-establishing floodplain benches, building point-bars and excavating pools, re-vegetating denuded areas, and stabilizing channel banks in combination with implementing ongoing infrastructure improvements.

Alternative 2 – Leave As-Is w/ Infrastructure Improvements (figure is N/A)

The purpose of this alternative is to let the channel stabilize and vegetate naturally over time while ongoing infrastructure improvements continue to be implemented. Leaving this reach in the post-flood alignment and not implementing any additional channel improvements is a feasible solution according to the results of the geomorphic assessment. The post-flood channel alignment is mostly in a stable state, with only minor areas of instability and ongoing channel adjustment taking place. However, it is important to note the channel corridor will not look mature for many more years, as it will take time for vegetation to establish and allow for natural channel processes to form natural channel features such as the low-flow channel, pools, point bars, etc.

Table D.7.1 Reach 7 Relative Cost Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restoration w/ Site Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Earthwork	1	2
Bridges / Culverts	1	1
Hydraulic Structures	1	2
Re-vegetation	2	1
Land / Property Acquisition	1	2
Utilities	1	1
Maintenance	1	2
	8	11

Table D.7.2 Reach 7 Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restoration w/ Site Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
Addresses Other Reach Objectives	2	1
Natural Channel Restoration	2	1
Recreation	2	1
Fish Habitat	2	1
Flood Conveyance	2	2
Flood Mitigation	2	2
Environmental Restoration	2	1
Public Safety	2	1
Transportation	2	1
Aesthetics	2	1
Permitting Requirements	1	1
Right Of Way Acquisition / Easements	1	2
Operations & Maintenance	2	1
Agricultural / Irrigation	N/A	N/A
Consistency with Local Policies & Plans	N/A	N/A

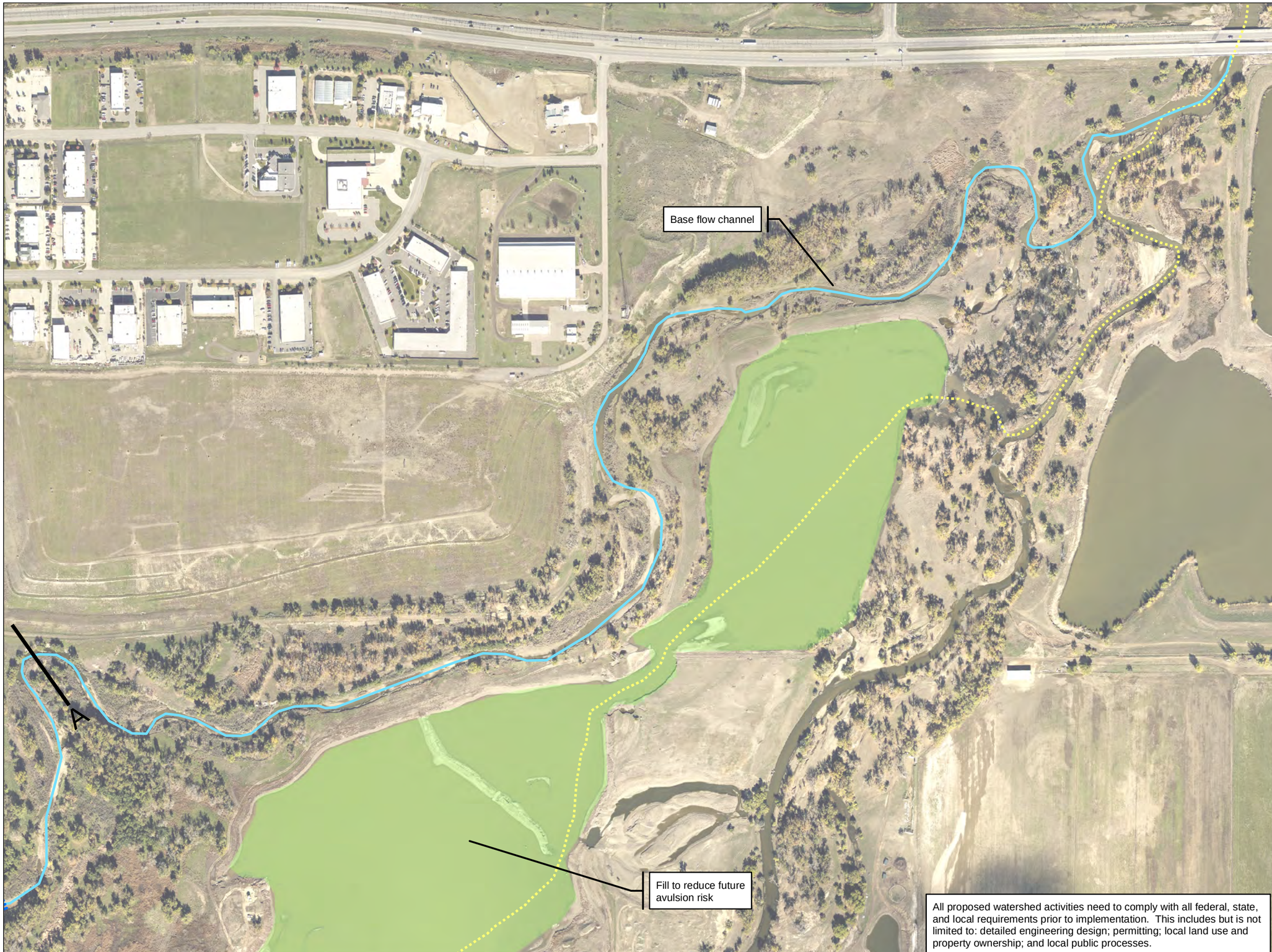
Table D.7.2 Reach 7 Relative Benefit Analysis
(1=less favorable; 2=more favorable)

Item	Alternative 1: Restoration w/ Site Specific Projects	Alternative 2: Leave As Is w/ Infrastructure Improvements
	24	16

7.4 Planning Recommendations

The results of the benefit cost analysis show that Alternative 1 is the higher cost alternative; however, it provides a higher overall benefit when compared to Alternative 2. Alternative 1 is the recommended alternative because it provides an immediate benefit for recreation, fish habitat, and overall aesthetic value. Additionally, Alternative 1 will likely result in improved public safety conditions and less operations and maintenance. It is important to note that Alternative 2 could eventually provide the same level of benefit; however, the level of benefit would not be recognized until many years from now when the stream corridor matures.

REACH 1 ALTERNATIVE 1: SPLIT CHANNEL MAP 1 OF 4



All proposed watershed activities need to comply with all federal, state, and local requirements prior to implementation. This includes but is not limited to: detailed engineering design; permitting; local land use and property ownership; and local public processes.

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Base Flow Split
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Crossing Replacement
- Cut & Revegatation
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

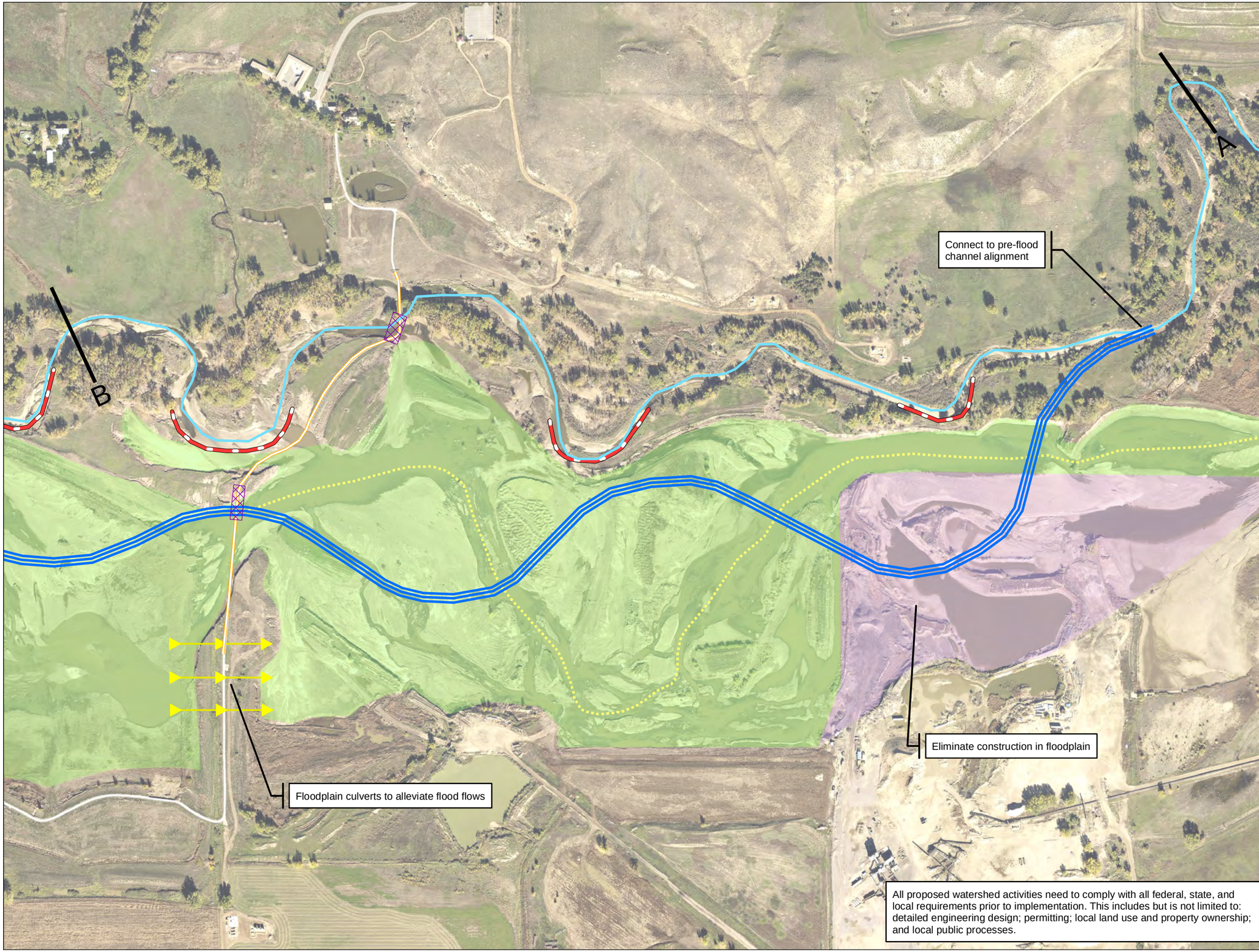
N

Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1 ALTERNATIVE 1: SPLIT CHANNEL MAP 2 OF 4



All proposed watershed activities need to comply with all federal, state, and local requirements prior to implementation. This includes but is not limited to: detailed engineering design; permitting; local land use and property ownership; and local public processes.

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Base Flow Split
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Crossing Replacement
- Cut & Revegatation
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

N

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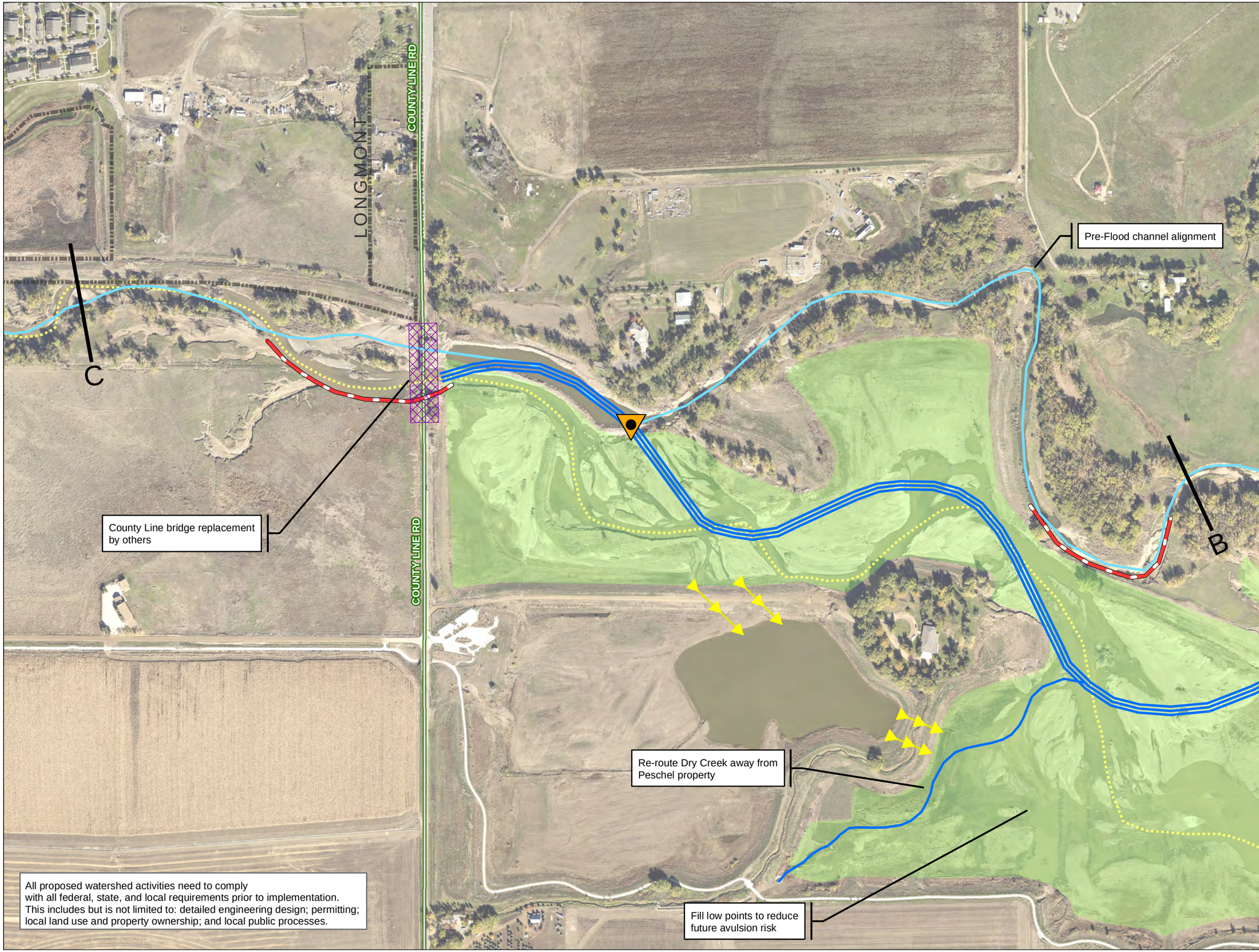
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1 ALTERNATIVE 1: SPLIT CHANNEL MAP 3 OF 4



LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Base Flow Split
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Crossing Replacement
- Cut & Revegatation
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

N

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LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1 ALTERNATIVE 1: SPLIT CHANNEL MAP 4 OF 4

All proposed watershed activities need to comply with all federal, state, and local requirements prior to implementation. This includes but is not limited to: detailed engineering design; permitting; local land use and property ownership; and local public processes.

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Base Flow Split
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Channel Plug
- Crossing Replacement
- Cut & Revegatation
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

N

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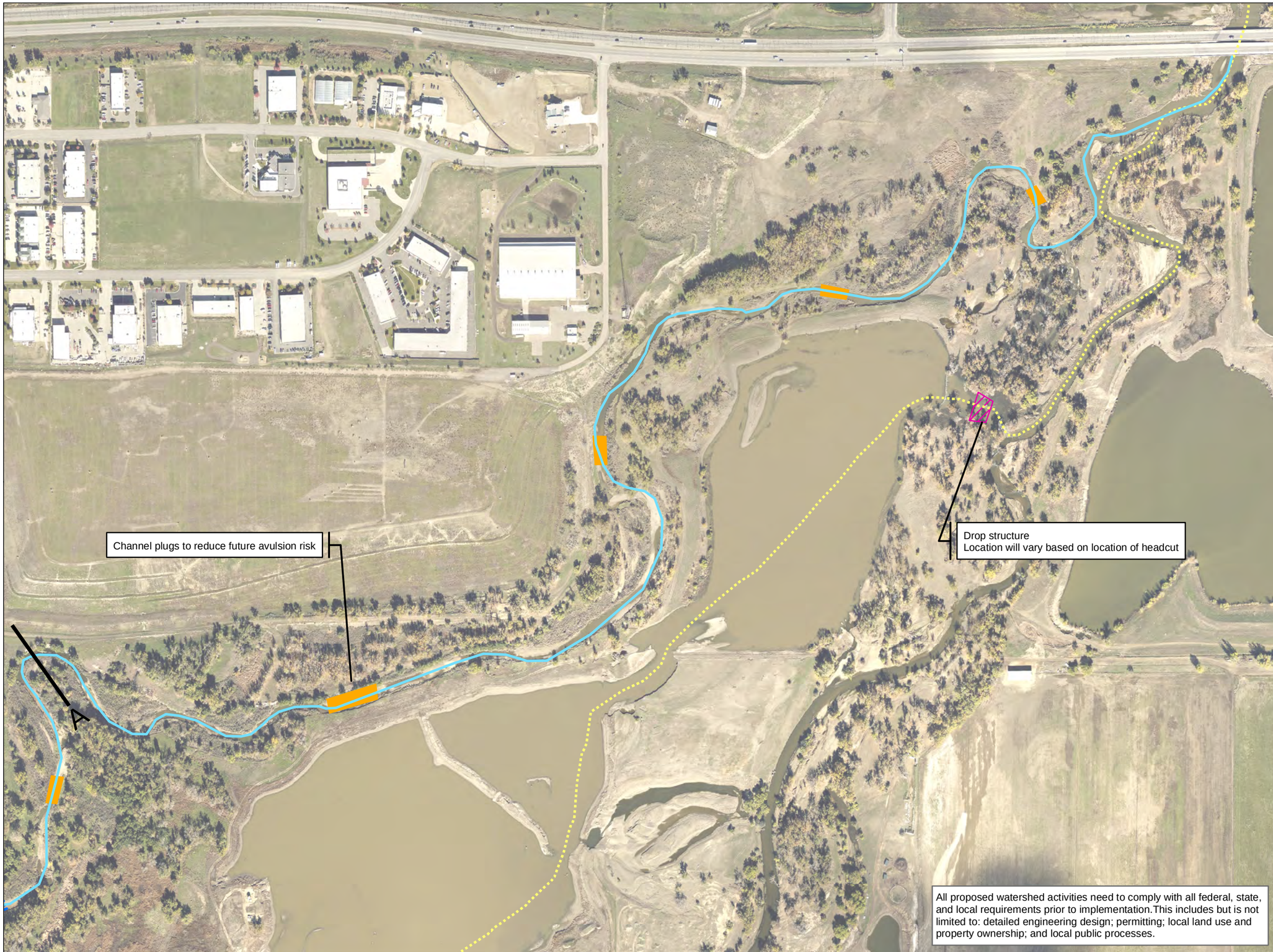
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1
ALTERNATIVE 2:
MINOR STABILIZATION
MAP 1 OF 4



All proposed watershed activities need to comply with all federal, state, and local requirements prior to implementation.This includes but is not limited to: detailed engineering design; permitting; local land use and property ownership; and local public processes.

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Channel Plug
- Drop Structure
- Crossing Replacement
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

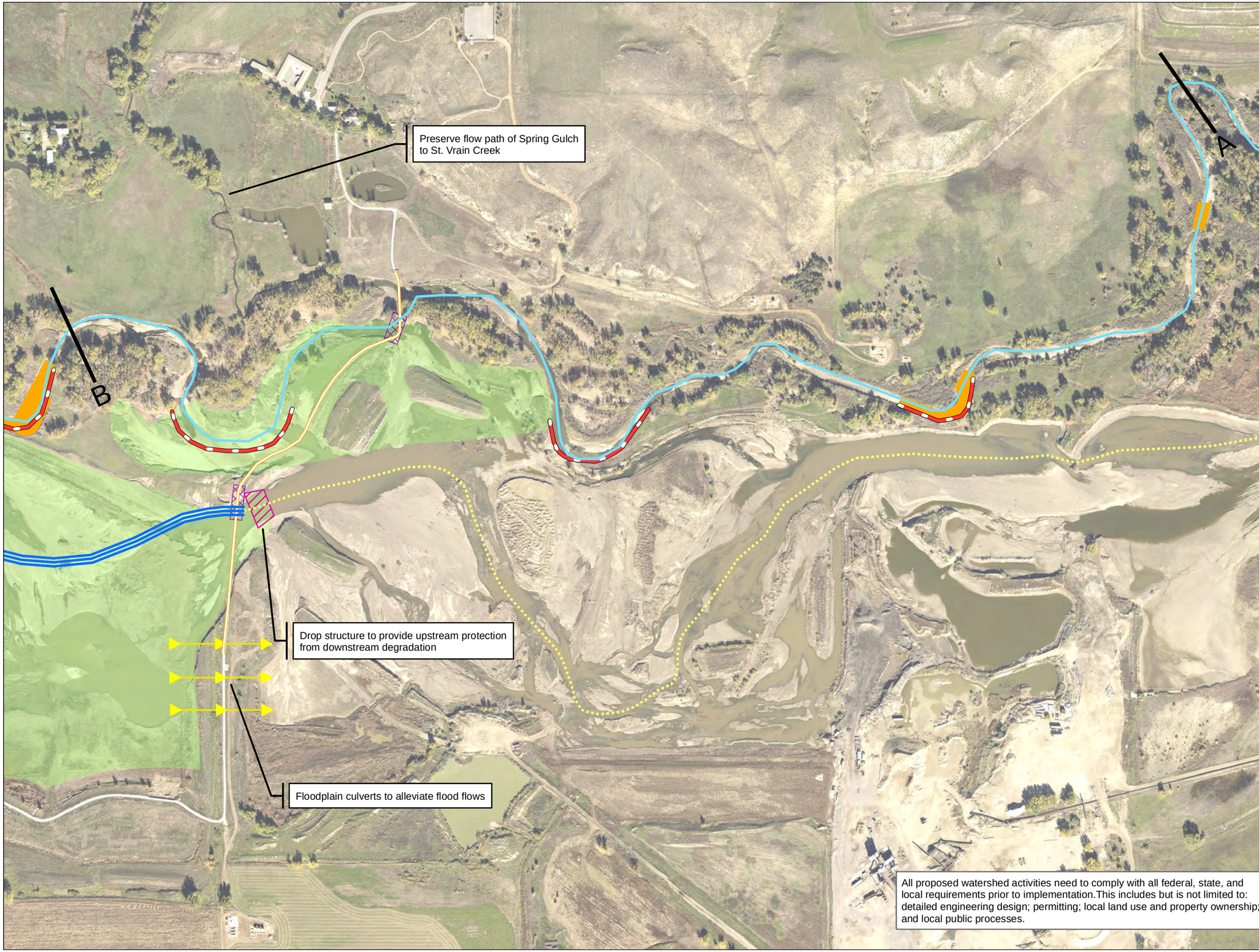
N

Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1
ALTERNATIVE 2:
MINOR STABILIZATION
MAP 2 OF 4



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0 100 200 300 400 Feet

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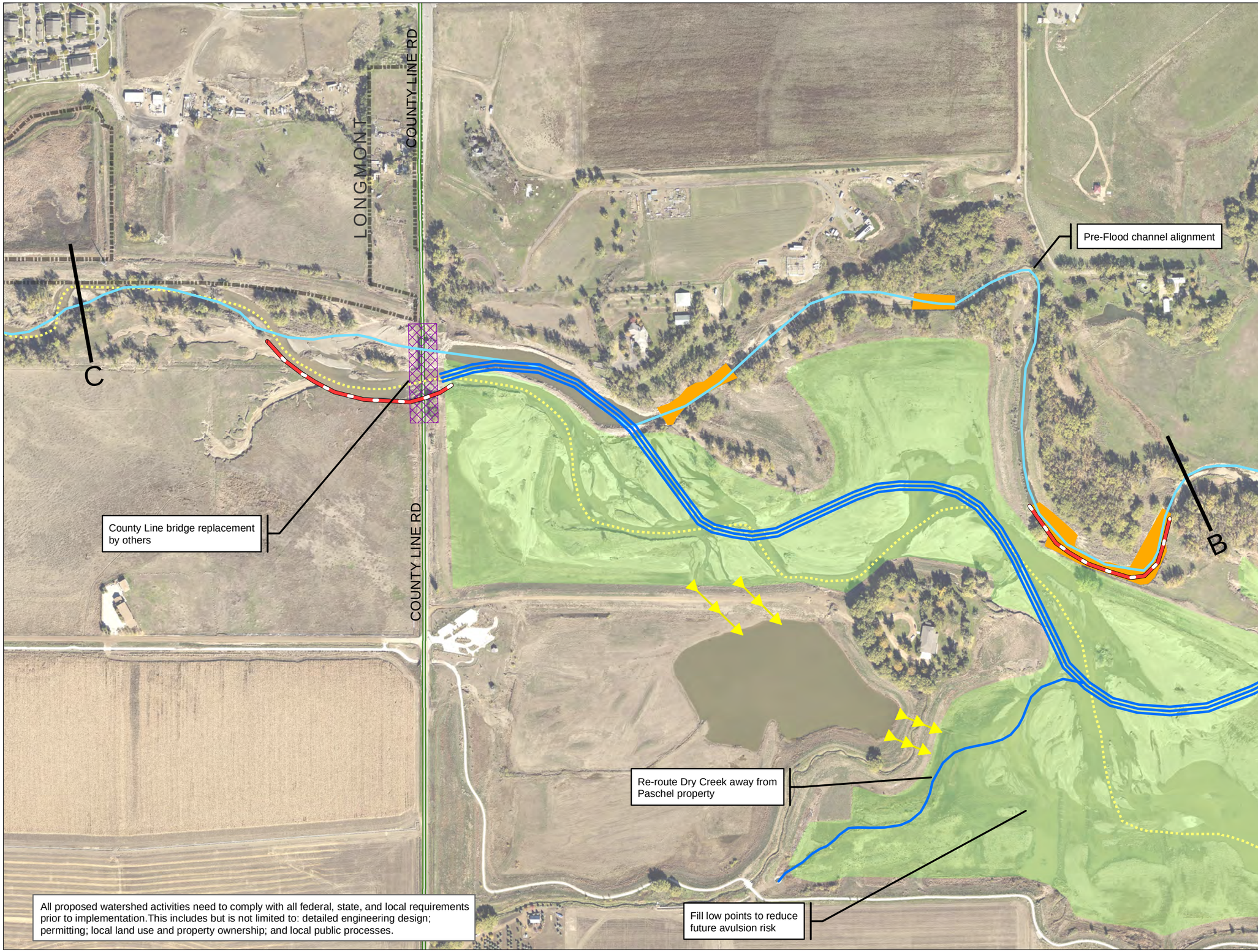
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 1 ALTERNATIVE 2: MINOR STABILIZATION MAP 3 OF 4

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
- Trail Replacement
- Floodplain Culvert
- Channel Plug
- Drop Structure
- Crossing Replacement
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0 100 200 300 400 Feet

N

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LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 1
ALTERNATIVE 2:
MINOR STABILIZATION
MAP 4 OF 4

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LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
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0 100 200 300 400 Feet

N

Baker
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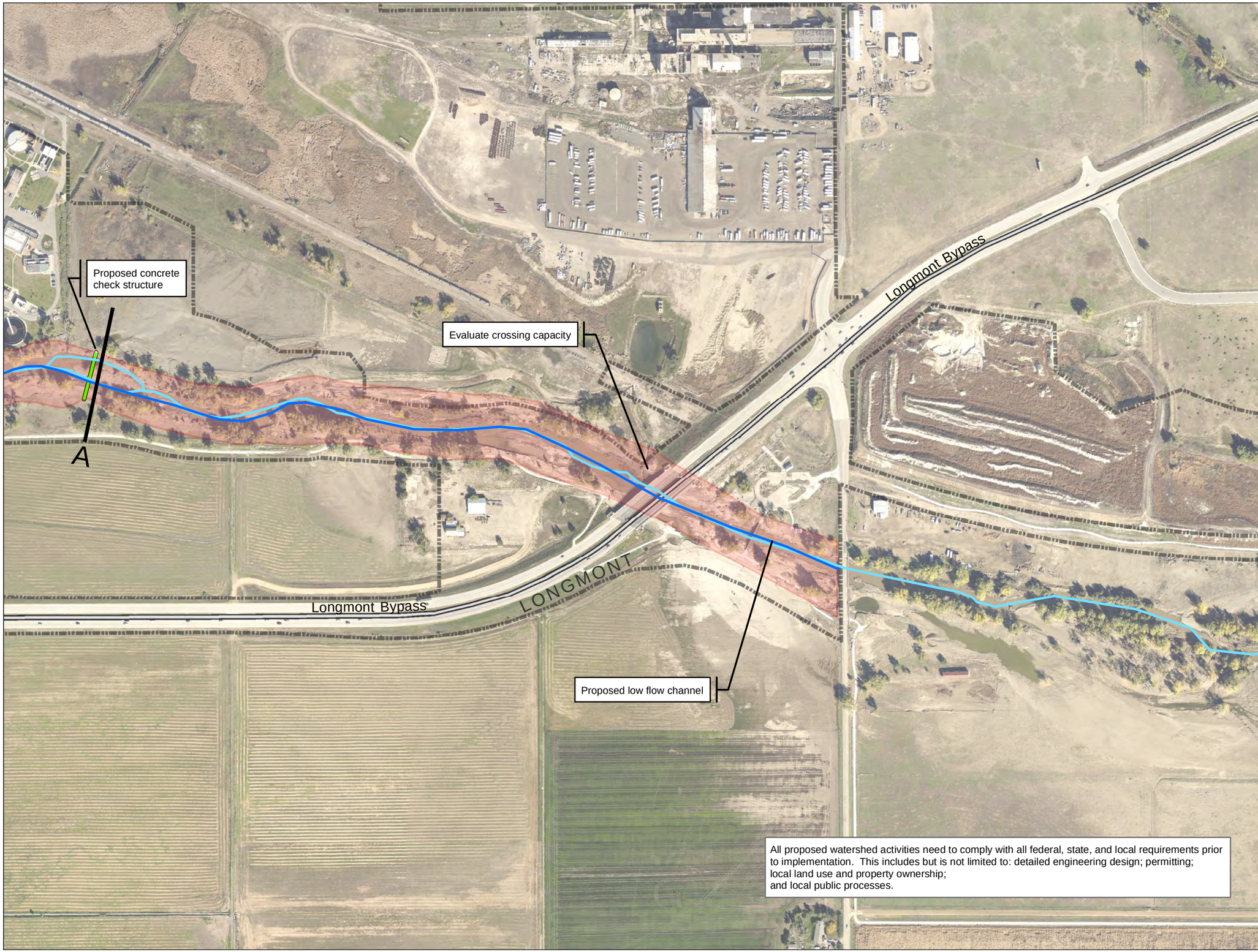
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 2 ALTERNATIVE 1: FLOOD CONTROL W/ LOW FLOW CHANNEL MAP 1 OF 5



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LEGEND

- Proposed Channel Alignment
- Pre-Flood Channel Alignment
- Check Structure
- Move Pond Embankment
- Drop Structure
- Crossing Replacement
- 100-Year Flood Control Channel
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

N

Baker
165 S. UNION BLVD.
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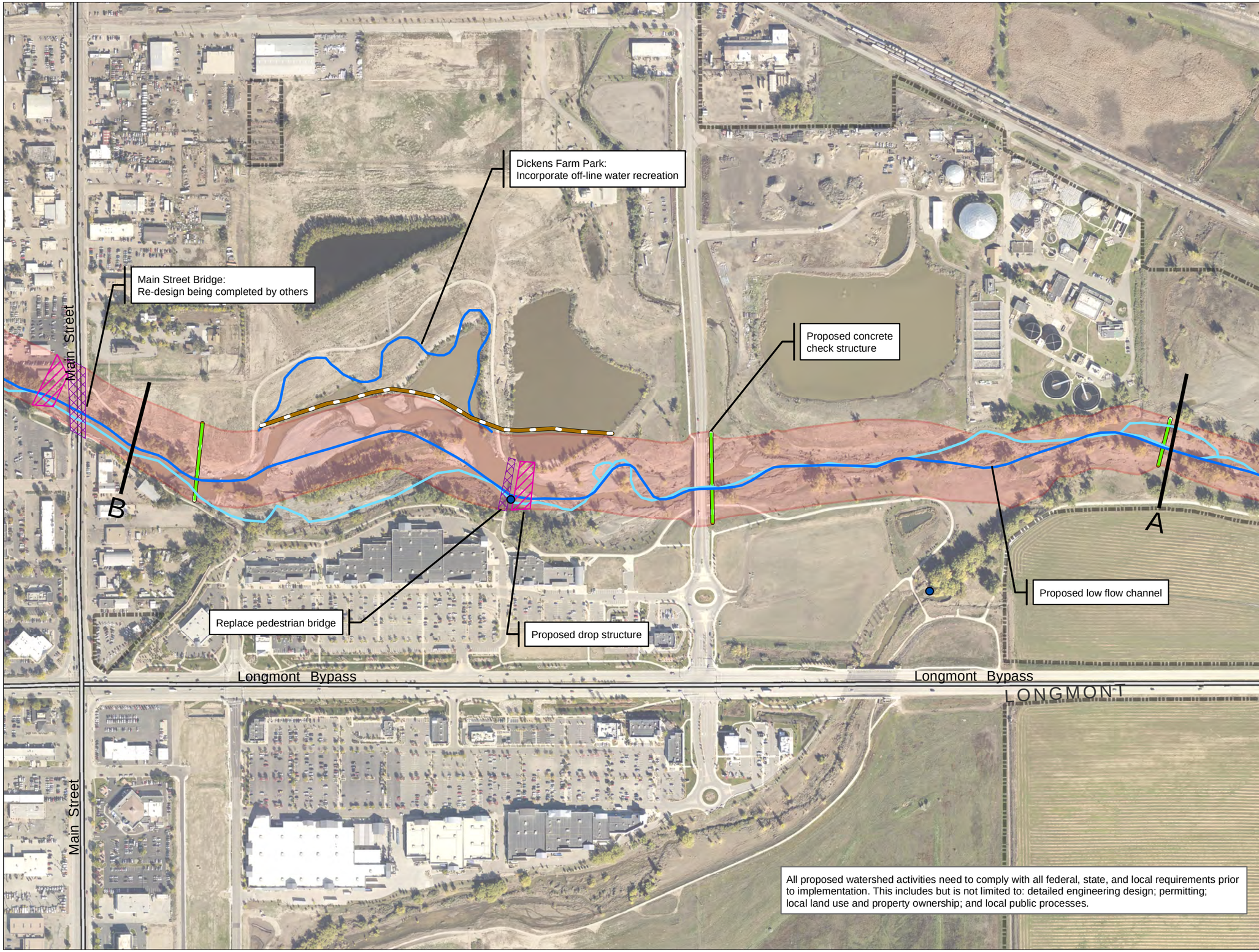
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 2 ALTERNATIVE 1: FLOOD CONTROL W/ LOW FLOW CHANNEL MAP 2 OF 5



LEGEND

- Headgates
- Proposed Channel Alignment
- Pre-Flood Channel Alignment
- Check Structure
- Move Pond Embankment
- Drop Structure
- Crossing Replacement
- 100-Year Flood Control Channel
- Highways
- Major Roads
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0 100 200 300 400 Feet

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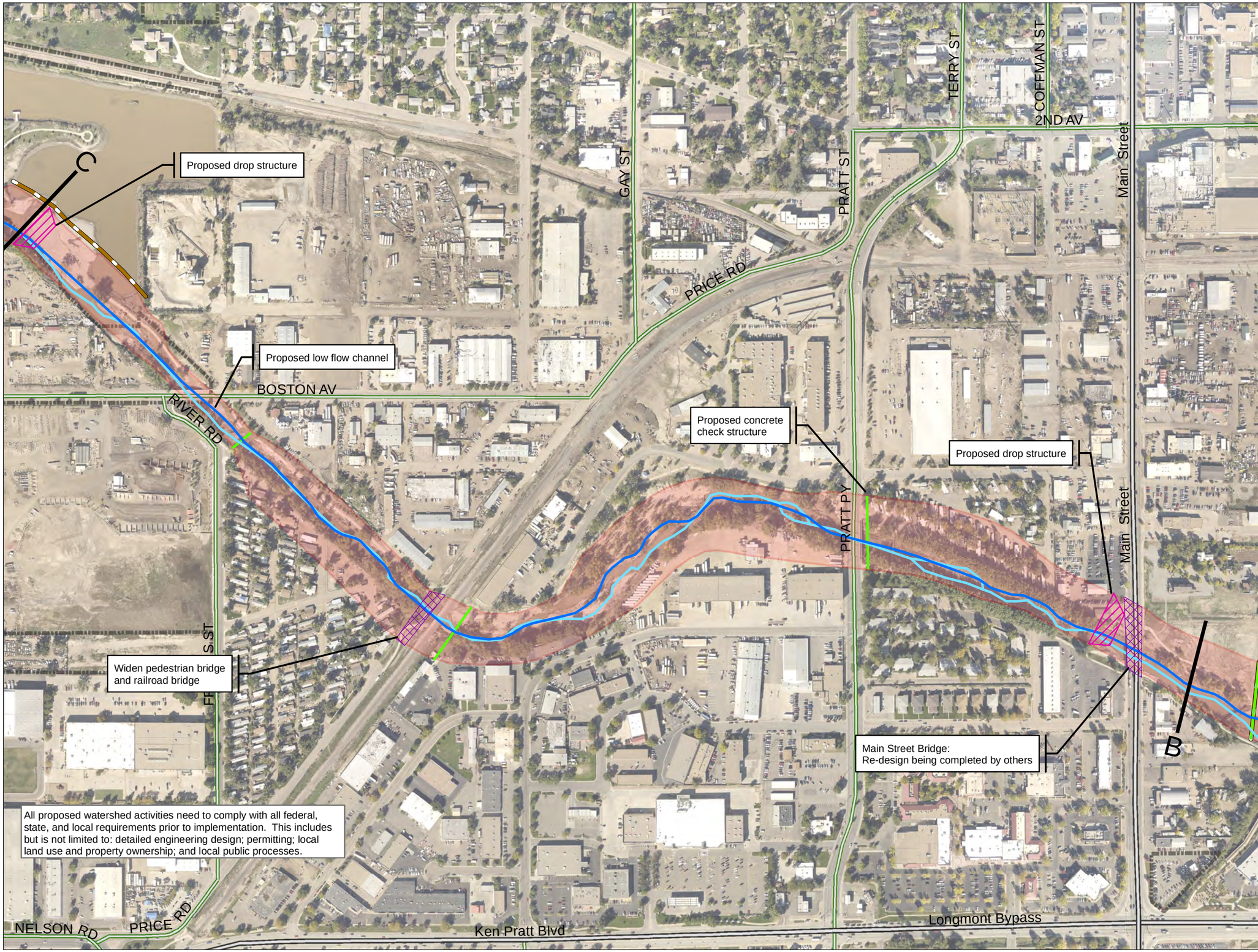
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 2 ALTERNATIVE 1: FLOOD CONTROL W/ LOW FLOW CHANNEL MAP 3 OF 5



LEGEND

- Proposed Channel Alignment
- Pre-Flood Channel Alignment
- Check Structure
- Move Pond Embankment
- Drop Structure
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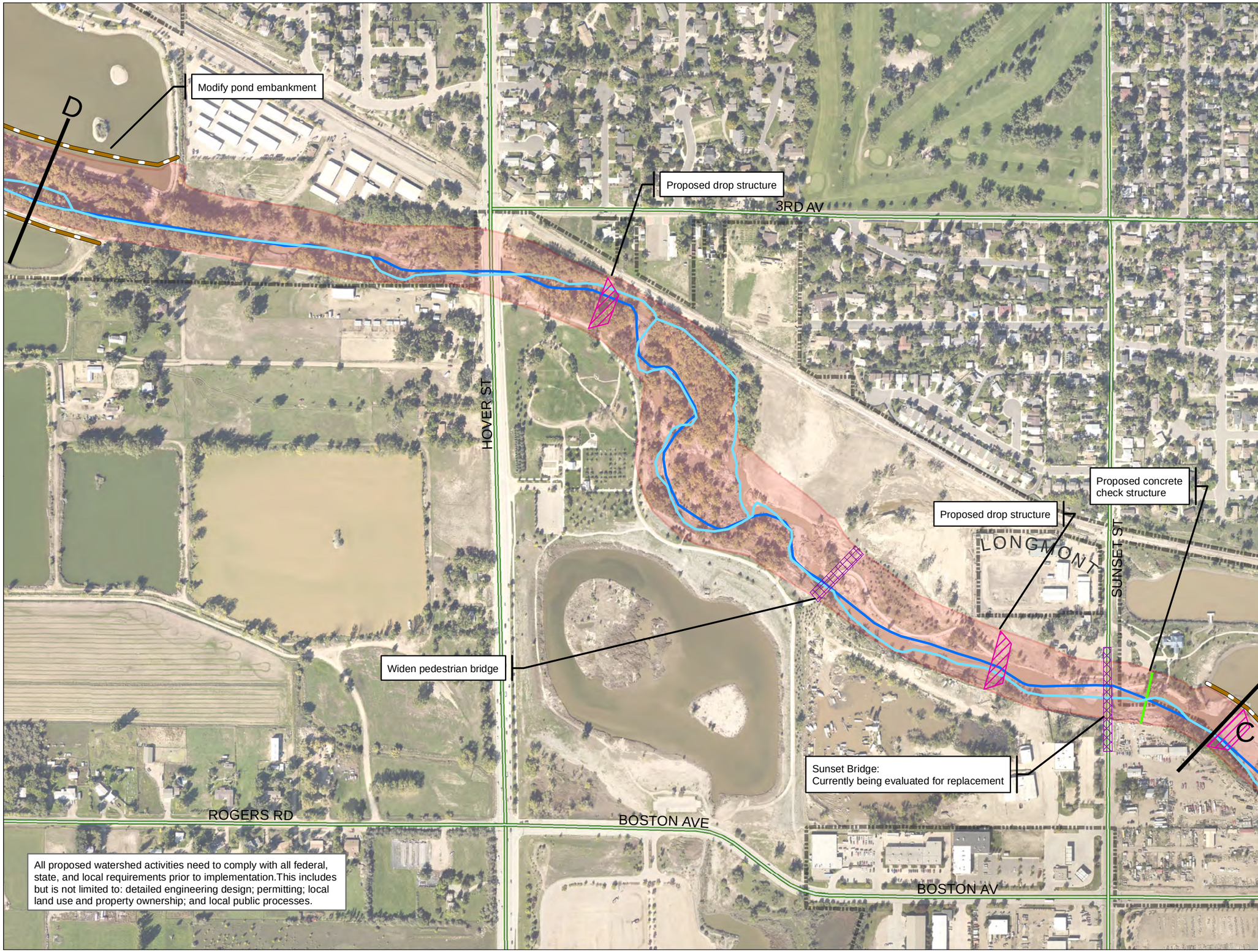
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 2 ALTERNATIVE 1: FLOOD CONTROL W/ LOW FLOW CHANNEL MAP 4 OF 5



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LEGEND

- Proposed Channel Alignment
- Pre-Flood Channel Alignment
- Check Structure
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- Drop Structure
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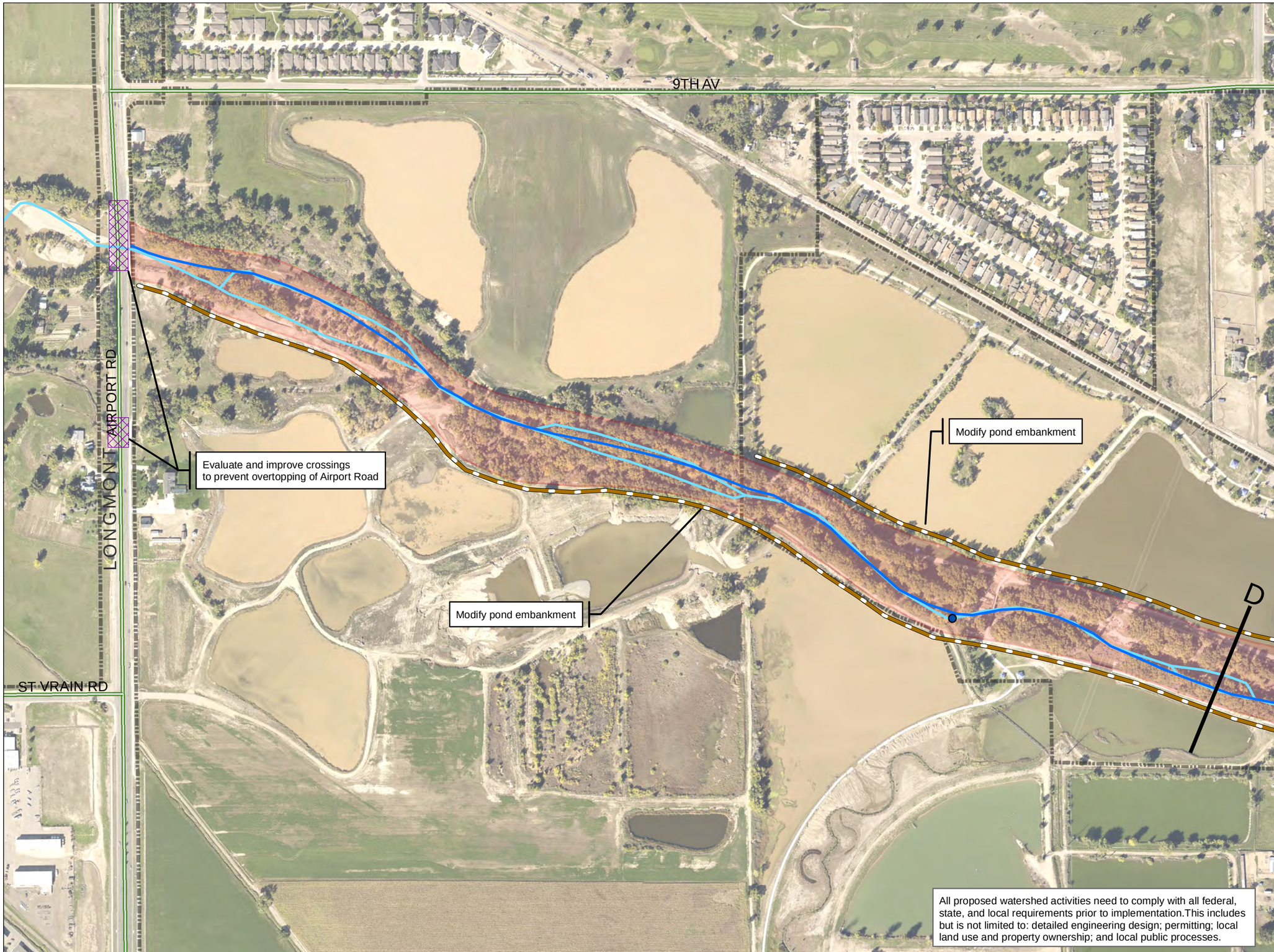
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 2 ALTERNATIVE 1: FLOOD CONTROL W/ LOW FLOW CHANNEL MAP 5 OF 5



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LEGEND

- Headgates
- Proposed Channel Alignment
- Pre-Flood Channel Alignment
- Check Structure
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- Drop Structure
- Crossing Replacement
- 100-Year Flood Control Channel
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- Major Roads
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0 100 200 300 400 Feet

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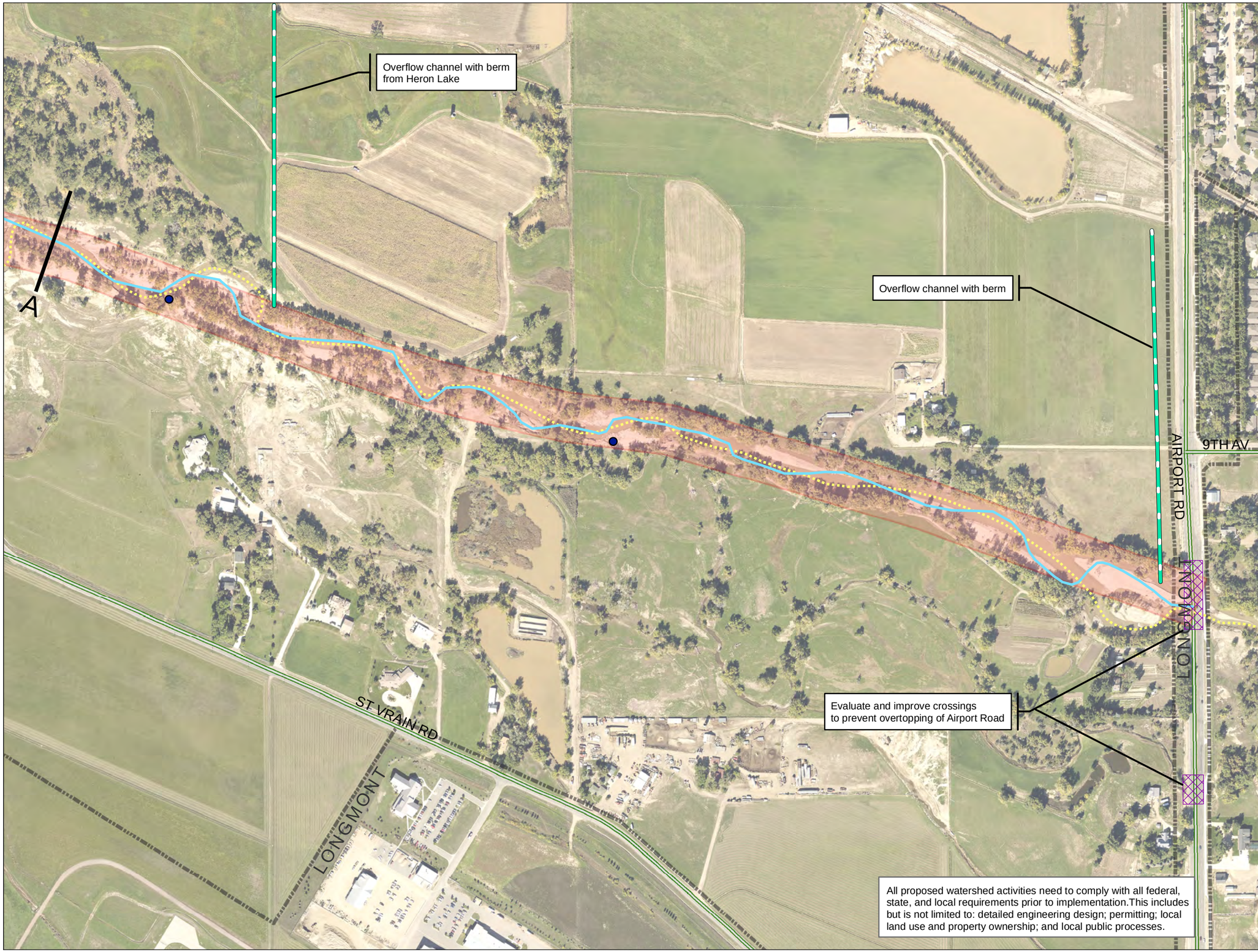
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 1 OF 6



LEGEND

- Pre-Flood Channel Alignment
- Headgates
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
- Crossing Replacement
- 100-Year Flood Control Channel
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegatation
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0 100 200 300 400 Feet

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Baker
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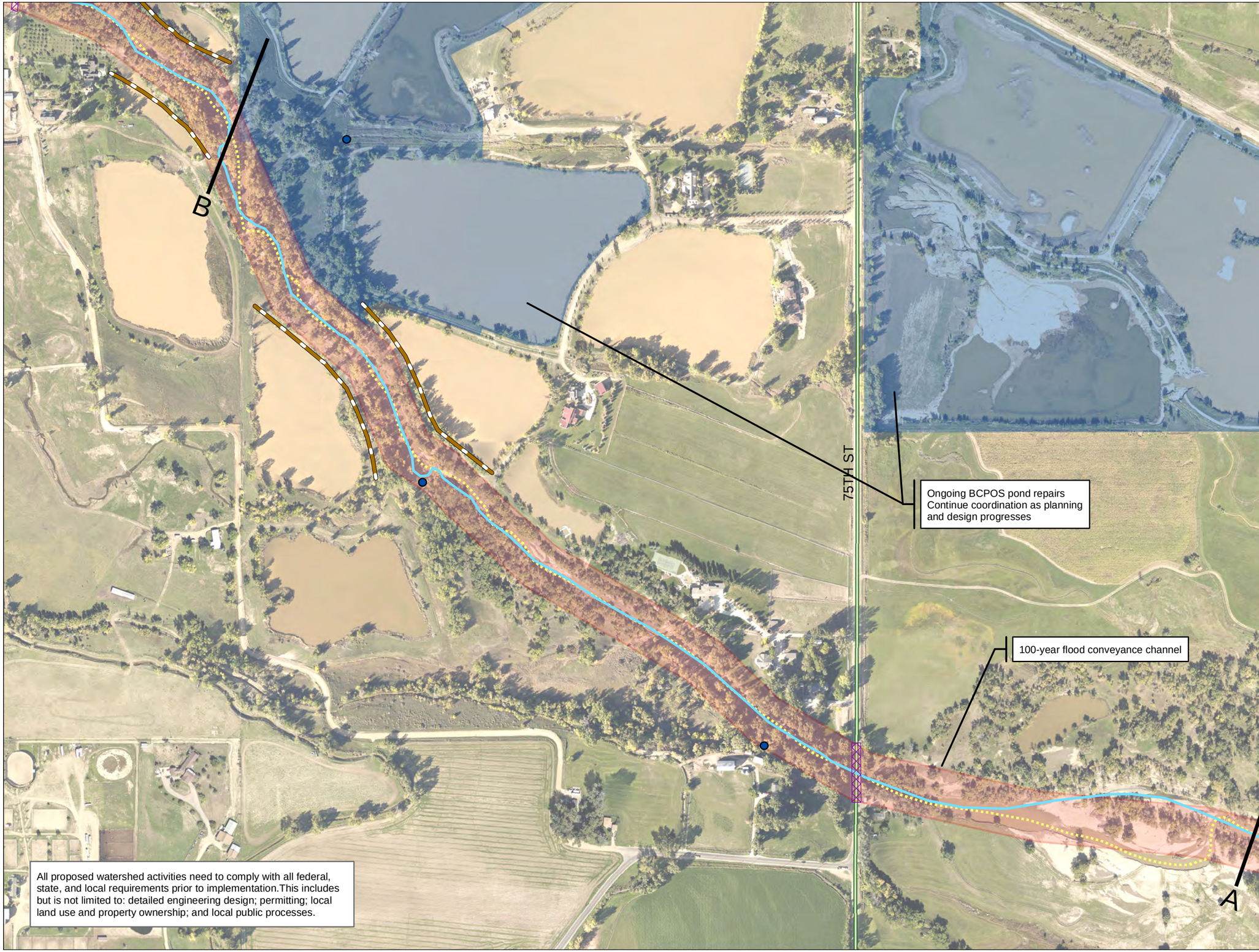
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 2 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
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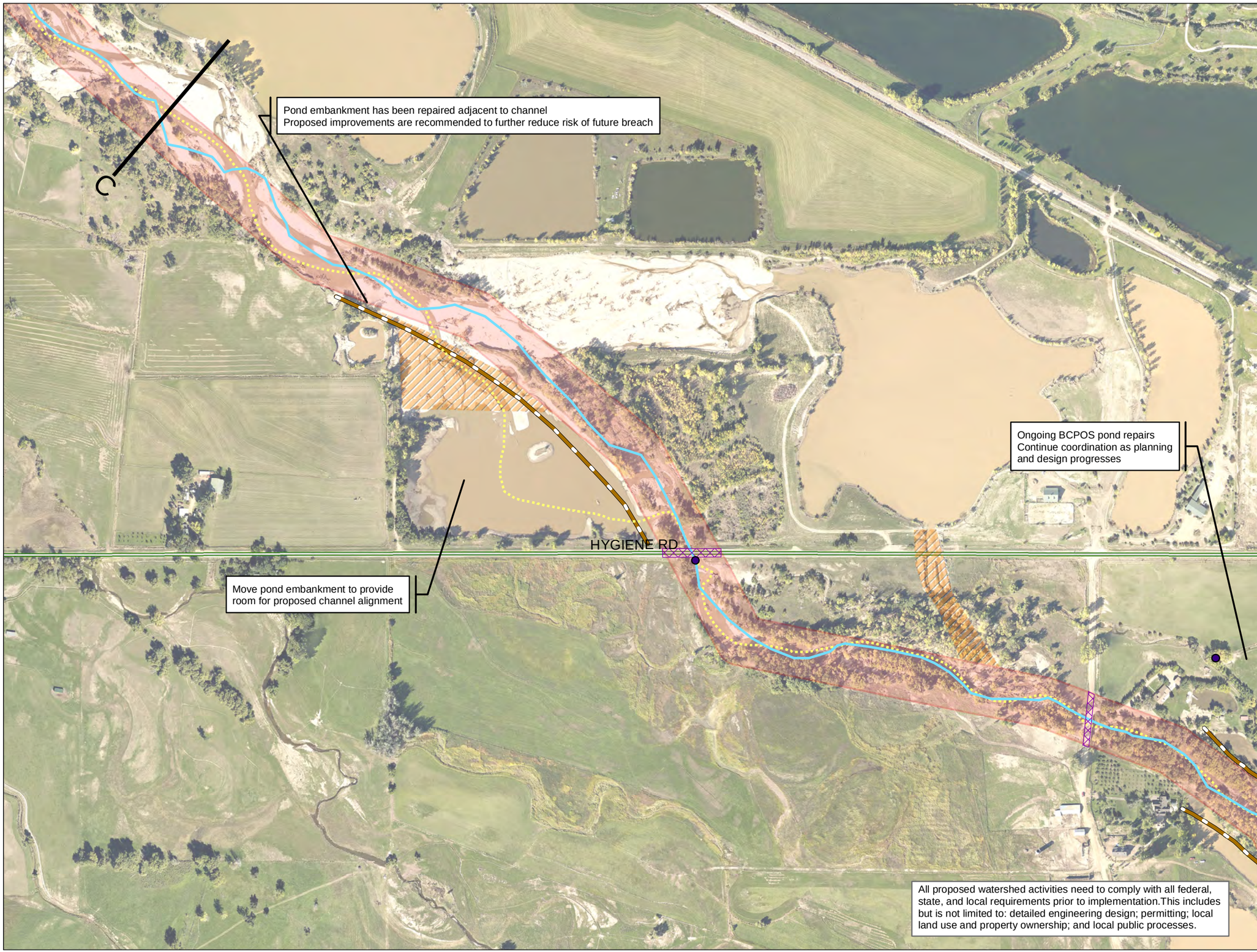
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 3 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
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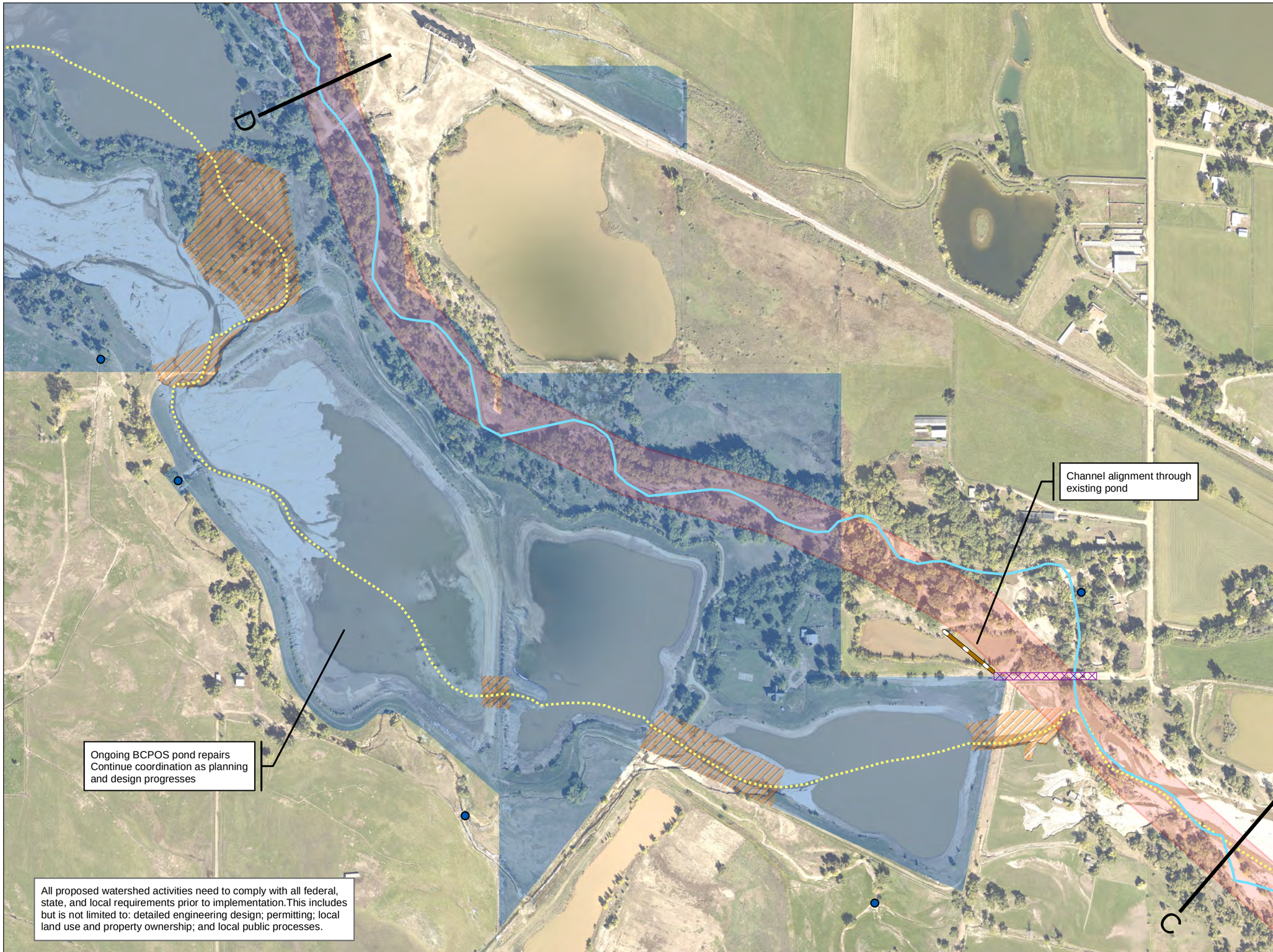
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 4 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
- Crossing Replacement
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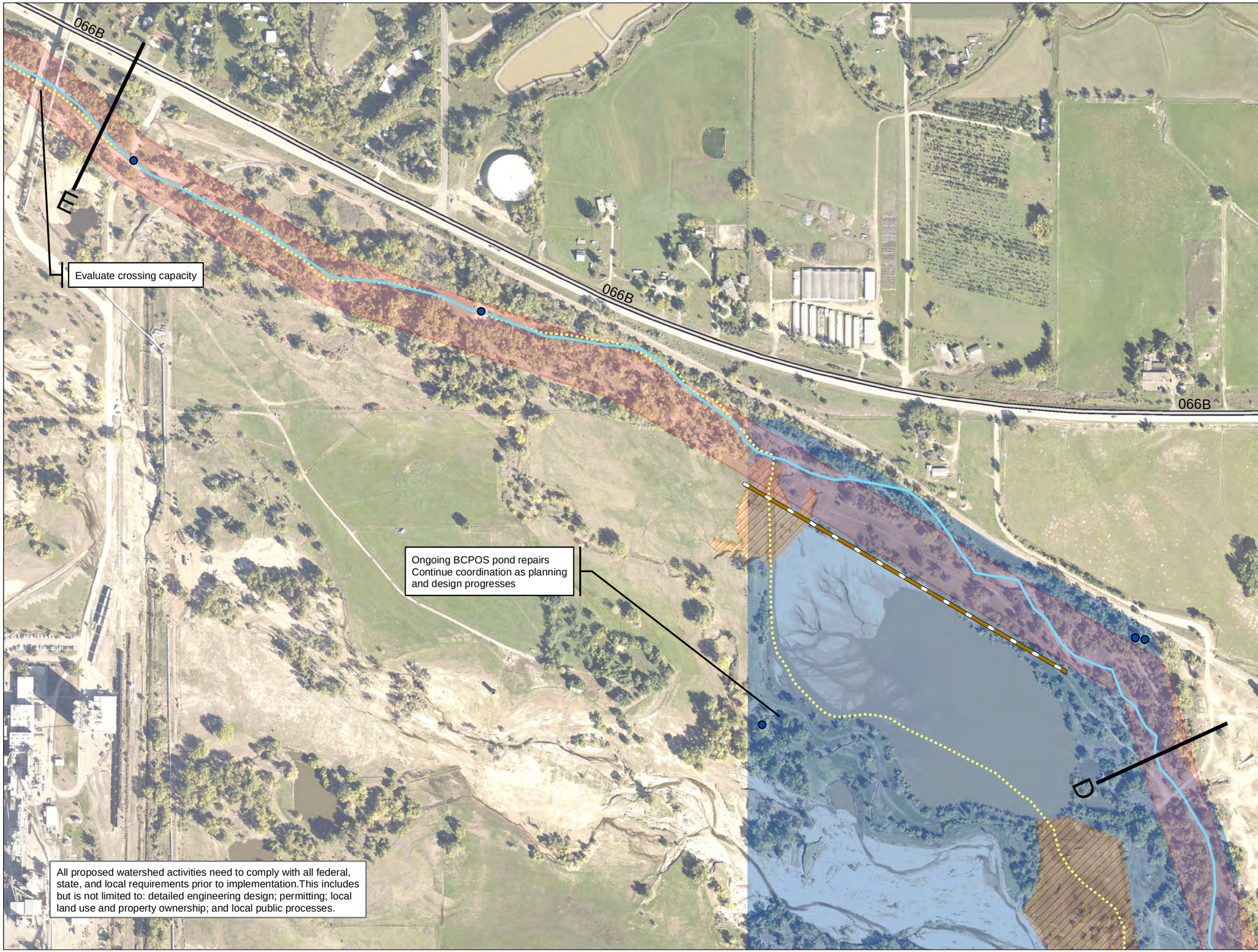
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 5 OF 6

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
- Crossing Replacement
- 100-Year Flood Control Channel
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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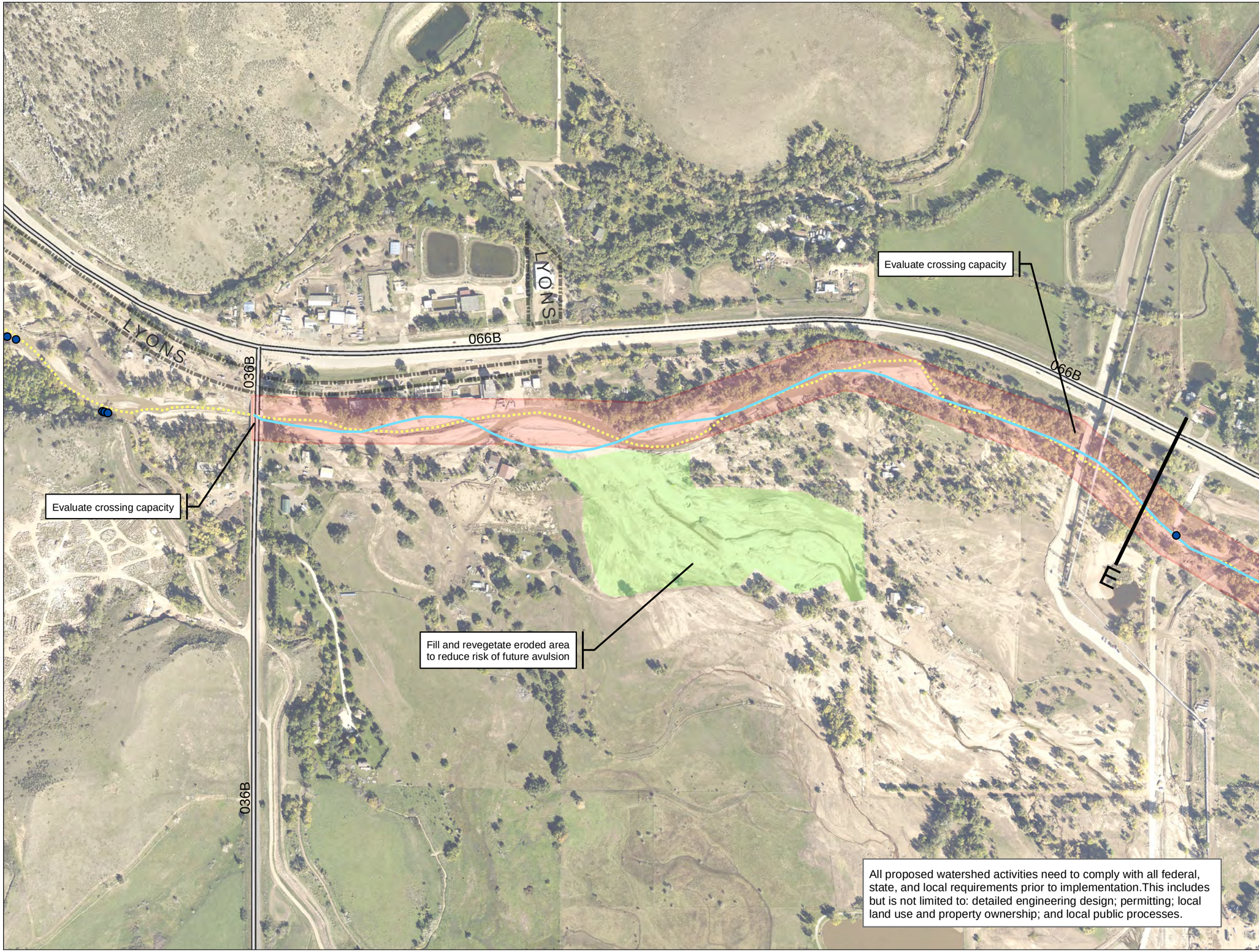
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 1: FLOOD CONTROL MAP 6 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Overflow Channel with Berm
- Move Pond Embankment
- Crossing Replacement
- 100-Year Flood Control Channel
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

N

Baker
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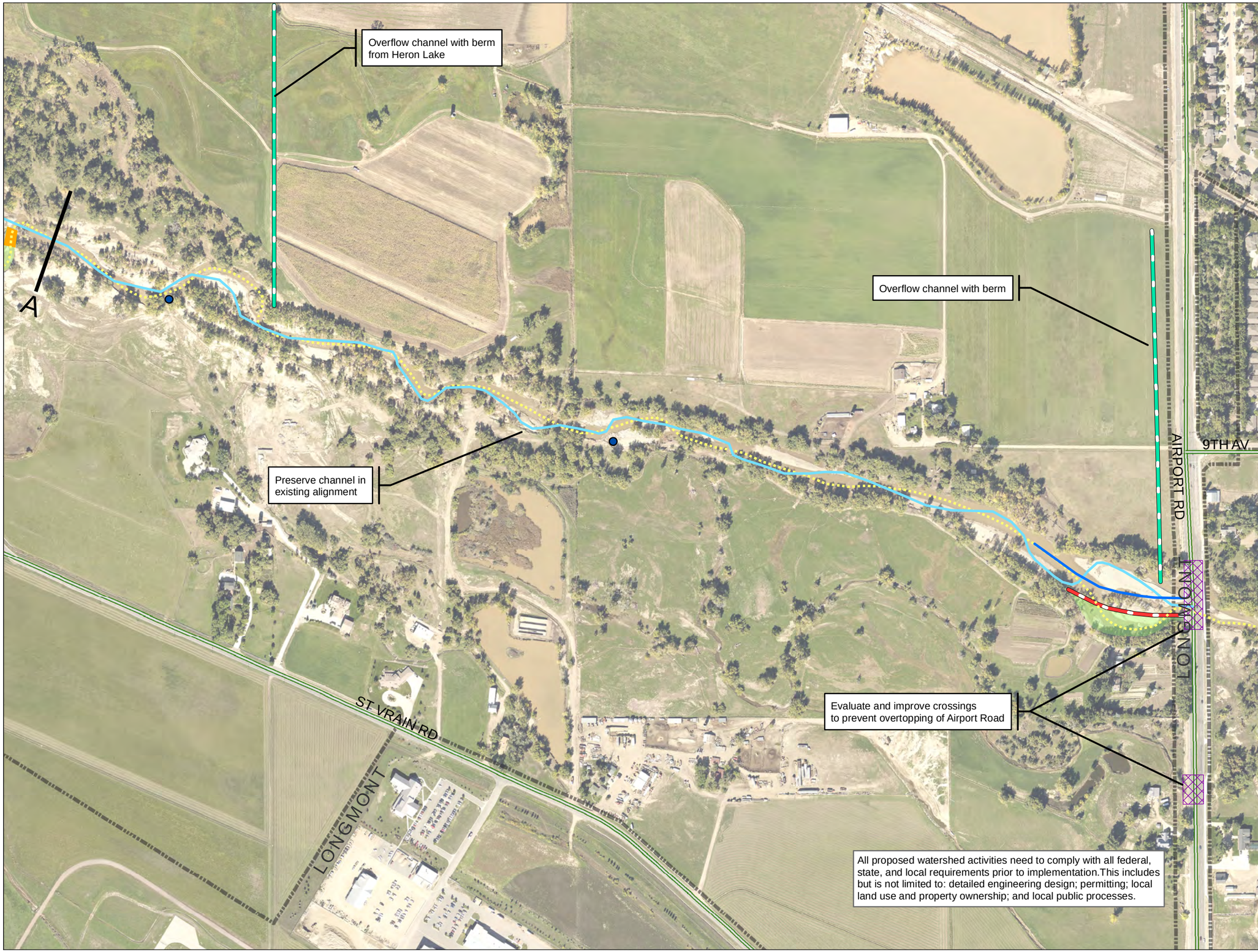
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 1 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Overflow Channel with Berm
- Bank Protection
- Move Pond Embankment
- Channel Plug
- Crossing Replacement
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- Repair Pond Breach
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- Highways
- Major Roads
- Municipalities

N

0 100 200 300 400 Feet

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165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
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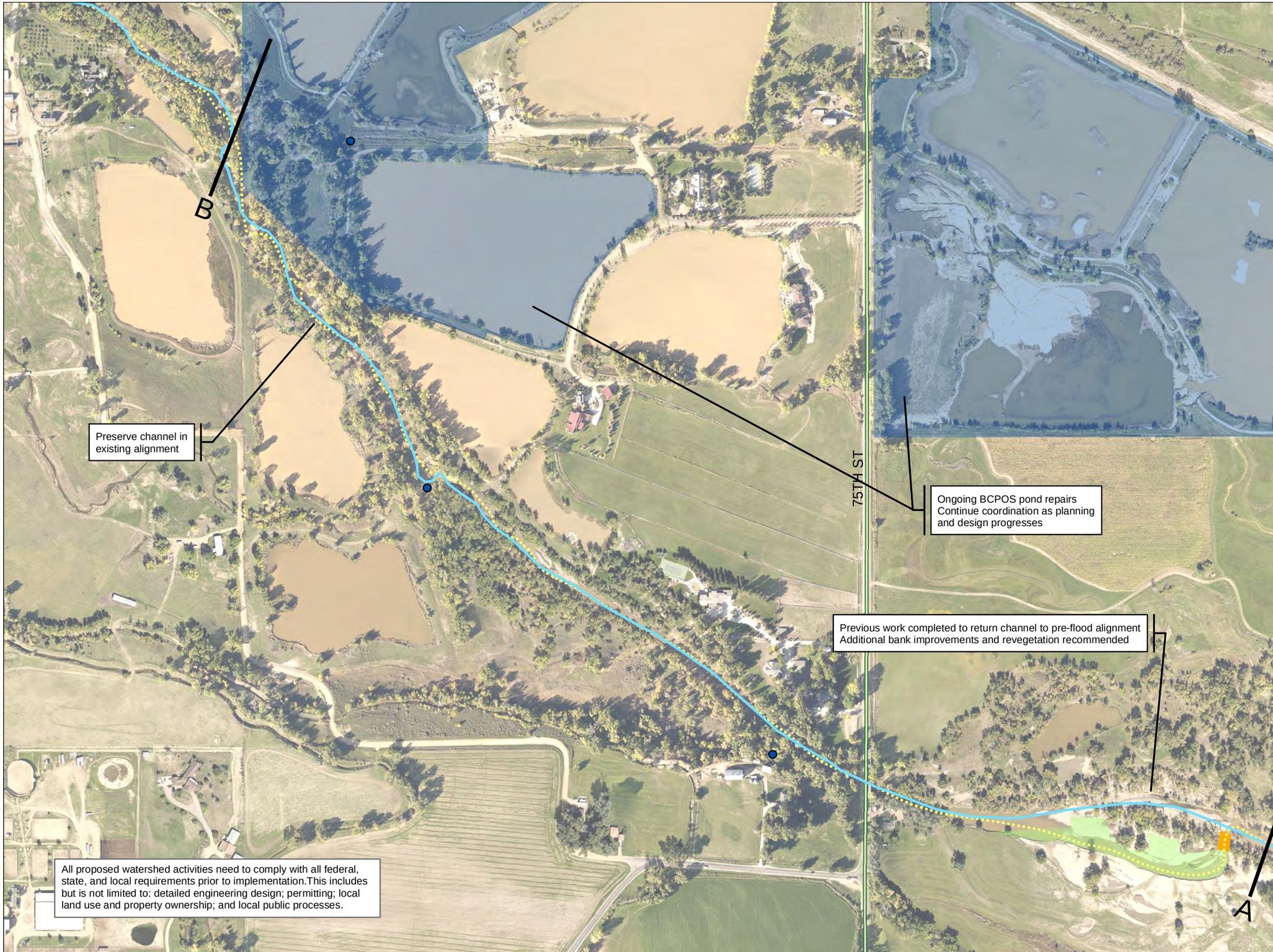
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 2 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Overflow Channel with Berm
- Bank Protection
- Move Pond Embankment
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N

0 100 200 300 400 Feet

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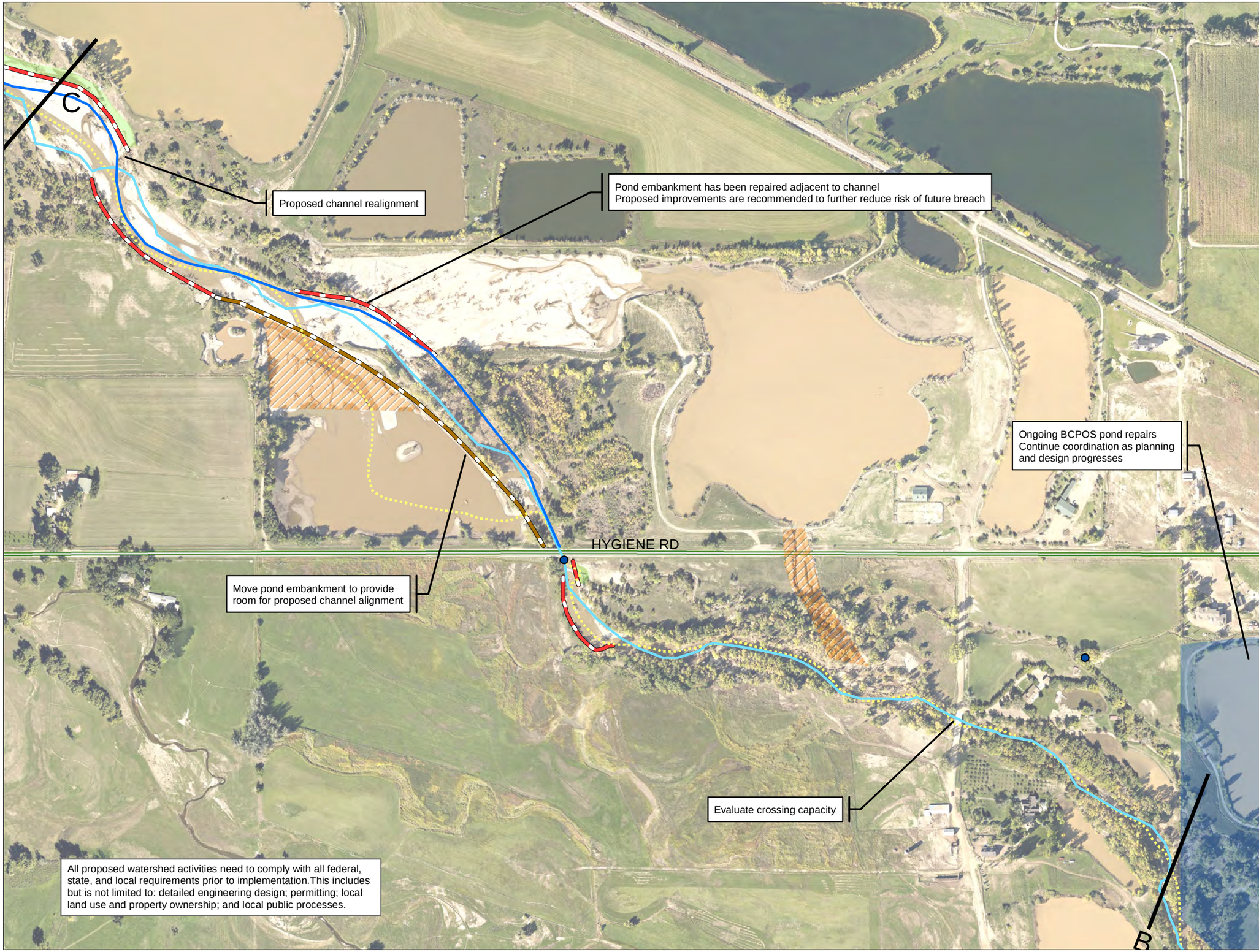
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 3 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Overflow Channel with Berm
- Bank Protection
- Move Pond Embankment
- Channel Plug
- Crossing Replacement
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegatation
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- Major Roads
- Municipalities

N

Feet
0 100 200 300 400

Baker
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SUITE 200
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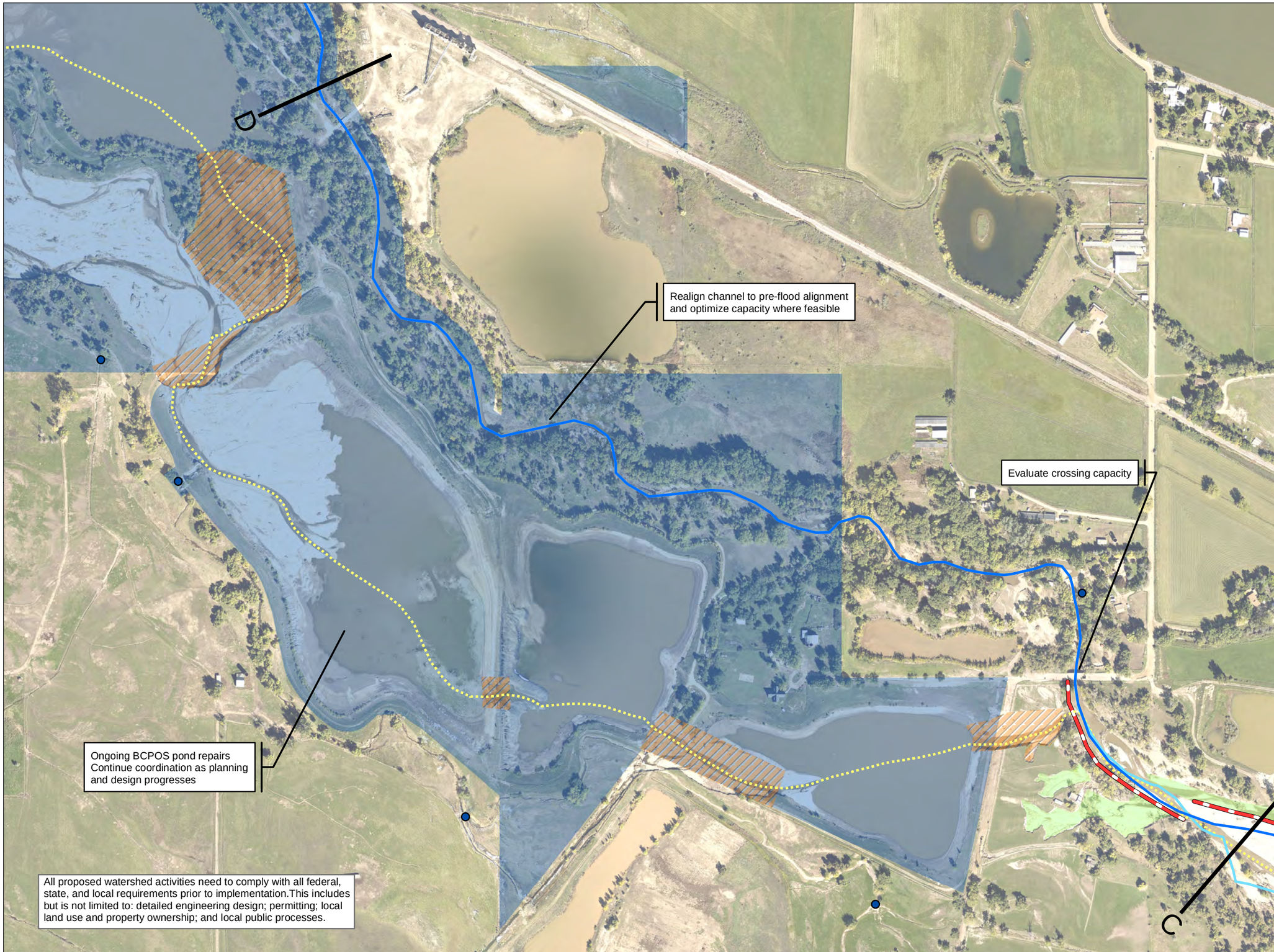
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 4 OF 6



LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Overflow Channel with Berm
- Bank Protection
- Move Pond Embankment
- Channel Plug
- Crossing Replacement
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- Repair Pond Breach
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0 100 200 300 400 Feet

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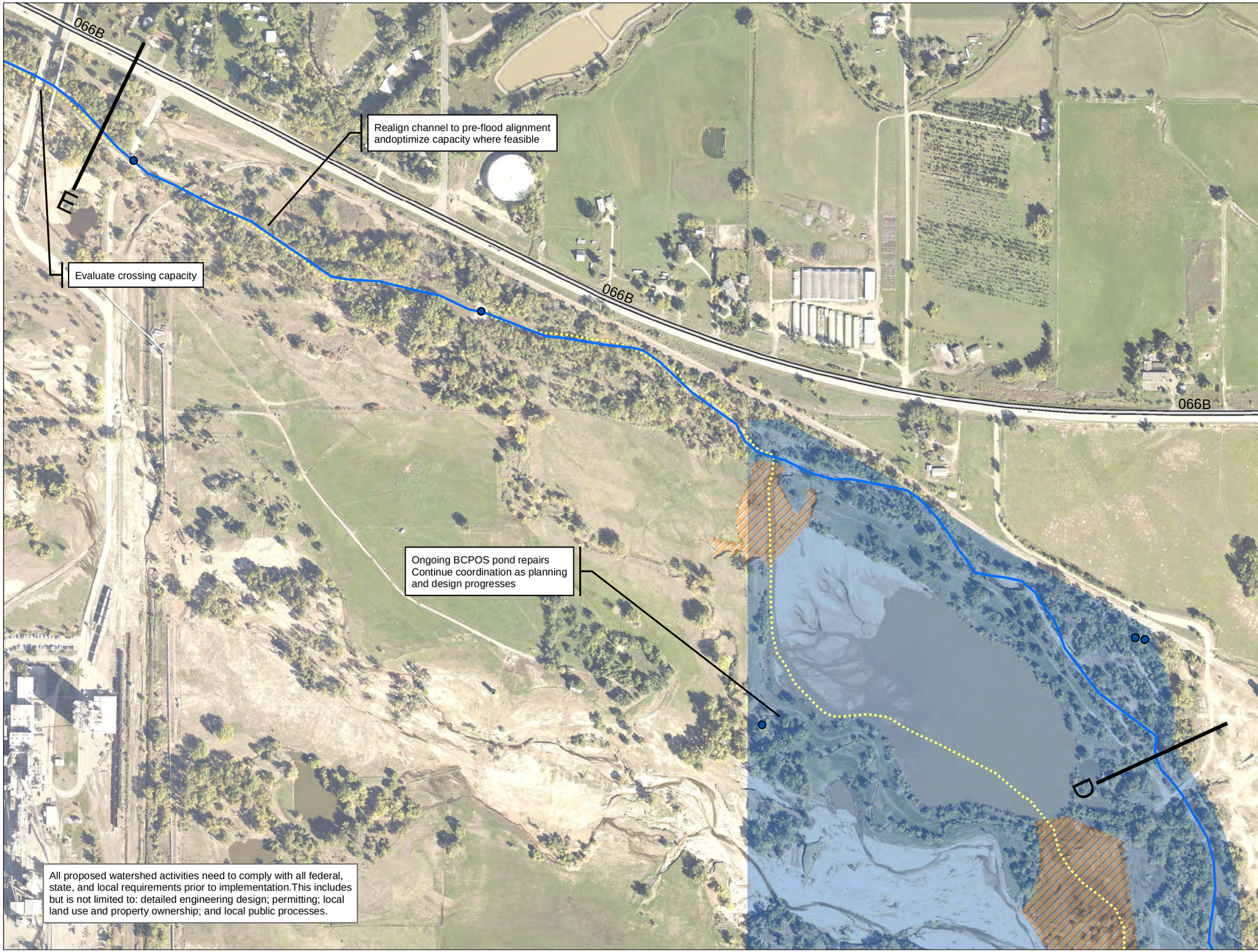
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 5 OF 6

LEGEND

- Headgates
- Post Flood Channel Alignment
- Proposed Channel Alignment (back to pre-flood)
- Overflow Channel with Berm
- Move Pond Embankment
- Channel Plug
- Crossing Replacement
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

N

0 100 200 300 400 Feet

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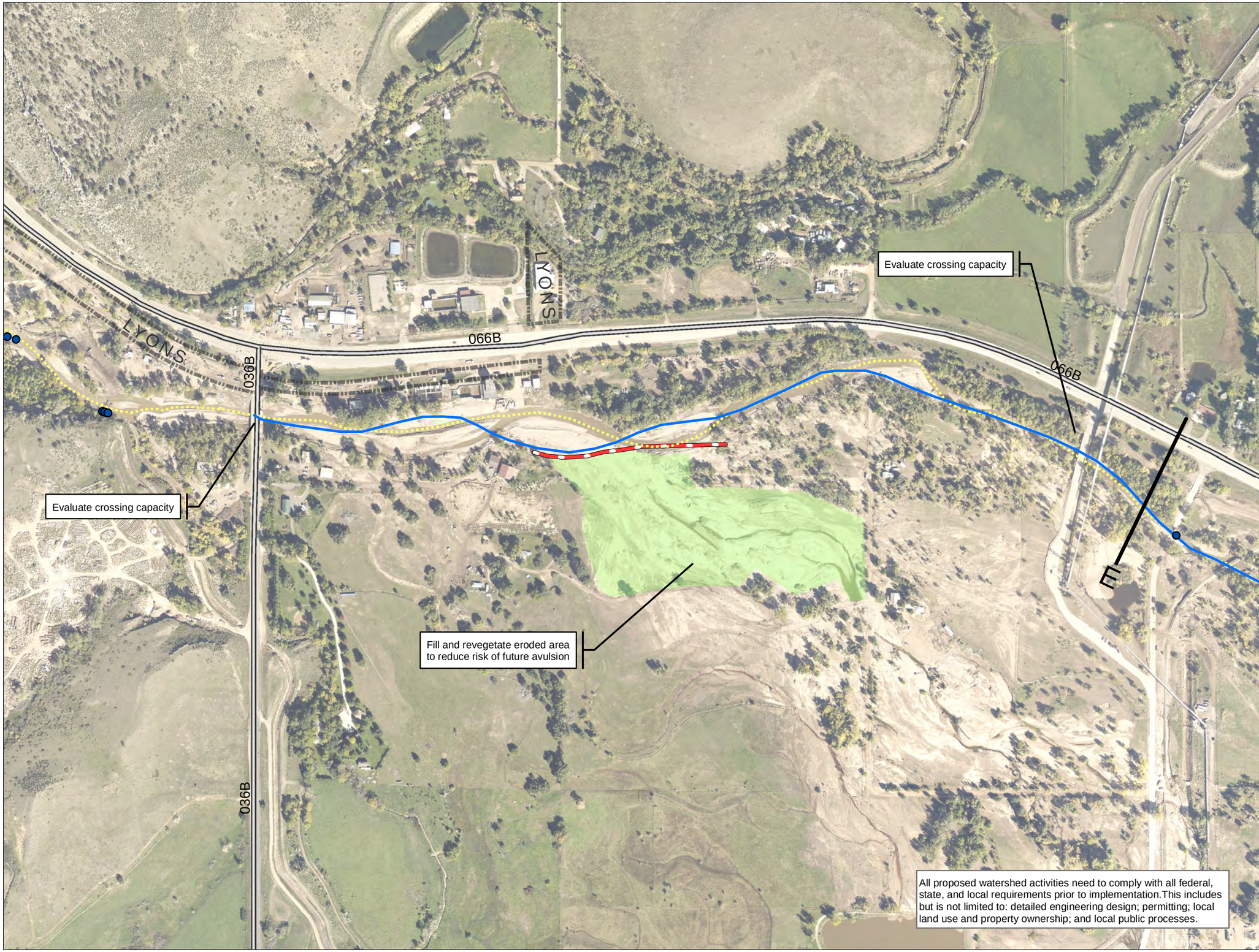
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 3 ALTERNATIVE 2: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 6 OF 6

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Overflow Channel with Berm
- Bank Protection
- Move Pond Embankment
- Channel Plug
- Crossing Replacement
- BCPOS Pond Repairs
- Repair Pond Breach
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

N

0 100 200 300 400 Feet

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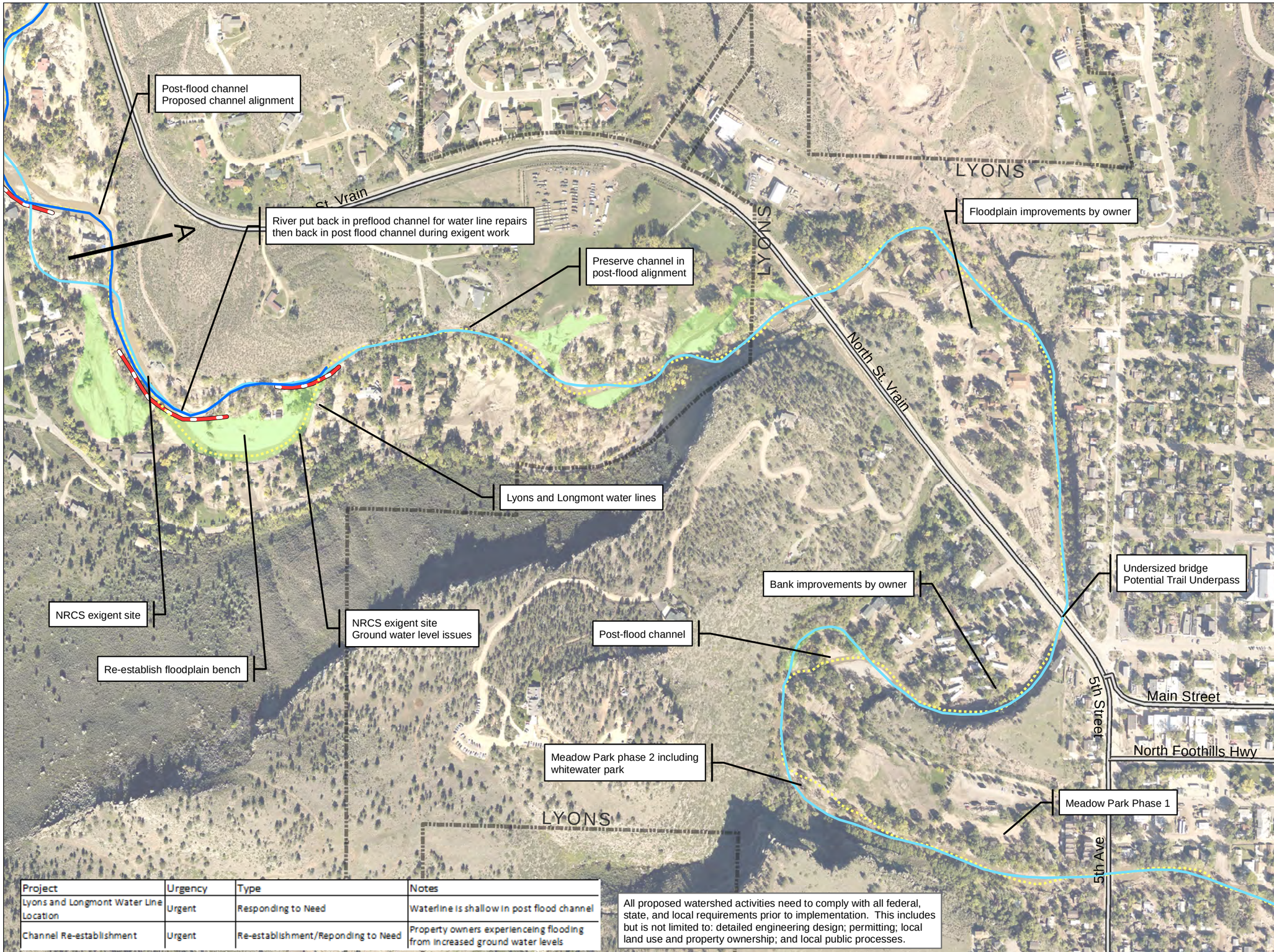
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 4a ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 1 OF 3



Project	Urgency	Type	Notes
Lyons and Longmont Water Line Location	Urgent	Responding to Need	Waterline is shallow in post flood channel
Channel Re-establishment	Urgent	Re-establishment/Reponding to Need	Property owners experienceing flooding from increased ground water levels

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LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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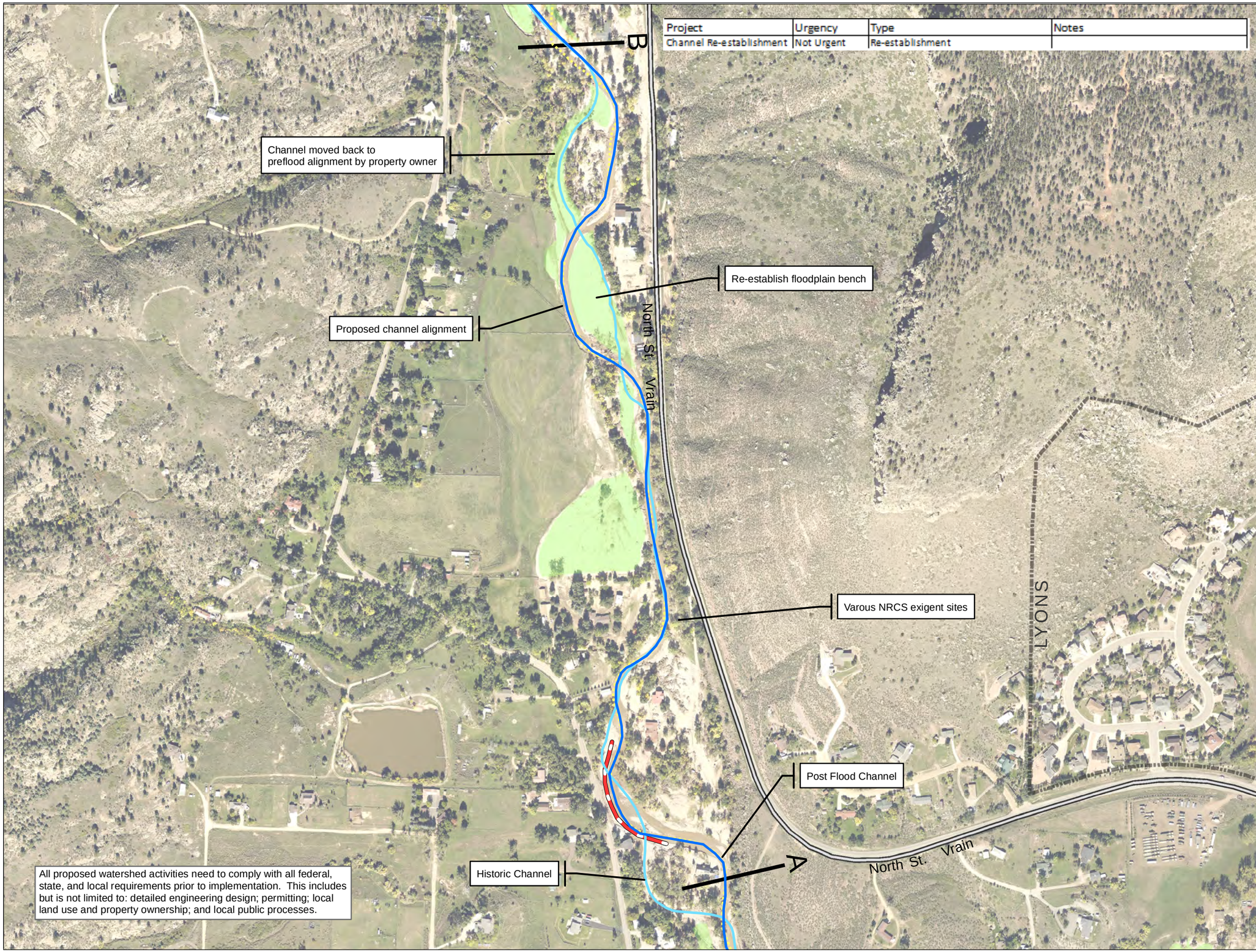
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

Project	Urgency	Type	Notes
Channel Re-establishment	Not Urgent	Re-establishment	



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REACH 4a ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 2 OF 3

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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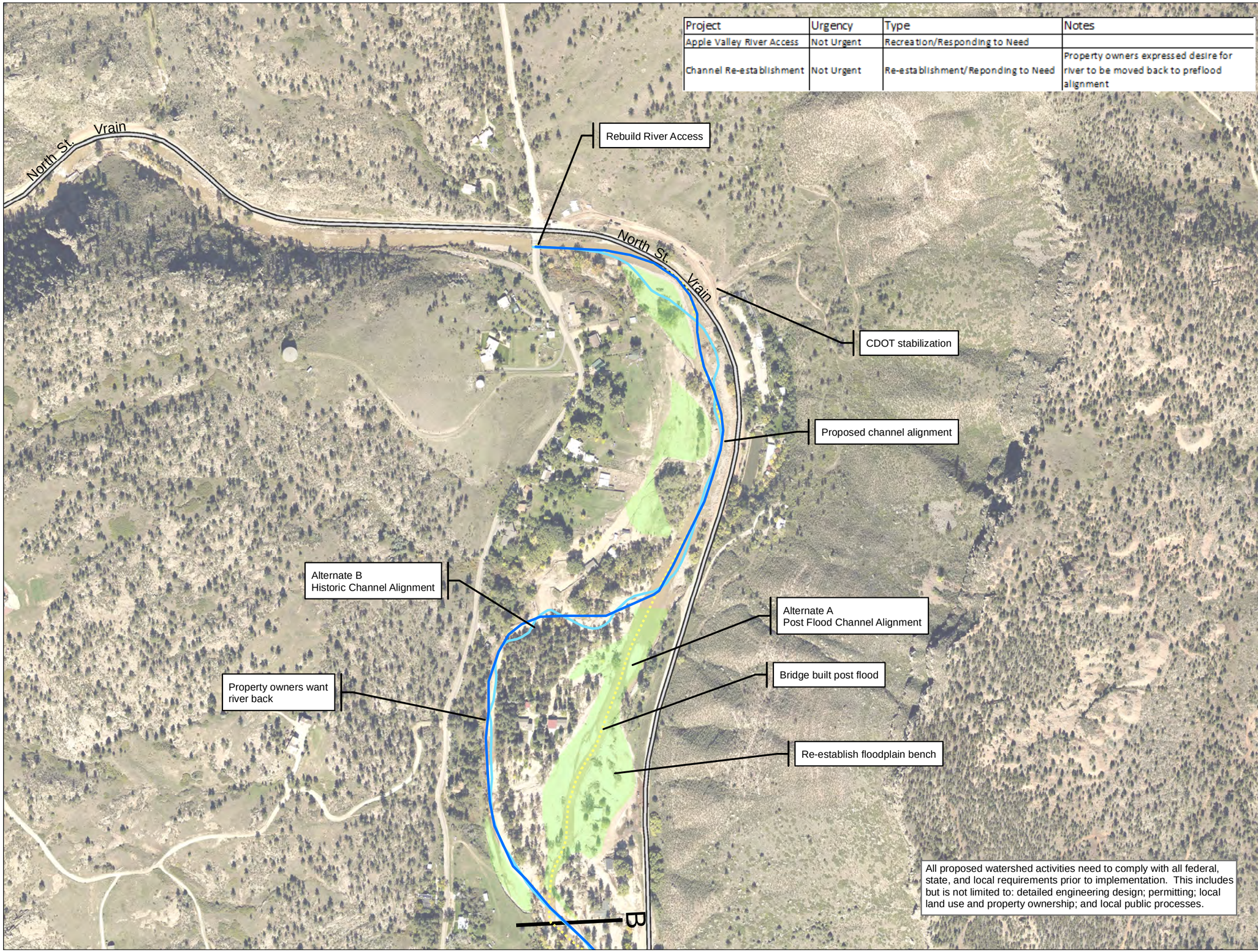
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

Project	Urgency	Type	Notes
Apple Valley River Access	Not Urgent	Recreation/Responding to Need	
Channel Re-establishment	Not Urgent	Re-establishment/Reponding to Need	Property owners expressed desire for river to be moved back to preflood alignment



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REACH 4a ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 3 OF 3

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
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- Highways
- Major Roads
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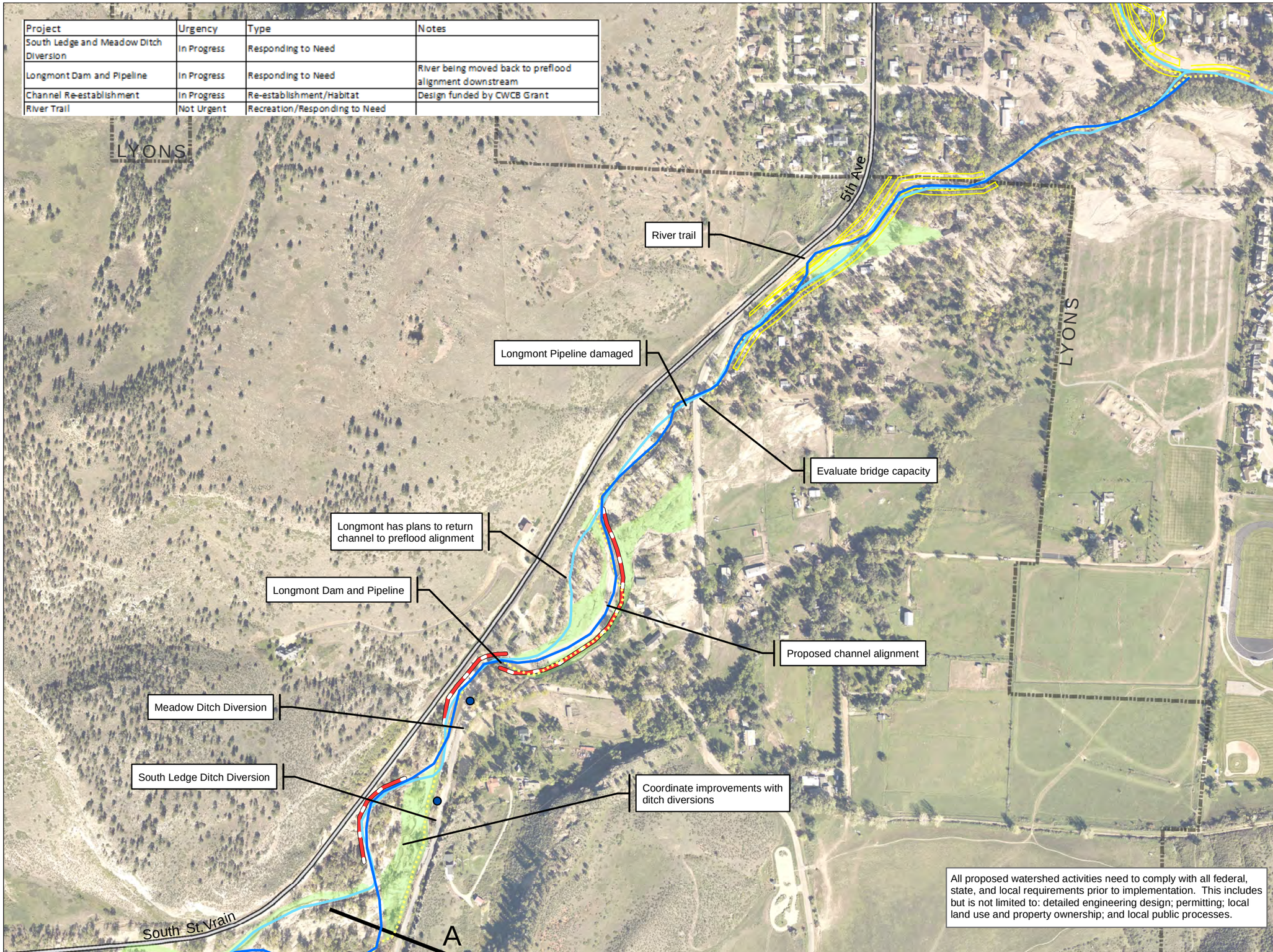
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

Project	Urgency	Type	Notes
South Ledge and Meadow Ditch Diversion	In Progress	Responding to Need	
Longmont Dam and Pipeline	In Progress	Responding to Need	River being moved back to preflood alignment downstream
Channel Re-establishment	In Progress	Re-establishment/Habitat	Design funded by CWCB Grant
River Trail	Not Urgent	Recreation/Responding to Need	



All proposed watershed activities need to comply with all federal, state, and local requirements prior to implementation. This includes but is not limited to: detailed engineering design; permitting; local land use and property ownership; and local public processes.

REACH 4b ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 1 OF 3

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- CDBG Projects
- Bank Protection
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

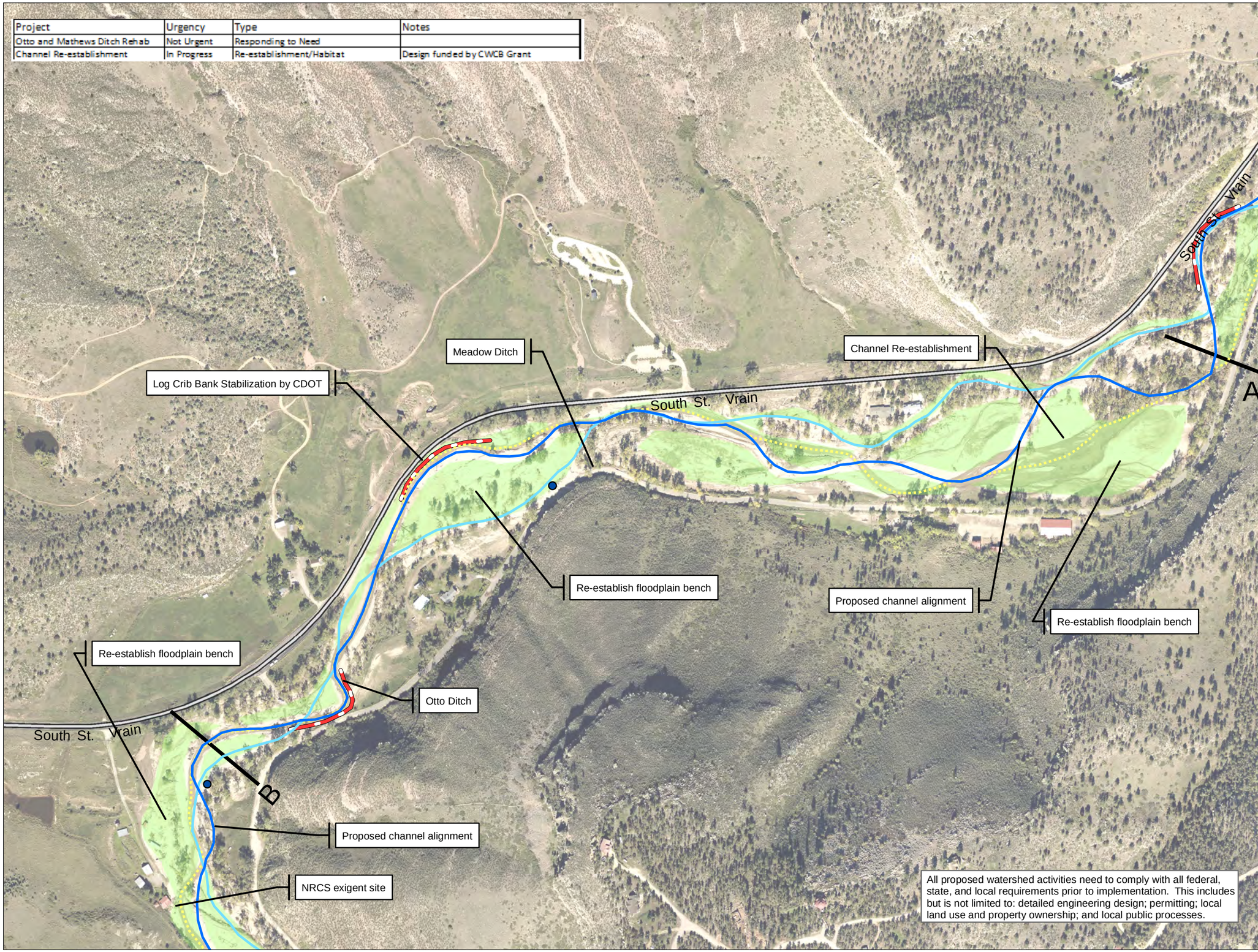
N

Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

Project	Urgency	Type	Notes
Otto and Mathews Ditch Rehab	Not Urgent	Responding to Need	
Channel Re-establishment	In Progress	Re-establishment/Habitat	Design funded by CWCB Grant



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REACH 4b ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 2 OF 3

LEGEND

- Headgates
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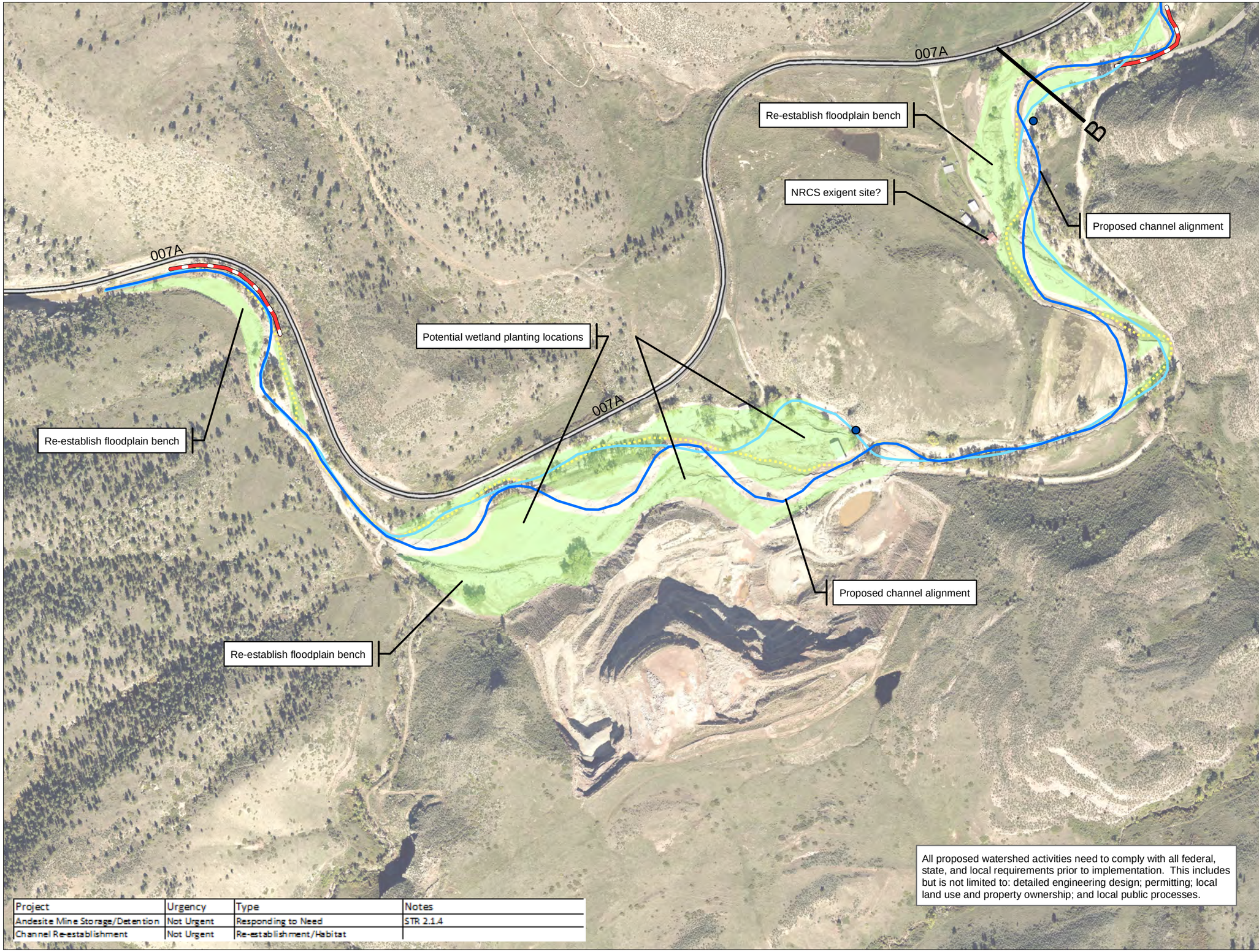
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 4b ALTERNATIVE 1: CHANNEL REALIGNMENT & SITE-SPECIFIC PROJ. MAP 3 OF 3



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Project	Urgency	Type	Notes
Andesite Mine Storage/Detention	Not Urgent	Responding to Need	STR 2.1.4
Channel Re-establishment	Not Urgent	Re-establishment/Habitat	

LEGEND

- Headgates
- Pre-Flood Channel Alignment
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- Bank Protection
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- Highways
- Major Roads
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0 100 200 300 400 Feet

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Baker
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SUITE 200
LAKEWOOD, CO 80228
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LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 4c
ALTERNATIVES 1 & 2
MAP 1 OF 3

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LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
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0 100 200 300 400 Feet

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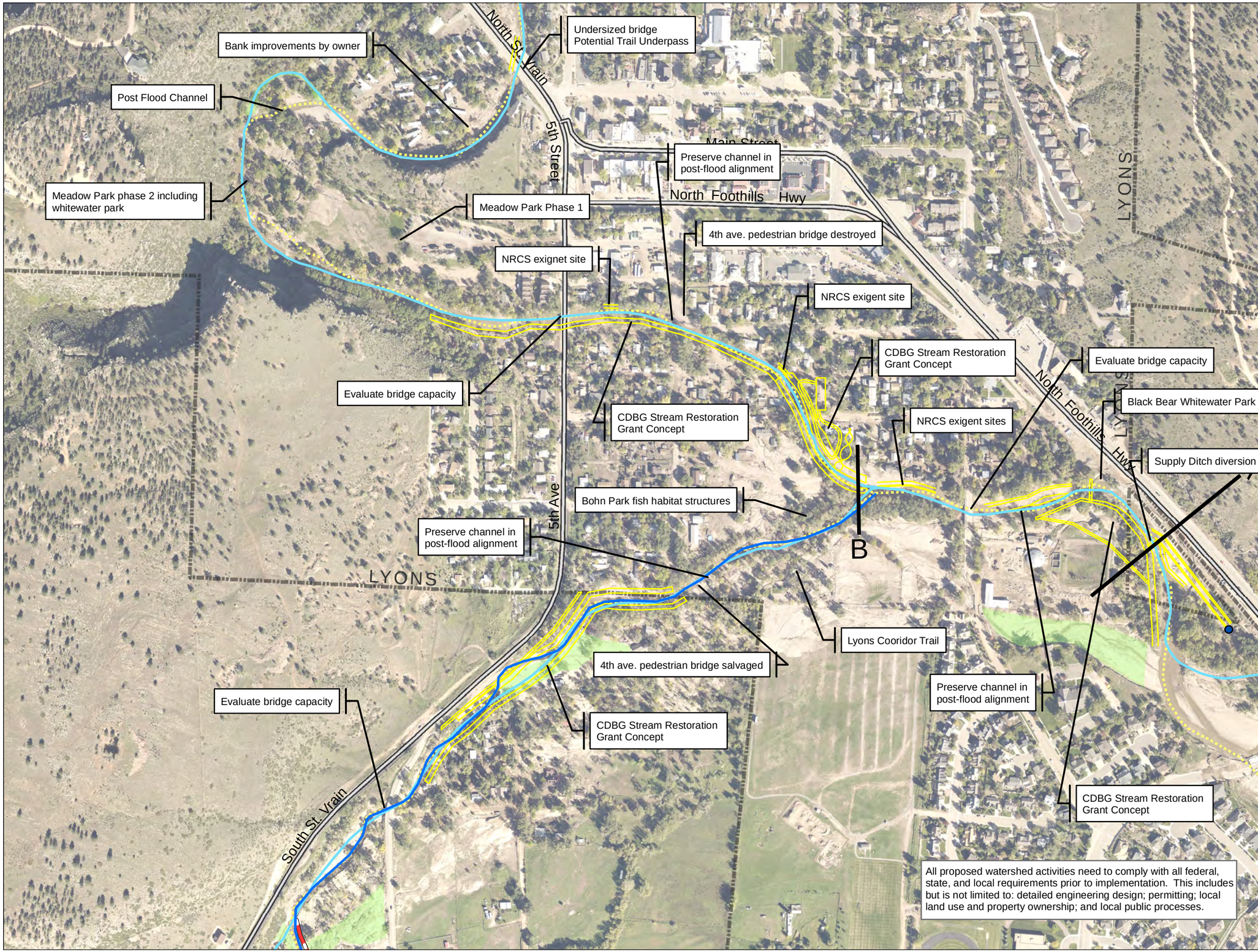
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 4c
MAP 2 OF 3

LEGEND

- Headgates
- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- CDBG Projects
- Bank Protection
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 4c
MAP 3 OF 3

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- CDBG Projects
- Bank Protection
- Fill & Revegetation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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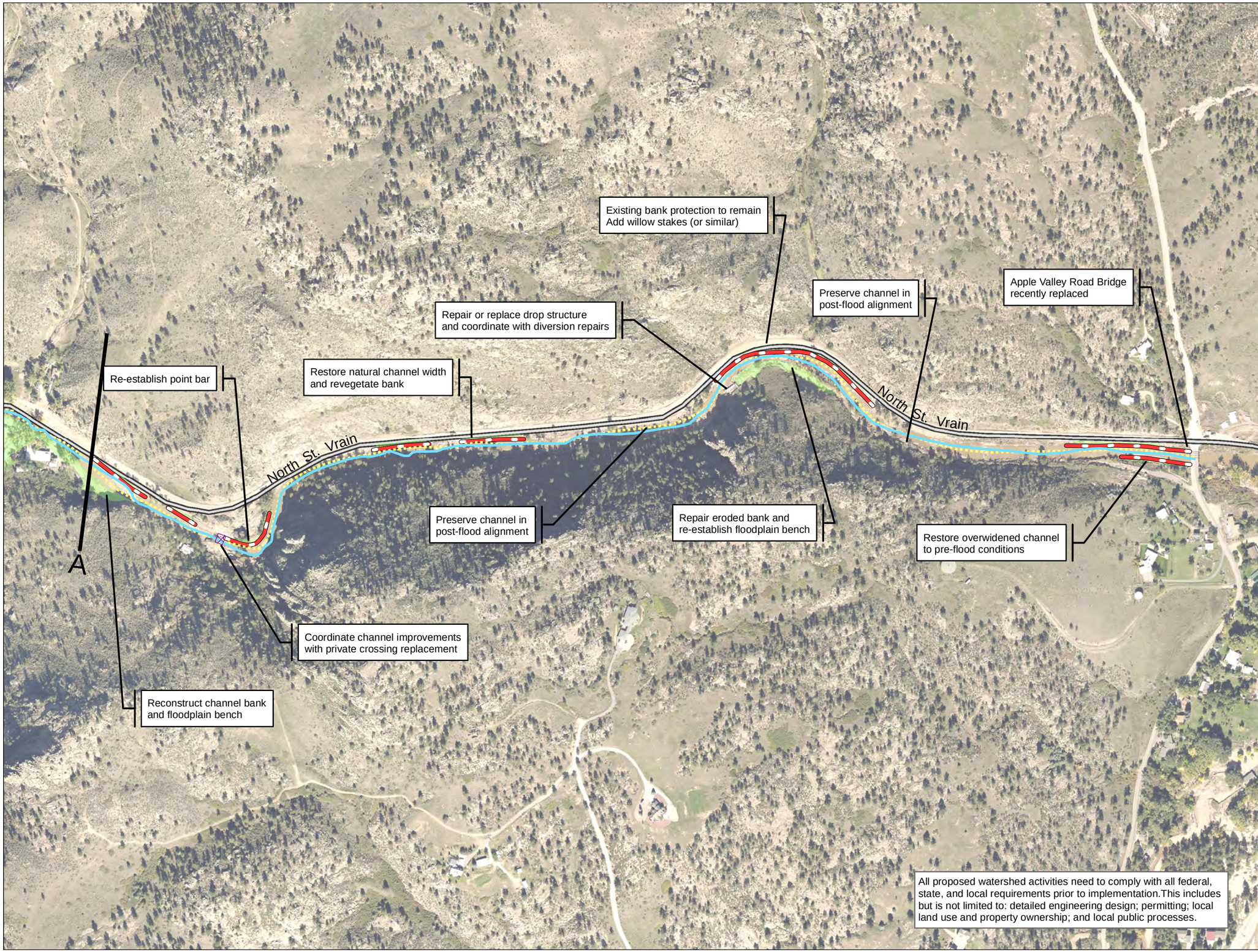
Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 5 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 1 OF 5



LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
- Crossing Replacement
- Dredge
- Fill & Revegatation
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- Major Roads
- Municipalities

0 100 200 300 400 Feet

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Baker
165 S. UNION BLVD.
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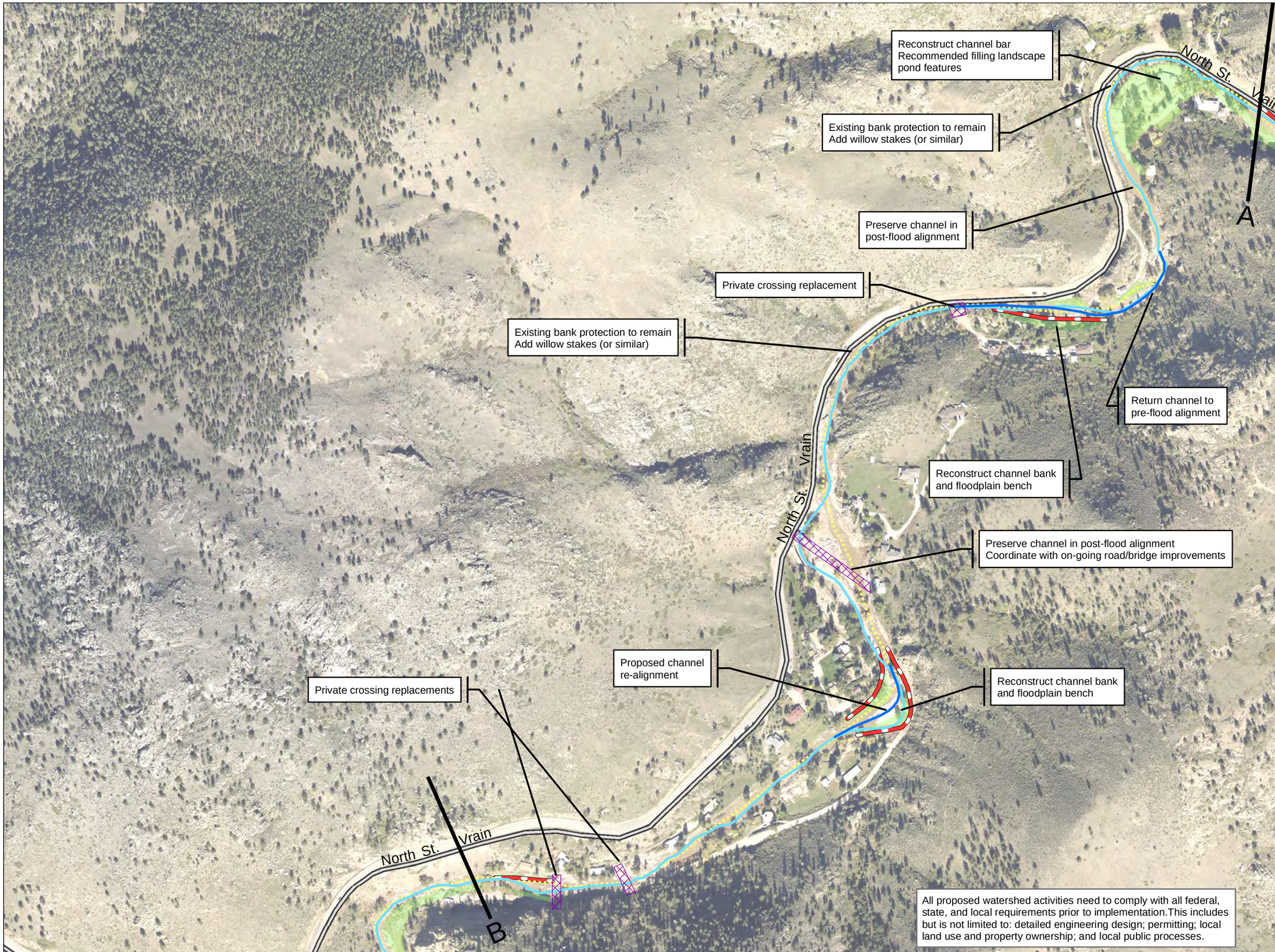
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 5 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 2 OF 5



LEGEND

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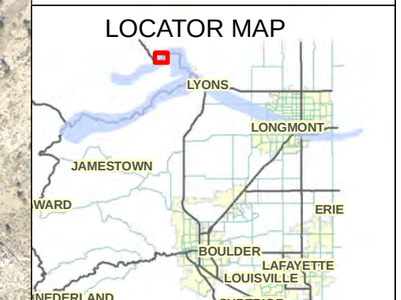
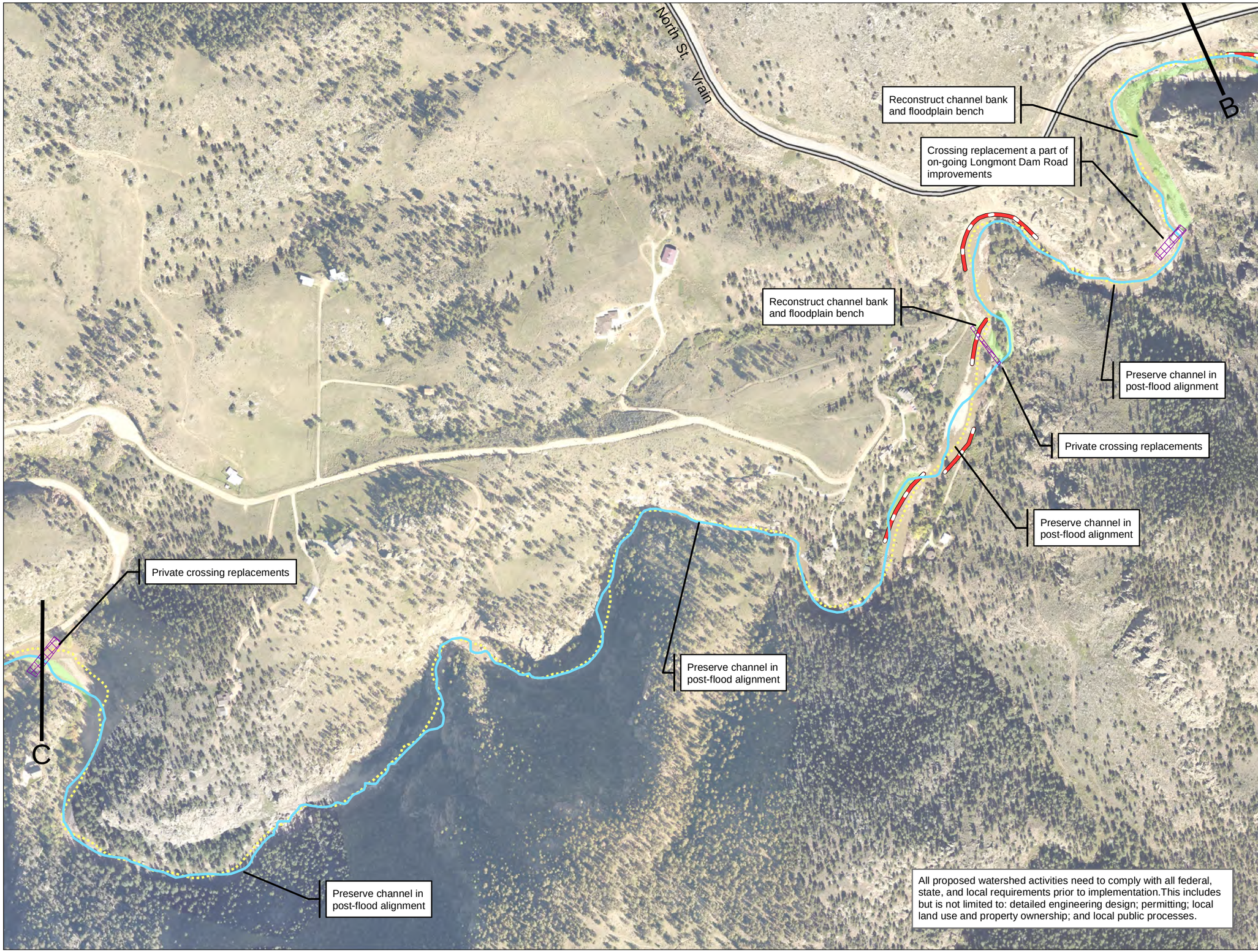


ST. VRAIN CREEK ALTERNATIVES

REACH 5 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 3 OF 5



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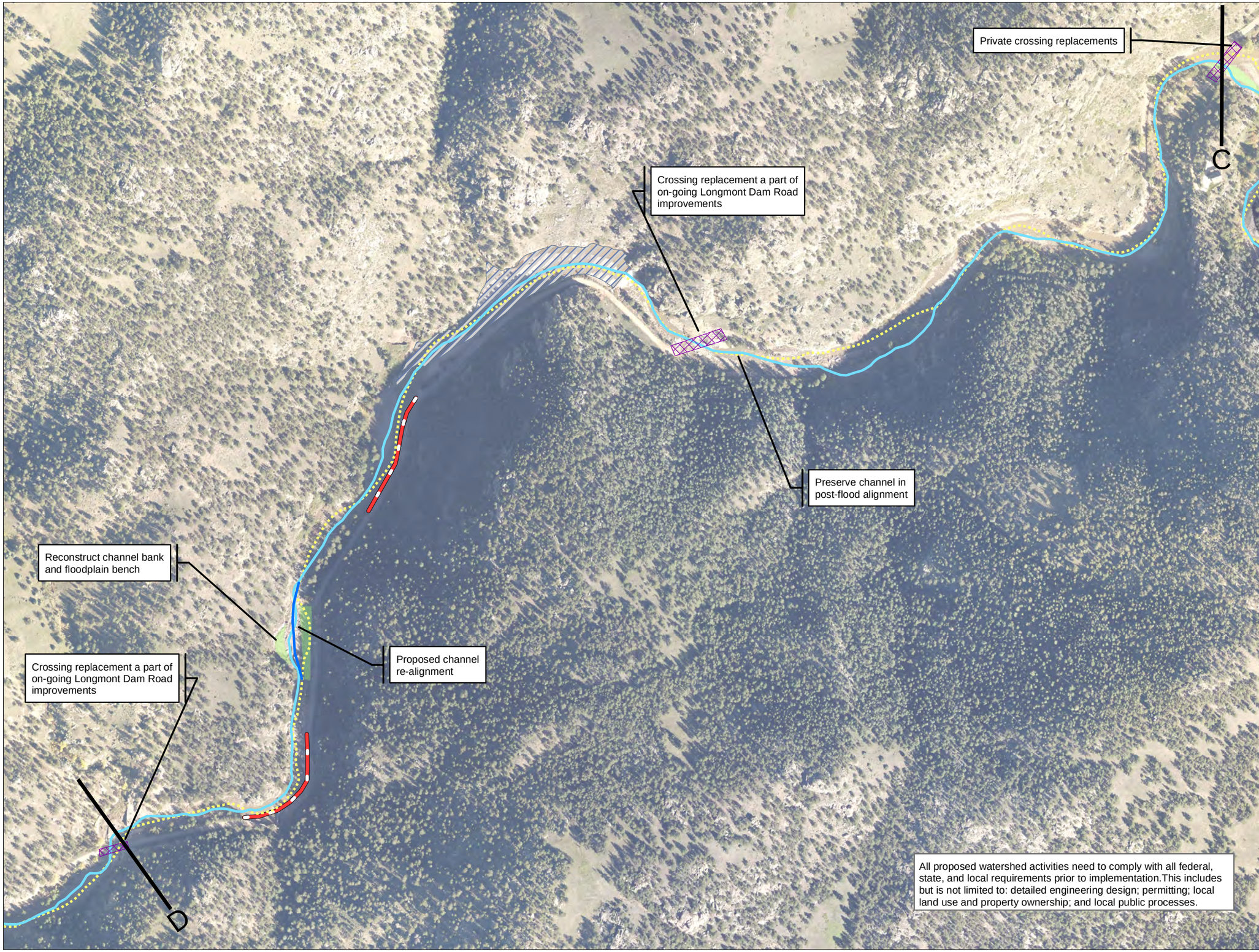
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 5 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 4 OF 5



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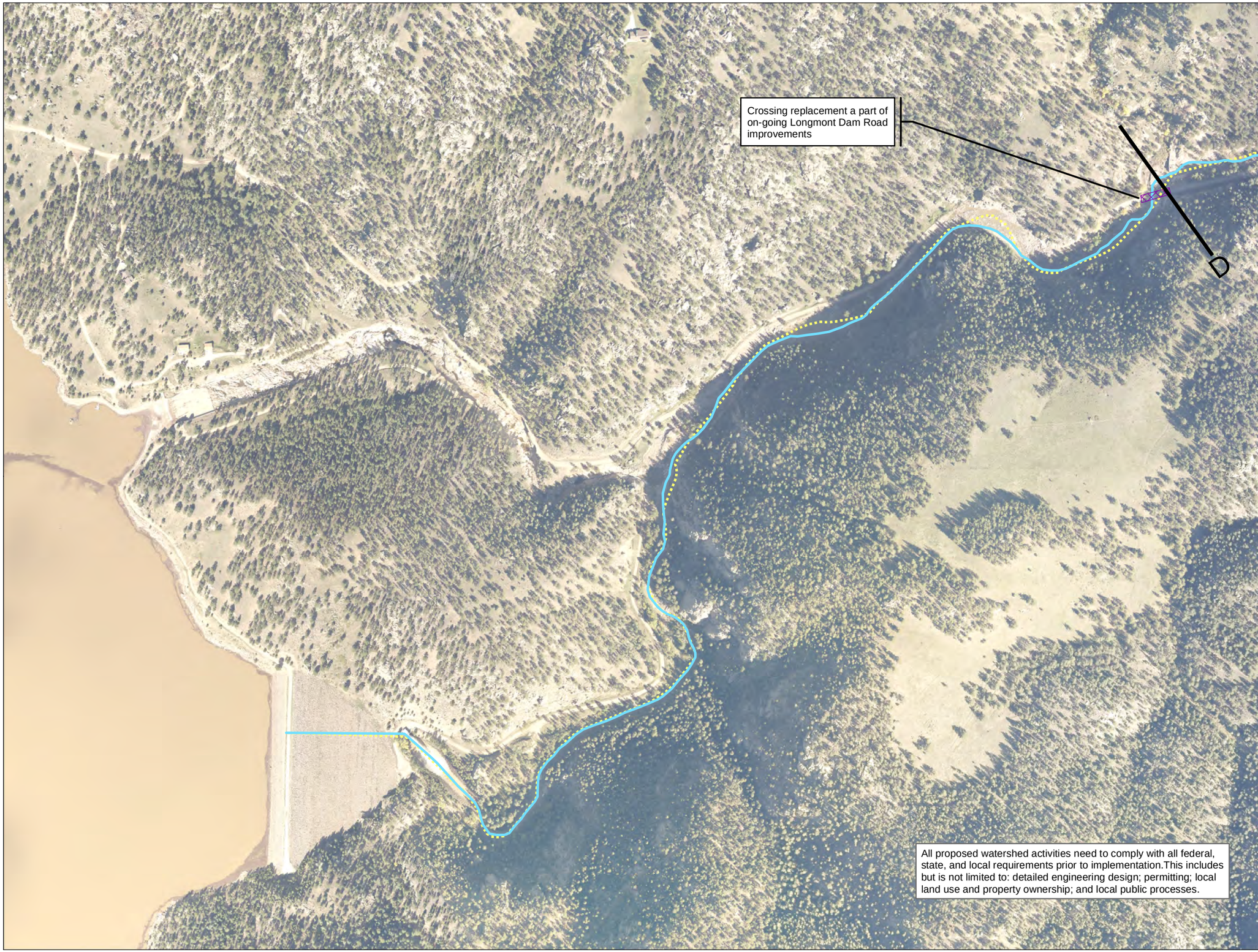
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES



REACH 5 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 5 OF 5

LEGEND

- Pre-Flood Channel Alignment
- Post Flood Channel Alignment
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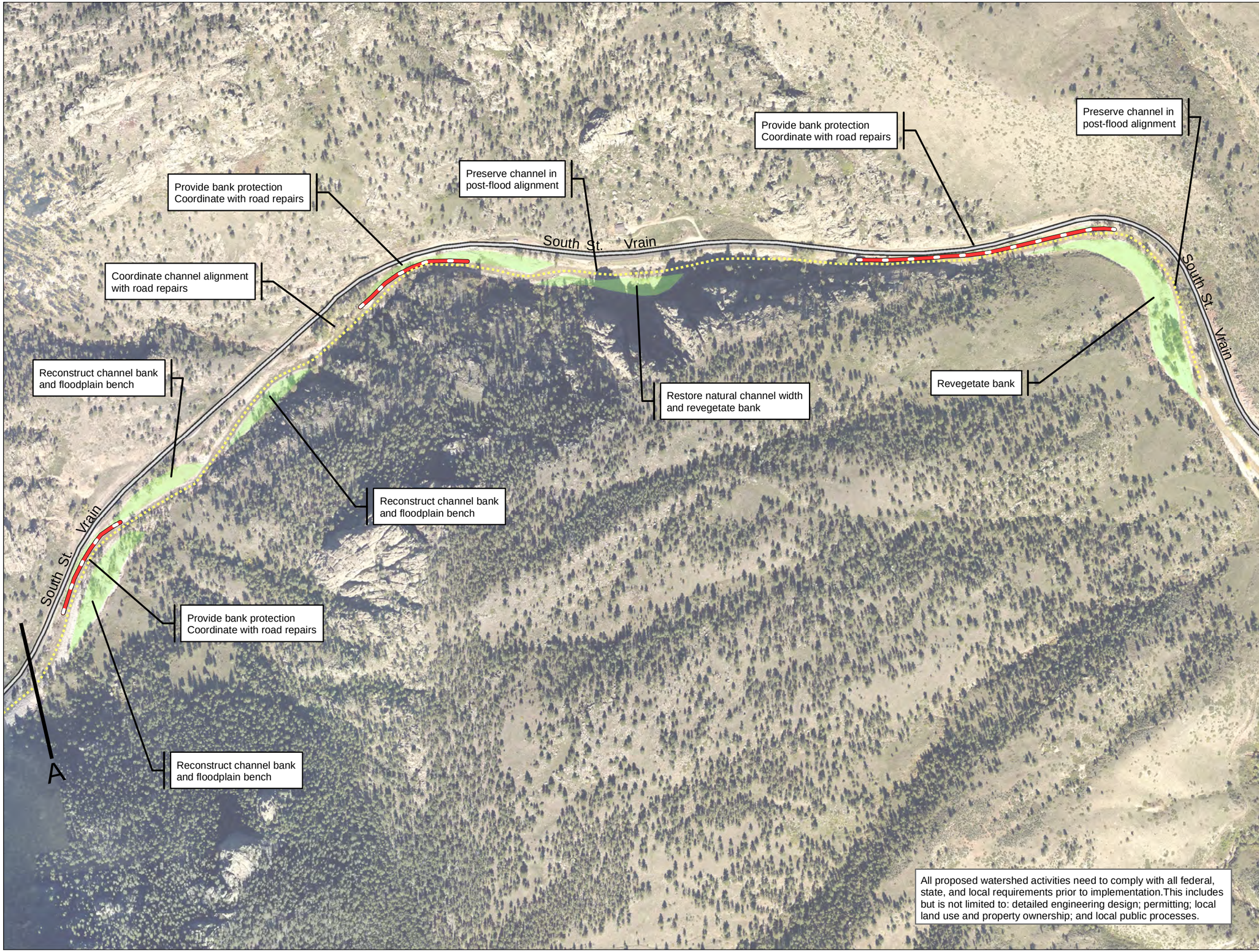
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 1 OF 9



LEGEND

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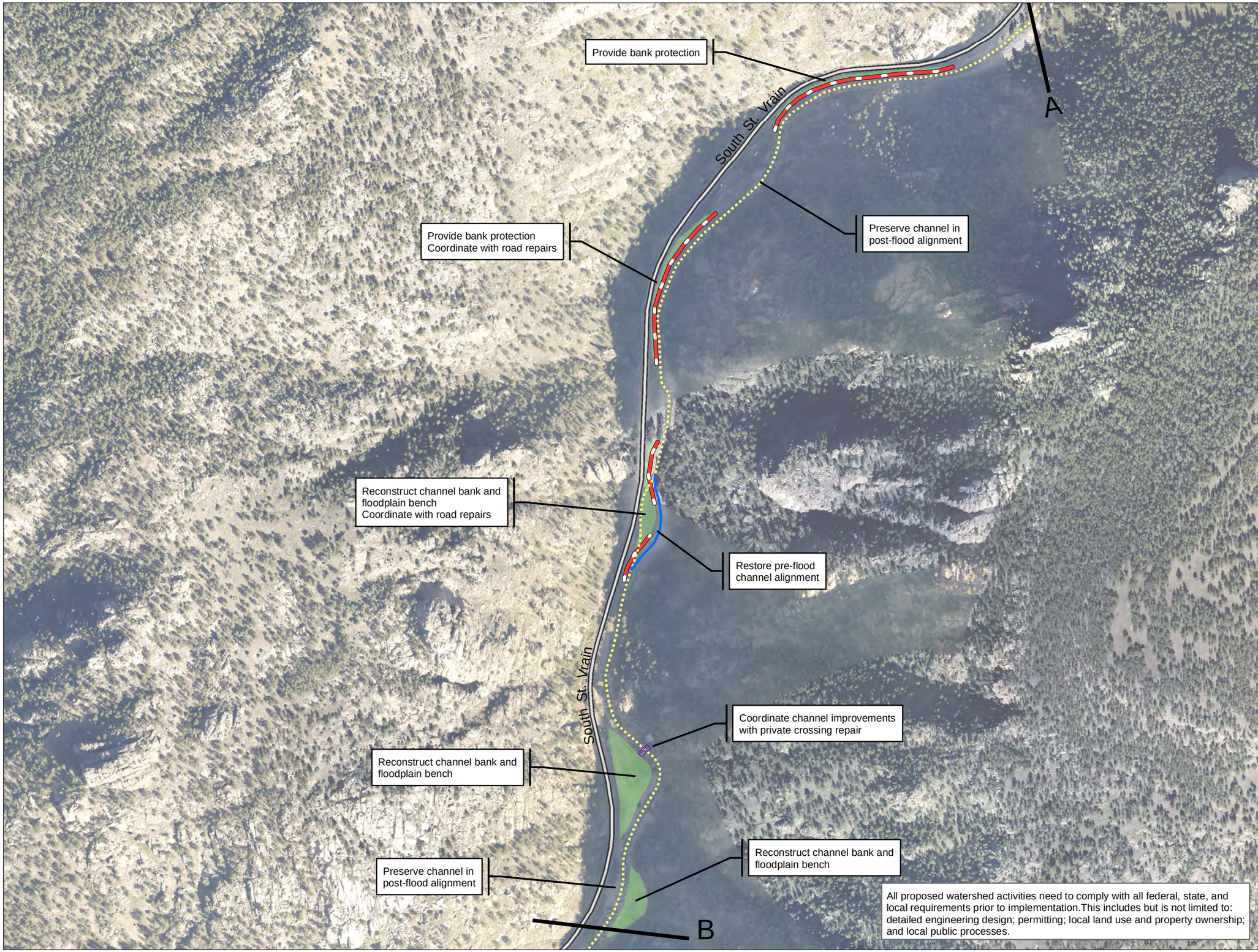
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 2 OF 9



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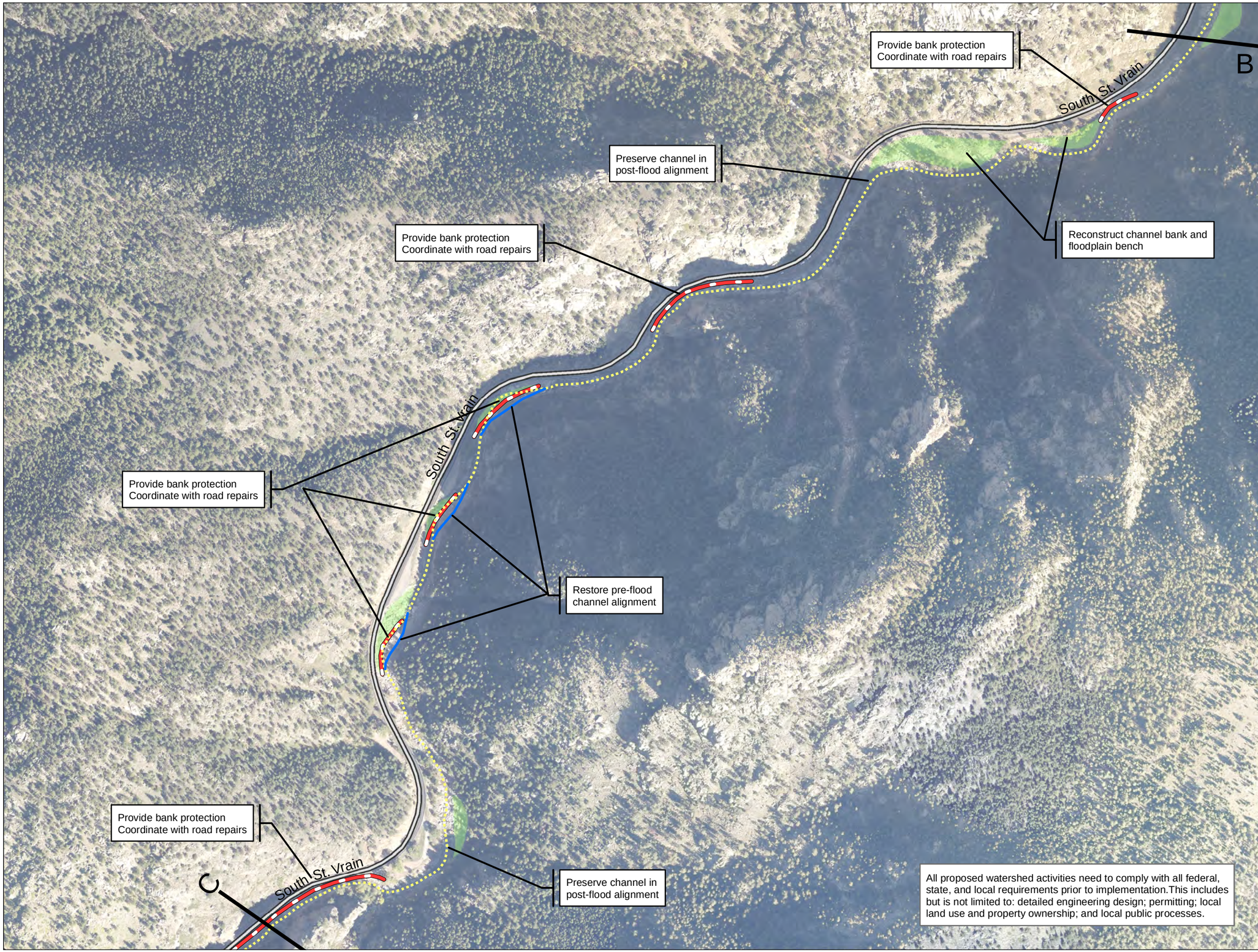
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 3 OF 9



LEGEND

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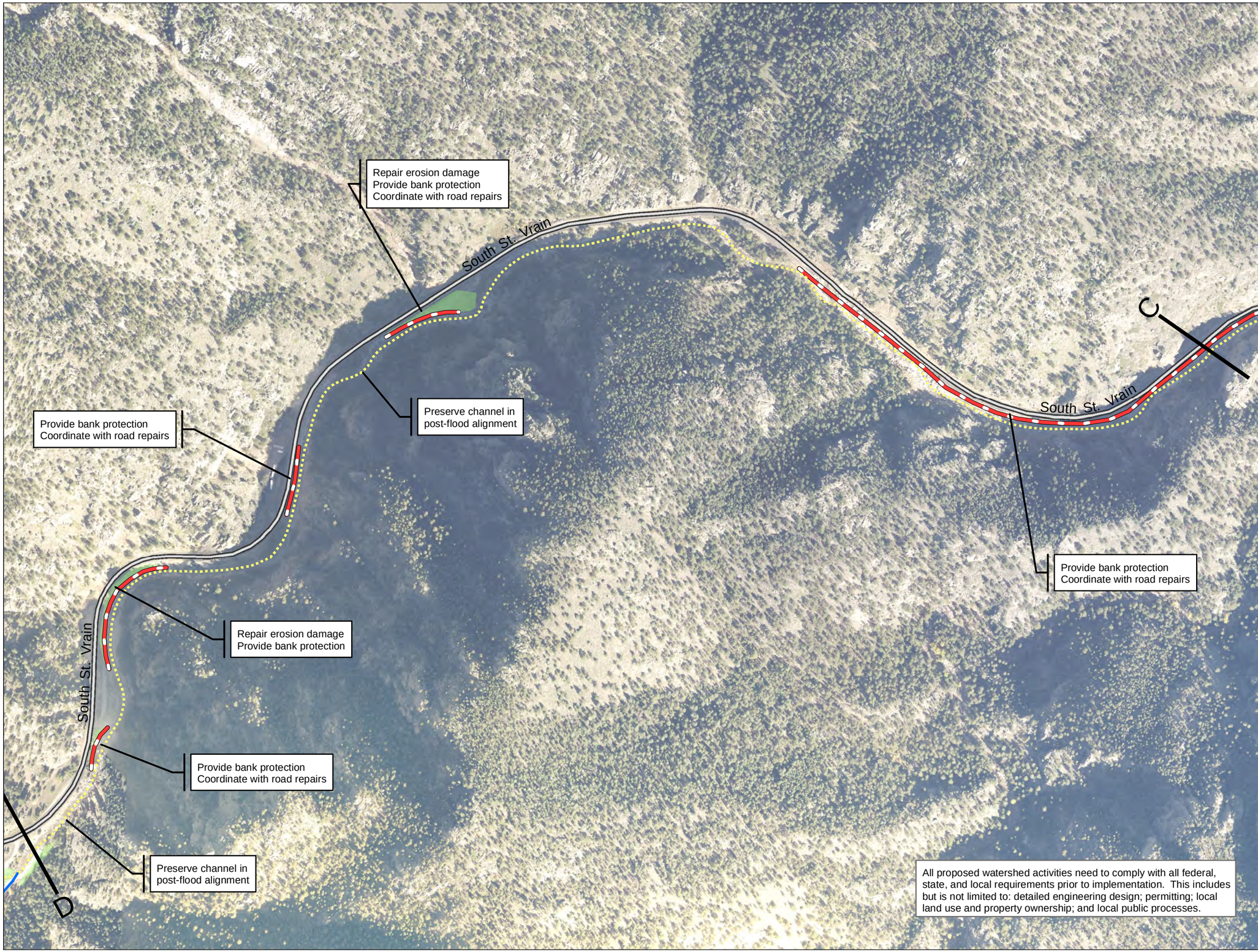
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6
ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ.
MAP 4 OF 9



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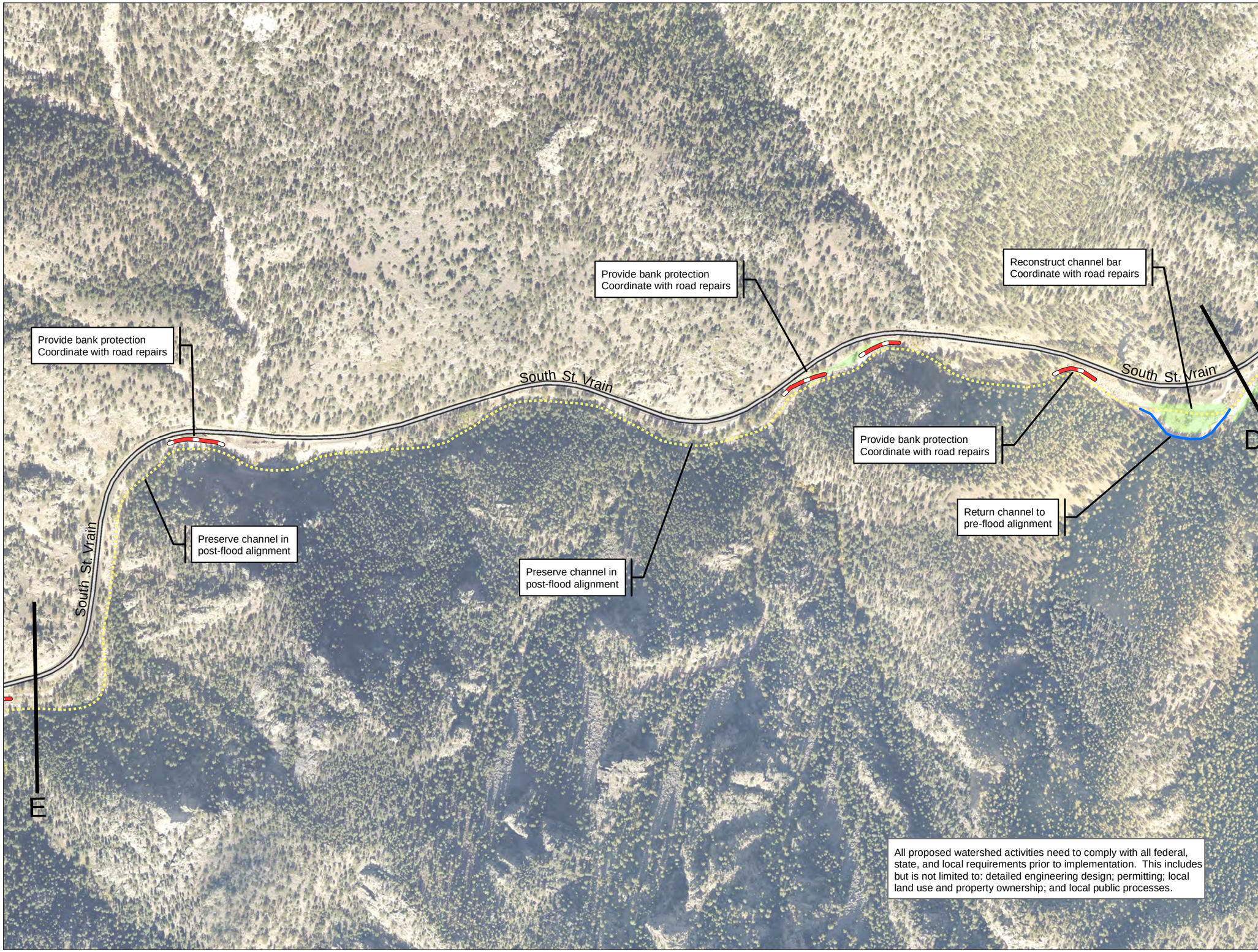
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6
ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ.
MAP 5 OF 9



LEGEND

- Post Flood Channel Alignment
- Proposed Channel Alignment
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- Municipalities

0 100 200 300 400 Feet

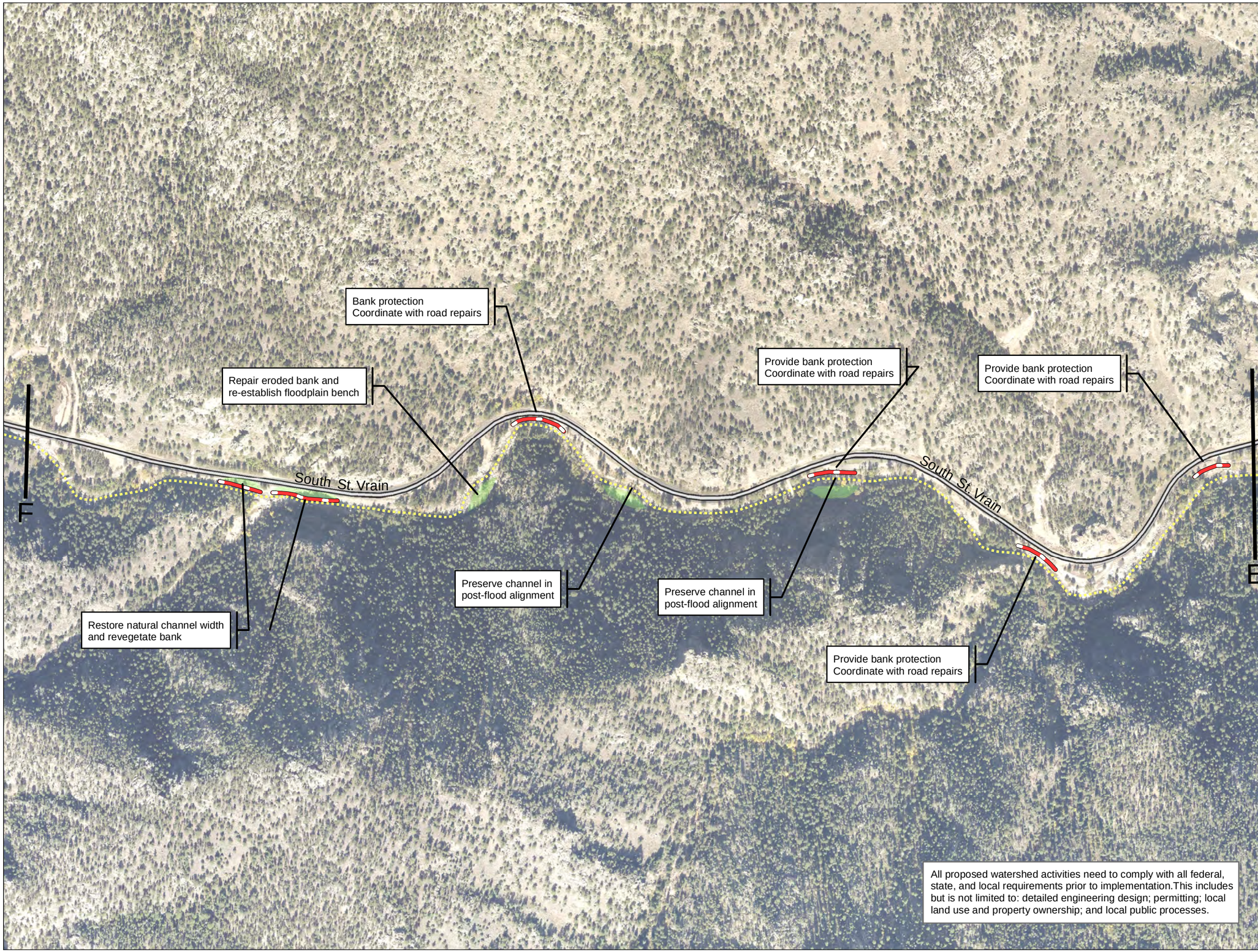
N

Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6
ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ.
MAP 6 OF 9



LEGEND

- Post Flood Channel Alignment
- Proposed Channel Alignment
- Bank Protection
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- Fill & Revegatation
- Highways
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0 100 200 300 400 Feet

N

Baker
165 S. UNION BLVD.
SUITE 200
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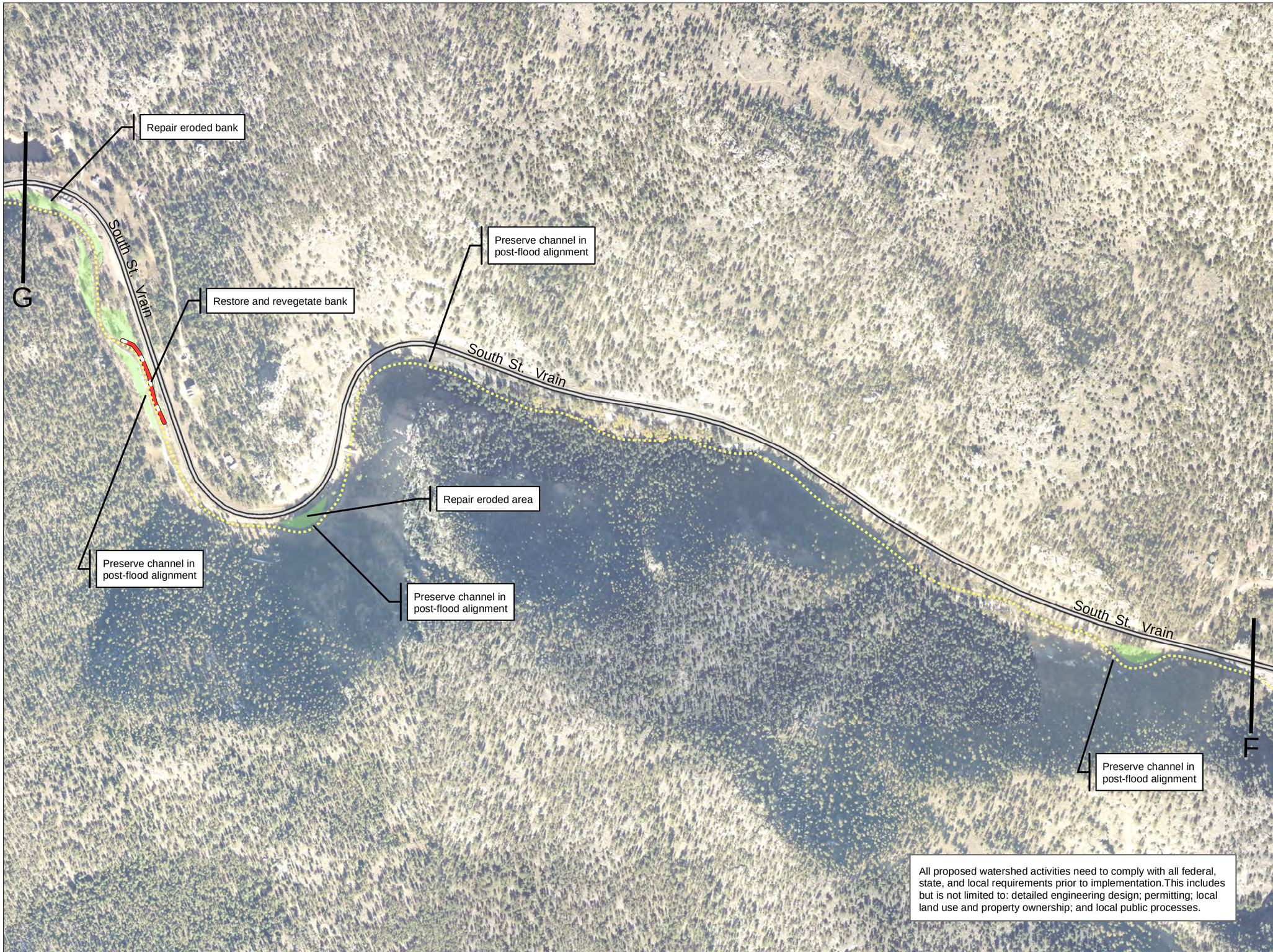
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 7 OF 9



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LEGEND

- Post Flood Channel Alignment
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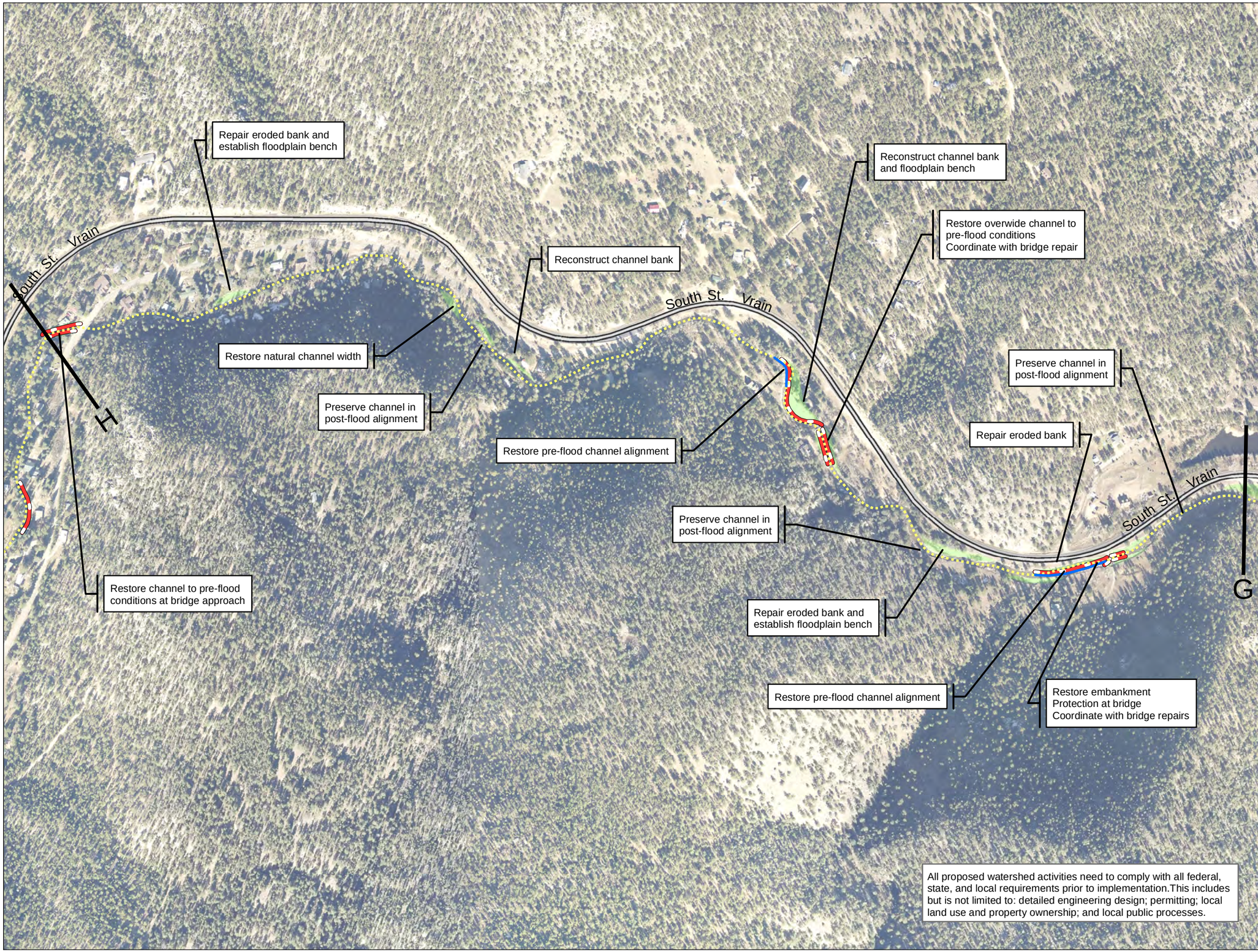
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6
ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ.
MAP 8 OF 9



LEGEND

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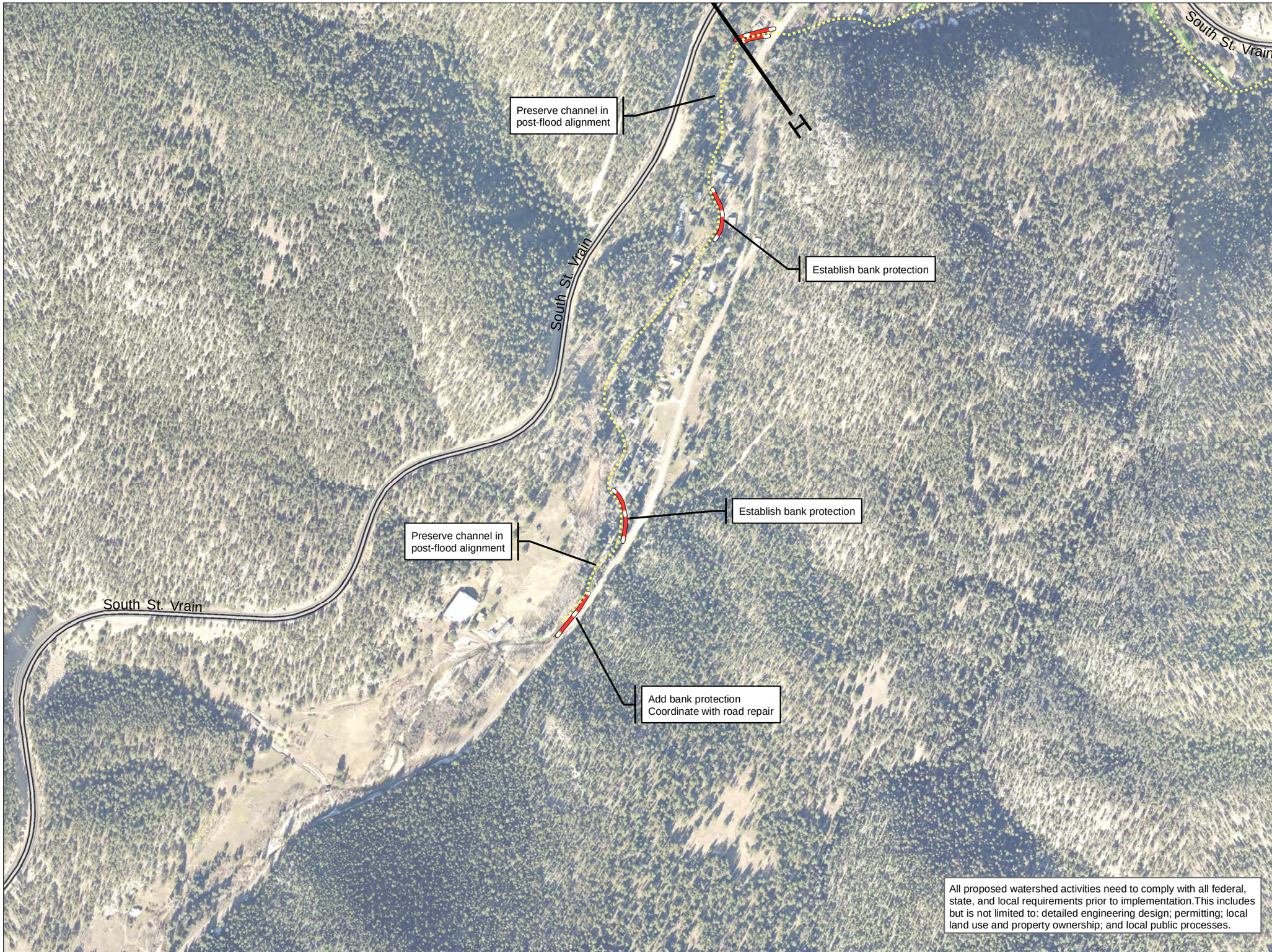
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 6 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 9 OF 9



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LEGEND

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- Major Roads
- Municipalities

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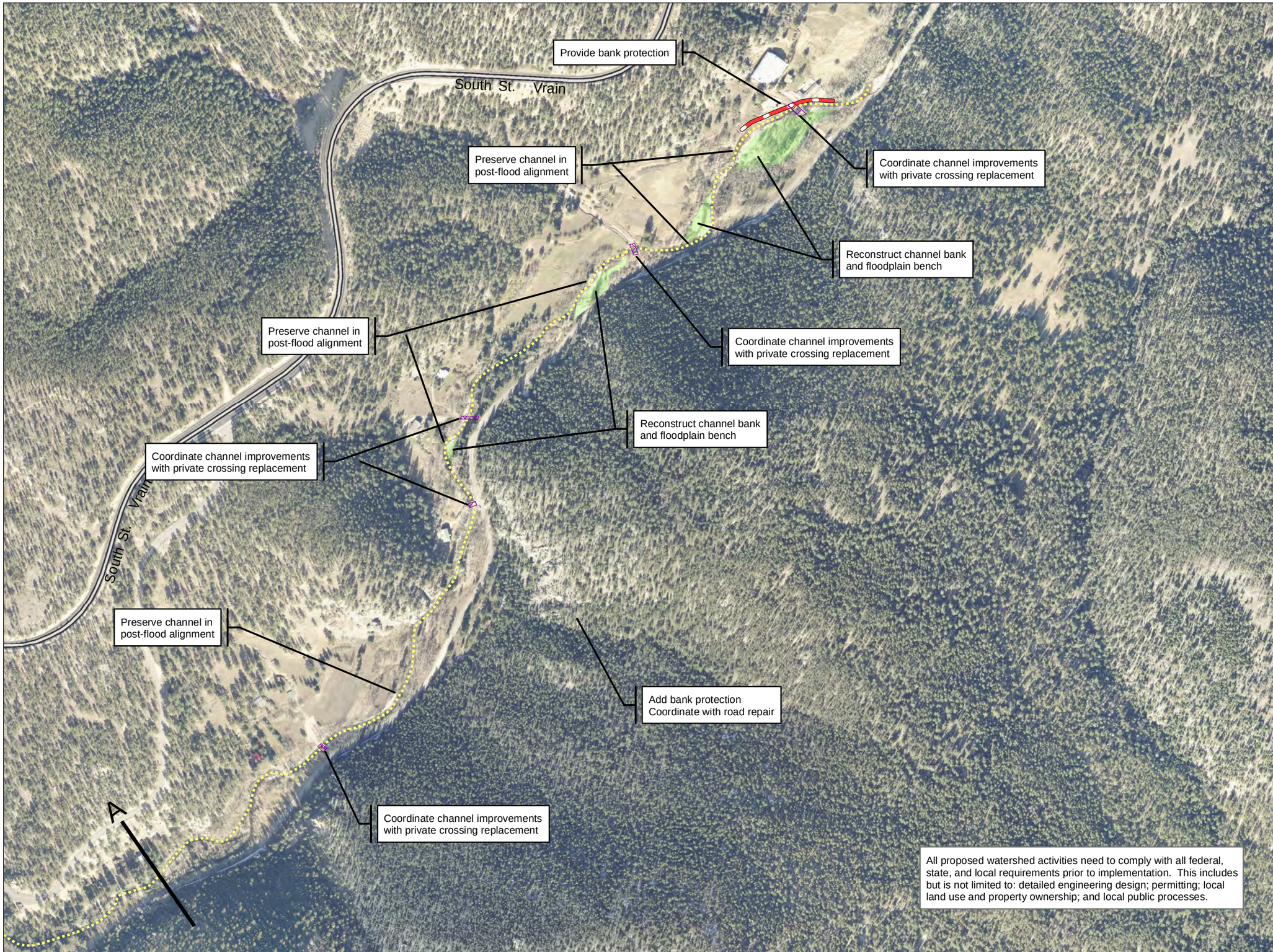
Baker
165 S. UNION BLVD.
SUITE 200
LAKEWOOD, CO 80228
PHONE: 720-514-1100

LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 7 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 1 OF 2



LEGEND

- Post Flood Channel Alignment
- Bank Protection
- Crossing Replacement
- Fill & Revegatation
- Highways
- Major Roads
- Municipalities

0 100 200 300 400 Feet

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Baker
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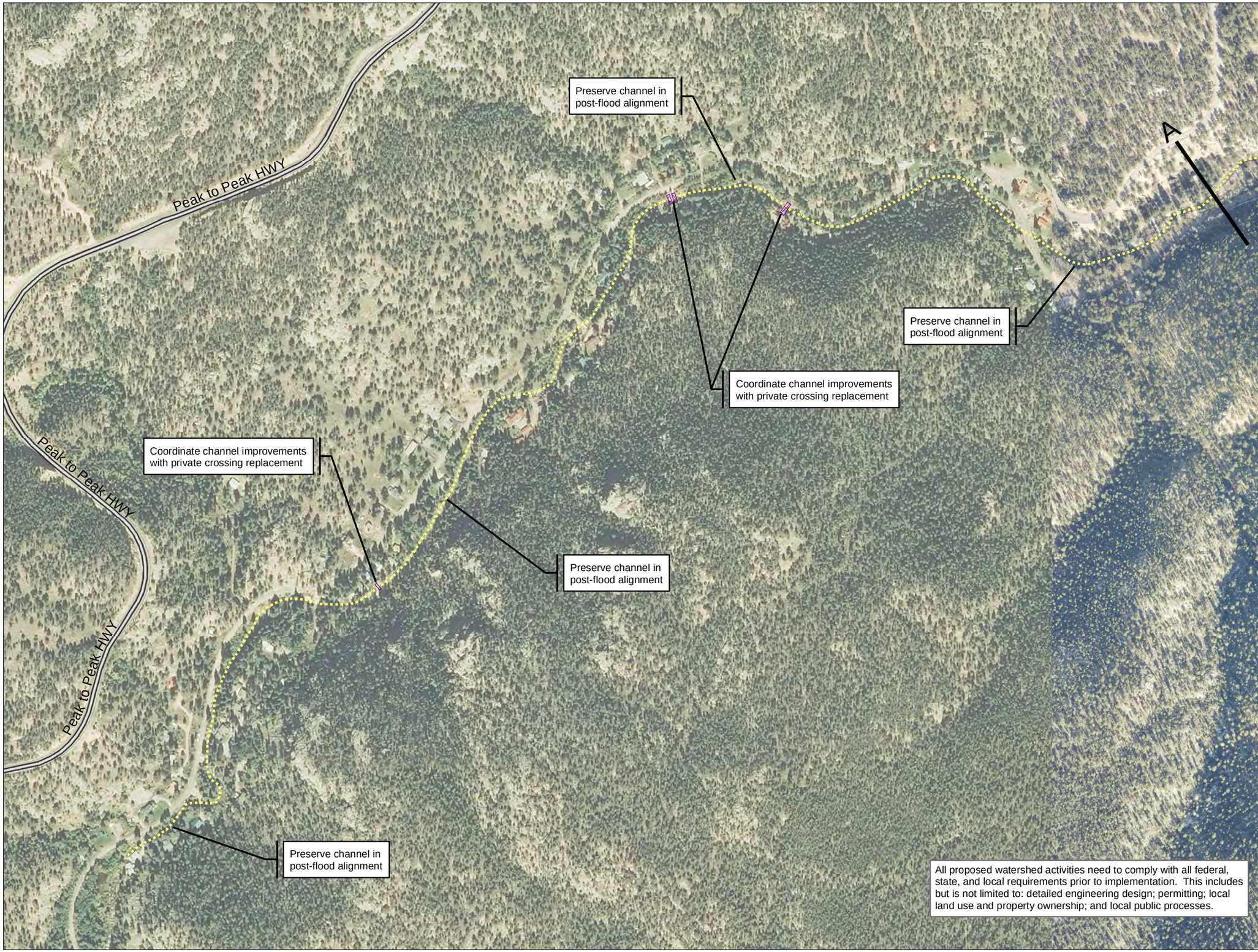
LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

REACH 7 ALTERNATIVE 1: RESTORATION W/ SITE-SPECIFIC PROJ. MAP 2 OF 2



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LOCATOR MAP

ST. VRAIN CREEK ALTERNATIVES

APPENDIX E

LITERATURE CITED

LITERATURE CITED

The following is a list of the planning documents and literature used to inform the development of the St. Vrain Watershed Master Plan (SVMP). These documents were included in the plan-roll up process at the start of the planning project and helped guide alternatives towards projects consistent with ongoing land use management, conservation, recreation, and hazard risk reduction activities in the region. This list is not a comprehensive list of all of the information used to develop the SVMP. A complete list of the technical data sets used to develop this plan (including GIS data, hydrology, and hydraulic data) is provided in Chapter 4.

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APPENDIX F

SUMMARY OF FLOOD AND DEBRIS FLOW IMPACTS AT CAMP ST. MALO

Summary of Flood and Debris flow Impacts at Camp St. Malo
Prepared for the St. Vrain Watershed Master Plan

October 15, 2014

Prepared by:

AMEC Environment and Infrastructure, Inc.

1002 Walnut Street, Suite 200, Boulder, CO 80302

Introduction

The following is summary of the impacts and recovery efforts undertaken for Camp St. Malo (CSM) in the aftermath of the September 2013 flood and debris flow. The intent of this document is to highlight key findings and issues for inclusion in the St Vrain Creek Watershed Master Plan.

Site Brief

Camp St. Malo is 160 acre religious retreat located in the upper St Vrain Watershed at 10758 Highway 7 in unincorporated Boulder County on the "Peak-to-Peak" Highway between Allenspark and Estes Park. The property is best known for the dramatic St Catherine Chapel aka 'Chapel on the Rock' which sits above a wetland area fed by Cabin Creek. Camp St Malo was incorporated in 1998 as a religious nonprofit 501(c)(3) entity within the territorial boundaries of the Archdiocese of Denver. Since 2000, land use and occupancy of the property has been governed by the Amended Special Use approved by Boulder County Resoultions #99-13 and #99-14. A Development Agreement and Conservation Easement, as well as a formal Stewardship Plan, also apply to the property as part of its Special Use authorization. The area served as a conference and retreat center until a structure fire destroyed the conference facility on November 14, 2011.

Event Summary

Camp St. Malo was severely impacted by debris flows and flooding during the devastating September 2013 Colorado floods. A debris flow originating high on Mt. Meeker approximately three miles west of the Camp descended the Cabin Creek drainage sometime during the evening of September 11, 2013, carving a path through the adjacent forest and depositing widespread rocks, soil and woody debris on the property. A literature review of post-flood hydrology studies indicates that the nearest measurements of flood flows were in the Fish Creek drainage near Estes Park; the flows measured in this area were roughly 5 times the 100 year event (Ref. 6). The debris flows, as opposed to floodwaters, caused the most damage to Camp St. Malo. CSM contracted with AMEC Environment and Infrastructure (AMEC) to perform a damage assessment, coordinate with recovery agencies, and research disaster recovery funding options for significant losses and costs incurred as a result of the flooding and debris flow. AMEC also assessed impacts to water storage and water rights at four ponds located on the property.

Damage Summary

AMEC assessed the damage to the property including the debris impacts to structures, parking and road infrastructure, water and waste water infrastructure, and the environment. Figure 1 at the end of this document depicts the extent of the debris and CSM damaged infrastructure.

Debris/Sediment

The event completely plugged the pre-flood Cabin Creek channel and inundated a significant area of the Camp St. Malo property with a debris fan, with estimated depths of up to 15 feet in some locations. A considerable portion of the surrounding forest was leveled, with much of the woody debris being deposited in the wetland area near the Chapel. The culvert beneath Highway 7 was quickly blocked during the event, causing water, debris, and sediment to back-up in the area surrounding the Chapel. A large amount of material was also deposited near the parking lot south of ponds 2 and 3. The total estimated amount of deposited material ranges between 22,000 and 74,000 cubic yards with an estimated 3,200 to 7,200 cubic yards on paved surfaces.

Parking/Roads

Parking lots were buried under debris and cut off from roads; various paved, dirt and gravel roads on the property were eroded and/or buried. There is no longer connectivity between the south and north entrances due to the debris flow. Access to the property is now limited primarily to the north entrance. Highway 7 sustained minor damage from overtopping of floodwaters and debris during the event. Damage to the highway could have been worse were it not for the actions of a local heavy equipment contractor who diverted flow along the west side of HWY 7 towards the south during the flood event.

Structures

A small cabin north of the leach field and south of the southern access road was completely destroyed by debris flow. Fortunately the Chapel, due to its position on a bedrock outcrop, was not destroyed, but was surrounded by floodwaters and woody debris during the event. Some minor damage to the Chapel buttressing, floodlights, and a propane tank was observed.

Utilities

The wastewater treatment plant (WWTP) building was inundated by the flood but was not in the primary path of the large diameter debris flow. While the interior of the building is intact, the bar screen, influent flow measurement flume, equalization tank, and extended aeration tank located outside of the WWTP building were covered with two to three feet of sediment and are considered a total loss. Boulders, sediment and debris covered the west half of the leach field. The extent of damage to the underground leach field piping and influent sewer lines is undetermined.

There was no visible damage to the two existing water supply wells or the Water Treatment Plant. A monitoring well located west of the leach field by the south archway was completely covered by debris and assumed destroyed. Other wells on the property appeared to have survived the event.

A tall, overhead light pole for the parking lot adjacent to ponds 2 and 3 was observed knocked off its foundation. An overhead utility pole was observed knocked down and assumed to be a phone line to the conference center.

Environment

Wetlands on the property were severely impacted by the event due to inundation by debris. The pond adjacent to the Chapel and Highway 7 was completely filled with woody debris and sediment. Approximately 5.1 of 8.4 acres of wetlands on the property were inundated with finer sediment and large woody debris. The Cabin Creek Trail (Pope John Paul II Trail) was intact in some places, and buried in other areas.

Approximately 3.7 acres of mature trees and bushes were removed or damaged by the storm event. Trees inundated with shallow sediment deposits are at risk of dying from sediment around their bases. Damage to habitat in the wetlands affected local beaver activity. Beavers have affected the local drainage from Rock Creek on the north side of the main access road to the property. Several aspen trees were harvested in this area by the beavers for dams on Rock Creek. Several brook trout were killed in the event per observations by the site caretaker around ponds 2 and 3.

Cost of Restoration

Total damages to the site were estimated at approximately $3.6M. This includes approximately $518,000 in CDOT emergency protection assistance, $898,240 in insured losses, and nearly $2.2 million in uninsured losses. When construction and engineering costs are taken into account to repair the site to its pre-flood condition the total losses are estimated at $4.9 million. There are significant uninsured costs related to removing the sediment and rock debris off the property, which is not practical in many areas due to the depth and amount of rock debris.

Site Recovery and Emergency Protective Efforts

AMEC prepared a Phase 1 report which summarized the key findings and results of the site/damage assessment, interagency coordination meetings and funding options research, and provided preliminary recommendations for recovery and hazard mitigation solutions and next steps. Funding sources explored included the Federal Emergency Management Agency (FEMA), Small Business Administration (SBA), U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS), Community Development Block Grant Program (CDBG), and State of Colorado post disaster assistance. Many disaster recovery grants and loans are not available to private nonprofit religious organizations, which made it more challenging to find financial assistance for Camp St. Malo. Camp St. Malo was denied assistance under the FEMA Public Assistance program, as well as the SBA. The options for recovery assistance narrowed to an offer for debris removal assistance from the Colorado Department of Transportation (CDOT) and insured vs. un-insured losses.

Camp St Malo entered into a Memorandum of Understanding (MOU) on January 17, 2014 with CDOT related to emergency protective measures needed for the culvert at Highway 7 near the Chapel. The MOU enabled CDOT to work beyond their right of way and approximately 1,000 feet west into the CSM property in the interest of protecting the health, safety, and welfare of the travelling public, and restoring the integrity of the highway. CDOT's emergency work within the temporary easement included debris removal and channel-realignment in preparation for spring runoff. CDOT contractors accomplished a tremendous amount of recovery work during the January-to early March timeframe, despite winter weather and various mechanical issues.

Several emergency protective measures related to drainage re-alignment and Highway 7 culvert protection were completed through the MOU with CDOT. This included the channel stabilization work on Cabin Creek and the construction of a high flow channel (see Figure 1) to divert flows and debris from ponds 2, 3, and 4. CDOT excavated Pond 1 based on AMEC's recommendation to have it serve as a sediment trap and a spillway for the high flow channel. The restored drainage on Cabin Creek provided water to the ponds and should improve wetland recovery. A large majority of the woody debris was collected, stockpiled and chipped on-site by CDOT crews.

Remaining Concerns

Recovery efforts made during the winter of 2014 have resulted in tremendous improvements on the site, but more work remains in addition to lingering concerns about continued erosion, deposition, and the potential for more debris flow events on the Cabin Creek drainage.

Woody debris and settlement on the debris field: Large woody debris piles remain near the WWTP and alongside the edge of the slide path west of the WWTP and on both sides of the channel above pond 1 (at least a half mile upstream and expected to extend much further). This woody debris has accumulated on the higher edges of the debris flow channel and is not anticipated to mobilize in future events, unless another event of extreme magnitude occurred. Differential settling on the debris field area was observed during the summer of 2014 in and around the CDOT-constructed high flow channel. Signs have been posted to discourage trespassing on this unstable ground.

Cabin Creek erosion and deposition: AMEC monitored the spring runoff during May-June of 2014. Severe bank erosion was observed on Cabin Creek between ponds 1 and 2, resulting in pond 2 completely filling with sediment. The high flow channel constructed by CDOT appears to have operated as intended periodically during heavier rain events, as evidenced by deposits in the channel and observations by the local caretaker. Ponds and channels on the property will need continued monitoring and periodic sediment removal.

Upper Cabin Creek debris flow potential: The slide event of September 2013 was a relatively rare event in terms of human timescales; however the resulting debris scar is now more susceptible to continued erosion. Thus, smaller rainfall events might mobilize additional debris. As of mid-October 2014 CDOT is in the process of conducting a geotechnical reconnaissance of the upper watershed with the intent to further assess the risk potential to the HWY 7 culvert.

Chapel pond/wetland restoration: The Archdiocese desires that the pond/wetland area by the Chapel is restored to its pre-event condition and is coordinating with CDOT on possibilities.

Wildlife issues: Sediment in the wetlands have filled in many beaver ponds, resulting in beaver activity near Pond 4 and on Rock Creek that has impacted pond and road infrastructure.

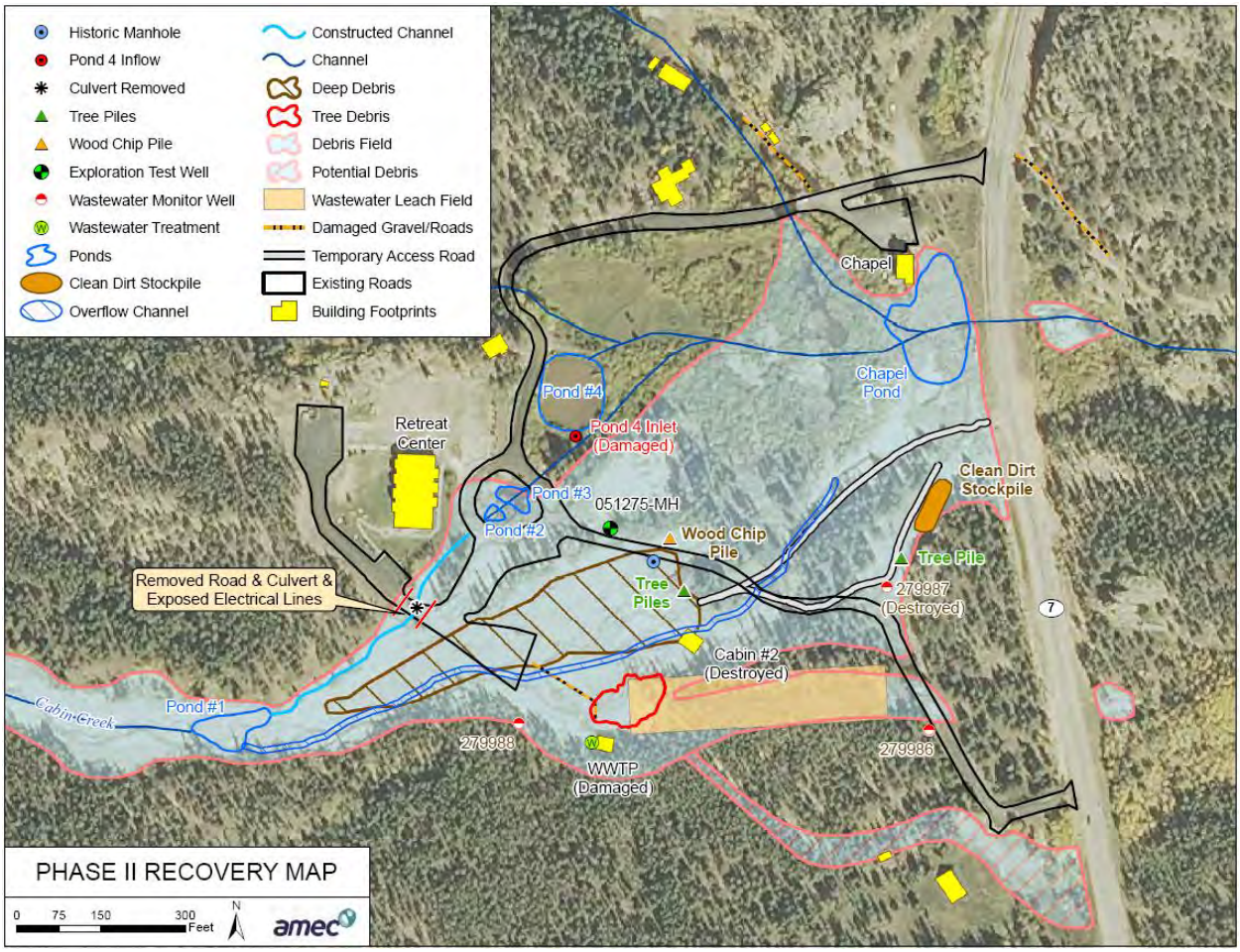
Long Term Site Recovery and Redevelopment Considerations

Continued coordination with CDOT and other agencies: CDOT is in the process of assessing the potential risk at the culvert at HWY 7 on the site in coordination with CSM. CDOT is also assessing options for improving the capacity of the culvert and that may also include improvements in the wetlands area adjacent to the highway embankment and culvert. The agency is also undertaking a highway resurfacing project between Estes Park and Allenspark that may include additional emergency protective measures with Federal Highway Administration Risk and Resilience funding. Additionally the agency is doing an aerial LiDAR survey that will include the debris field and a ground survey of the Cabin Creek

overflow channel. In addition to CDOT CSM has continued coordination on recovery needs with the Governor's recovery office, Colorado Water Conservation Board, Boulder County and the St Vrain Watershed Master Planning coalition.

Longer term there will continue to be some threats from flood and debris due to the instability higher within the Mt Meeker/Cabin Creek watershed. This is being taken into consideration as CSM is in the process of considering various long term options for recovery and redevelopment at the site. One of the challenges is that this watershed is entirely within the boundaries of Rocky Mountain National Park. Initial correspondence with the National Park Service indicates that there is reluctance to do soil stabilization and stream rehabilitation work on what was the result of a natural event, but there could be a mutual interest in the hazard assessment aspect. CSM is considering various options including a watershed master plan specific to the Cabin Creek drainage that could help outline viable alternatives for the property in the context of its exposure to natural hazards. Despite the risks made evident by the slide there are areas on the CSM property that could be developed or redeveloped safely. CSM is continuing to maintain water rights interests associated with the ponds on the property and working with AMEC on pond capacity surveying and maintenance plans.

Figure 1 Camp St Malo Recovery Map



APPENDIX G

HYDRAULICS REPORTS

MEMORANDUM

ANDERSON CONSULTING ENGINEERS, INC.
Civil • Water Resources • Environmental

DATE: October 31, 2014 **ACE PROJECT NO.:** COMBJ01.01

TO: Dave Jula, P.E., Michael Baker Corporation

FROM: Jamis Darrow, P.E., Anderson Consulting Engineers, Inc. JDD

SUBJECT: St. Vrain Creek Master Plan: 100-year Foodplain from 63rd Street to Highway 36

Anderson Consulting Engineers, Inc. was authorized by Michael Baker Corporation (Baker) in August 2014 to evaluate the 100-year flood hazard along St. Vrain Creek. A new study along 3.3 miles of the St. Vrain Creek, and nearly 3.9-miles of associated split flow paths were conducted with the intent of providing flood hazard mapping and modeling following the 2013 flood. ***It is noted that due to budget constraints, and at the direction of Baker staff, a divided flow path leaving the south overbank near Union Road was identified but not fully evaluated to its confluence with the St. Vrain Creek main flow path, which occurs at a location downstream of Hygiene Road (downstream of the current study reach). It is anticipated that a portion of the flow in this flow path will spill back toward the main flow path of St. Vrain Creek between Union Road and Hygiene Road. This area is represented as a shallow flooding zone in the attached floodplain mapping. Therefore, this hydraulic study will require additional modeling and mapping prior to regulatory adoption.*** This study included hydraulic modeling of the 100-year return period events along with the delineation of the associated floodplain for each flooding source. A copy of the hydraulic model, and shapefiles defining the hazard mapping are provided in the CD accompanying this memorandum.

Topography

The primary base topography, consisting of post-flood LiDAR, for St. Vrain Creek was provided by FEMA. This topographic data collected and processed by Photo Science, Inc. was based flight data collected in the fall of 2013 at a nominal pulse spacing (NPS) of 0.7 meters. Post-processed LiDAR data was used with hydro breaklines to generate a 0.75 meter Raster DEM.

LiDAR topography throughout the study reach was supplemented by field survey data collected for the current hydraulic study at all bridge and culvert crossings by King Surveyors. These survey data includes bridge low chord elevations, bridge pier configurations, culvert inverts and sizes, top of road profiles, and channel cross sectional geometry upstream and downstream of each structure. Detailed bridge survey along St. Vrain Creek included the following crossings: 63rd Street, Union Road, Highway 36, a railroad crossing, a private drive, two irrigation control structures, two berms connecting the main channel and overbank flow paths, and two berms and connecting culverts between overbank gravel pit ponds. Certified drawings showing all of the field survey data collected by King Surveyors for this project are provided in Attachment A. These data are also included in the CD accompanying this memorandum.

Vertical/Horizontal Coordinate Systems

All current topographic mapping and, consequently, the current hydraulic modeling and flood hazard mapping is based on the North American Vertical Datum (NAVD) of 1988. All survey data collected for this study was provided in NAVD 1988. The horizontal datum for the topographic base map is the North American Datum of 1983 (Colorado State Plane, Zone 501-Colorado North).

Manning's n

A detailed field reconnaissance program for St. Vrain Creek was conducted by ACE staff as part of the current study. This effort included making visual observations of stream corridor conditions and all stream crossings.

Photographic documentation of the stream corridor was completed as part of the field reconnaissance work. Photographs taken during the ACE field reconnaissance along St. Vrain Creek are

provided in Attachment B. These photographs were taken in August 2014 in the presence of the heavy vegetative cover that exists during flood season.

Manning's *n* roughness coefficients for each flooding source and its natural overbank areas were estimated using Cowen's Method and the "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains," [USGS, 1989]. Roughness coefficients for urbanized overbank areas (pavement, turf grass, etc.) within the floodplain were assigned based on generally accepted values presented in "Open-Channel Hydraulics," [Chow, 1959]. Roughness coefficients for the St. Vrain Creek analysis ranged between 0.052 and 0.079 in the channel, and 0.058 and 0.087 in the overbanks. Worksheets showing the Cowen's method and USGS procedure calculations for defining Manning's *n* values for the current study are included in Attachment C.

Hydrology

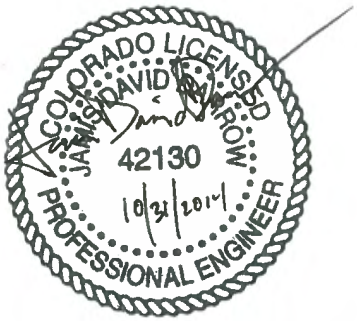
The discharges that provide the basis for the effective regulatory flood hazard mapping along St. Vrain Creek in the vicinity of Lyons, Colorado were originally defined by Water Resources Consultants, Inc. (WRC) in the "Floodplain Information, Flood Control and Floodplain Management Plan for the St. Vrain Creek at Longmont, Colorado" (April, 1981). The WRC report defines the 5-, 10-, 50-, 100-, and 500-year flood discharges between the confluence of the North and South St. Vrain Creeks and the Mouth of the canyon downstream of Platteville.

Following the September 2013 flood the Colorado Department of Transportation (CDOT) partnered with the Colorado Water Conservation Board (CWCB) to initiate hydrologic analyses along St. Vrain Creek to ascertain the magnitude of the September event. Results of these hydrologic analyses suggested that the regulatory discharges at the confluence of North and South St. Vrain Creeks should be increased by 34%. It is noted however that at this time hydrologic analyses for the St. Vrain Creek do not extend downstream of the confluence of the North and South St. Vrain Creeks.

Due to results of the CDOT analysis, the current philosophy of City of Longmont staff is that regulatory discharges for new designs and hydraulic studies should be increased by 34%. Therefore, due to current guidance provided by the City of Longmont, and at the direction of Baker staff, ACE utilized a 100-year discharge of 12,030 cfs for the current hydraulic study, which is 34% higher than the regulatory flow of 8,970 cfs.

Starting Water Surface Elevation

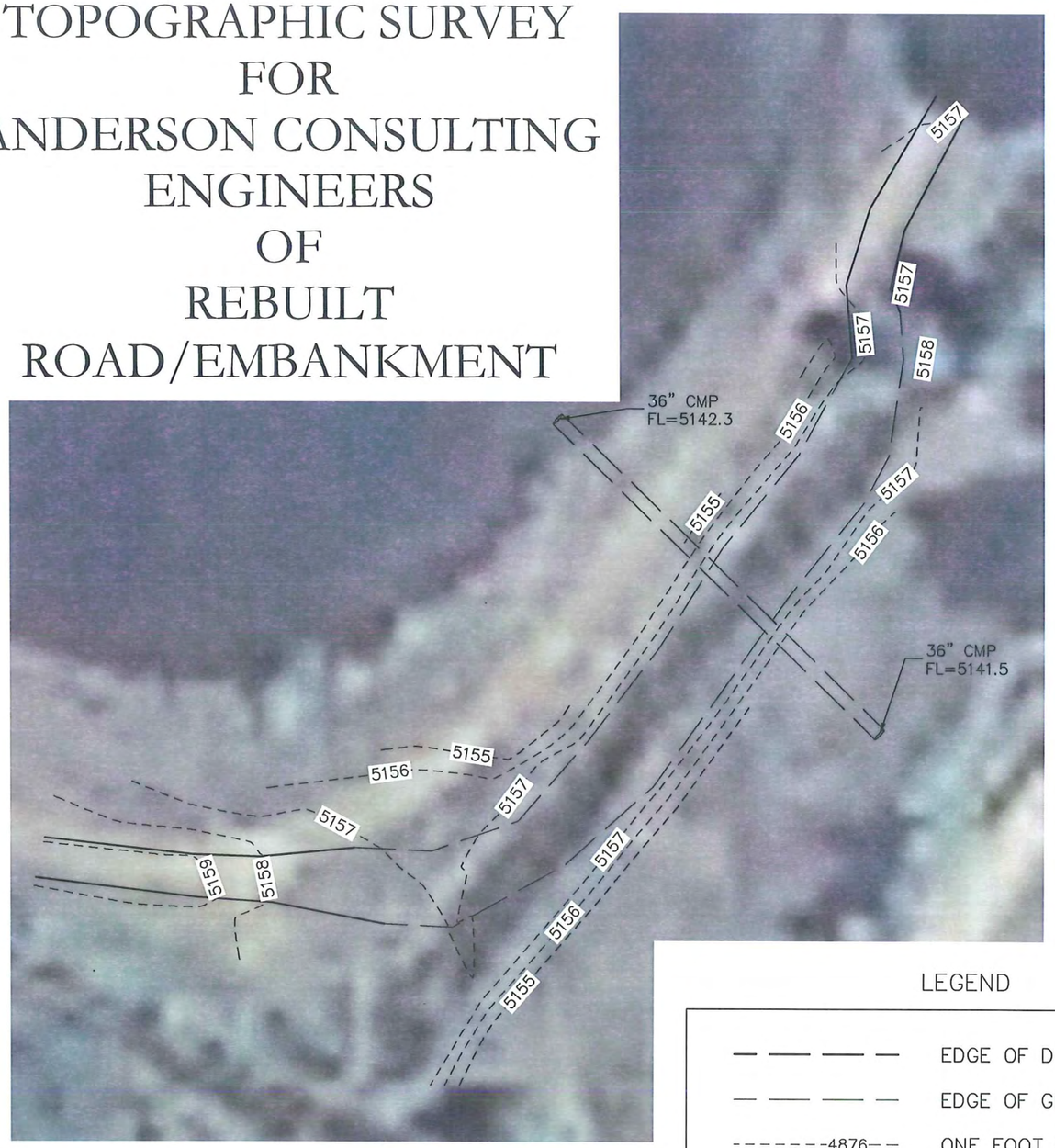
The hydraulic analyses were conducted assuming subcritical, steady state flow conditions. Consequently, boundary conditions were required only at the downstream ends of the St. Vrain Creek and the Highland Drive divided flow path. Because there are no existing condition models in the vicinity of the current study that utilized the increased 100-year discharges, normal depth was selected as the downstream boundary condition. Based on the post-flood 2013 topography at the downstream end of each of the two main flow paths the hydraulic model utilized slopes equal to 0.006 as the boundary condition for normal depth computations. A third flow path was analyzed which splits from the main channel, but re-connects with the main channel within the study reach and therefore utilized a junction for its boundary condition.

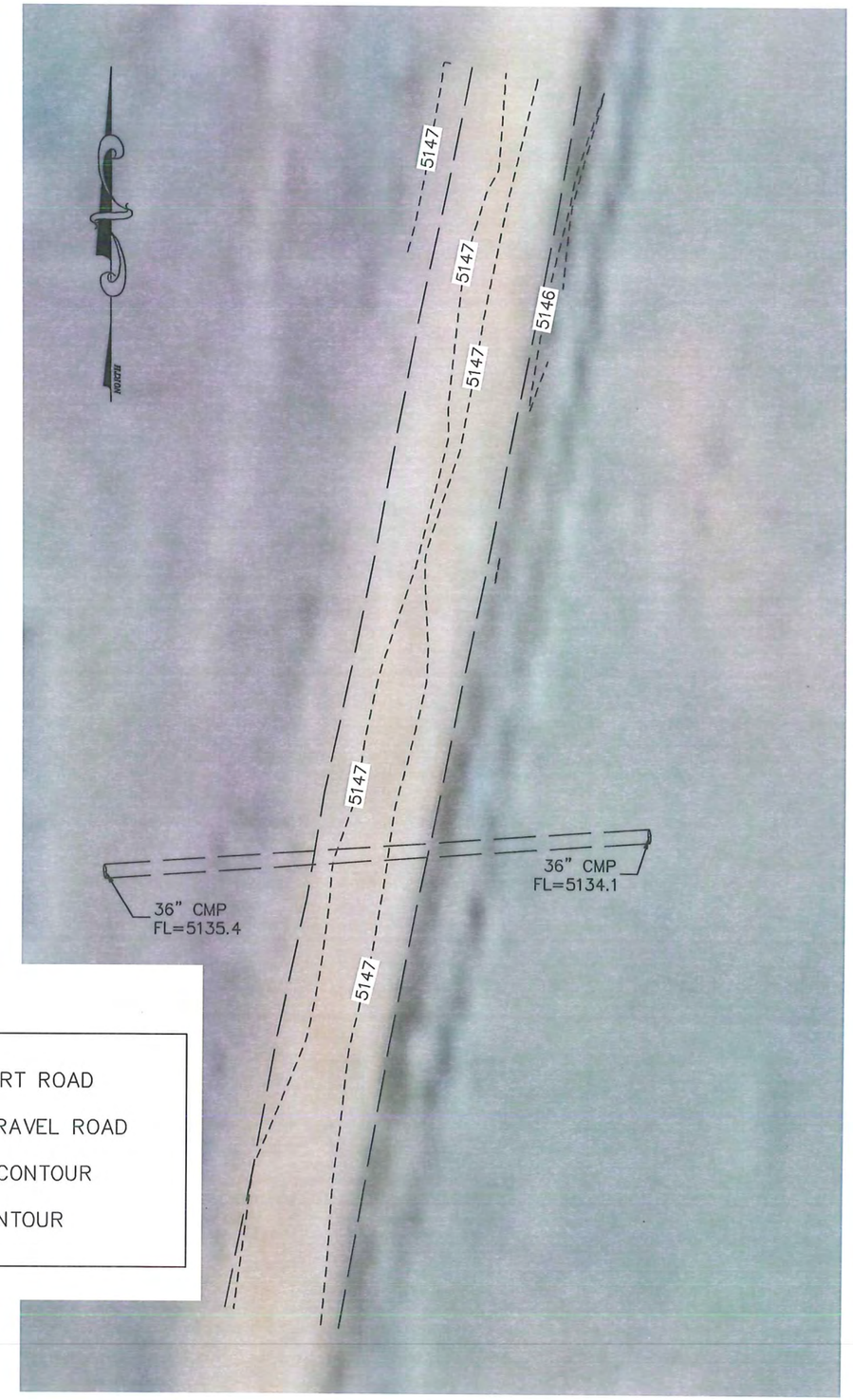


ATTACHMENT A

SURVEY INFORMATION

TOPOGRAPHIC SURVEY FOR ANDERSON CONSULTING ENGINEERS OF REBUILT ROAD/EMBANKMENT





LEGEND

— — — —	EDGE OF DIRT ROAD
— — — —	EDGE OF GRAVEL ROAD
- - - - - - -4876- -	ONE FOOT CONTOUR
- - - - - - -4835- -	5 FOOT CONTOUR

30' 15' 0 30'

1" = 30'

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

DATE: 9-30-2014
FILE NAME: 2014661TOP
SCALE: 1"=30'
DRAWN BY: AML
CHECKED BY: SRW

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS:	DATE:

TOPOGRAPHIC SURVEY
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2014661

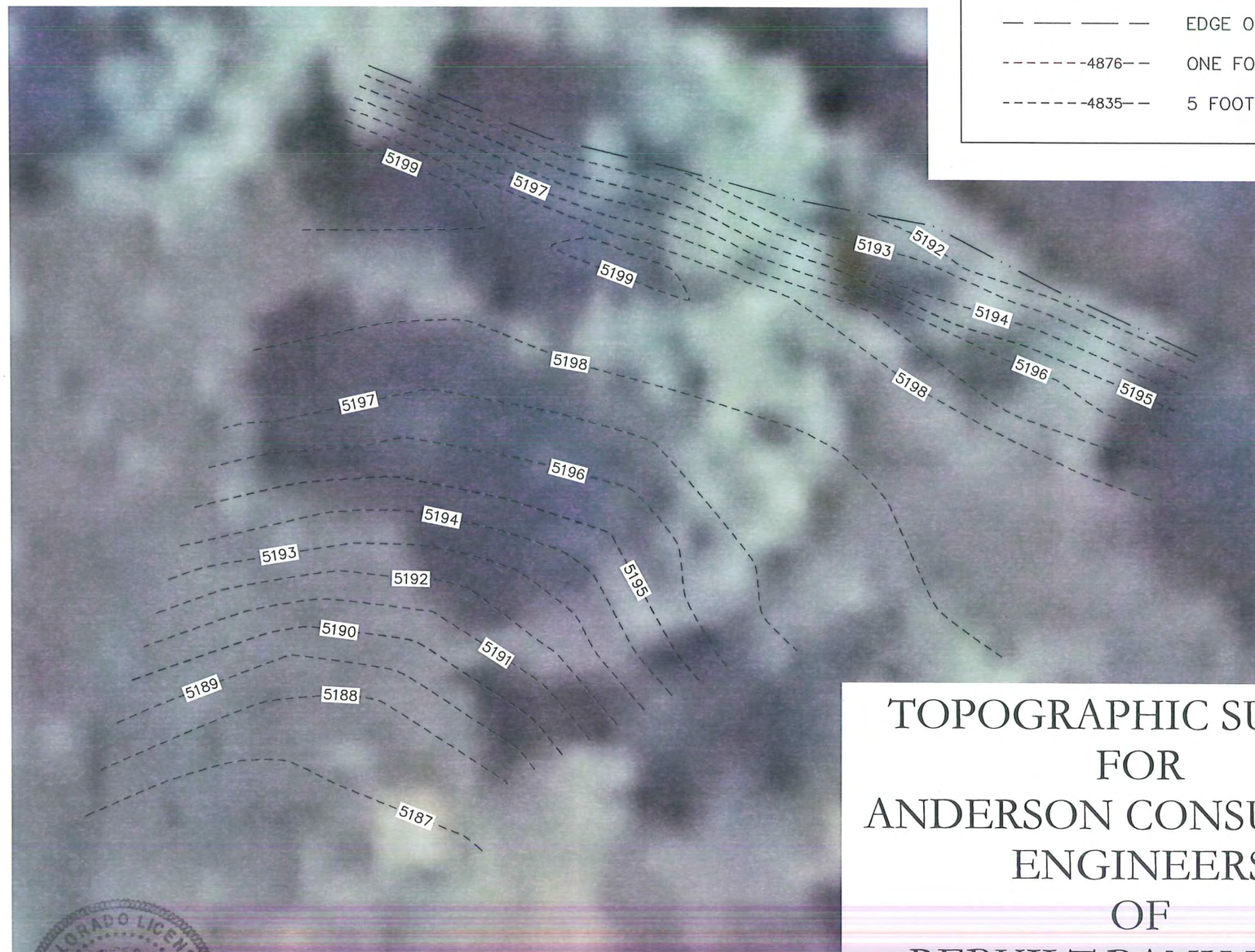
1

SHT 1 OF 3

NORTH

LEGEND

— — — —	EDGE OF DIRT ROAD
— — — —	EDGE OF GRAVEL ROAD
- - - - - - -4876- -	ONE FOOT CONTOUR
- - - - - - -4835- -	5 FOOT CONTOUR



TOPOGRAPHIC SURVEY FOR ANDERSON CONSULTING ENGINEERS OF REBUILT BANK FROM OVERBANK POND

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

COLORADO LICENSED PROFESSIONAL LAND SURVEYOR LAWRENCE S. PEPEK 33642

20' 10' 0 20'

1" = 20'

DATE: 9-30-2014
FILE NAME: 2014661TOP
SCALE: 1"=20'
DRAWN BY: AML
CHECKED BY: SRW

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

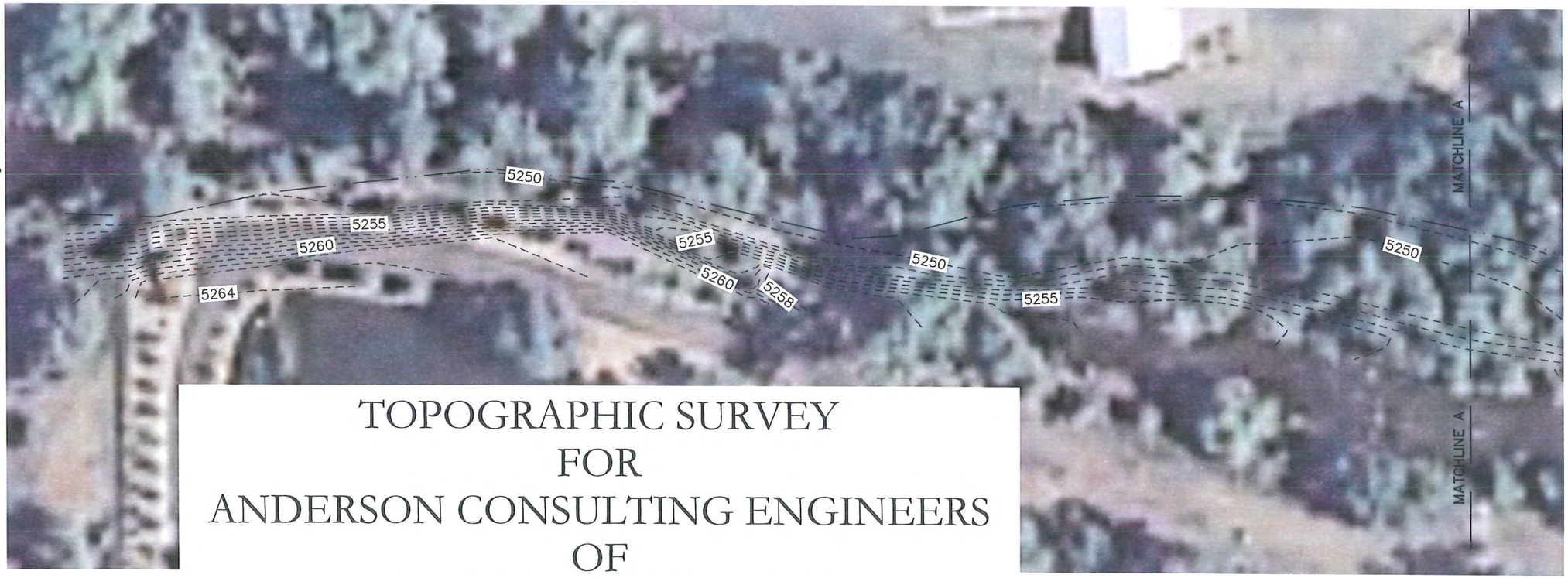
REVISIONS: DATE:

TOPOGRAPHIC SURVEY
FOR
ANDERSON CONSULTING ENGINEERS
375 E HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

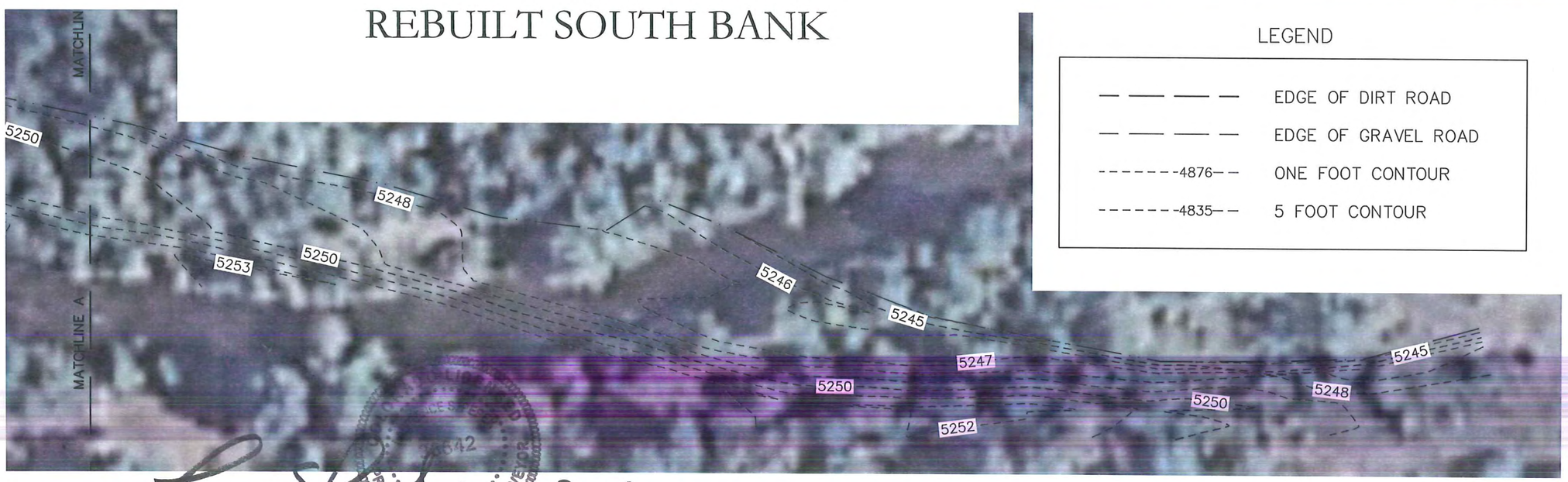
PROJECT # 2014661

2

SHT 2 OF 3



TOPOGRAPHIC SURVEY
FOR
ANDERSON CONSULTING ENGINEERS
OF
REBUILT SOUTH BANK



LEGEND

— — — —	EDGE OF DIRT ROAD
— — — —	EDGE OF GRAVEL ROAD
- - - - - - -4876- -	ONE FOOT CONTOUR
- - - - - - -4835- -	5 FOOT CONTOUR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

50' 25' 0 50'

1" = 50'

DATE: 9-30-2014
FILE NAME: 2014661TOP
SCALE: 1"=50'
DRAWN BY: AML
CHECKED BY: SRW

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE:

TOPOGRAPHIC SURVEY
FOR
ANDERSON CONSULTING ENGINEERS
375 E HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2014661

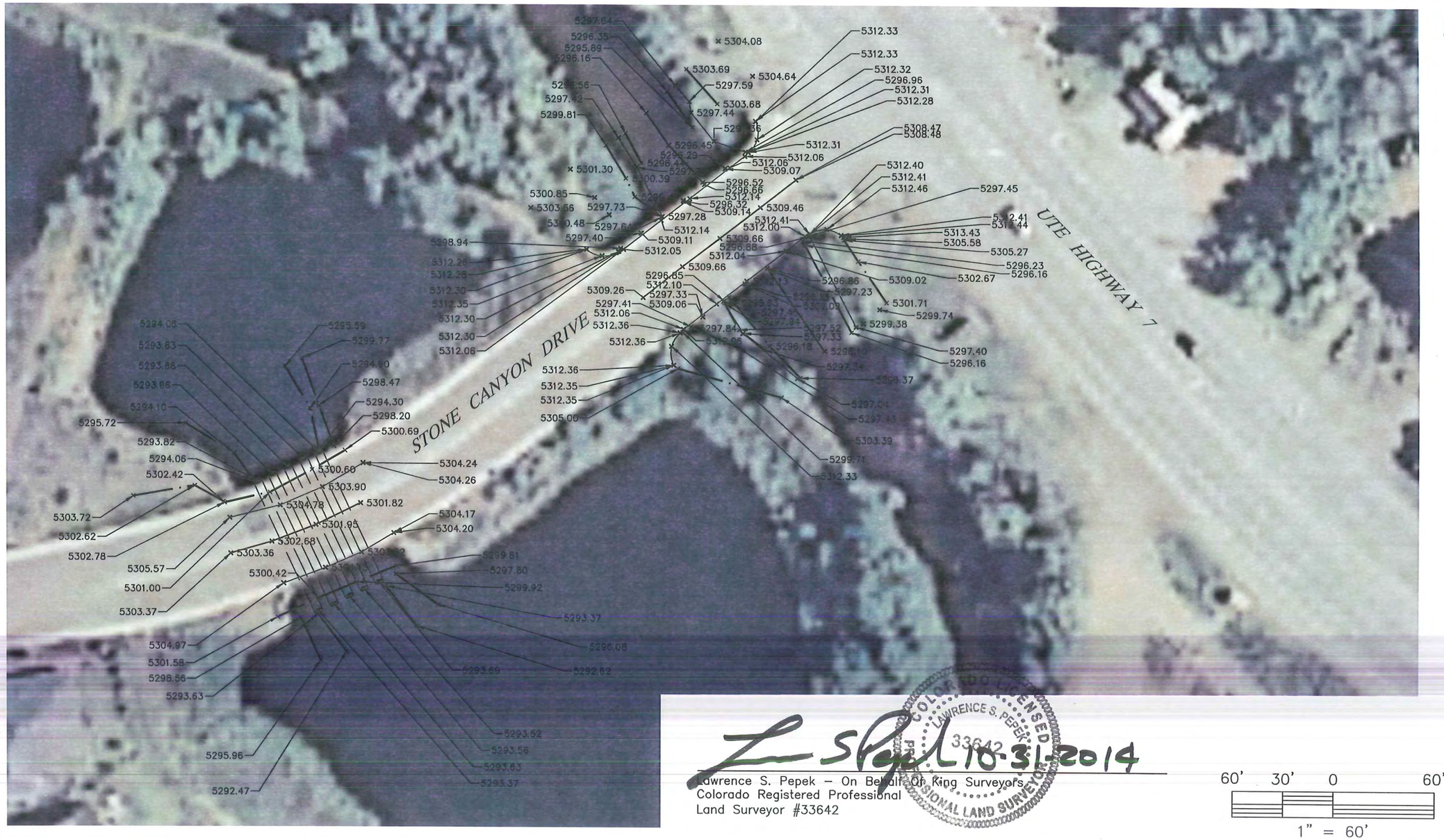
3

SHT 3 OF 3

STRUCTURE SURVEY
of
STONE CANYON DRIVE
for
ANDERSON CONSULTING ENGINEERS

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.



Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

COLORADO LICENSED PROFESSIONAL LAND SURVEYOR LAWRENCE S. PEPEK 33642

10-31-2014

60' 30' 0 60'

1" = 60'

NORTH

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 60'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

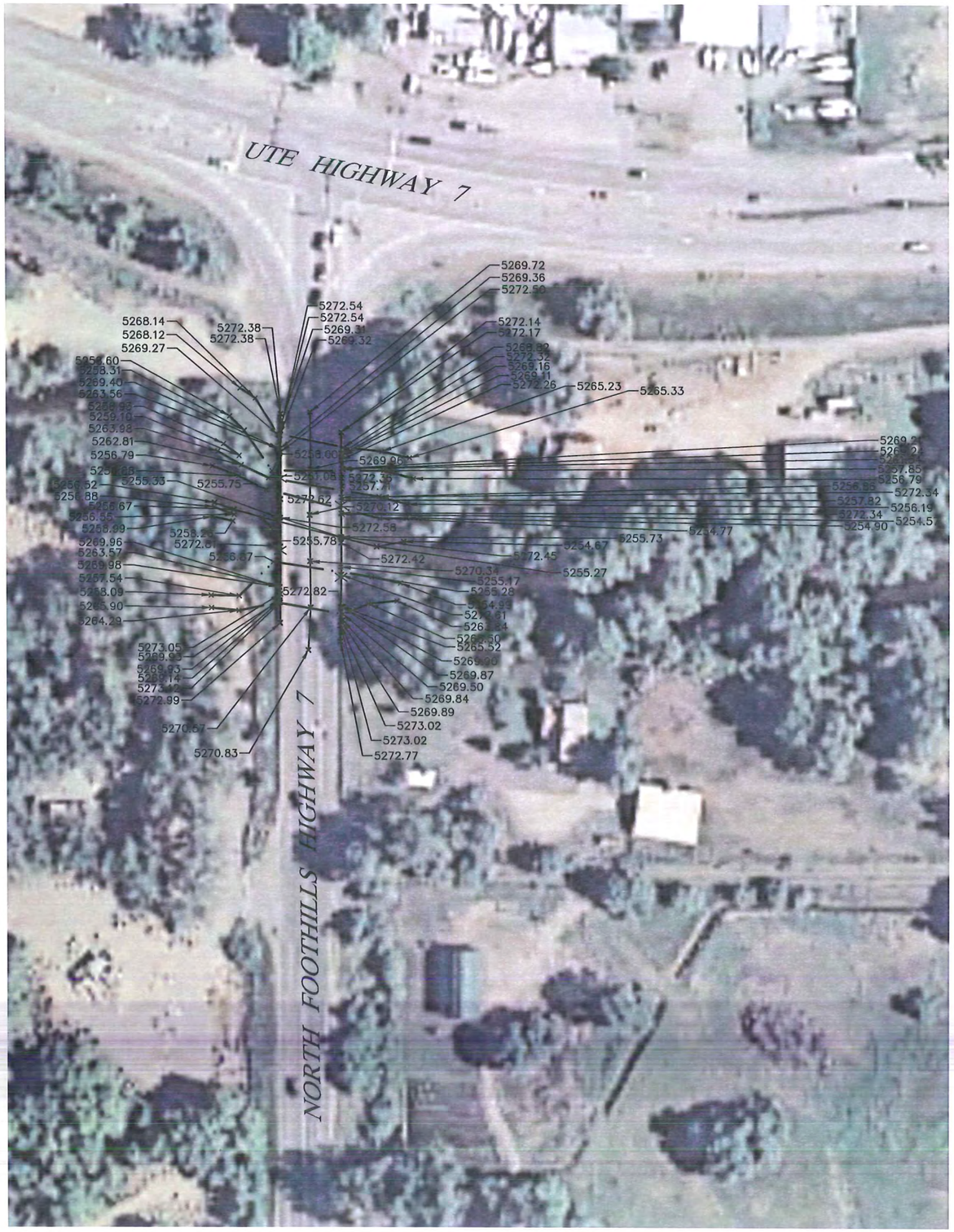
REVISIONS: DATE:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

1

SHT 1 OF 9



STRUCTURE SURVEY of NORTH FOOTHILLS HIGHWAY for ANDERSON CONSULTING ENGINEERS

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

100' 50' 0 100'

1" = 100'

COLORADO LICENSED LAWRENCE S. PEPEK 33642 PROFESSIONAL LAND SURVEYOR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 100'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

DATE:
REVISIONS:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

2

SHT 2 OF 9

STRUCTURE SURVEY
near
CEMEX PLANT
for
ANDERSON CONSULTING ENGINEERS

100' 50' 0 100'

1" = 100'

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 100'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT # 2008037

3

SHT 3 OF 9

STRUCTURE SURVEY
for
ANDERSON CONSULTING ENGINEERS

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

50' 25' 0 50'

1" = 50'

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 50'
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phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT # 2008037

4

SHT 4 OF 9

STRUCTURE SURVEY
of
RAILROAD ACCESS ROAD BRIDGE
for
ANDERSON CONSULTING ENGINEERS

100' 50' 0 100'

1" = 100'

NORTH

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

DATE: 10-31-2014
FILE NAME: 2014681-08037
SCALE: 1" = 100'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

5

SHT 5 OF 9

STRUCTURE SURVEY
of
63RD STREET BRIDGE
for
ANDERSON CONSULTING ENGINEERS

100' 50' 0 100'

1" = 100'

NORTH

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

COLORADO LICENSED
LAWRENCE S. PEPEK
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REVISIONS:	DATE:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

6

SHT 6 OF 9

STRUCTURE SURVEY of HYGIENE ROAD BRIDGE for ANDERSON CONSULTING ENGINEERS

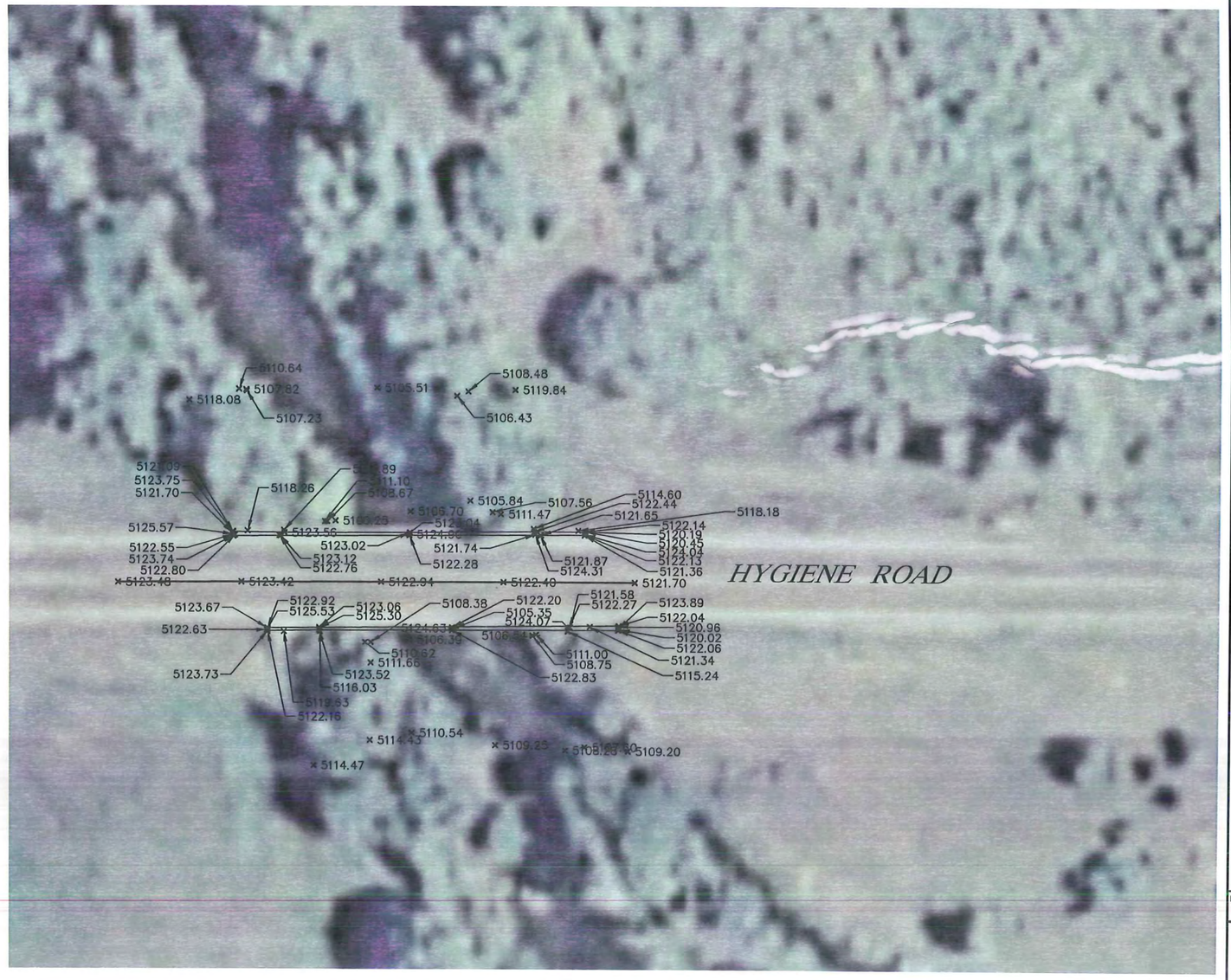
NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.

NORTH

50' 25' 0 50'

1" = 50'



Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

10-31-2014

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 50'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

7

SHT 7 OF 9

STRUCTURE SURVEY
of
CRANE HOLLOW ROAD
for
ANDERSON CONSULTING ENGINEERS

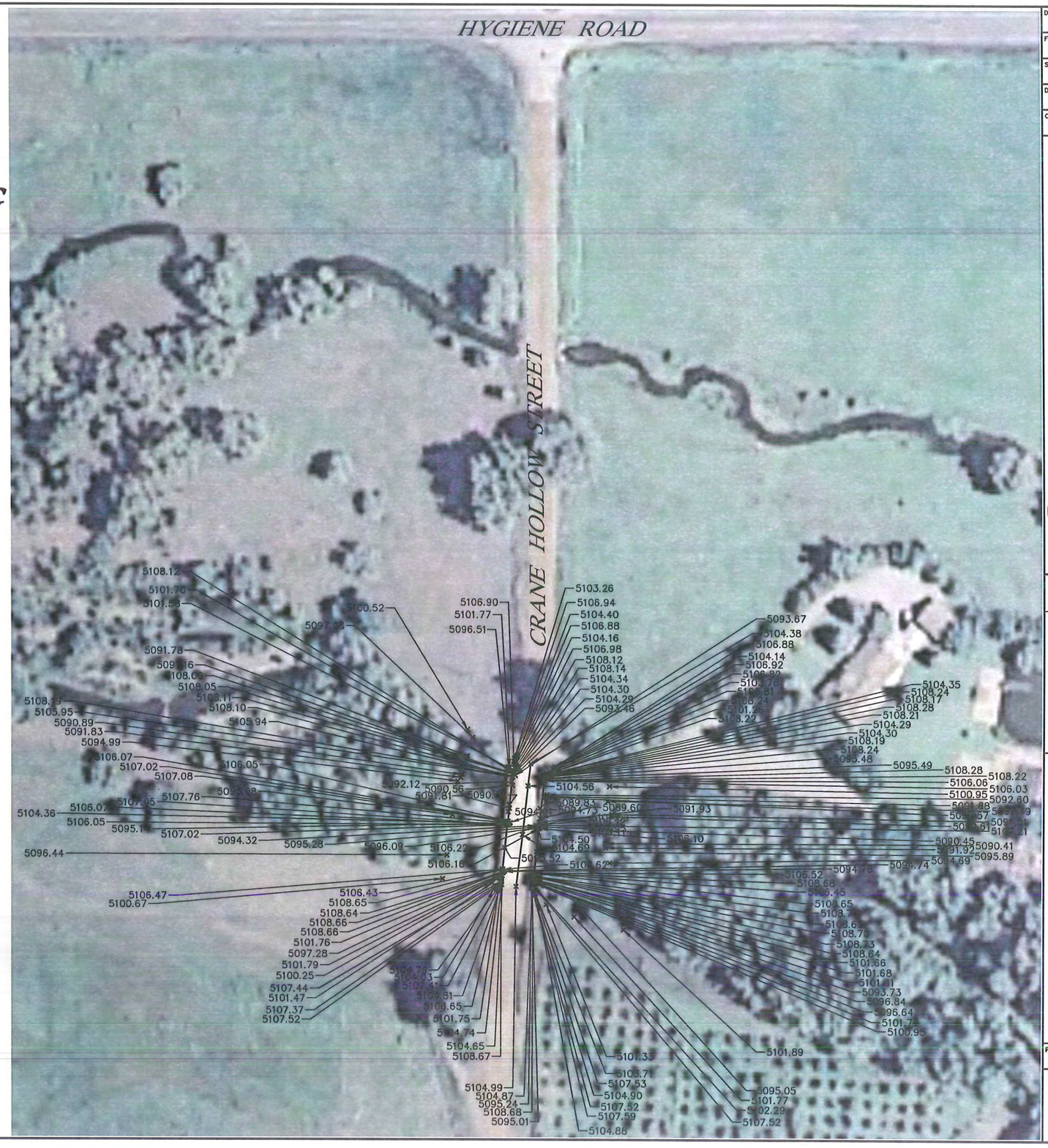
100' 50' 0 100'

1" = 100'

NORTH

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.



COLORADO LICENSED
LAWRENCE S. PEPEK
33642
LAND SURVEYOR

L S Pepek 10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 100'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

REVISIONS: DATE

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

8

SHT 8 OF 9

STRUCTURE SURVEY
of
NORTH 75TH STREET
for
ANDERSON CONSULTING ENGINEERS

LSPepek 10-31-2014

Lawrence S. Pepek – On Behalf Of King Surveyors
Colorado Registered Professional
Land Surveyor #33642

COLORADO LICENSED
LAWRENCE S. PEPEK
33642
PROFESSIONAL LAND SURVEYOR

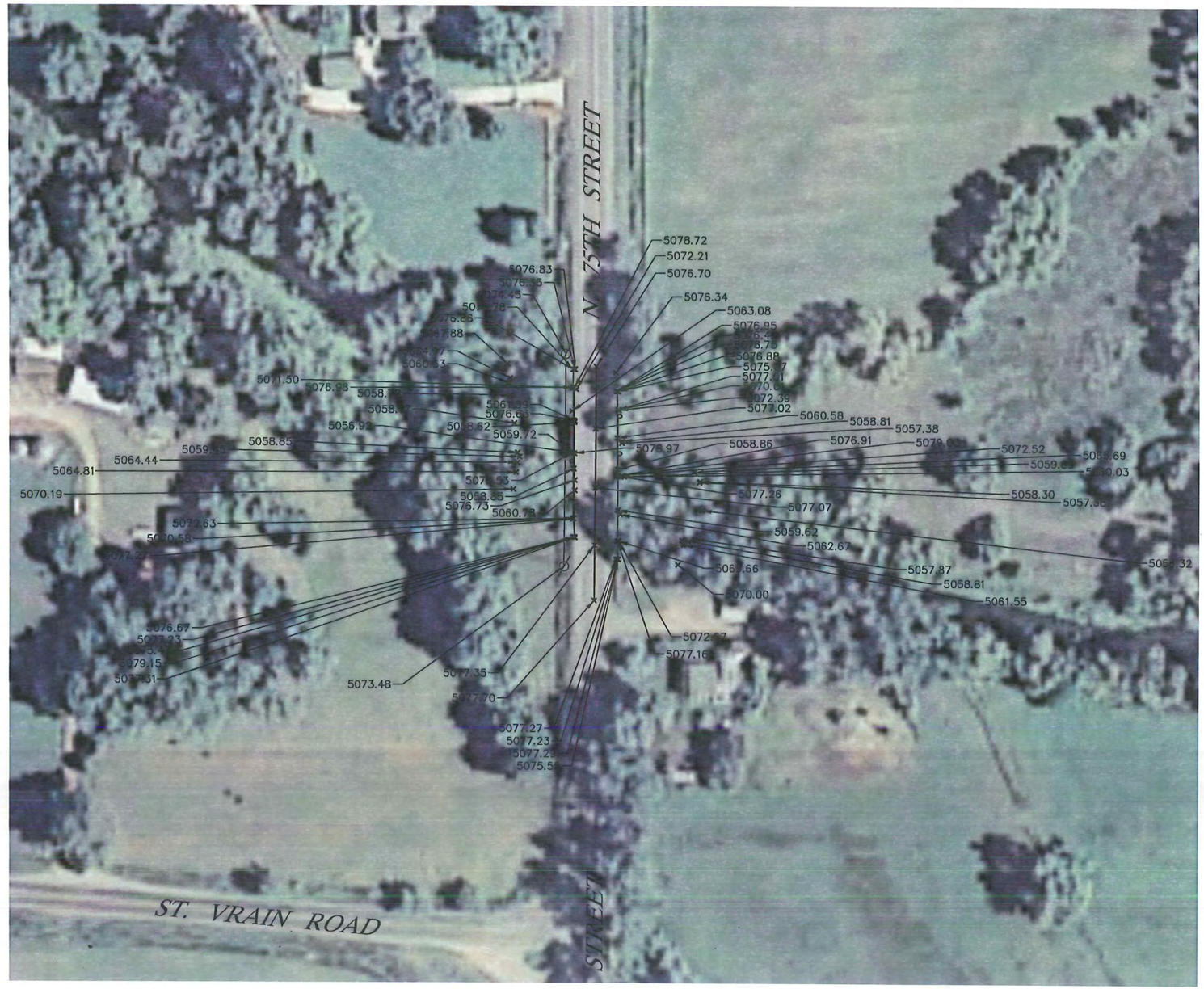
NORTH

100' 50' 0 100'

1" = 100'

NOTE: THIS DRAWING IS AT STATE PLANE.

VERTICAL DATUM IS NAVD88.



DATE: 10-31-2014
FILE NAME: 2014661-08037
SCALE: 1" = 100'
DRAWN BY: AML
CHECKED BY: LSP

KING SURVEYORS
650 E. Garden Drive | Windsor, Colorado 80550
phone: (970) 686-5011 | fax: (970) 686-5821

DATE:
REVISIONS:

STRUCTURE SURVEYS
FOR
ANDERSON CONSULTING ENGINEERS
375 E. HORSETOOTH ROAD, BLD 5
FORT COLLINS, CO 80525

PROJECT #: 2008037

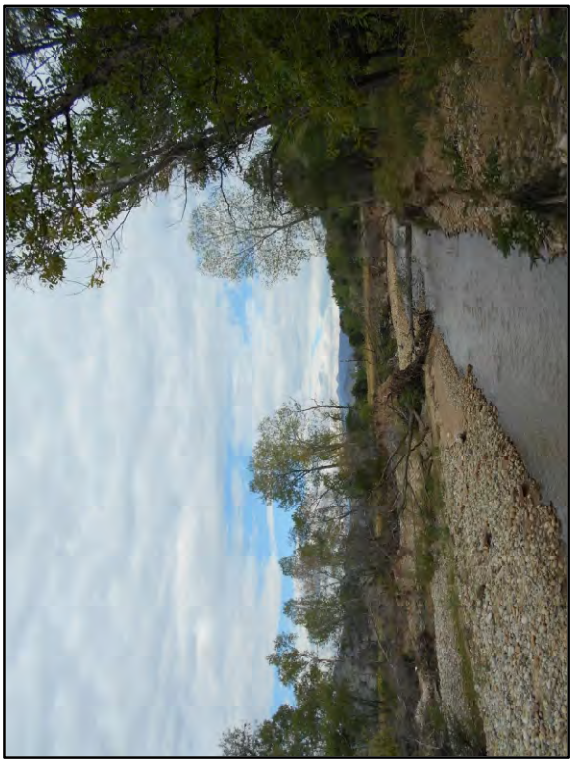
9

SHT 9 OF 9

ATTACHMENT B

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014



Log ID = 1 / File ID = DSCN0061.JPG WP # 1

Downstream of 63rd st. Bridge looking downstream

Log ID = 2 / File ID = DSCN0062.JPG WP # 1

Downstream of 63rd st. Bridge looking upstream

Log ID = 3 / File ID = DSCN0063.JPG WP # 1

Vegetation in Left Overbank

Log ID = 4 / File ID = DSCN0064.JPG WP # 1

downstream face of 63rd st. Bridge

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 5 / File ID = DSCN0065.JPG WP # 2
Looking downstream from 63rd st. Bridge

Log ID = 6 / File ID = DSCN0066.JPG WP # 2
Looking upstream from 63rd st. Bridge

Log ID = 7 / File ID = DSCN0067.JPG WP # 2
upstream face of 63rd st. Bridge

Log ID = 8 / File ID = DSCN0068.JPG WP # 2
Downstream of Irrigation Structure #1: Looking downstream

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 9 / File ID = DSCN0069.JPG WP # 3

Downstream of Irrigation Structure #1: Looking upstream

Log ID = 10 / File ID = DSCN0070.JPG WP # 3

Crest of Irrigation Structure #1

Log ID = 11 / File ID = DSCN0071.JPG WP # 3

Looking upstream from Irrigation Structure #1

Log ID = 12 / File ID = DSCN0072.JPG WP # 3

Looking upstream

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 14 / File ID = DSCN0074.JPG WP # 4

Along Ditch: Looking upstream

Log ID = 16 / File ID = DSCN0076.JPG WP # 4

Looking upstream Approximatly 200 feet upstream of Ditch Confluence

Log ID = 13 / File ID = DSCN0073.JPG WP # 4

Looking downstream

Log ID = 15 / File ID = DSCN0075.JPG WP # 4

Along Ditch: Looking downstream

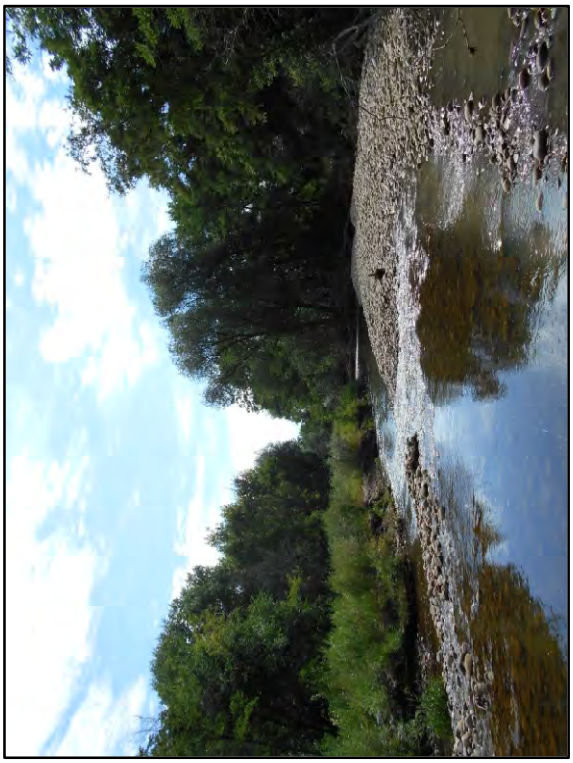
ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 18 / File ID = DSCN0078.JPG WP # 6

Looking upstream

Log ID = 20 / File ID = DSCN0080.JPG WP # 6

Looking upstream



Log ID = 17 / File ID = DSCN0077.JPG WP # 6

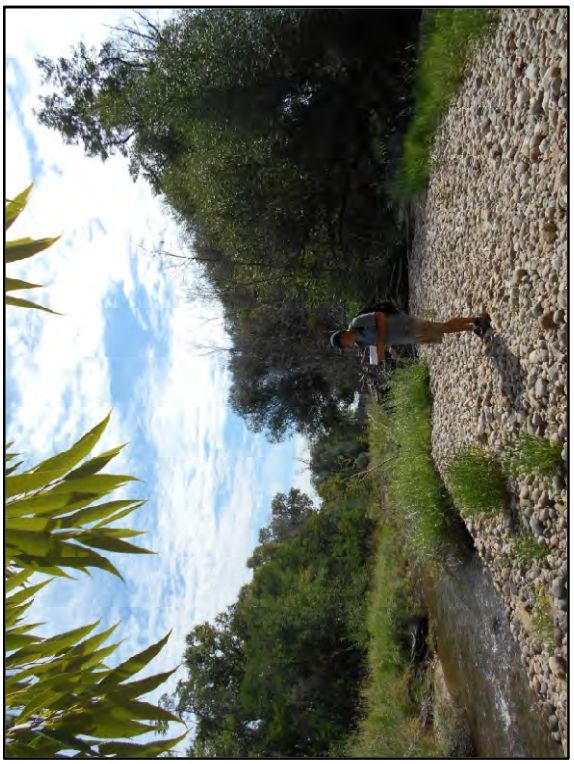
Looking downstream Approximalty 220 feet upstream of Ditch Confluence

Log ID = 19 / File ID = DSCN0079.JPG WP # 6

Looking downstream

Log ID = 21 / File ID = DSCN0081.JPG WP # 8
Looking downstream

Log ID = 22 / File ID = DSCN0082.JPG WP # 8
Vegetation in Right Overbank



Log ID = 23 / File ID = DSCN0083.JPG WP # 8
Looking upstream

Log ID = 24 / File ID = DSCN0084.JPG WP # 8
Looking downstream, Split on the Right

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 26 / File ID = DSCN0086.JPG WP # 12

Looking upstream

Log ID = 28 / File ID = DSCN0088.JPG WP # 12

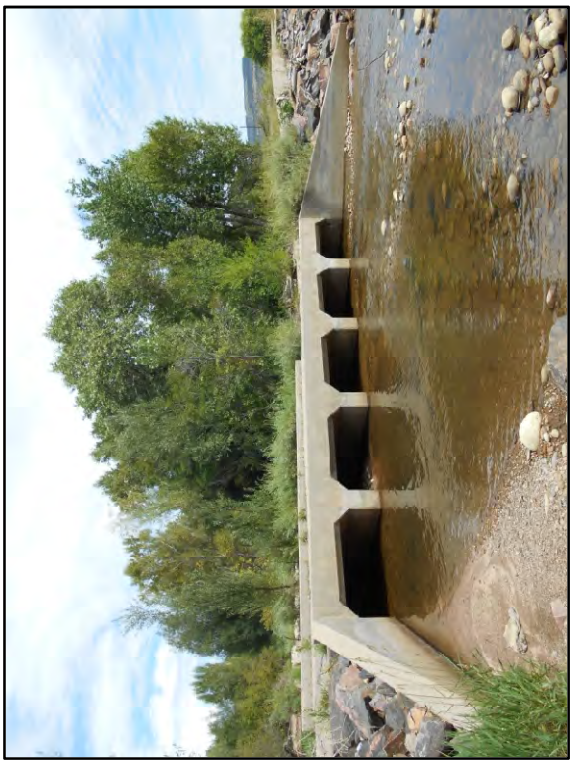
Downstream of Culverts: Looking upstream

Log ID = 25 / File ID = DSCN0085.JPG WP # 12

Gauging Station

Log ID = 27 / File ID = DSCN0087.JPG WP # 12

Looking downstream



Log ID = 30 / File ID = DSCN0090.JPG WP # 13
downstream face of Culverts

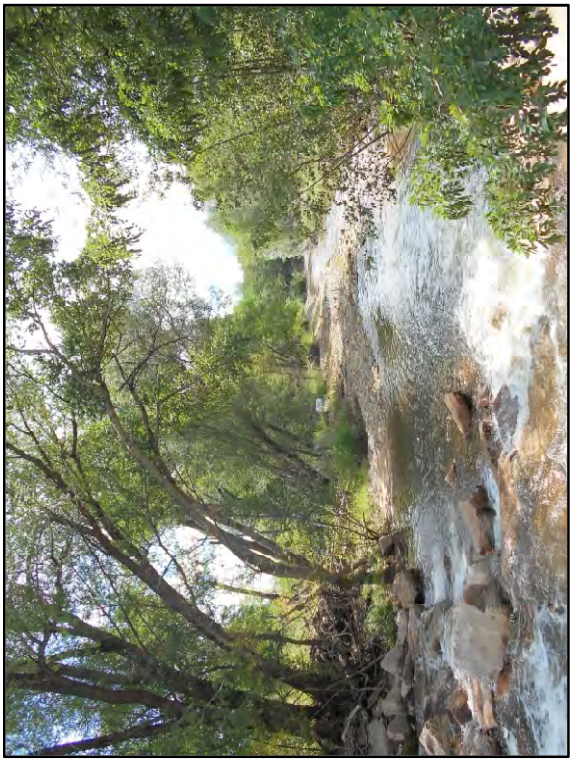
Log ID = 32 / File ID = DSCN0092.JPG WP # 13
Looging upstream from Culverts

Log ID = 29 / File ID = DSCN0089.JPG WP # 13
Downstream of Culverts: Looking downstream

Log ID = 31 / File ID = DSCN0091.JPG WP # 13
Looking downstream from Culverts

Log ID = 33 / File ID = DSCN0093.JPG WP # 13
upstream face of Culverts

Log ID = 34 / File ID = DSCN0094.JPG WP # 13
Irrigation Structure #2: Crest



Log ID = 35 / File ID = DSCN0095.JPG WP # 13
Looking downstream from Irrigation Structure #2

Log ID = 36 / File ID = DSCN0096.JPG WP # 13
Looking upstream from Irrigation Structure #2

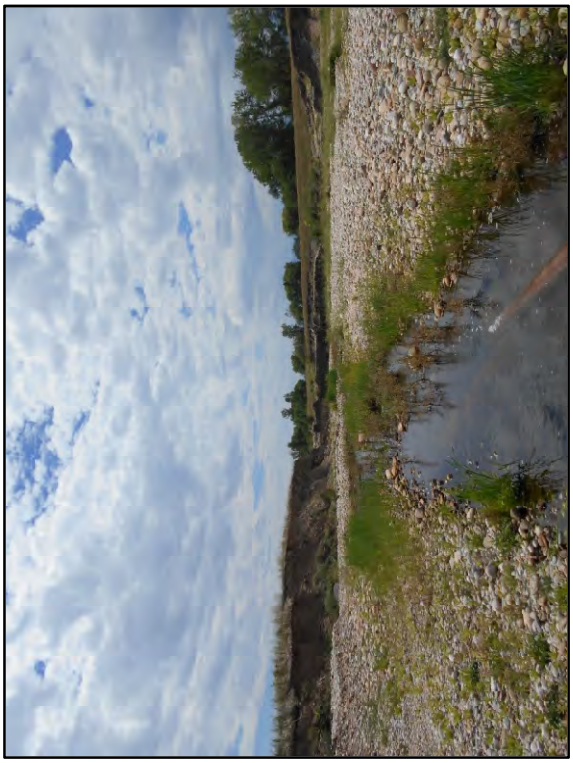
Log ID = 38 / File ID = DSCN0098.JPG WP # 15
Spillway: Looking downstream

Log ID = 40 / File ID = DSCN0100.JPG WP # 15
Gravel Mine Split: Looking Back towardsmain Channel

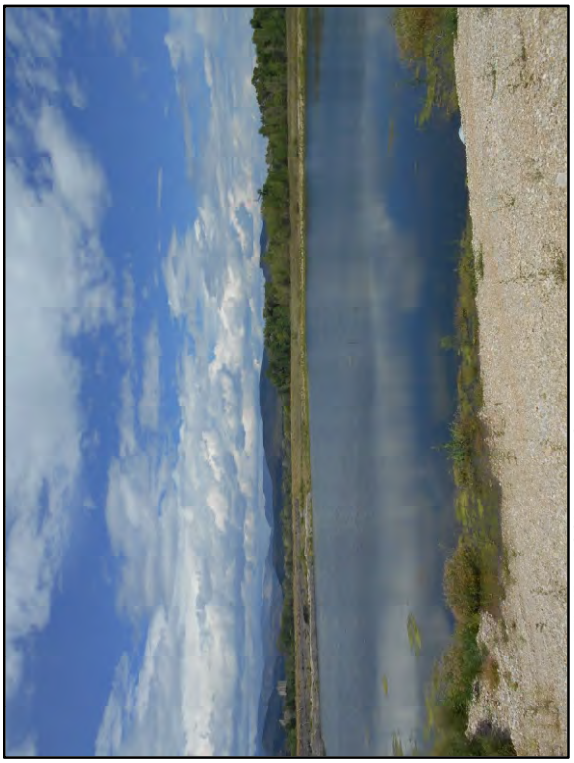
Log ID = 37 / File ID = DSCN0097.JPG WP # 15
Spillway at breach into gravel pits

Log ID = 39 / File ID = DSCN0099.JPG WP # 15
Spillway: Looking upstream

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

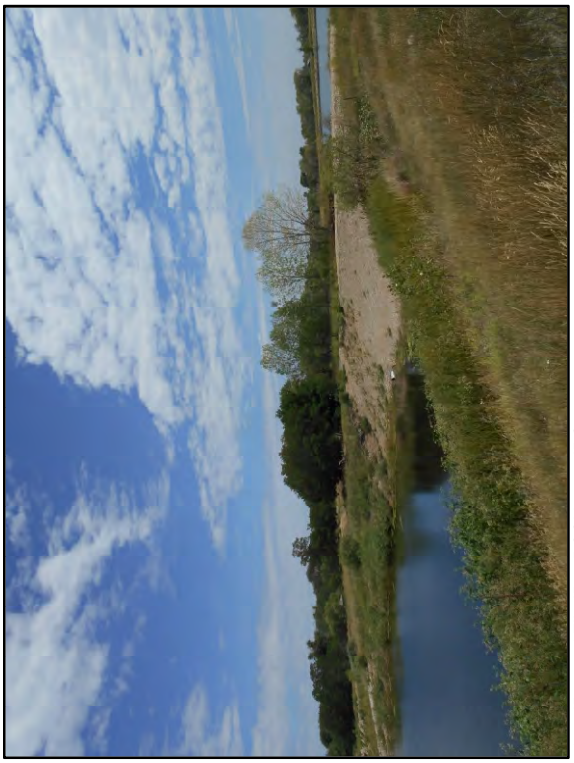


Log ID = 42 / File ID = DSCN0102.JPG WP # 16
Gravel Mine Split: Looking downstream



Log ID = 44 / File ID = DSCN0104.JPG WP # 16
Looking upstream

Log ID = 41 / File ID = DSCN0101.JPG WP # 16
Gravel Mine Split: Looking upstream

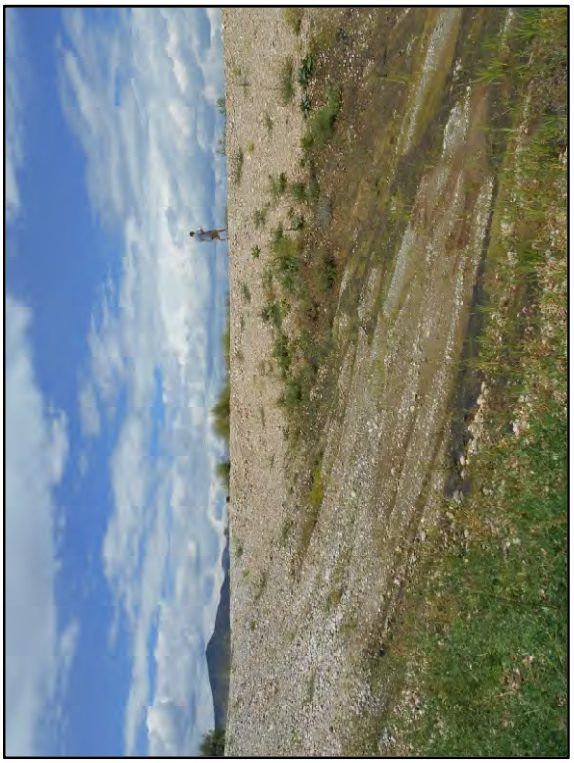


Log ID = 43 / File ID = DSCN0103.JPG WP # 16
upstream face of Dam

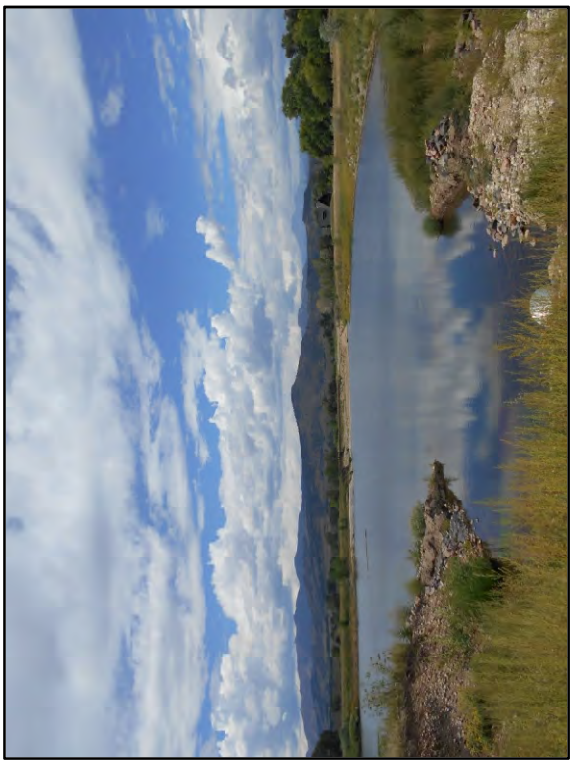
Log ID = 46 / File ID = DSCN0106.JPG WP # 17
downstream fae of Dam

Log ID = 48 / File ID = DSCN0108.JPG WP # 17
Leaking from Ditch

Log ID = 45 / File ID = DSCN0105.JPG WP # 17
Looking downstream



Log ID = 47 / File ID = DSCN0107.JPG WP # 17
Leaking from Ditch



Log ID = 50 / File ID = DSCN0110.JPG WP # 18
Looking upstream

Log ID = 52 / File ID = DSCN0112.JPG WP # 18
downstream face of Culvert at Split Confluence

Log ID = 49 / File ID = DSCN0109.JPG WP # 18
upstream face of Culvert at Split Confluence

Log ID = 51 / File ID = DSCN0111.JPG WP # 18
Looking downstream

Log ID = 54 / File ID = DSCN0114.JPG WP # 19
Looking upstream

Log ID = 56 / File ID = DSCN0116.JPG WP # 19
downstream face of HW 36 Bridge

Log ID = 53 / File ID = DSCN0113.JPG WP # 19
upstream face of HW 36 Bridge

Log ID = 55 / File ID = DSCN0115.JPG WP # 19
Looking downstream

Log ID = 58 / File ID = DSCN0118.JPG WP # 20
Looking downstream

Log ID = 60 / File ID = DSCN0120.JPG WP # 20
Looking downstream

Log ID = 57 / File ID = DSCN0117.JPG WP # 20
Looking upstream

Log ID = 59 / File ID = DSCN0119.JPG WP # 20
Looking upstream

Log ID = 62 / File ID = DSCN0122.JPG WP # 22
Looking downstream

Log ID = 64 / File ID = DSCN0124.JPG WP # 22
upstream face of Private Crossing #3

Log ID = 61 / File ID = DSCN0121.JPG WP # 22
Looking upstream

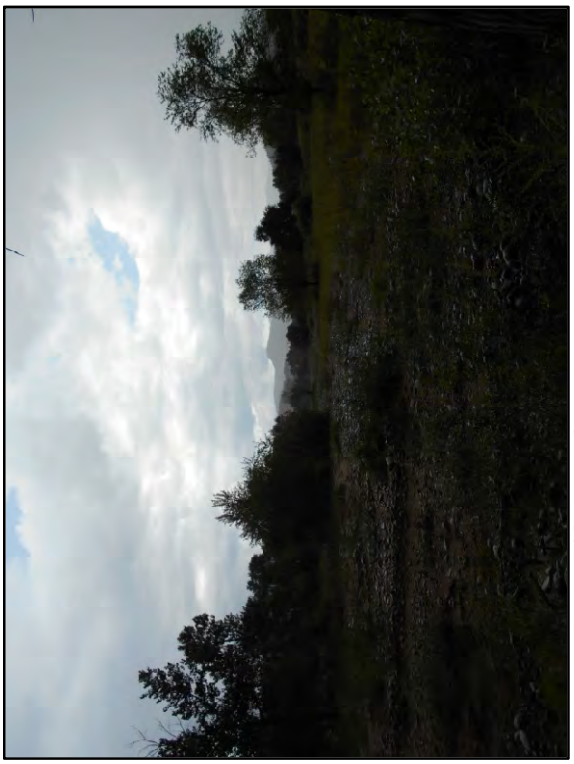
Log ID = 63 / File ID = DSCN0123.JPG WP # 22
upstream face of Private Crossing #3

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 65 / File ID = DSCN0125.JPG WP # 23
Looking upstream

Log ID = 66 / File ID = DSCN0126.JPG WP # 23
Looking downstream

Log ID = 67 / File ID = DSCN0127.JPG WP # 23
downstream face of Provate Crossing #3

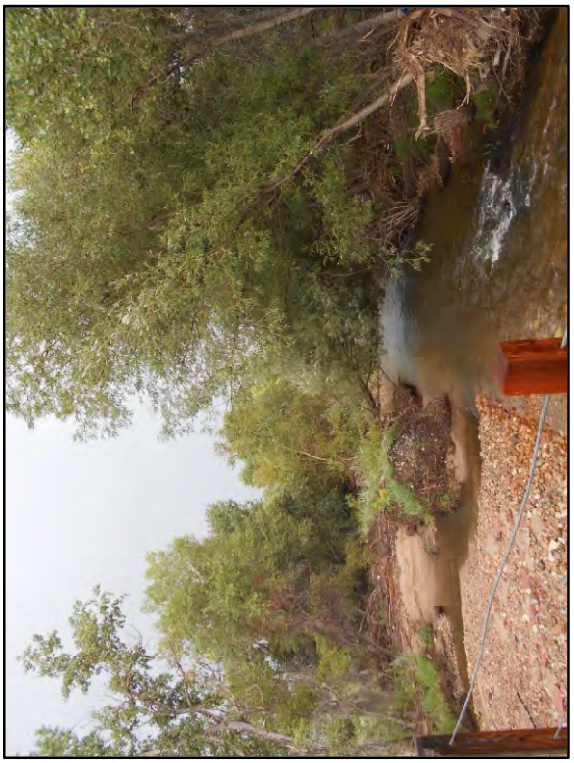


Log ID = 68 / File ID = DSCN0128.JPG WP # 23
Split Flow ar Plant: Looking upstream

Log ID = 70 / File ID = DSCN0130.JPG WP # 25
Looking upstream

Log ID = 72 / File ID = DSCN0132.JPG WP # 25
downstream face of RR Bridge

Log ID = 69 / File ID = DSCN0129.JPG WP # 25
upstream face of RR Bridge



Log ID = 71 / File ID = DSCN0131.JPG WP # 25
Looking downstream

ST. VRAIN CREEK PHOTOGRAPHIC DOCUMENTATION
ST. VRAIN CREEK MASTER PLAN
LYONS TO HYGIENE ROAD: AUGUST 14, 2014

Log ID = 74 / File ID = DSCN0134.JPG WP # 26
Looking upstream

Log ID = 76 / File ID = DSCN0136.JPG WP # 26
Looking downstream

Log ID = 73 / File ID = DSCN0133.JPG WP # 26
upstream face of Drop Structure

Log ID = 75 / File ID = DSCN0135.JPG WP # 26
downstream face of Drop Structure

APPENDIX C

MANNING'S ROUGHNESS COEFFICIENTS

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Step 1 - Channel material (n_b)

Reach: WP#1 to 63rd st (~600 D/S of 63rd St Bridge to D/S face of 63rd st Bridge)

Channel Reach Description:

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	- — 0.04
Boulder	>256	0.040-0.070	-

Photos: 1, 2, 5

Step 2 - Degree of Irregularity (n_1)

Notes:

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020 — .013

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010 — a little grass a few trees on cobble islands
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = .078

Channel 2

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionaly	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

grass, trees on banks

.035

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = .0771

Reach:

u/s side of 63rd st bridge to WP # 9 (~2,700' u/s of 63rd st)

Channel Reach Description:

Photos:

6

12+13 (WP # 4)

Notes:

Need to survey structures @ WP # 2

WP #6 is ≈ 100' u/s of confluence with in coming ditch, ditch is carrying ≈ 50 of flow, n' value of ditch = 0.035

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 3

Step 1 - Channel material (n_b)

Reach:

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

.035

Channel Reach Description:

Starting @ WP#9 → WP#11

(~2700' U/S of 63rd street) (~3400' U/S of 63rd street)

Photos:

23, 24

Step 2 - Degree of Irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Notes:

less trees, more veg, especially on bars, more irregular shape than d/s

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

0.01

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

mostly grass + willows

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.072

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 4

Step 1 - Channel material (n_b)

Reach:

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Channel Reach Description:

WP#11 to culvert crossing at WP#13

(~3400' U/S of 63rd Street)

box culvert crossing at private drive

Photos:

WP#12 - old gaging station

25, 26, 27

Step 2 - Degree of Irregularity (n_1)

Notes:

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005 — 0.003
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004 — some debris caught on trees
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050 — 0.04 — lots of willows / small trees
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.082

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 5

Step 1 - Channel material (n_b)

Reach:

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Channel Reach Description:

box culvert crossing to spill into pond where rock weir has been rebuilt. (WP#15) WP#13

Photos:

Step 2 - Degree of Irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Notes:

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050 - 0.03
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.057

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Reach: d/s side of railroad bridge to Way point #15

rebuilt weir to overbank pond

Channel Reach Description:

Photos:

Notes:

2 drops - d/s is ≈ 3'
u/s ≈ 9-10'

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.00-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004 - debris caught on trees
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050 — 0.04
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.079

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 9

Reach: U/s side of Union Rd (WP #23) to U/s side of railroad bridge

Channel Reach Description:

Photos:

Notes:

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of Irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005 — 0.003
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = .067

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 8

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of Irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.004-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025 — 0.02 — trees on overbanks
Large	0.025-0.050
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.065

Reach: ~800' d/s of Highway 36

WP#20 (old building on left bank) to U/S side of Union Rd (WP# 23)

Channel Reach Description:

Photos:

Notes:

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Reach: Highway 36 to WP #20

Channel Reach Description: ~800' d/s of highway 36

Photos:

Notes: lots of work done on this reach, cleared out some obstruction along left bank

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

.015 — some trees on left bank

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = .052

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Channel 6

Reach: u/s of 36

Channel Reach Description:

Photos: 54

Notes: Very large cobble, mounds of material, concrete

Step 1 - Channel material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Step 2 - Degree of Irregularity (n_1)

Smooth	0
Minor	0.001-0.005
Moderate	0.006-0.010
Severe	0.011-0.020

Step 3 - Variation in Channel Cross Section (n_2)

Gradual	0
Alternating Occasionally	0.001-0.005
Alternating Frequently	0.010-0.015

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004
Minor	0.005-0.015
Appreciable	0.020-0.030
Severe	0.040-0.060

Step 5 - Amount of Vegetation (n_4)

Small	0.002-0.010 - few trees on bank
Medium	0.010-0.025
Large	0.025-0.050
Very Large	0.050-0.100

Step 6 - Meandering (m)

$n = (n_b + n_1 + n_2 + n_3 + n_4)m$

Minor	1
Appreciable	1.15
Severe	1.3

COMPOSITE CHANNEL n VALUE = 0.075

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Overbank 1

Step 1 - Overbank material (n_b)

Reach: WP# 1 to 63rd st (~600' D/S of 63rd street)

Reach Description:

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

— some cobble near channel banks

Selected Overbank Material Value: Left: .028 Right: .028

Step 2 - Degree of Irregularity (n_1)

Notes:

Smooth	0	0
Minor	0.001-0.005	0.001-0.005
Moderate	0.006-0.010	0.006-0.010
Severe	0.011-0.020	0.011-0.020

Step 4 - Obstructions (n_3)

Negligible	.002 0.000-0.004	.002 0.000-0.004
Minor	0.005-0.019	0.005-0.019
Appreciable	0.020-0.030	0.020-0.030

— Some sporatic fencing

Step 5 - Amount of Vegetation (n_4)

Small	0.001-0.010	0.001-0.010
Medium	0.011-0.025	0.011-0.025
Large	0.025-0.050 - 0.04	0.025-0.050 - 0.04
Very Large	0.050-0.100	0.050-0.100
Extreme	0.100-0.200	0.100-0.200

COMPOSITE OVERBANK n VALUE = Left: 0.071 Right: 0.071

Photos: 3

Overbank 2

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Reach: U/S side of 63rd st to WP#25 old Union Rd Crossing

Reach Description:

Step 1 - Overbank material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Selected Overbank Material Value: Left: .026 Right: .026 – less cobble in overbank

Notes:

Step 2 - Degree of Irregularity (n_1)

Smooth	0	0
Minor	0.001-0.005	0.001-0.005
Moderate	0.006-0.010	0.006-0.010
Severe	0.011-0.020	0.011-0.020

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004	0.000-0.004
Minor	0.005-0.019	0.005-0.019 – fence, stumps, debris piles
Appreciable	0.020-0.030	0.020-0.030

Step 5 - Amount of Vegetation (n_4)

Small	0.001-0.010	0.001-0.010
Medium	0.011-0.025	0.011-0.025
Large	0.025-0.050	0.025-0.050
Very Large	0.050-0.100 – 0.055	0.050-0.100
Extreme	0.100-0.200	0.100-0.200

COMPOSITE OVERBANK n VALUE = Left: .087 Right: .087

Photos: 22

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Reach: WP#25 to Highway 36

dd union road crossing

Reach Description:

Step 1 - Overbank material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Selected Overbank Material Value: Left: .026 Right: .026

Notes:

Step 2 - Degree of Irregularity (n_1)

	Left	Right
Smooth	0	0
Minor	0.001-0.005	0.001-0.005
Moderate	0.006-0.010	0.006-0.010
Severe	0.011-0.020	0.011-0.020

Step 4 - Obstructions (n_3)

	Left	Right
Negligible	0.000-0.004	0.000-0.004
Minor	0.005-0.019	0.005-0.019
Appreciable	0.020-0.030	0.020-0.030

Step 5 - Amount of Vegetation (n_4)

	Left	Right
Small	0.001-0.010	0.001-0.010
Medium	0.011-0.025	0.011-0.025
Large	0.025-0.050	0.025-0.050
Very Large	0.050-0.100	0.050-0.100
Extreme	0.100-0.200	0.100-0.200

COMPOSITE OVERBANK n VALUE = Left: 0.082 Right: 0.082

Photos:

Manning's n Value Spreadsheet

"Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, Paper 2339)

Divided Flow Path @ CEMEX Plant

Reach: WP#24 ↑ Union Road near Cemex Plant

Reach Description: Use for divided flow path extending ≈ from WP#21 through waypoint 24, approximately 2,500' d/s towards west end of pond that no longer exists.

Step 1 - Overbank material (n_b)

Bed Material	Median Size of Bed Material (millimeters)	Base n Value: Straight Uniform Channel	Base n Value: Smooth Channel
	Sand Channels		
Sand	0.2	0.012	-
	0.3	0.017	-
	0.4	0.02	-
	0.5	0.022	-
	0.6	0.023	-
	0.8	0.024	-
	1	0.026	-
	Stable Channels and Flood Plains		
Concrete	-	0.012-0.018	0.011
Rock Cut	-	-	0.025
Firm Soil	-	0.025-0.032	0.02
Coarse Sand	1-2	0.026-0.035	-
Fine Gravel	-	-	0.024
Gravel	2-64	0.028-0.035	-
Coarse Gravel	-	-	0.026 — 0.028
Cobble	64-256	0.030-0.050	-
Boulder	>256	0.040-0.070	-

Selected Overbank Material Value: Left: _____ Right: _____

Notes: _____

Step 2 - Degree of Irregularity (n_1)

Smooth	0	0
Minor	0.001-0.005 — 0.03	0.001-0.005
Moderate	0.006-0.010	0.006-0.010
Severe	0.011-0.020	0.011-0.020

Step 4 - Obstructions (n_3)

Negligible	0.000-0.004	0.000-0.004
Minor	0.005-0.019	0.005-0.019
Appreciable	0.020-0.030	0.020-0.030

Step 5 - Amount of Vegetation (n_4)

Small	0.001-0.010	0.001-0.010
Medium	0.011-0.025	0.011-0.025
Large	0.025-0.050	0.025-0.050
Very Large	0.050-0.100	0.050-0.100
Extreme	0.100-0.200	0.100-0.200

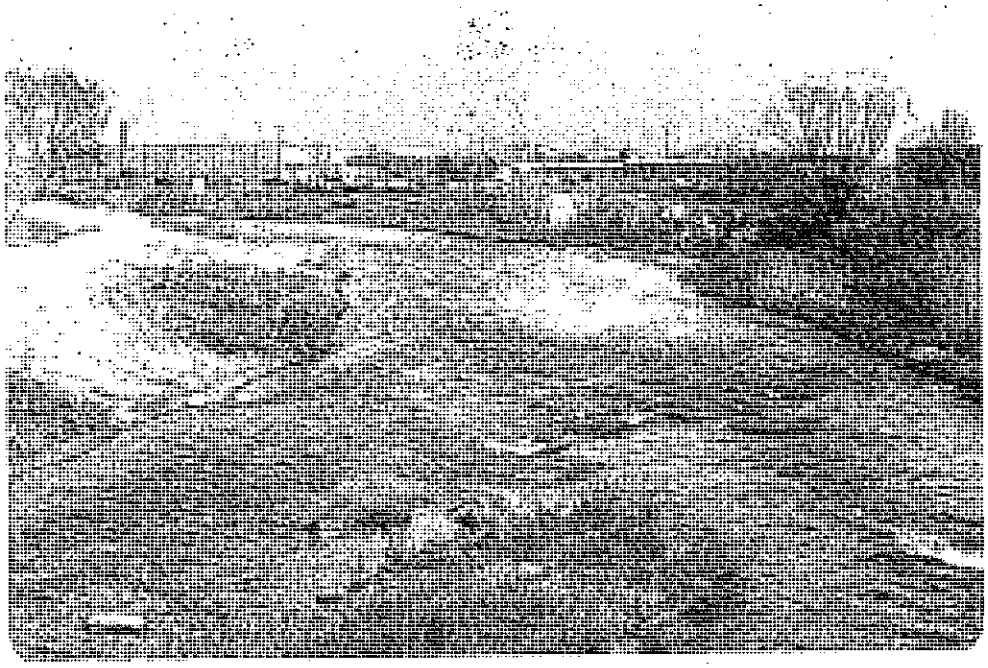
COMPOSITE OVERBANK n VALUE = Left: .058 Right: _____

Photos: _____

ATTACHMENT D

HYDROLOGIC DOCUMENTATION

FLOODPLAIN INFORMATION, FLOOD CONTROL AND FLOODPLAIN MANAGEMENT PLAN FOR ST. VRAIN CREEK AT LONGMONT, COLORADO



prepared for

CITY OF LONGMONT, BOULDER COUNTY

and the

COLORADO WATER CONSERVATION BOARD

prepared by

WATER RESOURCES CONSULTANTS, INC.

April, 1981

TABLE-4

ST. VRAIN CREEK DISCHARGES

(EXISTING CONDITIONS)

Station		Drainage Area (sq.mi.)	5-Year (c.f.s.)	10-Year (c.f.s.)	50-Year (c.f.s.)	100-Year (c.f.s.)	500-Year (c.f.s.)
Confluence, No. & So. St. Vrain		211, 102*	1,300	2,040	5,570	8,880	20,260
Lyons Gage		212, 103*	1,300	2,030	5,560	8,830	20,140
Tributaries	Above	111*	1,450	2,480	6,060	8,970	20,270
	Below	120*	1,650	3,050	6,850	9,750	21,440
Lykins Gulch	Above	132*	1,980	3,160	6,890	9,580	19,680
	Below	143*	2,450	3,690	7,610	10,160	20,500
Dry Creek	Above	144*	2,480	3,660	7,430	9,820	19,940
	Below	156*	2,780	4,110	8,240	10,580	21,200
Lefthand Cr. & The Slough	Above	157*	2,780	4,110	8,240	10,580	21,200
	Below	242*	3,500	5,250	10,950	14,850	28,670
Dry Creek & Spring Gulch	Above	245*	3,300	5,120	10,790	14,610	28,470
	Below	274*	4,000	6,010	12,580	16,440	31,790
Boulder Creek	Above	277*	4,000	6,010	12,500	16,440	31,790
	Below	825**	4,050	6,110	12,500	16,630	42,400
Idaho Creek	Above	837**	4,000	5,910	12,140	16,320	41,590
	Below	849**	4,050	6,070	12,500	16,510	41,960
Right Bank Tribs	Above	850**	3,900	5,760	12,350	16,350	41,360
	Below	881**	4,000	5,920	12,900	16,760	41,900
Left Bank Tribs	Above	904**	3,800	5,510	12,370	16,530	40,520
	Below	920**	3,800	5,520	12,400	16,560	40,590
Platteville Gage		976, 922*	3,700	5,410	12,200	16,540	40,230
Mouth		924**	3,650	5,350	12,120	16,520	40,080

* Contributing Area (Excludes Area Above Button Rock Dam)
** Contributing Area (Includes Area Above Button Rock Dam)

Hydrologic Evaluation of the St. Vrain Watershed

Post September 2013 Flood Event

Prepared for:

Colorado Department of Transportation
Region 4 Flood Recovery Office

Prepared by:

707 17th Street, Suite 2400
Denver, Colorado 80202

With Support from:

August 2014

Table ES-1. 100-year Modeled Peak Flows Compared to Current Regulatory Discharges

Location	Current Regulatory Discharge (cfs)	Modeled Discharge (cfs)	Percent Difference
Middle St. Vrain Creek at confluence with South St. Vrain Creek	2,000	2,160	+8%
Middle St. Vrain Creek at Peaceful Valley (State Route 72 Bridge)	1,180	1,400	+19%
North St. Vrain Creek at confluence with St. Vrain Creek and South St. Vrain Creek	4,310	6,390	+48%
South St. Vrain Creek at confluence with St. Vrain Creek and North St. Vrain Creek	5,430	7,230	+33%
South St. Vrain Creek at confluence with Middle St. Vrain Creek	3,990	5,260	+32%
St. Vrain Creek Just downstream of confluence of North St. Vrain Creek and South St. Vrain Creek	8,880	11,910	+34%

Based on the modeled discharges for the return periods analyzed, the peak discharges observed along St. Vrain Creek during the September 2013 Flood event had an estimated recurrence interval ranging from approximately 1 percent annual peak discharge to the 0.2 percent annual peak discharge, or from a 100-year to a 500-year storm event. There are two exceptions to this where lower peak discharges were estimated. These results are shown in Table ES-2.

Table ES-2. Estimate of September 2013 Peak Discharge Recurrence Interval

Location	Measured Discharge (cfs)	Annual Chance Peak Discharge (cfs)					Estimated Recurrence Interval (yr)
		10%	4%	2%	1%	0.2%	
Middle St. Vrain Creek at Riverside	1,750	364	700	1,170	1,820	4,110	~ 100
South St. Vrain Creek below Middle St. Vrain	2,700	1,190	2,345	3,658	5,369	10,962	25 to 50
South St. Vrain Creek above Lyons	9,000	1,464	2,890	4,496	6,598	13,435	100 to 500
North St. Vrain Creek at Highway 7	450	963	1,785	2,667	3,799	7,423	< 10
North St. Vrain Creek below Button Rock Dam	10,000	1,502	3,108	5,002	7,472	16,002	100 to 500
North St. Vrain Creek above Lyons	12,300	1,056	2,299	3,804	5,842	13,100	100 to 500
St. Vrain Creek at Hwy 36 Bridge (D-15-I)	23,000	2,202	4,860	7,949	12,089	26,599	100 to 500

Baker

MEMORANDUM

Date: October 16, 2014

To: Varda Blum
Boulder County Floodplain Manager

From: Andrew Friend, P.E.
Project Engineer for St. Vrain Master Plan project

Subject: **Approach to sizing structures in Riverside/Raymond**

This memo details a proposed approach to sizing replacement structures on Middle St. Vrain Creek in the Riverside/Raymond area. The intent of the proposed approach is to provide minimum box culvert sizing guidelines that can be used to inform the sizing and design of multiple private crossing permanent replacements in this reach.

In coming up with proposed guidelines, we have kept two primary goals in mind:

1. To meet the minimum sizing criteria in the in the Boulder County Storm Drainage Criteria Manually. Specifically, these structures need to be able to pass the 10-year event.
2. Meet all FEMA regulations and guidelines. Since the county regulates this floodplain as if it were a floodway, proposed structures need to either cause no rise in BFE, or be approved with a CLOMR.

Another goal that was initially considered, but later abandoned, was to create guidelines for culvert sizing such that they could pass the highest attainable flood that can be contained in the bank full channel. However, the bank full channel is inconsistent and not well defined in this area. In some areas there is no well-defined bank full channel at all. Therefore, this design criteria is not able to be applied in this area.

Hydrology

The Colorado Department of Transportation (CDOT) has been working, in partnership with the Colorado Water Conservation Board (CWCB), on development of new hydrologic models in the watersheds affected by the September 2013 floods. This has involved creation of new hydrologic models using a rainfall-runoff methodology in HEC-HMS. A significant amount of data was captured during the flood event and this data was significantly used in calibrating the new models. In addition, recent LIDAR and new rainfall data from the recently released NOAA Atlas 14 was used.

The primary purpose of the work is to create models for CDOT's use in repair of damaged infrastructure. However, it is the State's hope that these models be created to standards that would allow them to be made available to communities potentially for future regulatory purposes but there is no mandatory requirement at this time to use the new model results for design or floodplain management purposes.

The FEMA FIS discharge values are based on hydrology performed in 1978 by CDM. These values are compared to the new hydrology values in the following table.

Summary of Discharges on Middle St. Vrain Creek in the Riverside Area

Study Name and Location	Annual Chance Peak Discharge (cfs)				
	10%	4%	2%	1%	0.2%
Draft Hydrologic Evaluation of the St. Vrain Watershed (CDOT, 2014)	364	700	1,170	1,820	4,110
Effective discharges (from CDM, 1978)	550	(not given)	1,240	1,730	3,480

In order to be conservative for this analysis, we used the higher discharge calculated from these two studies. So, for the 10 year event, 550 cfs was used. For the 100 year event, 1,820 cfs was used.

10 year event

Per the Boulder County Storm Drainage Criteria Manual, private driveways at elevations above 6,000 feet are required to have the capacity to pass the 10-year event. Therefore, we performed HY-8 modeling to determine the culvert size that would be able to do this at all locations in this reach.

Several basic assumptions were made: first, the average slope of the stream through this reach is approximately 3.3%. However, slopes generally range from 2% to 4.5%. To be conservative, slope through the modeled culvert was taken to be 2%. Second, it was assumed that the typical culvert will be concrete box, with approximately 2.5 feet from the top of box elevation to the roadway crest. Third, the width of the driveway was taken to be 20 feet – based on pre-flood aerial imagery, this is a conservative estimate for most bridges.

The HY-8 modeling indicates that the minimum culvert opening to pass the 10 year event is 60 square feet. This area can be accomplished using several different potential sizes, but the sizing that makes the most sense given the typical size of the channel is 10ft (span) by 6ft (rise). Therefore, **in order for a box culvert to pass the 10 year event, it should be at least 10 feet by 6 feet.** This size culvert will pass the 10 year event at all locations, without the need for further detailed site-specific analysis. Output from the HY-8 modeling is attached to this memo.

There are some areas in this reach where the channel is either non-existent, or too small to carry the 10 year event in the bank full condition. In these locations, earthwork should be performed to create a channel that can carry 550 cfs.

100 year event

At many locations in this reach the channel is small or nonexistent, and the 100 year flood event inundates a wide area, filling up a large portion of the valley floor. 100 year inundation topwidths are highly variable, but generally range from approximately 40 feet to around 300 feet, with average topwidths around 150 feet. For this reason, it is not feasible to design driveway structures that clear-span the 100 year event.

The effective FEMA flooding zone in this area is detailed AE, without a floodway. However, Boulder County regulates this floodplain as if it were a floodway. Therefore, any proposed crossing

replacement, when combined with all other development, needs to cause lno rise in BFE when compared to “existing conditions”, or be approved with a CLOMR.

Based on recent guidance from the CWCB, “existing conditions” may be taken as either the true existing conditions, using post-flood LiDAR or more up to date survey data, or pre-flood conditions, using pre-flood LiDAR and reliable information about any washed out structures in the reach.

Unfortunately, a “one-size fits all” sizing solution is not possible for sizing multiple structures to meet FEMA 100-year flood event requirements in this reach. Instead, **each proposed structure replacement must be analyzed and modeled to ensure that they are not causing any increase in BFE**. Any other development that has occurred must be taken in to account in these models.

Conclusion

Replacement structures on the Middle St. Vrain in the Riverside/Raymond area must be thoughtfully designed. We recommend the following guidelines:

1. **In order to pass the 10 year event, the area of the structure opening must be at least 60 square feet. 10 foot by 6 foot box culverts are recommended.**
2. **In order to analyze impact on the 100 year flood event, each structure must be analyzed and modeled**.

HY-8 Analysis Results

Crossing Summary Table

Culvert Crossing: 10 year

Headwater Elevation (ft)	Total Discharge (cfs)	10 year Crossing Discharge (cfs)	Roadway Discharge (cfs)	Iterations
1001.19	20.00	20.00	0.00	1
1002.35	73.00	73.00	0.00	1
1003.22	126.00	126.00	0.00	1
1003.97	179.00	179.00	0.00	1
1004.64	232.00	232.00	0.00	1
1005.26	285.00	285.00	0.00	1
1005.86	338.00	338.00	0.00	1
1006.45	391.00	391.00	0.00	1
1007.05	444.00	444.00	0.00	1
1007.68	497.00	497.00	0.00	1
1008.33	550.00	550.00	0.00	1
1008.85	589.31	589.31	0.00	Overtopping

HY-8 Analysis Results

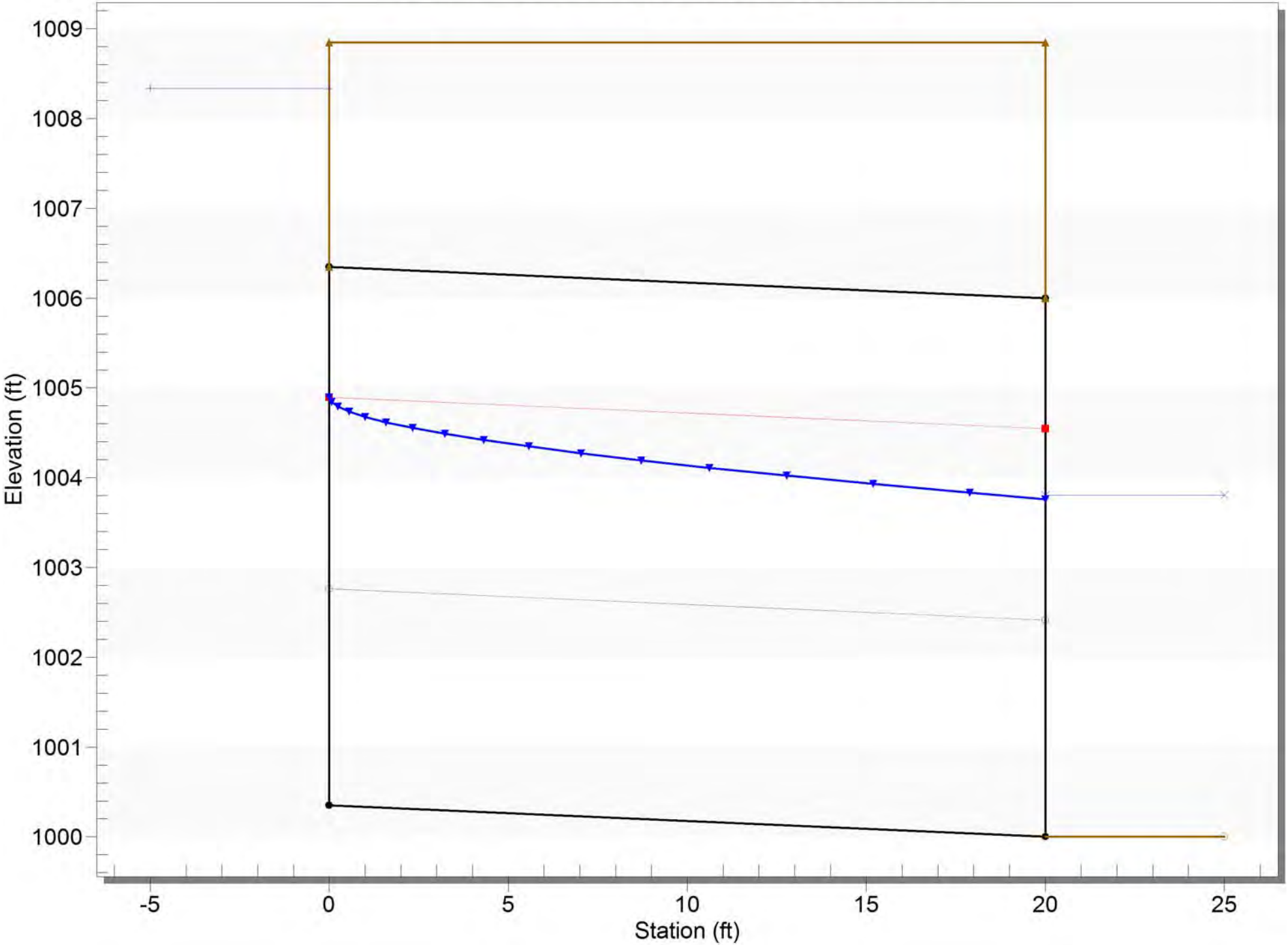
Culvert Summary Table - 10 year Crossing

Culvert Crossing: 10 year

Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
20.00	20.00	1001.19	0.84	0.19	1-S2n	0.20	0.50	0.32	0.54	6.20	3.52
73.00	73.00	1002.35	2.00	0.87	1-S2n	0.63	1.18	0.84	1.17	8.67	5.57
126.00	126.00	1003.22	2.87	1.46	1-S2n	0.89	1.70	1.27	1.62	9.94	6.68
179.00	179.00	1003.97	3.62	2.01	1-S2n	1.14	2.15	1.65	1.99	10.88	7.48
232.00	232.00	1004.64	4.29	2.56	1-S2n	1.34	2.56	1.99	2.32	11.63	8.11
285.00	285.00	1005.26	4.91	3.12	1-S2n	1.55	2.93	2.32	2.62	12.27	8.63
338.00	338.00	1005.86	5.51	3.69	1-S2n	1.73	3.29	2.63	2.89	12.84	9.09
391.00	391.00	1006.45	6.10	4.28	5-S2n	1.91	3.62	2.93	3.14	13.34	9.48
444.00	444.00	1007.05	6.70	4.90	5-S2n	2.08	3.94	3.22	3.37	13.80	9.84
497.00	497.00	1007.68	7.33	5.54	5-S2n	2.25	4.25	3.49	3.60	14.23	10.17
550.00	550.00	1008.33	7.98	6.93	5-S2n	2.41	4.55	3.76	3.81	14.62	10.46

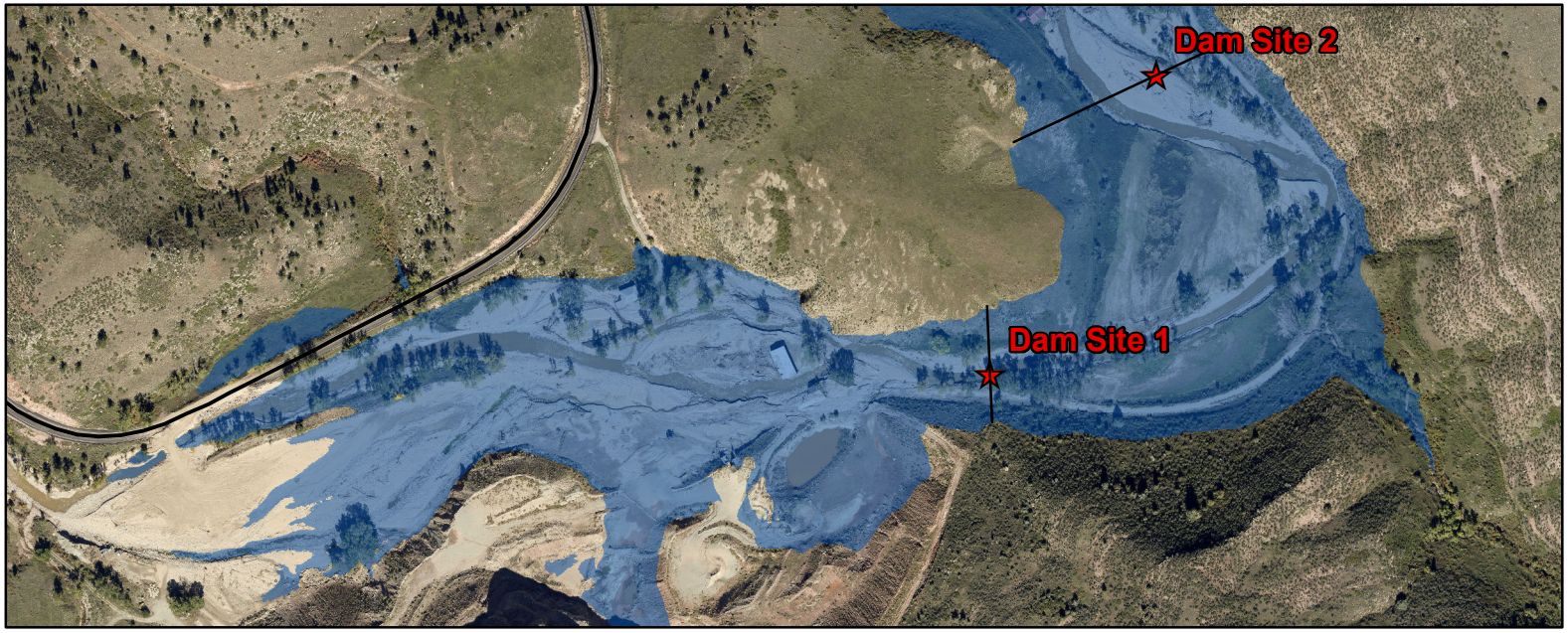
Crossing - 10 year, Design Discharge - 550.0 cfs

Culvert - 10 year Crossing, Culvert Discharge - 550.0 cfs



Potential Dam Sites - Andesite Mine Area

South St. Vrain Creek



Legend

★ Potential Dam Site

Inundation Area

Dam Site 1 - 320 ft wide, 38 ft tall

Dam Site 2 - 680 ft wide, 56 ft tall

Flow Reduction Capability

Recurrence Interval	Natural Peak Flow (cfs)	Dam 1 - Peak Flow (cfs)	Dam 1 - Reduction %	Dam 2 - Peak Flow (cfs)	Dam 2 - Reduction %
10 year	1460	890	39%	0	100%
25 year	2890	2530	12%	1640	43%
50 year	4500	4130	8%	3430	24%
100 year	6600	6150	7%	5440	18%
500 year	13440	12900	4%	12000	11%

N

1 inch = 500 feet

DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

Basin ID: Dam Site 1 - 10-year

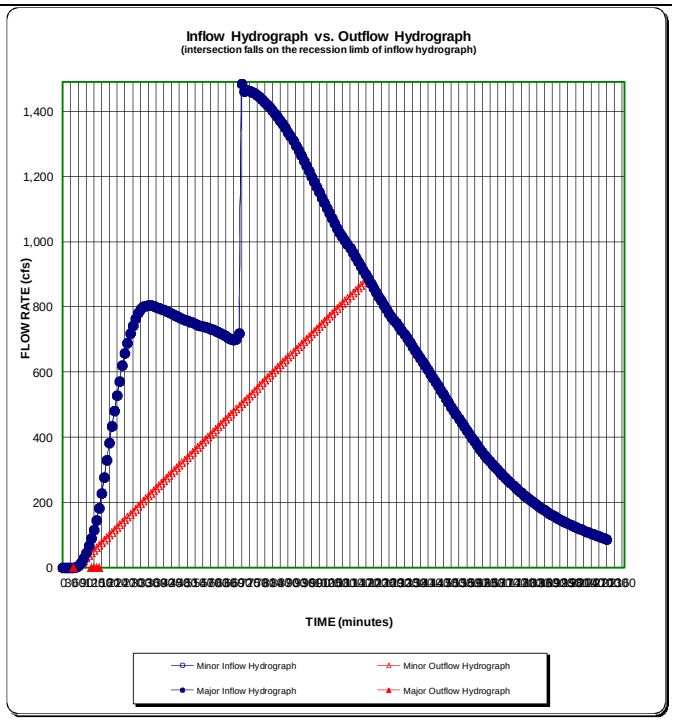
Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =	890.00		cfs
Time to Peak Outflow	Tp-out =	1180		minutes

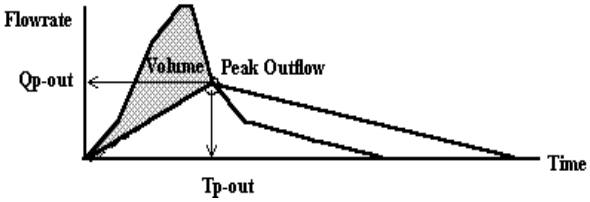
Minor Storage Volume (cubic ft.): **29,207,721**

Minor Storage Volume (acre-ft.): **350.56**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
0	0	0.00	0.00	0.00	0	#N/A	0.00	0.00
10	0	0.00	0.00	0.00	0	#N/A		
20	0	0.00	0.00	0.00	0	#N/A		
30	0	0.00	0.00	0.00	0	#N/A		
40	0	0.00	0.00	0.00	0	#N/A		
50	1.3251	1.33	0.00	0.00	1.3251	#N/A		
60	5.8683	5.87	0.00	0.00	5.8683	#N/A		
70	15.3333	13.76	0.02	0.02	15.3333	#N/A		
80	28.7736	21.66	0.10	0.12	28.7736	#N/A		
90	45.9999	29.55	0.23	0.35	45.9999	#N/A		
100	66.6336	37.44	0.40	0.75	66.6336	#N/A		
110	89.9175	45.34	0.61	1.36	89.9175	#N/A		
120	115.6623	53.23	0.86	2.22	115.6623	#N/A		
130	145.0038	61.13	1.16	3.38	145.0038	#N/A		
140	181.9173	69.02	1.56	4.93	181.9173	#N/A		
150	227.5386	76.91	2.07	7.01	227.5386	#N/A		
160	277.7031	84.81	2.66	9.66	277.7031	#N/A		
170	330.1392	92.70	3.27	12.93	330.1392	#N/A		
180	382.9539	100.60	3.89	16.82	382.9539	#N/A		
190	433.6863	108.49	4.48	21.30	433.6863	#N/A		
200	481.3899	116.38	5.03	26.33	481.3899	#N/A		
210	527.7684	124.28	5.56	31.89	527.7684	#N/A		
220	572.0646	132.17	6.06	37.95	572.0646	#N/A		
230	620.904	140.07	6.62	44.57	620.904	#N/A		
240	656.871	147.96	7.01	51.58	656.871	#N/A		
250	688.6734	155.85	7.34	58.92	688.6734	#N/A		
260	717.447	163.75	7.63	66.55	717.447	#N/A		
270	742.8132	171.64	7.87	74.41	742.8132	#N/A		
280	764.3934	179.54	8.06	82.47	764.3934	#N/A		
290	781.6197	187.43	8.18	90.65	781.6197	#N/A		
300	793.5456	195.33	8.24	98.89	793.5456	#N/A		
310	800.3604	203.22	8.23	107.12	800.3604	#N/A		
320	803.3892	211.11	8.16	115.28	803.3892	#N/A		
330	804.525	219.01	8.06	123.34	804.525	#N/A		
340	803.9571	226.90	7.95	131.29	803.9571	#N/A		
350	802.2534	234.80	7.82	139.11	802.2534	#N/A		
360	799.6032	242.69	7.67	146.78	799.6032	#N/A		
370	796.5744	250.58	7.52	154.30	796.5744	#N/A		
380	793.5456	258.48	7.37	161.67	793.5456	#N/A		
390	790.1382	266.37	7.21	168.88	790.1382	#N/A		
400	786.7308	274.27	7.06	175.94	786.7308	#N/A		
410	783.1341	282.16	6.90	182.84	783.1341	#N/A		
420	779.3481	290.05	6.74	189.58	779.3481	#N/A		
430	775.3728	297.95	6.58	196.16	775.3728	#N/A		
440	771.0189	305.84	6.41	202.57	771.0189	#N/A		
450	767.0436	313.74	6.24	208.81	767.0436	#N/A		
460	763.4469	321.63	6.09	214.89	763.4469	#N/A		
470	760.4181	329.52	5.94	220.83	760.4181	#N/A		
480	757.3893	337.42	5.78	226.61	757.3893	#N/A		
490	754.1712	345.31	5.63	232.25	754.1712	#N/A		
500	750.9531	353.21	5.48	237.72	750.9531	#N/A		
510	747.735	361.10	5.33	243.05	747.735	#N/A		
520	744.8955	368.99	5.18	248.23	744.8955	#N/A		
530	742.4346	376.89	5.04	253.26	742.4346	#N/A		
540	740.163	384.78	4.90	258.16	740.163	#N/A		
550	737.8914	392.68	4.76	262.91	737.8914	#N/A		
560	735.4305	400.57	4.61	267.53	735.4305	#N/A		
570	732.591	408.46	4.46	271.99	732.591	#N/A		
580	729.5622	416.36	4.31	276.30	729.5622	#N/A		
590	726.1548	424.25	4.16	280.46	726.1548	#N/A		
600	722.5581	432.15	4.00	284.46	722.5581	#N/A		
610	718.5828	440.04	3.84	288.30	718.5828	#N/A		
620	714.2289	447.93	3.67	291.97	714.2289	#N/A		
630	709.875	455.83	3.50	295.47	709.875	#N/A		
640	705.5211	463.72	3.33	298.80	705.5211	#N/A		
650	701.1672	471.62	3.16	301.96	701.1672	#N/A		
660	698.1384	479.51	3.01	304.97	698.1384	#N/A		
670	699.8421	487.40	2.93	307.90	699.8421	#N/A		
680	718.2042	495.30	3.07	310.97	718.2042	#N/A		
690	1484.3013	503.19	13.51	324.48	1484.3013	#N/A		
700	1459.6923	511.09	13.07	337.55	1459.6923	#N/A		
710	1463.6676	518.98	13.01	350.56	1463.6676	#N/A		
720	1461.9639	526.87	12.88	363.44	1461.9639	#N/A		
730	1458.7458	534.77	12.73	376.17	1458.7458	#N/A		
740	1454.3919	542.66	12.56	388.72	1454.3919	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

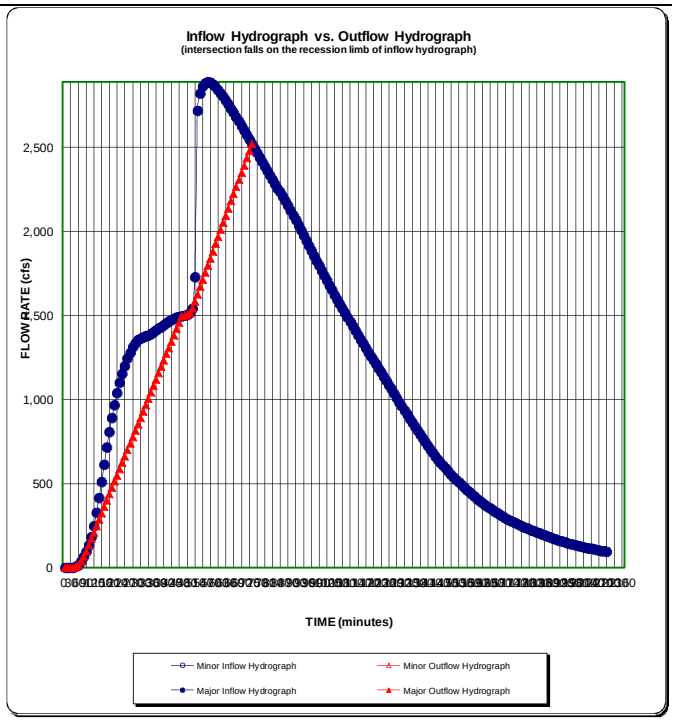
Basin ID: Dam Site 1 - 25-year

Design Information (Input):

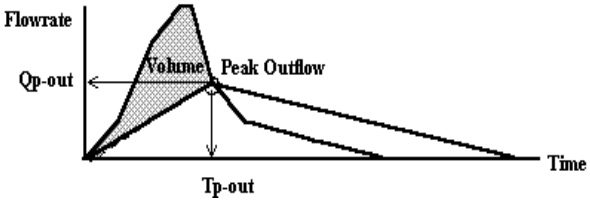
		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		2520.00	cfs
Time to Peak Outflow	Tp-out =		730	minutes

Major Storage Volume (cubic ft.): **15,592,581**
Major Storage Volume (acre-ft.): **356.98**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	0	0.00	0.00	0.00
10		#N/A			0	0.00	0.00	0.00
20		#N/A			0	0.00	0.00	0.00
30		#N/A			0.1373	0.14	0.00	0.00
40		#N/A			1.0984	1.10	0.00	0.00
50		#N/A			5.6293	5.63	0.00	0.00
60		#N/A			16.8879	16.89	0.00	0.00
70		#N/A			36.5218	36.52	0.00	0.00
80		#N/A			62.8834	62.88	0.00	0.00
90		#N/A			95.2862	95.29	0.00	0.00
100		#N/A			134.2794	133.17	0.02	0.02
110		#N/A			183.1582	171.06	0.17	0.18
120		#N/A			247.8265	208.94	0.54	0.72
130		#N/A			327.8724	246.83	1.12	1.83
140		#N/A			416.7055	284.72	1.82	3.65
150		#N/A			510.756	322.60	2.59	6.24
160		#N/A			613.1818	360.49	3.48	9.72
170		#N/A			715.4703	398.38	4.37	14.09
180		#N/A			807.324	436.26	5.11	19.20
190		#N/A			891.9008	474.15	5.75	24.96
200		#N/A			968.5142	512.03	6.29	31.24
210		#N/A			1037.5761	549.92	6.72	37.96
220		#N/A			1098.8119	587.81	7.04	45.00
230		#N/A			1153.0454	625.69	7.26	52.26
240		#N/A			1201.1004	663.58	7.40	59.67
250		#N/A			1243.3888	701.46	7.46	67.13
260		#N/A			1280.1852	739.35	7.45	74.58
270		#N/A			1311.6269	777.24	7.36	81.94
280		#N/A			1336.4782	815.12	7.18	89.12
290		#N/A			1353.9153	853.01	6.90	96.02
300		#N/A			1364.762	890.90	6.53	102.55
310		#N/A			1371.7643	928.78	6.10	108.65
320		#N/A			1377.119	966.67	5.65	114.31
330		#N/A			1382.7483	1004.55	5.21	119.52
340		#N/A			1390.4371	1042.44	4.79	124.31
350		#N/A			1402.7941	1080.33	4.44	128.75
360		#N/A			1413.6408	1118.21	4.07	132.82
370		#N/A			1422.8399	1156.10	3.67	136.49
380		#N/A			1432.1763	1193.98	3.28	139.77
390		#N/A			1441.9246	1231.87	2.89	142.67
400		#N/A			1452.9086	1269.76	2.52	145.19
410		#N/A			1464.7164	1307.64	2.16	147.35
420		#N/A			1474.4647	1345.53	1.78	149.13
430		#N/A			1482.4281	1383.42	1.36	150.49
440		#N/A			1488.8812	1421.30	0.93	151.42
450		#N/A			1492.8629	1459.19	0.46	151.89
460		#N/A			1495.6089	1495.61	0.00	151.89
470		#N/A			1498.9041	1498.90	0.00	151.89
480		#N/A			1503.9842	1503.98	0.00	151.89
490		#N/A			1515.5174	1515.52	0.00	151.89
500		#N/A			1542.2909	1542.29	0.00	151.89
510		#N/A			1728.0578	1584.80	1.97	153.86
520		#N/A			2719.2265	1627.31	15.04	168.90
530		#N/A			2822.6134	1669.82	15.88	184.78
540		#N/A			2863.5288	1712.33	15.86	200.64
550		#N/A			2883.7119	1754.84	15.55	216.19
560		#N/A			2889.4785	1797.35	15.04	231.23
570		#N/A			2884.9476	1839.85	14.40	245.63
580		#N/A			2874.1009	1882.36	13.66	259.29
590		#N/A			2859.4098	1924.87	12.87	272.16
600		#N/A			2841.9727	1967.38	12.05	284.20
610		#N/A			2822.3388	2009.89	11.19	295.40
620		#N/A			2801.1946	2052.40	10.31	305.71
630		#N/A			2778.8147	2094.91	9.42	315.13
640		#N/A			2755.1991	2137.42	8.51	323.64
650		#N/A			2730.7597	2179.93	7.59	331.23
660		#N/A			2705.6338	2222.44	6.66	337.88
670		#N/A			2679.9587	2264.95	5.72	343.60
680		#N/A			2653.8717	2307.45	4.77	348.37
690		#N/A			2627.5101	2349.96	3.82	352.19
700		#N/A			2601.0112	2392.47	2.87	355.06
710		#N/A			2574.2377	2434.98	1.92	356.98
720		#N/A			2547.4642	2477.49	0.96	357.95
730		#N/A			2520.6907	2520.00	0.01	357.96
740		#N/A			2493.9172	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

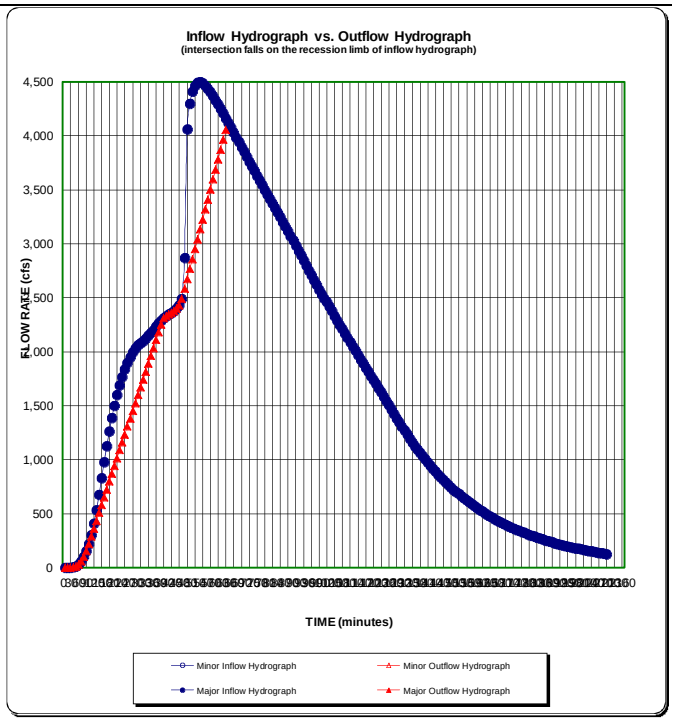
Basin ID: Dam Site 1 - 50-year

Design Information (Input):

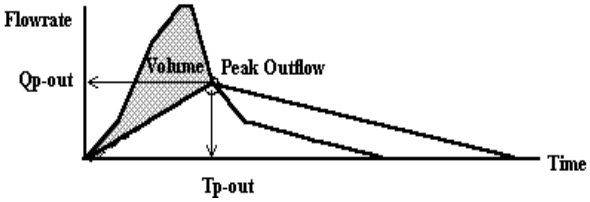
		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		4130.00	cfs
Time to Peak Outflow	Tp-out =		638	minutes

Major Storage Volume (cubic ft.): **15,552,405**
Major Storage Volume (acre-ft.): **357.03**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	0.1559	0.00	0.00	0.00
10		#N/A			0.3118	0.31	0.00	0.00
20		#N/A			0.6236	0.62	0.00	0.00
30		#N/A			1.4031	1.40	0.00	0.00
40		#N/A			3.5857	3.59	0.00	0.00
50		#N/A			11.3807	11.38	0.00	0.00
60		#N/A			29.7769	29.78	0.00	0.00
70		#N/A			60.801	60.80	0.00	0.00
80		#N/A			102.1145	102.11	0.00	0.00
90		#N/A			153.0938	153.09	0.00	0.00
100		#N/A			216.3892	216.39	0.00	0.00
110		#N/A			299.6398	289.13	0.14	0.14
120		#N/A			407.9903	361.88	0.64	0.78
130		#N/A			535.0488	434.62	1.38	2.16
140		#N/A			672.8644	507.36	2.28	4.44
150		#N/A			830.4793	580.11	3.45	7.89
160		#N/A			979.3638	652.85	4.50	12.39
170		#N/A			1124.1949	725.60	5.49	17.88
180		#N/A			1262.3223	798.34	6.39	24.27
190		#N/A			1389.3808	871.08	7.14	31.41
200		#N/A			1502.0965	943.83	7.69	39.10
210		#N/A			1601.4048	1016.57	8.06	47.15
220		#N/A			1688.0852	1089.31	8.25	55.40
230		#N/A			1765.2557	1162.06	8.31	63.71
240		#N/A			1834.7871	1234.80	8.26	71.97
250		#N/A			1897.303	1307.54	8.12	80.10
260		#N/A			1952.3357	1380.29	7.88	87.98
270		#N/A			1998.1703	1453.03	7.51	95.49
280		#N/A			2034.8068	1525.78	7.01	102.50
290		#N/A			2061.6216	1598.52	6.38	108.88
300		#N/A			2080.6414	1671.26	5.64	114.52
310		#N/A			2101.3761	1744.01	4.92	119.44
320		#N/A			2125.0729	1816.75	4.25	123.68
330		#N/A			2149.5492	1889.49	3.58	127.27
340		#N/A			2173.8696	1962.24	2.92	130.18
350		#N/A			2200.8403	2034.98	2.28	132.47
360		#N/A			2232.9557	2107.73	1.72	134.19
370		#N/A			2261.7972	2180.47	1.12	135.31
380		#N/A			2286.8971	2253.21	0.46	135.78
390		#N/A			2309.5026	2309.50	0.00	135.78
400		#N/A			2328.8342	2328.83	0.00	135.78
410		#N/A			2346.1391	2346.14	0.00	135.78
420		#N/A			2361.885	2361.89	0.00	135.78
430		#N/A			2378.2545	2378.25	0.00	135.78
440		#N/A			2398.2097	2398.21	0.00	135.78
450		#N/A			2429.3897	2429.39	0.00	135.78
460		#N/A			2490.6584	2490.66	0.00	135.78
470		#N/A			2871.9898	2582.76	3.98	139.76
480		#N/A			4061.195	2674.85	19.10	158.86
490		#N/A			4297.0717	2766.95	21.08	179.93
500		#N/A			4409.4756	2859.05	21.36	201.29
510		#N/A			4467.0027	2951.15	20.88	222.17
520		#N/A			4492.5703	3043.25	19.96	242.13
530		#N/A			4496.9355	3135.34	18.75	260.88
540		#N/A			4485.7107	3227.44	17.33	278.22
550		#N/A			4463.7288	3319.54	15.76	293.98
560		#N/A			4435.6668	3411.64	14.11	308.08
570		#N/A			4403.3955	3503.73	12.39	320.47
580		#N/A			4368.0062	3595.83	10.64	331.11
590		#N/A			4330.2784	3687.93	8.85	339.96
600		#N/A			4290.8357	3780.03	7.04	346.99
610		#N/A			4249.834	3872.13	5.20	352.20
620		#N/A			4207.5851	3964.22	3.35	355.55
630		#N/A			4164.2449	4056.32	1.49	357.03
640		#N/A			4120.2811	#N/A		
650		#N/A			4075.8496	#N/A		
660		#N/A			4030.9504	#N/A		
670		#N/A			3985.8953	#N/A		
680		#N/A			3940.8402	#N/A		
690		#N/A			3895.6292	#N/A		
700		#N/A			3850.73	#N/A		
710		#N/A			3805.8308	#N/A		
720		#N/A			3761.3993	#N/A		
730		#N/A			3717.1237	#N/A		
740		#N/A			3673.1599	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

Basin ID: Dam Site 1 - 100-year

Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		6150.00	cfs
Time to Peak Outflow	Tp-out =		570	minutes

Major Storage Volume (cubic ft.): **15,518,847**
Major Storage Volume (acre-ft.): **356.26**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time	Inflow hydrograph cfs	**Outflow** Rising Hy cfs	Increm. Volume acre-ft	**Storage** Volume acre-ft	Inflow hydrograph cfs	**Outflow** Rising Hy cfs	Increm. Volume acre-ft	**Storage** Volume acre-ft
minutes (input)	(input)	(output)	(output)	(output)	(input)	(output)	(output)	(output)
0		#N/A	0.00	0.00	1.48	0.00	0.00	0.00
10		#N/A			2.664	2.66	0.00	0.00
20		#N/A			4.588	4.59	0.00	0.00
30		#N/A			7.4	7.40	0.00	0.00
40		#N/A			13.32	13.32	0.00	0.00
50		#N/A			27.824	27.82	0.00	0.00
60		#N/A			57.424	57.42	0.00	0.00
70		#N/A			104.192	104.19	0.00	0.00
80		#N/A			166.056	166.06	0.00	0.00
90		#N/A			246.568	246.57	0.00	0.00
100		#N/A			355.052	355.05	0.00	0.00
110		#N/A			497.872	478.35	0.27	0.27
120		#N/A			669.404	601.65	0.93	1.20
130		#N/A			871.128	724.94	2.01	3.22
140		#N/A			1073.444	848.24	3.10	6.32
150		#N/A			1280.94	971.54	4.26	10.58
160		#N/A			1490.656	1094.83	5.45	16.03
170		#N/A			1696.376	1218.13	6.59	22.62
180		#N/A			1888.184	1341.43	7.53	30.15
190		#N/A			2057.348	1464.72	8.16	38.31
200		#N/A			2201.204	1588.02	8.45	46.76
210		#N/A			2328.484	1711.32	8.50	55.26
220		#N/A			2447.92	1834.61	8.45	63.71
230		#N/A			2552.556	1957.91	8.19	71.90
240		#N/A			2644.76	2081.21	7.76	79.66
250		#N/A			2726.012	2204.50	7.18	86.84
260		#N/A			2796.016	2327.80	6.45	93.29
270		#N/A			2856.992	2451.10	5.59	98.88
280		#N/A			2914.86	2574.39	4.69	103.57
290		#N/A			2977.316	2697.69	3.85	107.43
300		#N/A			3052.796	2820.99	3.19	110.62
310		#N/A			3112.884	2944.28	2.32	112.94
320		#N/A			3166.164	3067.58	1.36	114.30
330		#N/A			3222.7	3190.88	0.44	114.74
340		#N/A			3284.416	3284.42	0.00	114.74
350		#N/A			3344.8	3344.80	0.00	114.74
360		#N/A			3398.82	3398.82	0.00	114.74
370		#N/A			3452.248	3452.25	0.00	114.74
380		#N/A			3505.528	3505.53	0.00	114.74
390		#N/A			3568.428	3568.43	0.00	114.74
400		#N/A			3654.564	3654.56	0.00	114.74
410		#N/A			3778.144	3778.14	0.00	114.74
420		#N/A			4057.272	3926.39	1.80	116.54
430		#N/A			4995.296	4074.63	12.68	129.22
440		#N/A			5881.964	4222.87	22.85	152.07
450		#N/A			6230.652	4371.11	25.61	177.69
460		#N/A			6414.616	4519.35	26.11	203.79
470		#N/A			6525.764	4667.59	25.59	229.39
480		#N/A			6585.112	4815.83	24.37	253.76
490		#N/A			6582.744	4964.07	22.30	276.05
500		#N/A			6552.108	5112.31	19.83	295.89
510		#N/A			6508.004	5260.55	17.18	313.07
520		#N/A			6455.464	5408.80	14.42	327.49
530		#N/A			6397.3	5557.04	11.57	339.06
540		#N/A			6335.436	5705.28	8.68	347.74
550		#N/A			6270.612	5853.52	5.75	353.48
560		#N/A			6203.568	6001.76	2.78	356.26
570		#N/A			6134.896	6134.90	0.00	356.26
580		#N/A			6064.892	#N/A		
590		#N/A			5993.852	#N/A		
600		#N/A			5922.072	#N/A		
610		#N/A			5849.848	#N/A		
620		#N/A			5777.328	#N/A		
630		#N/A			5704.808	#N/A		
640		#N/A			5633.028	#N/A		
650		#N/A			5564.504	#N/A		
660		#N/A			5498.052	#N/A		
670		#N/A			5429.38	#N/A		
680		#N/A			5358.784	#N/A		
690		#N/A			5288.78	#N/A		
700		#N/A			5219.516	#N/A		
710		#N/A			5150.844	#N/A		
720		#N/A			5083.06	#N/A		
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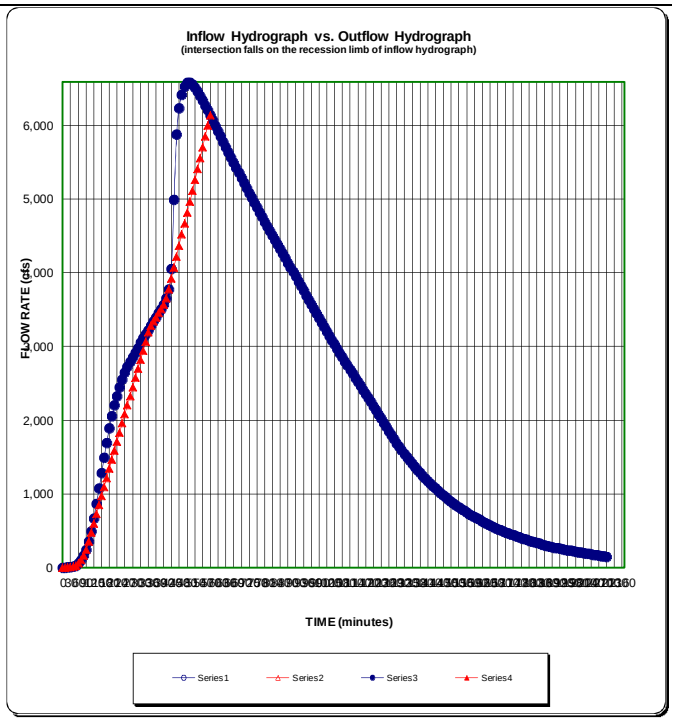
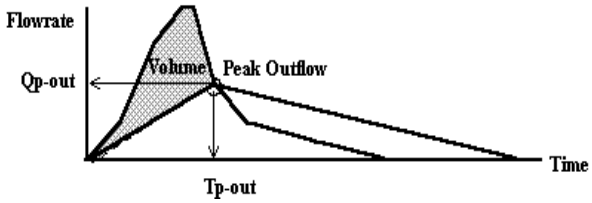
740		#N/A			4949.564	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

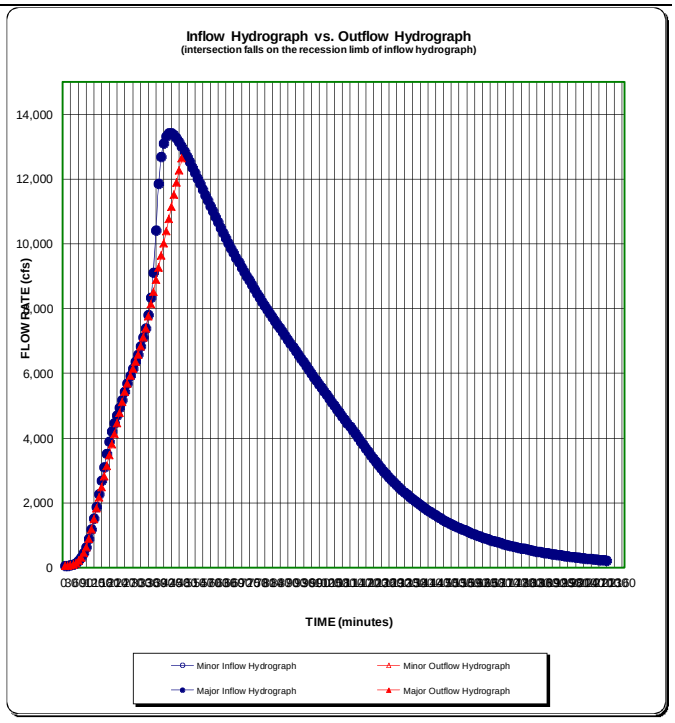
Basin ID: Dam Site 1 - 500-year

Design Information (Input):

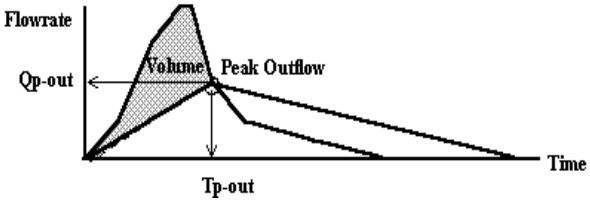
		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		12900.00	cfs
Time to Peak Outflow	Tp-out =		467	minutes

Major Storage Volume (cubic ft.): **15,588,900**
Major Storage Volume (acre-ft.): **357.87**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	40.0059	0.00	0.00	0.00
10		#N/A			50.3778	50.38	0.00	0.00
20		#N/A			63.309	63.31	0.00	0.00
30		#N/A			79.2036	79.20	0.00	0.00
40		#N/A			101.9679	101.97	0.00	0.00
50		#N/A			142.3779	142.38	0.00	0.00
60		#N/A			210.132	210.13	0.00	0.00
70		#N/A			309.9447	309.94	0.00	0.00
80		#N/A			444.9141	444.91	0.00	0.00
90		#N/A			628.3755	628.38	0.00	0.00
100		#N/A			881.7462	881.75	0.00	0.00
110		#N/A			1179.7026	1179.70	0.00	0.00
120		#N/A			1515.7791	1508.00	0.11	0.11
130		#N/A			1886.3388	1836.30	0.69	0.80
140		#N/A			2281.818	2164.60	1.61	2.41
150		#N/A			2690.4978	2492.90	2.72	5.13
160		#N/A			3104.5656	2821.20	3.90	9.04
170		#N/A			3520.6539	3149.50	5.11	14.15
180		#N/A			3896.0628	3477.80	5.76	19.91
190		#N/A			4208.4321	3806.10	5.54	25.45
200		#N/A			4470.8277	4134.40	4.63	30.08
210		#N/A			4703.1852	4462.70	3.31	33.40
220		#N/A			4934.061	4791.00	1.97	35.37
230		#N/A			5179.7538	5119.30	0.83	36.20
240		#N/A			5442.8229	5442.82	0.00	36.20
250		#N/A			5697.9447	5697.94	0.00	36.20
260		#N/A			5927.2041	5927.20	0.00	36.20
270		#N/A			6143.8017	6143.80	0.00	36.20
280		#N/A			6362.2851	6362.29	0.00	36.20
290		#N/A			6586.9647	6586.96	0.00	36.20
300		#N/A			6837.5067	6837.51	0.00	36.20
310		#N/A			7105.8291	7105.83	0.00	36.20
320		#N/A			7398.6669	7398.67	0.00	36.20
330		#N/A			7798.1871	7772.91	0.35	36.55
340		#N/A			8334.0237	8147.15	2.57	39.12
350		#N/A			9106.6629	8521.39	8.06	47.18
360		#N/A			10408.8078	8895.63	20.84	68.03
370		#N/A			11863.8372	9269.87	35.73	103.76
380		#N/A			12692.781	9644.11	41.99	145.75
390		#N/A			13098.9015	10018.35	42.43	188.18
400		#N/A			13319.9442	10392.59	40.32	228.50
410		#N/A			13415.4465	10766.83	36.48	264.99
420		#N/A			13421.7774	11141.07	31.41	296.40
430		#N/A			13365.4728	11515.31	25.48	321.88
440		#N/A			13265.9295	11889.55	18.96	340.84
450		#N/A			13139.8503	12263.79	12.07	352.91
460		#N/A			12998.2806	12638.03	4.96	357.87
470		#N/A			12846.4737	#N/A		
480		#N/A			12688.0665	#N/A		
490		#N/A			12524.6754	#N/A		
500		#N/A			12357.9168	#N/A		
510		#N/A			12188.8683	#N/A		
520		#N/A			12018.4728	#N/A		
530		#N/A			11847.2691	#N/A		
540		#N/A			11676.0654	#N/A		
550		#N/A			11505.1311	#N/A		
560		#N/A			11334.8703	#N/A		
570		#N/A			11165.5524	#N/A		
580		#N/A			10997.5815	#N/A		
590		#N/A			10830.9576	#N/A		
600		#N/A			10665.8154	#N/A		
610		#N/A			10502.4243	#N/A		
620		#N/A			10340.7843	#N/A		
630		#N/A			10181.0301	#N/A		
640		#N/A			10023.4311	#N/A		
650		#N/A			9867.9873	#N/A		
660		#N/A			9714.9681	#N/A		
670		#N/A			9564.3735	#N/A		
680		#N/A			9416.4729	#N/A		
690		#N/A			9270.9969	#N/A		
700		#N/A			9130.2354	#N/A		
710		#N/A			8999.307	#N/A		
720		#N/A			8869.0521	#N/A		
730		#N/A			8733.8133	#N/A		
740		#N/A			8599.3827	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

Basin ID: Dam Site 2 - 10-year

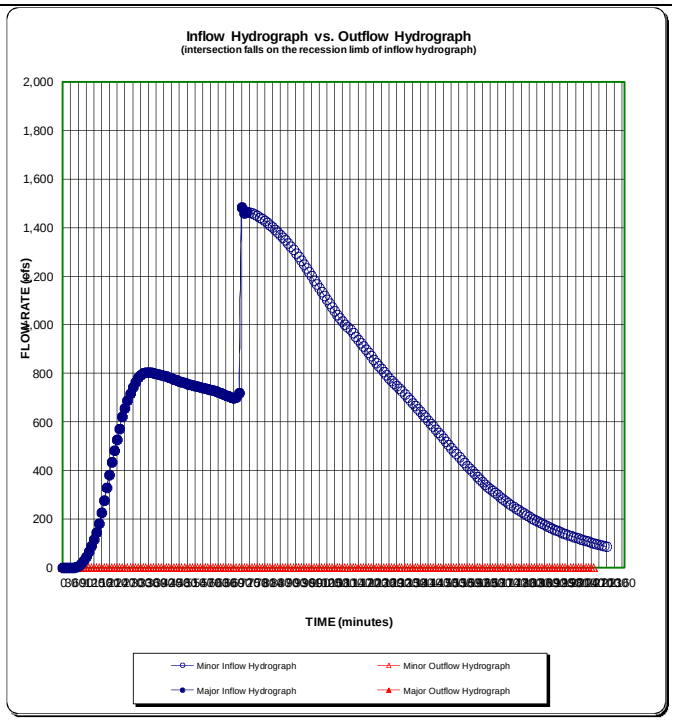
Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =	0.00		cfs
Time to Peak Outflow	Tp-out =	2050		minutes

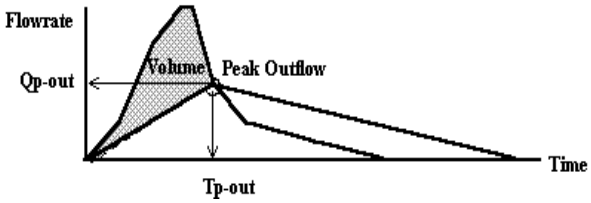
Minor Storage Volume (cubic ft.): **80,805,921**

Minor Storage Volume (acre-ft.): **589.15**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
0	0	0.00	0.00	0.00	0	#N/A	0.00	0.00
10	0	0.00	0.00	0.00	0	#N/A		
20	0	0.00	0.00	0.00	0	#N/A		
30	0	0.00	0.00	0.00	0	#N/A		
40	0	0.00	0.00	0.00	0	#N/A		
50	1.3251	0.00	0.02	0.02	1.3251	#N/A		
60	5.8683	0.00	0.08	0.10	5.8683	#N/A		
70	15.3333	0.00	0.21	0.31	15.3333	#N/A		
80	28.7736	0.00	0.40	0.71	28.7736	#N/A		
90	45.9999	0.00	0.63	1.34	45.9999	#N/A		
100	66.6336	0.00	0.92	2.26	66.6336	#N/A		
110	89.9175	0.00	1.24	3.50	89.9175	#N/A		
120	115.6623	0.00	1.59	5.09	115.6623	#N/A		
130	145.0038	0.00	2.00	7.09	145.0038	#N/A		
140	181.9173	0.00	2.51	9.59	181.9173	#N/A		
150	227.5386	0.00	3.13	12.73	227.5386	#N/A		
160	277.7031	0.00	3.83	16.55	277.7031	#N/A		
170	330.1392	0.00	4.55	21.10	330.1392	#N/A		
180	382.9539	0.00	5.27	26.37	382.9539	#N/A		
190	433.6863	0.00	5.97	32.35	433.6863	#N/A		
200	481.3899	0.00	6.63	38.98	481.3899	#N/A		
210	527.7684	0.00	7.27	46.25	527.7684	#N/A		
220	572.0646	0.00	7.88	54.13	572.0646	#N/A		
230	620.904	0.00	8.55	62.68	620.904	#N/A		
240	656.871	0.00	9.05	71.73	656.871	#N/A		
250	688.6734	0.00	9.49	81.21	688.6734	#N/A		
260	717.447	0.00	9.88	91.10	717.447	#N/A		
270	742.8132	0.00	10.23	101.33	742.8132	#N/A		
280	764.3934	0.00	10.53	111.86	764.3934	#N/A		
290	781.6197	0.00	10.77	122.62	781.6197	#N/A		
300	793.5456	0.00	10.93	133.55	793.5456	#N/A		
310	800.3604	0.00	11.02	144.58	800.3604	#N/A		
320	803.3892	0.00	11.07	155.64	803.3892	#N/A		
330	804.525	0.00	11.08	166.72	804.525	#N/A		
340	803.9571	0.00	11.07	177.80	803.9571	#N/A		
350	802.2534	0.00	11.05	188.85	802.2534	#N/A		
360	799.6032	0.00	11.01	199.86	799.6032	#N/A		
370	796.5744	0.00	10.97	210.83	796.5744	#N/A		
380	793.5456	0.00	10.93	221.77	793.5456	#N/A		
390	790.1382	0.00	10.88	232.65	790.1382	#N/A		
400	786.7308	0.00	10.84	243.49	786.7308	#N/A		
410	783.1341	0.00	10.79	254.27	783.1341	#N/A		
420	779.3481	0.00	10.73	265.01	779.3481	#N/A		
430	775.3728	0.00	10.68	275.69	775.3728	#N/A		
440	771.0189	0.00	10.62	286.31	771.0189	#N/A		
450	767.0436	0.00	10.57	296.87	767.0436	#N/A		
460	763.4469	0.00	10.52	307.39	763.4469	#N/A		
470	760.4181	0.00	10.47	317.86	760.4181	#N/A		
480	757.3893	0.00	10.43	328.29	757.3893	#N/A		
490	754.1712	0.00	10.39	338.68	754.1712	#N/A		
500	750.9531	0.00	10.34	349.03	750.9531	#N/A		
510	747.735	0.00	10.30	359.33	747.735	#N/A		
520	744.8955	0.00	10.26	369.59	744.8955	#N/A		
530	742.4346	0.00	10.23	379.81	742.4346	#N/A		
540	740.163	0.00	10.20	390.01	740.163	#N/A		
550	737.8914	0.00	10.16	400.17	737.8914	#N/A		
560	735.4305	0.00	10.13	410.30	735.4305	#N/A		
570	732.591	0.00	10.09	420.39	732.591	#N/A		
580	729.5622	0.00	10.05	430.44	729.5622	#N/A		
590	726.1548	0.00	10.00	440.44	726.1548	#N/A		
600	722.5581	0.00	9.95	450.40	722.5581	#N/A		
610	718.5828	0.00	9.90	460.29	718.5828	#N/A		
620	714.2289	0.00	9.84	470.13	714.2289	#N/A		
630	709.875	0.00	9.78	479.91	709.875	#N/A		
640	705.5211	0.00	9.72	489.63	705.5211	#N/A		
650	701.1672	0.00	9.66	499.29	701.1672	#N/A		
660	698.1384	0.00	9.62	508.90	698.1384	#N/A		
670	699.8421	0.00	9.64	518.54	699.8421	#N/A		
680	718.2042	0.00	9.89	528.43	718.2042	#N/A		
690	1484.3013	0.00	20.44	548.88	1484.3013	#N/A		
700	1459.6923	0.00	20.11	568.98	1459.6923	#N/A		
710	1463.6676	0.00	20.16	589.15	1463.6676	#N/A		
720	1461.9639	0.00	20.14	609.28	1461.9639	#N/A		
730	1458.7458	0.00	20.09	629.38	1458.7458	#N/A		
740	1454.3919	0.00	20.03	649.41	1454.3919	#N/A		



NOTE: THIS IS A FIRST APPROXIMATION ONLY



DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

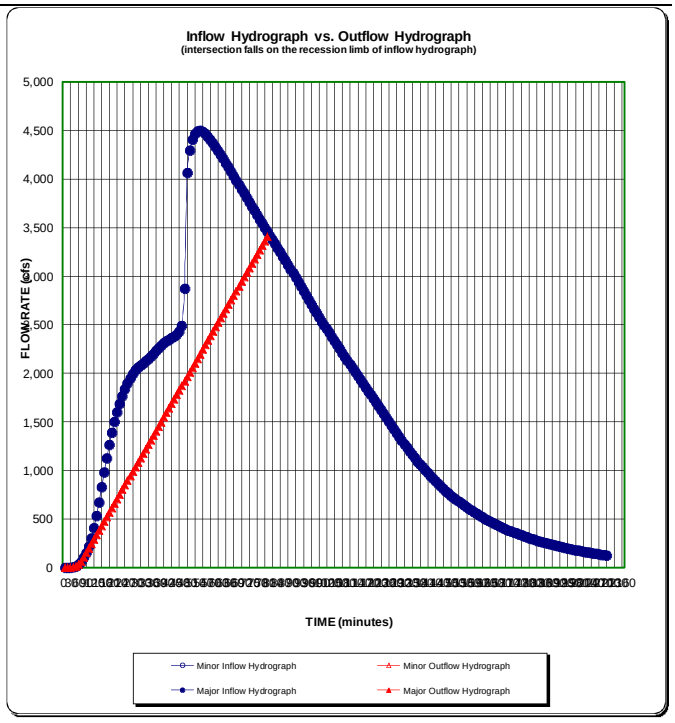
Basin ID: Dam Site 2 - 50-year

Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		3430.00	cfs
Time to Peak Outflow	Tp-out =		795	minutes

Major Storage Volume (cubic ft.): **43,029,213**
Major Storage Volume (acre-ft.): **947.64**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	0.1559	0.00	0.00	0.00
10		#N/A			0.3118	0.31	0.00	0.00
20		#N/A			0.6236	0.62	0.00	0.00
30		#N/A			1.4031	1.40	0.00	0.00
40		#N/A			3.5857	3.59	0.00	0.00
50		#N/A			11.3807	11.38	0.00	0.00
60		#N/A			29.7769	29.78	0.00	0.00
70		#N/A			60.801	60.80	0.00	0.00
80		#N/A			102.1145	102.11	0.00	0.00
90		#N/A			153.0938	148.66	0.06	0.06
100		#N/A			216.3892	195.20	0.29	0.35
110		#N/A			299.6398	241.75	0.80	1.15
120		#N/A			407.9903	288.29	1.65	2.80
130		#N/A			535.0488	334.83	2.76	5.56
140		#N/A			672.8644	381.38	4.01	9.57
150		#N/A			830.4793	427.92	5.54	15.12
160		#N/A			979.3638	474.47	6.95	22.07
170		#N/A			1124.1949	521.01	8.31	30.38
180		#N/A			1262.3223	567.55	9.57	39.95
190		#N/A			1389.3808	614.10	10.68	50.63
200		#N/A			1502.0965	660.64	11.59	62.22
210		#N/A			1601.4048	707.18	12.32	74.54
220		#N/A			1688.0852	753.73	12.87	87.41
230		#N/A			1765.2557	800.27	13.29	100.70
240		#N/A			1834.7871	846.82	13.61	114.31
250		#N/A			1897.303	893.36	13.83	128.13
260		#N/A			1952.3357	939.90	13.95	142.08
270		#N/A			1998.1703	986.45	13.94	156.02
280		#N/A			2034.8068	1032.99	13.80	169.81
290		#N/A			2061.6216	1079.54	13.53	183.34
300		#N/A			2080.6414	1126.08	13.15	196.49
310		#N/A			2101.3761	1172.62	12.79	209.28
320		#N/A			2125.0729	1219.17	12.48	221.76
330		#N/A			2149.5492	1265.71	12.17	233.93
340		#N/A			2173.8696	1312.25	11.87	245.80
350		#N/A			2200.8403	1358.80	11.60	257.40
360		#N/A			2232.9557	1405.34	11.40	268.80
370		#N/A			2261.7972	1451.89	11.16	279.96
380		#N/A			2286.8971	1498.43	10.86	290.82
390		#N/A			2309.5026	1544.97	10.53	301.35
400		#N/A			2328.8342	1591.52	10.16	311.50
410		#N/A			2346.1391	1638.06	9.75	321.26
420		#N/A			2361.885	1684.61	9.33	330.59
430		#N/A			2378.2545	1731.15	8.91	339.50
440		#N/A			2398.2097	1777.69	8.55	348.05
450		#N/A			2429.3897	1824.24	8.34	356.38
460		#N/A			2490.6584	1870.78	8.54	364.92
470		#N/A			2871.9898	1917.32	13.15	378.07
480		#N/A			4061.195	1963.87	28.89	406.96
490		#N/A			4297.0717	2010.41	31.50	438.45
500		#N/A			4409.4756	2056.96	32.40	470.86
510		#N/A			4467.0027	2103.50	32.56	503.41
520		#N/A			4492.5703	2150.04	32.27	535.68
530		#N/A			4496.9355	2196.59	31.69	567.37
540		#N/A			4485.7107	2243.13	30.89	598.25
550		#N/A			4463.7288	2289.68	29.95	628.20
560		#N/A			4435.6668	2336.22	28.92	657.12
570		#N/A			4403.3955	2382.76	27.83	684.95
580		#N/A			4368.0062	2429.31	26.70	711.65
590		#N/A			4330.2784	2475.85	25.54	737.20
600		#N/A			4290.8357	2522.39	24.36	761.56
610		#N/A			4249.834	2568.94	23.15	784.71
620		#N/A			4207.5851	2615.48	21.93	806.64
630		#N/A			4164.2449	2662.03	20.69	827.33
640		#N/A			4120.2811	2708.57	19.45	846.78
650		#N/A			4075.8496	2755.11	18.19	864.97
660		#N/A			4030.9504	2801.66	16.93	881.90
670		#N/A			3985.8953	2848.20	15.67	897.57
680		#N/A			3940.8402	2894.75	14.41	911.98
690		#N/A			3895.6292	2941.29	13.15	925.12
700		#N/A			3850.73	2987.83	11.89	937.01
710		#N/A			3805.8308	3034.38	10.63	947.64
720		#N/A			3761.3993	3080.92	9.37	957.01
730		#N/A			3717.1237	3127.46	8.12	965.13
740		#N/A			3673.1599	3174.01	6.88	972.01



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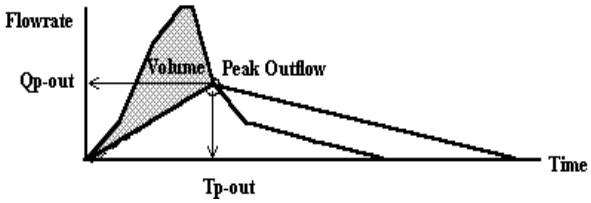

DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

Basin ID: Dam Site 2 - 100-year

Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		5440.00	cfs
Time to Peak Outflow	Tp-out =		675	minutes

Major Storage Volume (cubic ft.): **40,943,312**
Major Storage Volume (acre-ft.): **939.93**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	1.48	0.00	0.00	0.00
10		#N/A			2.664	2.66	0.00	0.00
20		#N/A			4.588	4.59	0.00	0.00
30		#N/A			7.4	7.40	0.00	0.00
40		#N/A			13.32	13.32	0.00	0.00
50		#N/A			27.824	27.82	0.00	0.00
60		#N/A			57.424	57.42	0.00	0.00
70		#N/A			104.192	104.19	0.00	0.00
80		#N/A			166.056	166.06	0.00	0.00
90		#N/A			246.568	246.57	0.00	0.00
100		#N/A			355.052	335.34	0.27	0.27
110		#N/A			497.872	424.12	1.02	1.29
120		#N/A			669.404	512.90	2.16	3.44
130		#N/A			871.128	601.67	3.71	7.15
140		#N/A			1073.444	690.45	5.28	12.43
150		#N/A			1280.94	779.23	6.91	19.34
160		#N/A			1490.656	868.00	8.58	27.92
170		#N/A			1696.376	956.78	10.19	38.10
180		#N/A			1888.184	1045.56	11.61	49.71
190		#N/A			2057.348	1134.33	12.71	62.42
200		#N/A			2201.204	1223.11	13.47	75.90
210		#N/A			2328.484	1311.89	14.00	89.90
220		#N/A			2447.92	1400.66	14.43	104.32
230		#N/A			2552.556	1489.44	14.64	118.97
240		#N/A			2644.76	1578.22	14.69	133.66
250		#N/A			2726.012	1666.99	14.59	148.25
260		#N/A			2796.016	1755.77	14.33	162.57
270		#N/A			2856.992	1844.55	13.95	176.52
280		#N/A			2914.86	1933.32	13.52	190.04
290		#N/A			2977.316	2022.10	13.16	203.20
300		#N/A			3052.796	2110.88	12.97	216.17
310		#N/A			3112.884	2199.65	12.58	228.75
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330		#N/A			3222.7	2377.21	11.65	252.49
340		#N/A			3284.416	2465.98	11.27	263.76
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410		#N/A			3778.144	3087.42	9.51	332.01
420		#N/A			4057.272	3176.20	12.14	344.14
430		#N/A			4995.296	3264.97	23.83	367.98
440		#N/A			5881.964	3353.75	34.82	402.80
450		#N/A			6230.652	3442.53	38.40	441.21
460		#N/A			6414.616	3531.30	39.72	480.92
470		#N/A			6525.764	3620.08	40.02	520.94
480		#N/A			6585.112	3708.86	39.62	560.56
490		#N/A			6582.744	3797.63	38.36	598.92
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530		#N/A			6397.3	4152.74	30.92	734.39
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550		#N/A			6270.612	4330.29	26.73	789.95
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590		#N/A			5993.852	4685.40	18.02	875.19
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610		#N/A			5849.848	4862.95	13.59	904.60
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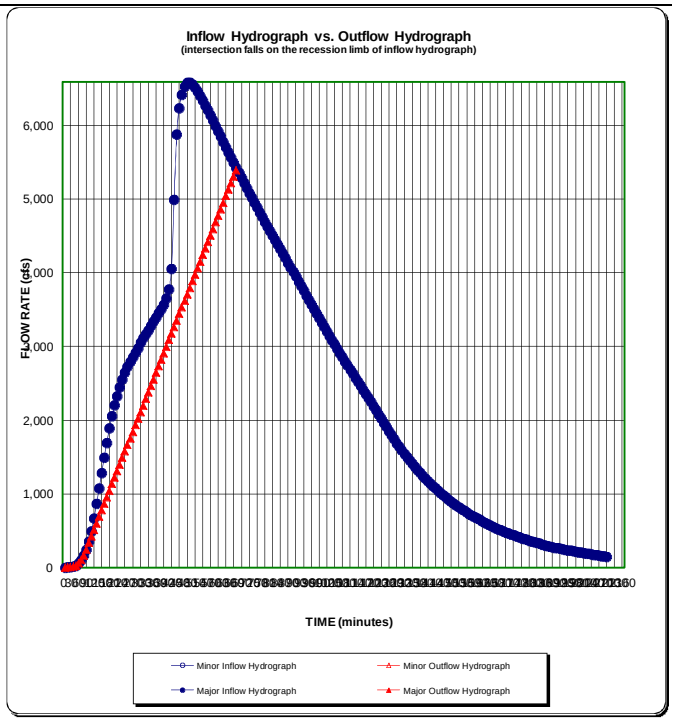

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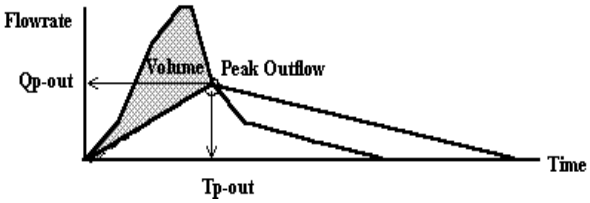

DETENTION VOLUME BY THE HYDROGRAPH METHOD

Project: St. Vrain Creek Master Plan

Basin ID: Dam Site 2 - 500-year

Design Information (Input):

		MINOR	MAJOR	
Max. Allowable Peak Outflow	Qp-out =		12000.00	cfs
Time to Peak Outflow	Tp-out =		522	minutes

Major Storage Volume (cubic ft.): **40,191,710**
Major Storage Volume (acre-ft.): **922.67**

10	MINOR (e.g. 2-, 5-, OR 10-year) EVENT				MAJOR (e.g. 25-, 50-, or 100-year) EVENT			
Time minutes (input)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)	Inflow hydrograph cfs (input)	**Outflow** Rising Hy cfs (output)	Increm. Volume acre-ft (output)	**Storage** Volume acre-ft (output)
		#N/A	0.00	0.00	40.0059	0.00	0.00	0.00
10		#N/A			50.3778	50.38	0.00	0.00
20		#N/A			63.309	63.31	0.00	0.00
30		#N/A			79.2036	79.20	0.00	0.00
40		#N/A			101.9679	101.97	0.00	0.00
50		#N/A			142.3779	142.38	0.00	0.00
60		#N/A			210.132	210.13	0.00	0.00
70		#N/A			309.9447	309.94	0.00	0.00
80		#N/A			444.9141	444.91	0.00	0.00
90		#N/A			628.3755	628.38	0.00	0.00
100		#N/A			881.7462	881.75	0.00	0.00
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120		#N/A			1515.7791	1408.68	1.48	1.95
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150		#N/A			2690.4978	2199.07	6.77	16.44
160		#N/A			3104.5656	2462.54	8.84	25.28
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180		#N/A			3896.0628	2989.47	12.49	48.71
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290		#N/A			6586.9647	5887.60	9.63	177.98
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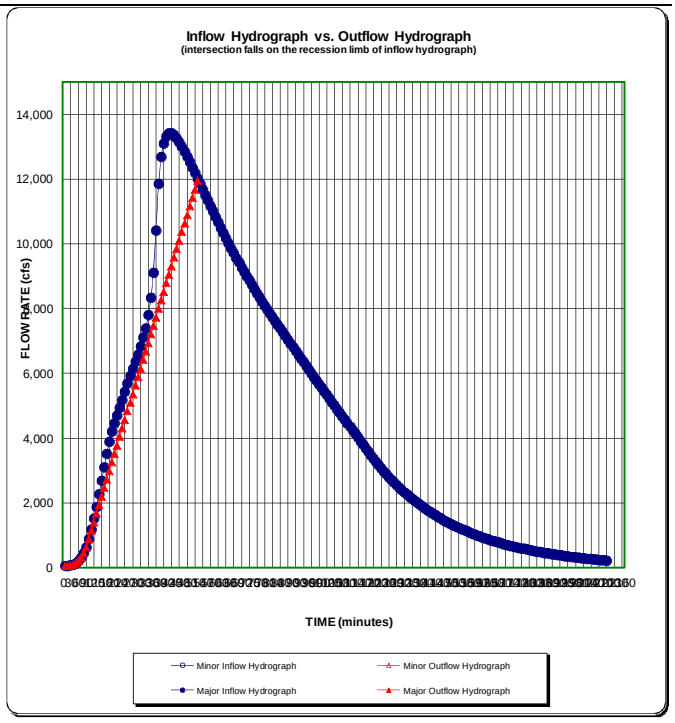

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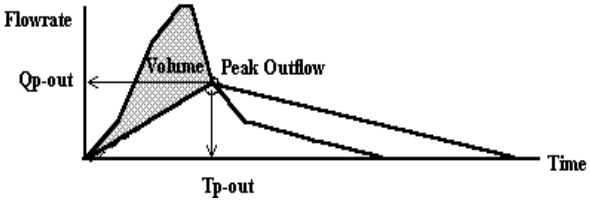


APPENDIX H

GUIDANCE FOR HYDROLOGIC AND HYDRAULIC ANALYSES

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

1313 Sherman Street, Room 721
Denver, CO 80203

Memorandum

To: Matthew Buddie, CFM MSB
National Flood Insurance Program Specialist, FEMA Region VIII
From: Jamie Prochno, PE, CFM JCP
Community Assistance Program Coordinator
Date: September 21, 2014

Subject: Guidance for Hydrologic and Hydraulic Analyses

BACKGROUND

The September 2013 floods caused widespread damage to many communities along Colorado's Front Range. The amount of rainfall, over 15" in some areas, and steep topography resulted in major erosion, deposition, and relocation of several rivers and streams in the affected area. Therefore, many of the mapped Special Flood Hazard Areas (SFHAs) on effective Flood Insurance Rate Maps (FIRMs) no longer reflect current conditions. As communities begin permanent recovery work, the Colorado Water Conservation Board (CWCB) recognizes the need to provide guidance to local officials, property owners, and contractors for projects where the SFHA and current conditions no longer match. The purpose of this document is to help guide recovery efforts and ensure communities stay in compliance with minimum requirements of the National Flood Insurance Program (NFIP). Scenarios not described here should be discussed with the FEMA Region VIII Office or the CWCB.

It is the community's responsibility to manage all development occurring in the SFHA. Communities must ensure all local, State, and Federal permits are received, including a local floodplain development permit, and specific requirements are met before the project commences. In instances where there is a conflict between local, State, or Federal requirements the more restrictive regulation shall prevail.

The requirement to conduct a hydrologic and hydraulic analysis for proposed development in floodways is outlined in Title 44 of the Code of Federal Regulations, Section 60.3(d)(3). Pursuant to NFIP regulations, an analysis is required to show that proposed projects in the floodway will not cause any increase in Base Flood Elevations (BFE), which is referred to as a no-rise analysis. Section 60.3(d)(4) states that encroachments into the floodway may cause an increase in BFEs, provided that the community first applies for and receives a Conditional Letter of Map Revision (CLOMR). The CWCB Rules and Regulations for Regulatory Floodplains in Colorado, Rule 8(B) includes a higher standard than 44 CFR 60.3(c)(10) and stipulates that a CLOMR is required when a proposed project will increase BFEs more than 0.5 foot on a waterway with BFEs for which a regulatory floodway has not been computed. The requirements for submitting new technical data to FEMA are contained in 44 CFR 65.3 and require a community to submit technical or scientific data, in the form of a Letter of Map Revision (LOMR), to FEMA within six months of project completion when BFEs have increased or decreased as the result of a physical change to the floodplain.

POLICY GUIDANCE

The following guidance applies to projects that are located within a regulatory floodway or in a floodplain with BFEs where a floodway has not been defined; and therefore, may require a no-rise analysis, CLOMR or LOMR.

Restoring to Effective Conditions

Channels may be restored to effective conditions without further analysis. Effective condition is considered the modeled condition reflected in the effective Flood Insurance Study, including floodplain and floodway boundaries, base flood elevations, flows, and channel geometry. The project must adhere to any other federal, state or local regulations and permit requirements.

Projects that were properly designed, permitted, and constructed prior to the flood may be replaced in-kind without further analysis so long as the conveyance equals that of the original structure. The project must adhere to any other federal, state or local regulations and permit requirements. Reduction in conveyance as a result of sedimentation may require channel modification. Changes in structure design or channel modification must go through the normal review process which may include a no-rise analysis, CLOMR, and LOMR.

Stream Crossings and Restoration Projects

Where current and effective conditions do not match and the community does not intend to return the channel to effective conditions, hydrologic and hydraulic analysis will be required for proposed projects. A no-rise analysis must show that the proposed project does not increase water surface elevations of the base flood. A no-rise analysis may be defined as:

- The proposed conditions model shows no increase in water surface elevations compared to the existing conditions models; or
- The proposed conditions model shows no increase in water surface elevations compared to the pre-flood conditions model.

Additional engineering will be required to determine existing conditions in areas where the channel has migrated. Existing conditions should not reflect any man-made temporary work such as temporary crossings, bridges, culverts, hydraulic structures, or other developments that have been constructed since the flood. Structures present before the flood may be included in the existing conditions model even if they were washed out as a result of the flood. Pre-flood conditions may only be used for the no-rise analysis if sufficient data exists to determine the channel geometry and structures that were present prior to the flood.

CLOMR Requirements

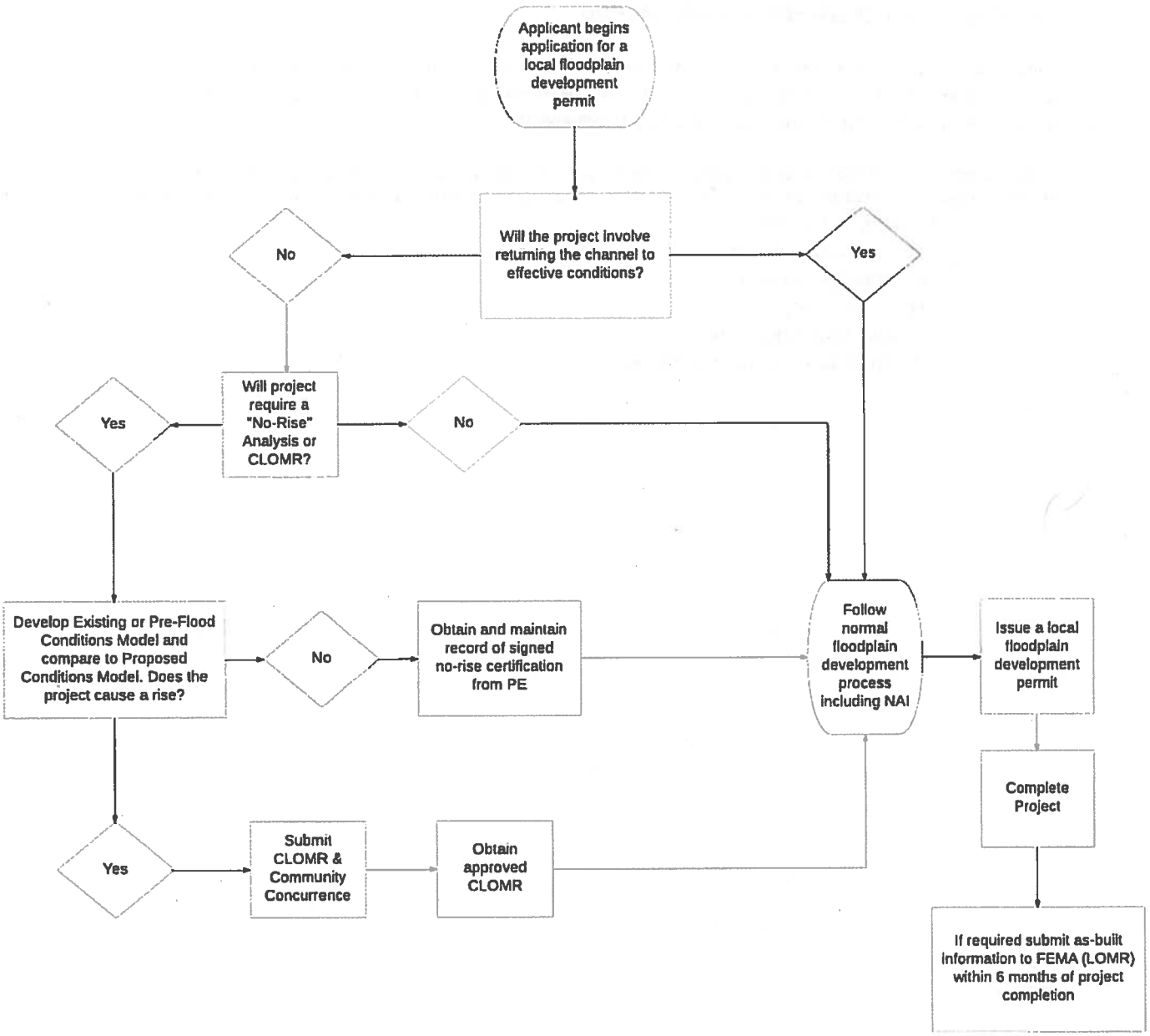
A CLOMR may be required when proposed conditions show increases in water surface elevations of the base flood compared to existing conditions. If the project is located in a floodway, a CLOMR is required if a no-rise analysis cannot be completed according to the guidance outlined above. If the project is located in a floodplain with BFEs and no floodway, a CLOMR is required if the project causes more than 0.5 foot of increase in water surface elevations. For CLOMRs, the standard MT-2 process must be followed.

LOMR Requirements

A LOMR must be submitted within six months of completion for all projects when the proposed conditions model shows an increase or decrease in BFEs compared to the effective model. The standard MT-2

process must be followed, including as-built information showing post-project conditions. It is the community's responsibility to ensure all information is submitted to FEMA in a timely manner.

The following flow chart illustrates a simplified representation of the process for floodplain permitting:



RECOMMENDED PRACTICES

CWCB encourages communities to look holistically at projects and ensure the effects of one project will not negatively impact others. In the event potential adverse impacts are identified, the local jurisdiction should be prepared to take steps to minimize and mitigate the impacts. The Association of State Floodplain Managers refers to this principal as "No Adverse Impact" (NAI). NAI should be a lens in which local officials, property owners, and contractors look at every project. Additional information on NAI can be found at http://www.floods.org/index.asp?menuID=460.

Local floodplain development permits should also be considered outside of the effective SFHA where projects are now subject to flood damage as a result of channel migration. This determination must be made by the local floodplain administrator using Best Available Data.

CWCB encourages communities to ensure that proposed projects within rivers and floodplains are aligned with community, regional and watershed plans. Projects should also consider multiple objectives, which may include:

- Restoring stream channels,
- Providing habitat for aquatic and terrestrial species,
- Restoring riparian areas,
- Reducing erosion,
- Reducing flood hazards, or
- Increasing the capacity to utilize water.

APPENDIX I

RESOURCE FOR MANAGEMENT OF WOODY DEBRIS

Management of Large Wood in Streams of Colorado's Front Range: A Risk Analysis Based on Physical, Biological, and Social Factors

by

Ellen Wohl

Kevin Bestgen

Brian Bledsoe

Kurt Fausch

Mike Gooseff

Natalie Kramer

Abstract

Instream and floodplain wood can provide many benefits to river ecosystems, but can also create risks to inhabitants, infrastructure, property, and recreational users in the river corridor. In this report we outline a decision process for managing large wood, and particularly for assessing the relative benefits and risks associated with individual wood pieces and with accumulations of wood. This process can be applied at varying levels of effort, from a relatively cursory visual assessment to more detailed numerical modeling. Decisions of whether to retain, remove, or modify wood in a channel or on a floodplain are highly dependent on the specific context: the same piece of wood might require removal in a highly urbanized setting, for example, but provide sufficient benefits to justify retention in a natural area. Our intent is that the decision process outlined here can be used by individuals with diverse technical backgrounds and in a range of urban to natural river reaches.

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I. Introduction

Large wood has been systematically studied and described in the scientific literature since the 1970s (e.g., Swanson et al., 1976; Harmon et al., 1986; Montgomery et al., 2003). The phrase 'large woody debris' (LWD) has been in widespread use for decades, but this phrase is a legacy from timber harvest, when the unused slash was typically left on the ground and in streams as debris. Because debris has very negative connotations, we instead refer to downed wood greater than 10 cm in diameter and 1 m in length simply as large wood.

Rivers in forested regions currently have little wood compared to their condition prior to European settlement of the United States. Historical descriptions of the entire spectrum of rivers across the country, from the smallest headwater creeks in New England to the lower Mississippi and the large rivers of the Pacific Northwest, clearly indicate that much more downed wood was present within channels and across floodplains (Triska, 1984; Harmon et al., 1986; Collins et al., 2002; Wohl, in review). One of the first activities of European settlers in a region was to remove wood from rivers (Sedell et al., 1991), both directly, by pulling wood from channels, and indirectly via deforestation that reduced natural inputs of wood (wood recruitment) into channels. Congress made appropriations to remove wood from rivers as early as 1776 (Harmon et al., 1986), and individuals or small groups of people began wood removal even earlier. In 1824, Congress assigned the 'improvement' of inland rivers to the Army Corps of Engineers (Reuss, 2004). Much of this improvement focused on removing wood.

Direct removal to facilitate navigation and control floods involved the use of snag boats that broke up logjams and pulled up wood pieces partly buried in the streambed or banks (Paskoff, 2007). Indirect removal occurred not only by timber harvest that reduced subsequent recruitment of wood to channels, but also via; channelization (dredging, straightening, bank stabilization) that removed existing wood and reduced the ability of a river to retain subsequently recruited wood; log floating in association with timber harvest, which included removing naturally occurring instream wood, as well as cut logs; and flow regulation, which limited downstream transport of wood. The net effect of these activities was to remove almost all instream and floodplain wood, typically prior to the 20th century (Wohl, 2001). Consequently, most people do not expect downed wood to be abundant in the riverine environment (Chin et al., 2008), and so are not accustomed to seeing the elements that make up a naturally functioning river flowing through a forested region.

Extensive September 2013 rain and post-storm flooding in northern Colorado resulted in abundant wood in river channels and floodplains of streams originating in the Front Range. This event motivated us to seek a dialogue with municipalities and managers of these streams to consider leaving some wood in streams and floodplains because wood is a natural landscape feature with high ecological benefit. In this paper we describe a process that managers can use to evaluate the risks and benefits of instream wood, first presenting the ecological benefits of retention or addition of wood in streams. We first discuss the benefits and risks associated with the presence of large wood in channels and on floodplains, in the context of physical and biological processes occurring within river environments, as well as public safety. The discussion with respect to public safety recognizes that potential risk to humans and infrastructure created by wood is a primary motivation for managers to remove wood. We then present a check-list based decision-making and risk-assessment process for managers to use in order to evaluate the merits of keeping or removing individual pieces of wood or jams. This section further describes wood treatment options that may reduce risk, and tools to measure stability and habitat created by wood left in the channel or floodplain. Decision bands allow managers to further quantify merits and risks of retaining or adding wood to a stream reach. We finish by describing a case study for wood removal or retention in an urban reach of the Cache la Poudre River, near Fort Collins, Colorado, where wood deposition was extensive after flooding.

Extensive September 2013 rain and post-storm flooding in northern Colorado resulted in abundant wood in river channels and floodplains of streams originating in the Front Range. This event motivated us to seek a dialogue with municipalities and managers of these streams to consider leaving some wood in streams and floodplains, because wood is a natural landscape feature with high ecological benefit. However, large wood in rivers also poses risks to human infrastructure and safety. Current practices involve automatically removing all large wood from Front Range rivers. Under this approach, there is no systematic evaluation of benefits and risks, and managers do not differentiate between wood that creates hazards and wood that creates little or no risk. Wood that creates little or no risk is removed at the expense of ecological benefits that might result from this wood. Wood deposited during the September 2013 flood, for example, was almost universally perceived as a risk to infrastructure and safety, irrespective of the actual location and condition of the wood. This underscored the need for a risk assessment framework

that managers can use to systematically and transparently weigh multiple considerations, including safety, infrastructure, recreation, and ecological aspects of wood.

In this paper, we describe a process that managers can use to evaluate the risks and benefits of instream wood. We first discuss the benefits and risks associated with large wood in channels and on floodplains regarding the physical and biological processes occurring within river environments, as well as public safety. For example, potential risk to humans and infrastructure created by wood is a primary motivation for managers to remove wood. We then present a check-list based decision-making and risk-assessment process for managers, to evaluate the merits of keeping or removing individual pieces of wood or jams. This section further describes wood treatment options that may reduce risk, and tools to measure stability and habitat created by wood left in the channel or floodplain. Decision bands allow managers to further evaluate merits and risks of retaining or adding wood to a stream reach. We finish by describing a case study for wood removal or retention in an urban reach of the Cache la Poudre River, near Fort Collins, Colorado, where wood deposition was extensive after flooding.

Our aim is to offer a straightforward management procedure that incorporates realistic analysis of human and infrastructure risk, but also integrates the ecological benefit of wood in streams and floodplains. Thus, goals of human safety and infrastructure preservation may be achieved while also increasing the geomorphic and ecological functioning and environmental health of river systems in settings with high human use.

II. Benefits and Risks associated with Large Wood

This section provides a discussion of the benefits and risks that result from the presence of large wood in channels and on floodplains. We first discuss the beneficial effects of wood on the movement of water and sediment at the surface and within the hyporheic zone that is present beneath the bed of river systems. This is followed by discussion of the biological benefits of wood for fish, stream invertebrates, and other aquatic and terrestrial invertebrates and vertebrates. The final portion discusses public safety considerations associated with wood, in the context of hazard to inhabitants and infrastructure within the river system, and to recreational users of the river environment.

1. Physical benefits of large wood

The physical benefits of large wood result from the interaction of wood with water and sediment moving down the channel. The magnitude of the effects that result from these interactions largely depends on the orientation and stability of the wood, and on the volume of wood within the channel relative to the cross-sectional area of the channel (Klaar et al., 2011): a single piece of wood within a large channel will have only very local effects, whereas a large jam that spans a channel can influence process and form along an entire channel reach. These and other scale considerations are schematically illustrated in Figure 1.

Individual pieces of wood and wood collected into jams create obstructions that can substantially increase the frictional resistance to flow (Shields and Smith, 1992; Shields and Gippel, 1995; Curran and Wohl, 2003; Mutz, 2003). This reduces average flow velocity (Daniels and Rhoads, 2004; Davidson and Eaton, 2013), which can in turn lead to slower passage of flood waves and local storage of sediment and organic matter around the wood (Bilby and Likens, 1980; Nakamura and Swanson, 1993; Faustini and Jones, 2003). If sufficient wood is present within the channel during high flows, the resulting flow obstruction can increase the magnitude, duration, and frequency of overbank flows (Triska, 1984; Brummer et al., 2006). Increased overbank flows enhance the connections of water, sediment, nutrients, and organisms between the channel and floodplain (Collins et al., 2012). This greater “connectivity” can facilitate storage of sediment and nutrients on floodplains, access to floodplain habitat by aquatic organisms, lateral channel movement across the floodplain (O’Connor et al., 2003), and the formation of secondary channels that provide additional, diverse aquatic habitat (Abbe and Montgomery, 2003; Wohl, 2011; Collins et al., 2012).

Wood can increase habitat diversity within channel and on floodplains through various processes. Instream wood typically causes flow separation and localized scour of the bed and banks, resulting in pools and undercut banks (Buffington et al., 2002; Collins et al., 2002). Localized deposition associated with the flow separation creates areas of finer substrate on the streambed (e.g., patches of sand along a cobble-bed stream) (Keller and Swanson, 1979). Larger wood obstructions, such as jams, typically have upstream backwater areas of lower velocity and greater water depth (Brummer et al., 2006). Wood can alter the type and dimensions of bedforms present along a channel. Diverse studies have documented scenarios where wood traps sufficient sediment to create an alluvial channel instead of a bedrock channel (Massong and Montgomery, 2000), for example, and alters the dimensions of pool-riffle and step-pool bedforms (Robison and Beschta, 1990). Wood on floodplains provides substrate and cover for a range of organisms, including aquatic types that prefer wood as a substrate during overbank floods (Benke and Wallace, 1990), plants that use the nutrient-rich decaying logs as germination sites (Schowalter et al., 1998), and small mammals, birds, amphibians and reptiles that use the wood for feeding or nesting sites (Harmon et al., 1986).

The influence of wood on the geomorphic form of stream and river channels commonly results in increased roughness, which results in a more diverse hydraulic gradients not only in the channel, but also between the channel and aquifer. Increased heterogeneity of channel morphology is often associated with enhanced stream-groundwater exchange, and in particular hyporheic exchange (the exchange of stream water through stream-adjacent aquifers in which mixing with groundwater occurs) (Gooseff et al., 2007). Wood-caused steps have been identified as important morphologic features that drive hyporheic exchange in some headwater streams (Kasahara and Wondzell 2003; Wondzell, 2006). Hyporheic zones of streams have been described as analogous to livers for their ability to remove pollutants from stream water (Fischer et al., 2005), thus providing a self-cleansing process to improve water quality. Hyporheic exchange also moderates stream water temperature as a result of interaction with groundwater (Arrigoni et al., 2008).

There is a direct influence of hyporheic exchange on stream aquatic ecosystem condition, habitat, and processes. For example, hyporheic exchange has been shown to influence selection by spawning fish of nest sites, and subsequent embryo survival (Baxter and Hauer, 2000; Malcolm et al., 2004). Hyporheic zones also provide habitat for a variety of macroinvertebrates,

in one or more of their several life stages (Stanley and Boulton, 1993; Williams, 1993). Hence, instream wood has the potential to significantly impact stream ecosystems through its direct influence on hyporheic exchange.

Finally, instream wood is particularly important because of the variable flow velocities created around wood. For example, reduction in flow velocity around wood can increase the retention of particulate organic matter that is the fundamental energy source in many stream ecosystems. If this finer particulate organic matter is stored for even a few hours, rather than remaining in transit, it can be accessed by microbial and macroinvertebrate communities that extract nutrients from the organic matter (Bilby, 1981; Raikow et al., 1995). In addition, large wood commonly traps leaves, sticks, and other plant parts that fall into streams, thereby providing a site for larger macoinvertebrate "shredders" to begin breaking down this coarse particulate organic matter into finer size fractions that can be used by other organisms (Flores et al., 2011, 2013). Slow as well as fast water velocities created by wood provide a variety of habitat for stream fishes and macroinvertebrates because habitat selection is commonly dictated by body size- and velocity-dependent processes (e.g., Fausch, 1984, 2014). Consequently, a variety of flow velocities may provide habitat for several species or life stages.

In contrast to the beneficial physical effects of instream and floodplain wood, removal of wood can create physical risks. Because wood enhances sediment storage, removal of wood and consequent reduced flow resistance and obstruction can result in erosion of stream beds. Wood removal on diverse streams has resulted in significantly increased bed erosion and channel widening, with individual river reaches changing from sediment storage areas when wood is present to sediment source areas when wood is removed (Brooks et al., 2003; Erskine and Webb, 2003).

Figure 1. (A) At spatial scales of stream lengths of 1 to 100 km (10^3 to 10^5 m), the effects of wood strongly depend on valley geometry and location within a drainage basin. In confined, steep headwater valleys, wood primarily affects channel process and form. In lowland channels with floodplains, wood within the channel also affects floodplain process and form.

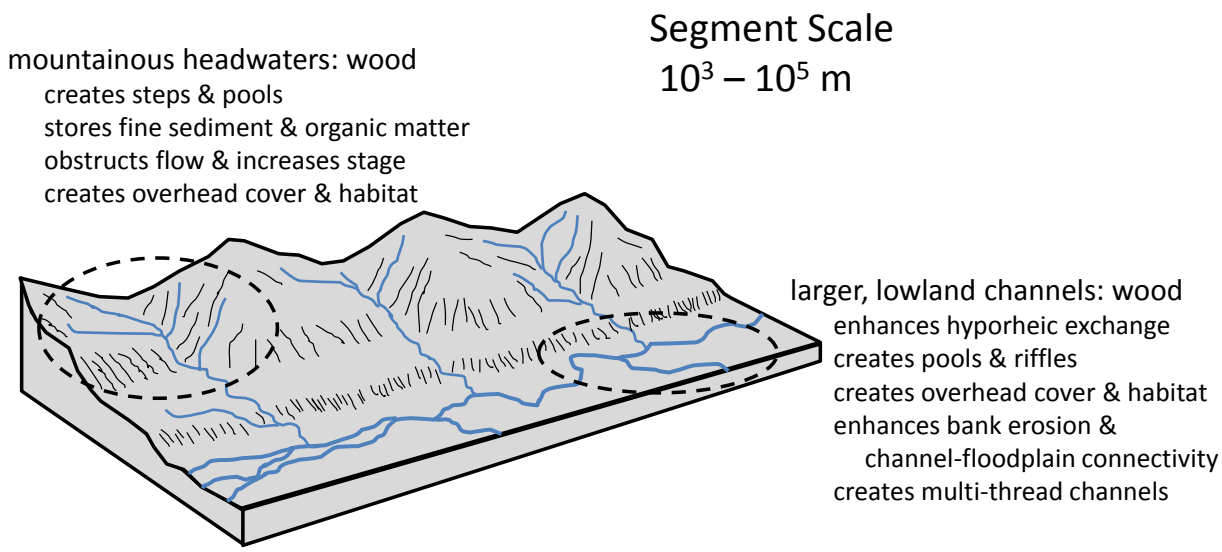


Figure 1. (B) At spatial scales of stream lengths of tens to thousands of meters, wood can strongly influence channel planform and morphology. By forming obstructions to flow, logjams can create backwater pools upstream from the jam and plunge pools downstream from the jam, and enhance overbank flows. Greater overbank flows increase channel-floodplain connectivity, bank erosion, channel avulsion, and the formation of secondary channels (1). Backwater pools enhance storage of finer sediment and organic matter within the stream (2), increasing habitat diversity for stream organisms. Flow separation around individual pieces of wood or jams can create localized bed and bank scour (3). Wood can also create pressure differentials that drive hyporheic exchange (4), with downwelling into the stream bed upstream from the wood and upwelling from the stream bed downstream from the wood.

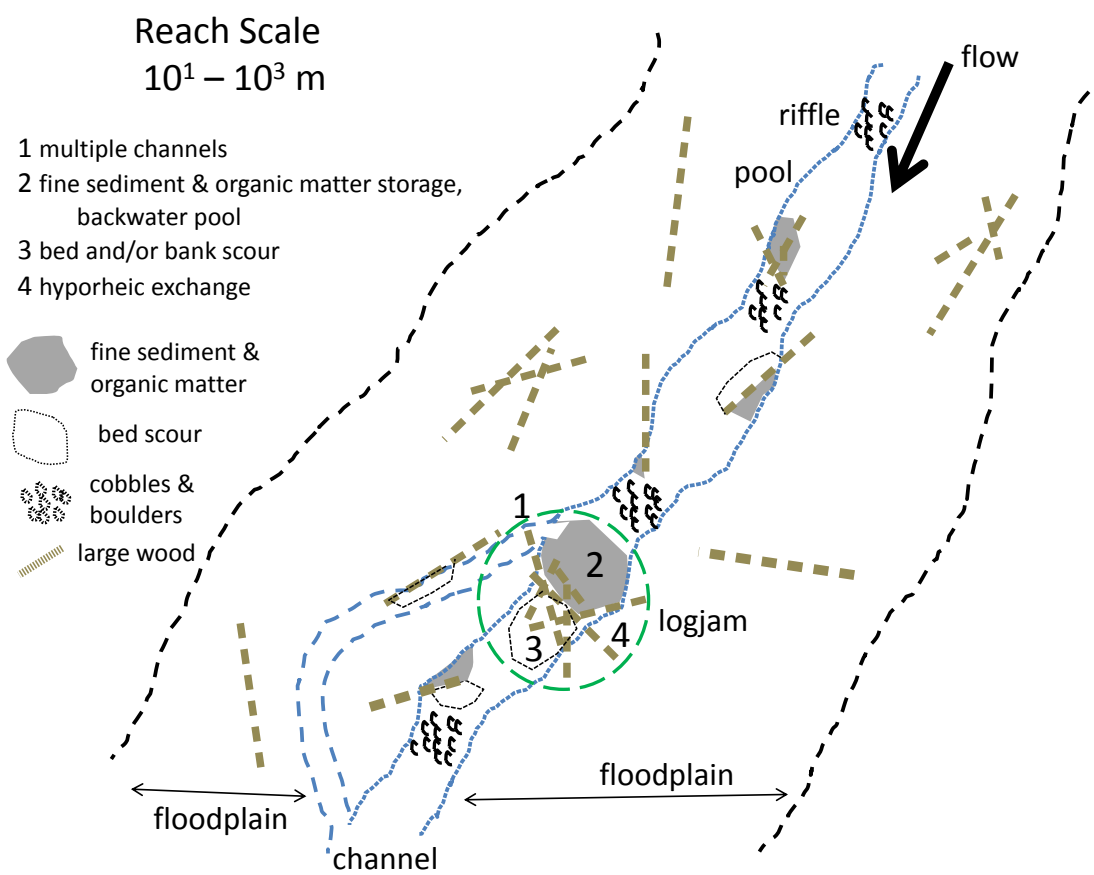
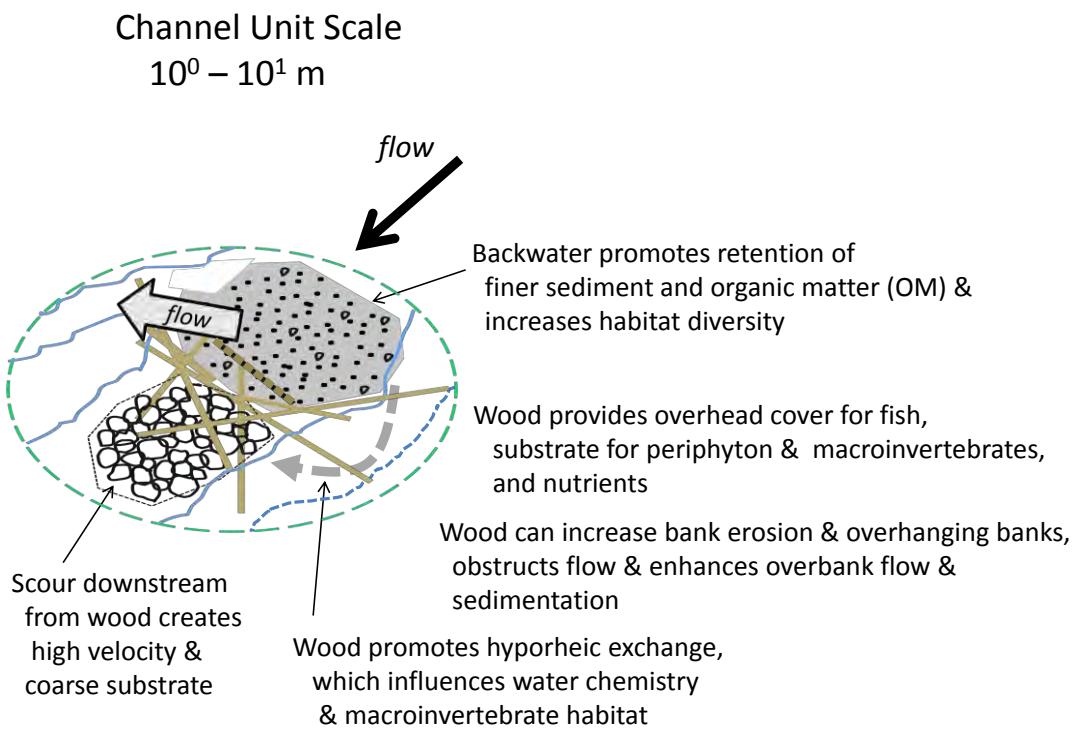


Figure 1. (C) At spatial scales of stream lengths of a meter to tens of meters, individual pieces of wood or logjams create the effects described for the reach scale, and illustrated below. Among these effects are overhead cover, velocity refuges, and visual isolation, all of which are important to fish (Fausch, 1993).



2. Biological benefits of large wood

The benefits of large wood to river organisms like fish and aquatic invertebrates are likely to be of three main types. First, the geomorphic effects of wood on channel structure create pools, runs, and riffles (termed mesohabitats) required by these biota to complete their life cycles, across a range of scales from reaches to riverscapes (Fausch et al. 2002). Second, the habitat complexity created by wood provides critical microhabitats that fish and other organisms need for feeding, resting, and isolation and protection from competitors and predators (e.g., Sechnick et al. 1986; Fausch 1993; Nagayama et al. 2012). And third, stable wood pieces provide hard surfaces that are colonized by aquatic invertebrates that fish eat, and hard surfaces that grow algae that these invertebrates eat (Benke and Wallace 2003). These hard surfaces are particularly scarce in lowland streams that are dominated by silt substrate.

2.1. Fish

Most of what we know about the role and functions of wood that benefit fish is from comparative studies and experiments conducted on salmon and trout in small and medium-sized coldwater streams (e.g., Gowan and Fausch 1996; Lehane et al. 2002; see Whiteway et al. 2010 for a review). Moreover, given the widespread decline in wood in streams owing to clearing and snagging, and deforestation of riparian zones, much of the research has been done to understand what kinds of habitat restoration are most useful to increase numbers of trout and salmon. Nevertheless, there are recent research reports and reviews of the importance of wood in lowland warmwater streams, especially in Australia (Crook and Robertson 1999; Howell et al. 2012) and the southeastern US (Benke and Wallace 2003). The key points of this research will be emphasized here, and placed in the context set by other research on coldwater streams. One main difference is that coldwater streams and rivers are often inhabited by fewer fish species, so the responses measured are simpler than those of the many-species assemblages occupying warmwater lowland streams and rivers. The transition zone of rivers along Colorado's Front Range, after they exit the mouths of canyons, traverse a transition between coldwater segments that support primarily trout throughout the year to cool- and warmwater segments that support more fish species (often 15-20 species total; Fausch and Bestgen 1997). Therefore, research on the benefits of wood in both coldwater and warmwater lowland streams are of relevance here.

Fish typically need different habitats that are dispersed throughout reaches to riverscapes during different stages of their life cycle, and at different times of year (Schlosser 1991), and move among these to fulfill their needs (Fausch et al. 2002; Falke and Fausch 2010). For example, large wood can create pools with overhead cover that are critical for fish to survive during winter, and also provides physical refuges from swift currents that can displace fish during high flows and floods, especially during spring snowmelt runoff (Shuler and Nehring 1993; Crook and Robertson 1999). Adding stable wood structures that create pools in Colorado mountain streams can increase trout biomass by about 50% (Gowan and Fausch 1996) and this increase can be sustained for more than two decades (White et al. 2011). Likewise, in a large lowland river of Australia, two large native predatory fish (both percichthyids, related to striped bass *Morone saxitalis*, in North America) were more often associated with patches of large wood than other habitat types, and this was consistent across four segments of different geomorphic character that spanned about 400 km of the Barwon-Darling River (Boys and Thoms 2006).

Boys and Thoms (2006) hypothesized that large wood provides important foraging sites for these predators, which ambush their prey, as well as hard substrates for invertebrates to colonize in these lowland rivers (see Crook and Robertson 1999 for a review). These relationships are important because 97% of the river length in Australia is in lowland rivers, 83% of which are dryland rivers like those in the lowlands of Colorado.

Both comparative data and experiments also provide strong evidence that fish select locations near large wood and other structures that provide refuges from high current velocities, and visual isolation and overhead cover from competitors and predators. For example, Nagayama et al. (2012) found that an assemblage of coldwater salmon, charr, large minnows, sticklebacks, and lamprey was more abundant and diverse in habitat patches formed by large wood than in patches without wood, in a lowland river in Hokkaido, northern Japan. Of interest was that the four dominant species selected the patches with wood for different habitat features. The salmon and charr selected locations with high current variability, where they can find low-velocity foraging locations close to swift currents (see Fausch 1984), whereas the sticklebacks and lamprey require low velocities with fine substrate. Given that fish in streams and rivers worldwide evolved with much higher loads of wood than are now present, it stands to reason that many different species would be adapted to use the habitat structure created by these natural materials.

Several investigators have used artificial structures to separate the preference of fish for the velocity refuges, visual isolation from other fish, and overhead cover from predators that large wood provides. For example, Fausch (1993) installed artificial structures in a lowland British Columbia stream that isolated these variables, by using clear Plexiglas structures to provide only velocity refuges, and then painting parts of them black to create lateral visual isolation or overhead cover. Results of this research and other studies on charr, salmon, and smallmouth bass (6 species total) showed that all responded most strongly to the overhead cover features, but in many cases also selected structures that offered velocity refuges and visual isolation (see Table 1 in Crook and Robertson, 1999). Many lowland rivers are naturally turbid, and so the overhead cover and visual isolation features of large wood may be less important there.

2.2. Stream invertebrates

As for fish, large wood can create habitat conditions favorable to certain groups of aquatic invertebrates, such as pools or backwaters, but can also provide hard substrate for growth of stream algae and subsequent colonization by invertebrates (Benke and Wallace 2003). Some of these invertebrates scrape algae as a food source, others use the wood as attachment sites from which to filter particles from the water flowing by, and still other taxa gouge and burrow in the wood itself.

Large wood can have profound effects on the diversity, abundance, biomass, and production of stream invertebrates, especially in lowland rivers where most other substrates are shifting sand or silt. Extensive research in low-gradient rivers of the Coastal Plain in the southeastern U.S. showed that large "snags" in several rivers in Georgia supported a unique assemblage of invertebrates, some of which use it for egg-laying sites (above or below the water), to find refuge from predation, or forage across it themselves for other invertebrate prey. Because animals that colonize stable wood substrates are larger than those on sand and silt, biomass of invertebrates on snags in one southeastern Georgia river was 10-60 times greater per square meter than on the bottom substrates, and production ($g/m^2/yr$) was more than 4 times higher. Although the surface area of snags made up only 4% of habitat area, snags contained 60% of the invertebrate biomass per lineal meter of river, and produced 70-80% of the numbers and biomass of drifting invertebrate prey. In turn, the biomass in diets of 5 of 6 fish species examined in detail that ate primarily invertebrates (insectivores) consisted of about 45-75% invertebrates that originated from large wood substrates. Other smaller species of fishes (e.g., minnows and darters) not analyzed ate more prey from the bottom substrates, and the abundance of these fish can increase when wood is removed (Angermeier and Karr 1984).

Across studies, large wood is a hotspot for invertebrate biomass, production, and diversity. Mean annual biomass was higher on wood habitats than in streambed sediments in 6 of 8 studies in lowland streams of the southeastern US and Australia (Benke and Wallace 2003). Likewise, annual invertebrate (secondary) production was higher on wood in 5 of 6 studies in these same locations. When averaged across surface area of substrates, wood often contributed 20% or more of the total numbers of invertebrates and 30-60% of the total biomass of invertebrates in these lowland rivers. Likewise, wood habitat often supports more than half the invertebrate species (i.e., diversity) found in rivers like these where it makes up much of the

stable substrate, such as in southeastern US rivers with sandy habitats and those in New Zealand with pumice substrates (Benke and Wallace 2003). As for fish, various experiments adding wood have been conducted and their effects on invertebrates measured. In several cases, abundance and biomass was significantly higher (often by 2-8 times or more) on the added wood, or in habitats created by it, than on other surrounding substrates like sand, gravel, or cobble (e.g., Wallace et al. 1995; Coe et al. 2009).

2.3. Effects of wood on other aquatic and terrestrial invertebrates, vertebrates, and floodplain vegetation

Although not considered in detail, large wood in streams and in riparian floodplains may have important effects on other vertebrates and invertebrates, from stream and pond-dwelling amphibians to riparian spiders, reptiles, birds, and small mammals. However, these groups have received far less study than fish or macroinvertebrates. Roni (2003) reported no detectable effects of large wood placement on giant salamanders (*Dicamptodon* spp.) in paired treatment-control reaches of 29 coastal streams of Washington and Oregon, based on a careful extensive post-treatment study, although lamprey and sculpins (a bottom-dwelling fish) did increase in various ways (e.g., density and growth). Fish owls (*Bubo blakistoni*) in far-eastern Russia used nesting and foraging locations associated with large old trees and riparian old-growth forests, which the authors inferred were also important in creating suitable river habitat for salmon and charr, their primary prey (Slaght et al. 2013). Small mammals, such as Preble's jumping mouse (*Zapus hudsonius preblei*; listed as Threatened under the Endangered Species Act), also use riparian habitat. Trainor et al. (2007, 2012) reported that this species used habitats close to streams, and detected some evidence that it was associated with large wood, probably because the wood supported both invertebrates and fungi that are food sources. Benjamin et al. (2011, and unpublished data) found that tetragnathid spiders, which live only near and above streams, were especially dense on downed wood that provided web supports directly over the stream, because these spiders eat only insects emerging from streams.

Several studies have demonstrated the importance of large wood to floodplain ecosystems. Floodplain wood creates germination sites for riparian vegetation (Schowalter et al. 1998; Pettit and Naiman 2006). Water-transport of propagules is important to many riparian species, and water-borne seeds are preferentially deposited against floodplain logs (Schneider and Sharitz, 1988). Floodplain wood also enhances nutrient cycling and soil formation (Zalamea

et al. 2007), provides invertebrate habitat (Benke 2001; Braccia and Batzer 2001), and enhances habitat diversity for various species of plants and animals (Harmon et al. 1986).

3. Public safety considerations associated with large wood

3.1. Potential hazards for inhabitants and infrastructure

Physical risks associated with large wood, like benefits from wood, strongly depend on the volume of wood within a channel, and on whether the wood remains stationary or becomes mobile during high discharges. The three primary risks to people and infrastructure are increased flow stage, altered movement of sediment and patterns of erosion and deposition, and mobile debris.

By increasing resistance and obstructions to flow, wood can create higher water levels for any discharge. This can create overbank flooding hazards along segments of a stream where overbank flow is not desirable. Wood can accumulate at bridges, for example, causing increased scour of piers and abutments or exacerbate upstream flooding. Wood can also block culverts, increasing flooding and eroding roadbeds. Large amounts of wood can potentially raise water elevations above existing regulatory mandates, such as the 100-year flood used for FEMA compliance. An indirect effect of wood may be to encourage beaver to build dams that contribute to flooding of adjacent areas.

Because wood alters velocity and sediment transport capacity in its immediate vicinity, the presence of wood can alter localized sediment dynamics. A concentration of wood along one bank can deflect flow toward the opposite bank, for example, accelerating erosion of that bank. Altered sediment dynamics can also result in lateral channel movement across the floodplain or local aggradation or scour, each of which can cause flooding or endanger infrastructure.

Finally, wood within the channel or floodplain can be transported during higher discharges, creating mobile debris that can damage downstream infrastructure such as bridges or pipelines.

3.2. Potential hazards for recreational users

Concerns regarding instream wood and public safety can also apply to river reaches that are frequently visited for such activities as wildlife viewing, fishing, picnicking, swimming, tubing, boating, hiking, walking and jogging, among others. Some instream wood is a risk to recreational users in the channel as an entrapment hazard. However, other instream wood can

make a reach safer for recreational users by providing zones of lower velocity and opportunities to rest, regroup or escape. What follows is a discussion of potential factors which increase or decrease the level of risk that instream wood has on the safety of recreational users. Eight categories are discussed: access, reach characteristics, snagging potential, porosity of jams, placement, anchoring, ability to avoid, and prior knowledge.

The following discussion is based on personal experience of the last author (a professional kayaker), as well as reports on wood and public safety by an advocacy group for kayakers and rafter (American Whitewater; Colburn, n.d.) and by the Bureau of Reclamation (Svoboda et al. 2013). The American Whitewater report is an excellent general reference for understanding river features and risk from the point of view of a boater. The Bureau of Reclamation report goes beyond public safety and outlines research needs for large wood design and placement, structure stability, risk analysis and liability.

1. *Access.* The first considerations are whether the reach is accessible to the general public and what type of recreational user is likely to visit. The risk that instream wood has on public safety increases with the frequency of recreation use because there are more chances for wood-human interaction. However, risk decreases quickly for recreational users experienced in navigating through and around rivers. For example, wood placement is safer along reaches visited only by experienced kayakers and anglers than along favorite family swimming locales or popular tubing destinations.
2. *Reach Characteristics.* Risk increases with water velocity because faster flow decreases the reaction time and capabilities that a swimmer, tuber, or boater has to avoid a hazard. Placing or keeping wood in lower velocity reaches is less risky than placing wood in reaches with swift current. In natural streams, most large log jams and most wood are located along slower rather than higher velocity sections. However, drowning can occur when a swimmer has no chance to reach shore because velocities are swift for long distances. This occurs in straight sections of rivers with uniformly swift velocity from bank to bank. In this scenario, instream wood jams with few dangerous crevices to trap boats or swimmers can be used to increase the safety of a reach by creating areas of lower velocities near shorelines.
3. *Snagging potential.* Although used previously to refer to the historic practice of removing pieces of wood from the channel, snagging to the water enthusiast refers to the potential

of a river hazard, such as wood, to snag a piece of clothing or gear as a swimmer or boat passes. Wood with many larger limbs is more of a risk to swimmers and boaters, especially if the wood is within the channel. Wood can be stripped of large branches and branch stubs to reduce snagging potential, although this may reduce the ecological benefits of the wood (see text in section II.2). If more complex wood with more branches is highly desired for ecological reasons, it should be placed in low risk locations on the margins of the channel or on reaches that are rarely visited by recreationalists or only visited by highly experienced recreationalists.

4. *Porosity of jams.* Although a single piece of wood with few to no branches creates relatively low risk, a porous jam can be hazardous. Jams with high porosity are those in which water runs swiftly through the jam rather than pooling upstream. These are known in the boating community as strainers. A person can be easily pushed up against the jam by water currents and not be able to swim through. However, a jam with enough wood and litter such as twigs and leaves will create an upstream backwater that is an advantageous and safe feature because it creates a safe place away from the swift main current for boaters and swimmers to rest, get out or regroup.
5. *Placement.* The placement of jams and single pieces has important effects on the risk associated with instream wood. For example, wood that is placed close to the water surface creates higher risk than wood far enough above the channel for recreational users to float under, or far enough below the water surface to float over. Because vertical position changes with water level, fluctuations in water level should be taken into account. Wood in contact with the bed so that no water is flowing underneath it has very low risk. Any wood near the bed with some water flowing under creates a foot entrapment hazard. Drownings from foot entrapment can occur in very shallow rivers at low flows because once the foot is entrapped, the person can fall face-first into the stream and not be able move from that position. This is a concern for anglers or for anyone wading in streams. For wood above the water column, American Whitewater (Colburn, n.d.) suggests a generous 3 ft of clearance for kayaks and 6 ft for rafts. Skilled kayakers are adept at safely passing beneath smooth logs as close as 1 ft above the water.
   With respect to the horizontal dimension, wood that spans the entire length of the channel is fairly dangerous unless it is in contact with the bed all the way across. Wood or wood

jams that partially span the channel are much safer because a route around the wood remains open. Vertical orientation of logs (like fenceposts) should be avoided because floating items such as rafts can be wrapped around the wood.

6. *Anchoring.* Although securing wood in place with cables, ropes, rebar, or other artificial material may help to ensure that wood does not threaten infrastructure downstream, these anchoring devices can be hazardous to public safety if they are exposed within the channel. This can occur if the channel scours around secured wood or if the wood becomes detached. It is recommended that wood is secured naturally through burial or weighting with natural materials.
7. *Ability to avoid.* Upstream visibility and an onshore escape route strongly reduce hazards caused by instream wood. Structures just around corners or just downstream of large drops can be difficult for boaters or swimmers to see and avoid. A boater or swimmer should have ample time to see the wood and react by either navigating around it or moving to the shore and getting out above it. A signed route to walk around the wood structure is particularly helpful. If something such as private property or steep terrain prevents avoiding the wood via the shore, the wood should be readily visible from far upstream, with ample room to paddle or swim around it.
8. *Prior knowledge.* Most importantly, prior knowledge of new wood along commonly navigated sections is vitally important to reduce risk. Regardless of location placement, new pieces of wood in previously clear channels typically create the greatest hazards. Boaters become complacent with sections of river that they run often and thus are not as attentive to their surroundings as they navigate downriver. In addition, boaters often become habitualized to navigating through a section of river the same way. Unknown, new wood along the normal route can be dangerous because it is not expected. One of the best risk-reducing measures that can be taken is to make sure that new instream wood is not a surprise to river enthusiasts.

When placing or leaving wood in streams, contacting the local boating community and/or American Whitewater is useful. Boaters often safely navigate many sections of streams with large amounts of wood. Thus, they are a good resource to include in the decision-making process because they can help make decisions about the safe placement of new wood. If boaters are included early in the project, they will be informed about the wood and will be less likely to

remove it. The boating community is well connected and word will spread quickly. In addition to contacting American Whitewater, there are numerous online boating and angling forums that can be useful to managers if they seek public comments. For example, in Colorado, MountainBuzz.com is a very active boating forum.

The perception by the general public is that wood is not natural in a stream and detracts from the esthetics (Piégay et al. 2005), in part because much of the wood historically in streams has been removed and people are not accustomed to seeing it (Chin et al., 2008). It is important that the public becomes knowledgeable and informed about wood structures through signs and public outreach to avoid an outcry against leaving wood in streams, to prevent citizens and boaters from removing carefully placed or retained wood features, and to decrease the risk to public safety associated with new wood installments.

III. Description of Tools that can be Used to Assess Large Wood

As discussed in previous sections, we need to understand the stability of individual wood pieces and jams within channels and on floodplains, and the physical and ecological effects created by this wood, in order to effective manage the wood. This section briefly introduces two categories of tools that can be used to better understand wood stability, benefits, and risks. Section III.1 introduces a spreadsheet-based program designed specifically to evaluate wood. Section III.2 reviews a group of numerical models designed to assess hydraulics and aquatic habitat, which can be applied to the understanding of instream and floodplain wood.

1. Large Wood Structure Stability Analysis Tool

The Large Wood Structure Stability Analysis Tool is a spreadsheet-based tool that can be used to efficiently evaluate wood stability and options for the design and placement of wood, based on factors including the size and species of wood, configurations, and anchor requirements. Users are required to input basic information on channel dimensions, discharge, streambed substrate, and wood characteristics. A companion report summarizes the design rationale, methodologies, procedure, limitations, and example applications to illustrate how the tool can be used to design stable wood structures.
http://www.engr.colostate.edu/~bbledsoe/streamtools/

2. Flow and Habitat Models

Several tools are available to assist with evaluation of the effects of wood on flow and potential benefits of wood for fish in Front Range streams. For example, the HEC-RAS (Hydrologic Engineering Center River Analysis System, http://www.hec.usace.army.mil/software/hec-ras/) software program can be used to model the flow of water in a variety of channel types. Developed mainly to model floodplain management and insurance studies for potential flood damage, an implicit component of HEC-RAS allows modeling one-dimensional changes in water surface elevation (stage) as it varies with flow (discharge). Large wood can impede flow velocity in a stream channel or on an inundated floodplain, and thereby increase the stage and alter channel or floodplain flow dynamics. Thus, when properly applied, HEC-RAS has value in estimating the lateral extent of flooding when wood has been placed or retained in the active river channel or floodplain. The HEC-RAS software may also be used to estimate flow velocities to help predict scour or erosion resulting from placement or retention of wood in the stream channel.

Modeling tools are also available for estimating the quantity and quality of fish habitat. One such tool is the instream flow incremental methodology (IFIM), and the associated physical habitat simulation tool (PHABSIM), which allows estimating usable fish habitat at different stream flows (Stalnaker et al. 1995; Bovee et al. 1998). This technique incorporates curves describing fish use (and assumed preference) of depth, velocity, and substrate microhabitat characteristics, which differ by fish species and life stage (e.g., fry, juveniles, adults, spawning adults). These characteristics are then predicted using hydraulic assessments of the stream cross-section, and the results combined into an index of "weighted usable area" for a given fish species and life stage. Such techniques may be useful in assessing placement or retention of wood in streams, especially to predict how wood affects the diversity of habitat at particular transects. For example, flow and depth variability may be greater in a habitat transect that contains large wood than one without, and these characteristics may be important to certain fish species, as described above. Two key caveats are that 1) hydraulic habitats are characterized by complex three-dimensional flow patterns that are typically poorly represented by one-dimensional simulation models, and 2) habitats that are critical for fish reproduction, growth, and survival may be important at spatial scales larger than the microhabitat scale (Fausch et al. 2002). Thus, such models should be used judiciously.

Flow and habitat assessments based on one-dimensional models can incorporate variable discharge levels but are not useful to assess spatial changes in habitat. Spatially explicit flow models that can be mapped in either two- and three-dimensions are necessary to describe more fully the spatial and temporal heterogeneity in a river system. Such models are useful to predict physical features of the habitat as well as understand relationships between fish, flows, and habitat quality and diversity (Bovee 1996; Ghanem et al. 1996). For example, Stewart et al. (2005) used two-dimensional modeling to correlate meso-habitat variables to fish biomass at a river-reach scale. They also validated the model, predicting fish biomass in different channel types over a range of flows, and attendant depth and velocity conditions.

Mean depth and velocity characteristics of streams can be measured in less time with the simpler one-dimensional models. However, two-dimensional models have the advantage of predicting habitat change as flows fluctuate seasonally and as channel shape changes, and also allows incorporating predictions of biomass as flows and spatial habitat change. This is an

important consideration when evaluating potential effects of large wood addition or retention in a stream reach, because wood effects can be modeled as a spatially explicit variable.

The additional effort and resources involved in using two-dimensional flow models can be justified when detailed information on habitat associated with wood is required. Consequently, users may want to consider the following models, which are in the public domain and can be obtained free of cost:

- RIVER2D: a two-dimensional, depth-averaged, finite element hydrodynamic model that has been customized for fish habitat evaluation studies. The model suite consists of four programs, each of which has a graphical user interface that is supported by any 32-bit version of Windows. http://www.river2d.ualberta.ca/
- SRH-2D: a two-dimensional hydraulic, depth-averaged, finite-volume numerical model for sediment, temperature, and vegetation in systems developed by the U.S. Bureau of Reclamation. The model suite consists of modules for hydraulics (in existence), and bed sediment transport, temperature and vegetation (under development). http://www.usbr.gov/pmts/sediment/model/srh2d/index.html
- Other models are also available commercially: commercial codes include MIKE 21c (http://www.mikebydhi.com/Products/WaterResources/MIKE21C.aspx), but most users would only go to a commercial code for three-dimensional modeling, and this code would likely be FLOW3d (http://www.flow3d.com/) or FLUENT (http://www.ansys.com/Products/Simulation+Technology/Fluid+Dynamics/Fluid+Dynamics+Products/ANSYS+Fluent)

IV. Decision Process for Managing Large Wood

1. Background on Risk Assessment

Engineers have a long tradition of performing risk assessments focused on structural stability or safety. However, it is only recently, with an upsurge in the practice of river restoration involving intentional placement and retention of large wood, that the need for risk assessments focused on wood has become pressing. Given longstanding concerns about public safety, property, and infrastructure in the river environment, risk assessments are increasingly being incorporated into river management and restoration efforts to ensure that the potential adverse consequences of projects have been adequately considered.

Risk is inherent in river management given the range of complexity in channel responses to changes in delivery water, sediment, and large wood. The purpose of any risk assessment is not to eliminate risk, but to objectively evaluate the potential risk elements and assess how a particular design or management action can address and alleviate those risks. It is important to note that there is commonly a significant risk of continued geomorphic and ecological degradation if large wood is not retained or re-introduced to a stream or river, and this risk should be included in every risk assessment. Therefore, a primary purpose of risk assessment is to assure designers, managers, stakeholders, and the general public that the potential short and long term effects of the proposed action have been considered, and that the expected benefits of the project outweigh the potential negative consequences (Abbe et al. 2014).

Risk is commonly defined as the potential of losing something of value, weighed against the potential to gain something of value. Risk may be mathematically defined as the probability of an event happening multiplied by the resulting consequences (cost or benefit) if it does:

$$Risk = P(E) \times \sum(C)$$

in which $P(E)$ is the probability of a specific event (E) or combination of events occurring, and $\sum(C)$ is the summation of the consequences of the event occurring (typically presented as a monetary cost). If there are no negative consequences of a particular event occurring, then there is no risk. If the consequences are grave, then even an event with low probability of occurring may pose more risk than is tolerable.

2. Procedure for Assessing Risks Posed by Large Wood

Risk assessment for large wood in streams is best regarded as an ongoing process because of likely changes in risk through time as a result of natural processes (e.g., high stream flows) and human modifications (e.g., stabilizing or pruning the wood). Consequently, we suggest a process illustrated by the flow chart in Figure 2, which incorporates four "tools." If wood is present in a channel, a simple checklist (Tool 1) can be used for an initial assessment of whether to remove the wood or consider other options. If options other than immediate removal are considered, the Large Wood Structure Stability Analysis tool (Tool 2) can be used to assess the likely stability of the wood during differing discharges. The outcome of Tool 2 can then be used with the Decision Bands (Figure 3; Tool 3) to qualitatively assess the alternative actions listed within the oval in Figure 2. The Decision Bands are used to assign risk to a high, medium or low category with respect to three characteristics: legal/property/infrastructure/inhabitants, recreation, and ecosystem.

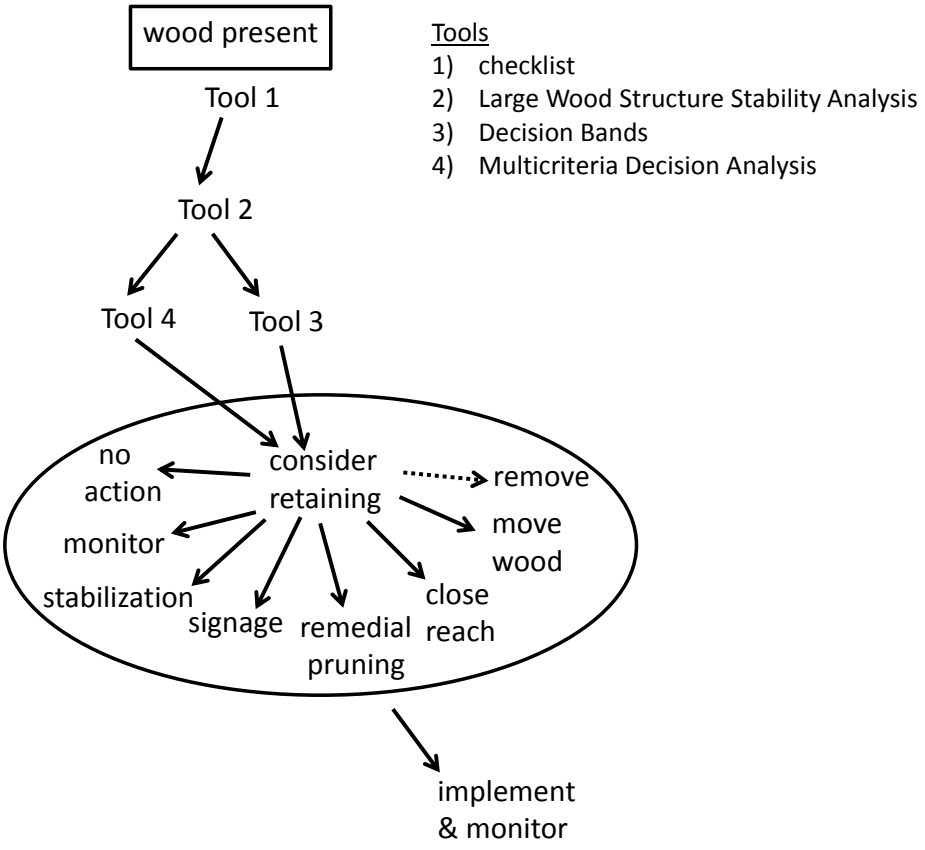
The outcome of Tool 2 can also be used in a more quantitative approach based on a multi-criterion decision analysis (MCDA) approach (e.g., Pomerol and Romero 2000; Kiker et al. 2005; Suedel et al. 2011). MCDA provides a flexible, rational, and transparent means to establish decision-making criteria and prioritize options and typically involves five steps (Chee 2004):

1. Define the goals and objectives.
2. Identify decision options.
3. Select the criteria that measure performance relative to the objectives.
4. Determine the weights for the various criteria.
5. Apply the procedures and perform the mathematical calculations to rank options.

In MCDA, criteria are scored on interval or ratio scales and then transformed to ensure commensurability before ranking options. Then criteria scores are aggregated using weights that reflect values, preferences, and expert judgment to transparently compare and rank options. MCDA is essentially a method for combining multiple criteria and value judgments into a concise set for decision making. The MCDA approach is more structured and defensible than 'best professional judgment,' yet more interpretable and less complex and data intensive than sophisticated optimization schemes. Users can also adapt the system to different decision-making

situations by adjusting the criteria and weights as knowledge and preferences evolve. Thus, the great strengths of MCDA are its transparency and flexibility.

Figure 2. Illustration of the sequence of tasks, and associated tools, which can be used to assess risk created by large wood in streams.



3. Tools

Tool 1. Checklist for Initial Assessment of Wood

1. *Imminent Threat to Public Safety*

a) Has a river recreation accident involving wood been reported?
If yes, remove.
If no, proceed to consider retaining.

b) Does the wood accumulation have crevices that can trap recreational users (i.e., is it porous) and completely spanning the active river channel in a location and season known for high recreational use?
If yes, remove.
If no, proceed to consider retaining.

2. *Imminent Threat to Property and Infrastructure*

a) Has the wood already damaged a flood district facility or public or private structure?
If yes, remove.
If no, proceed to consider retaining.

b) Could the wood potentially create, or increase the extent of, damage to a flood district facility or public or private structure that may cause loss of function to the facility or structure?
If yes, remove.
If no, proceed to consider retaining.

3. *Legalities*
For any reason, are you legally bound to extract the wood?
If yes, remove
If no, proceed to consider retaining

4. *Overall*
If the answer to all of the preceding questions was a clear 'no,' retain wood.
If the answers involved some qualifications, proceed to consider retaining.

Tool 2. Large Wood Structure Stability Analysis (see section III.1)

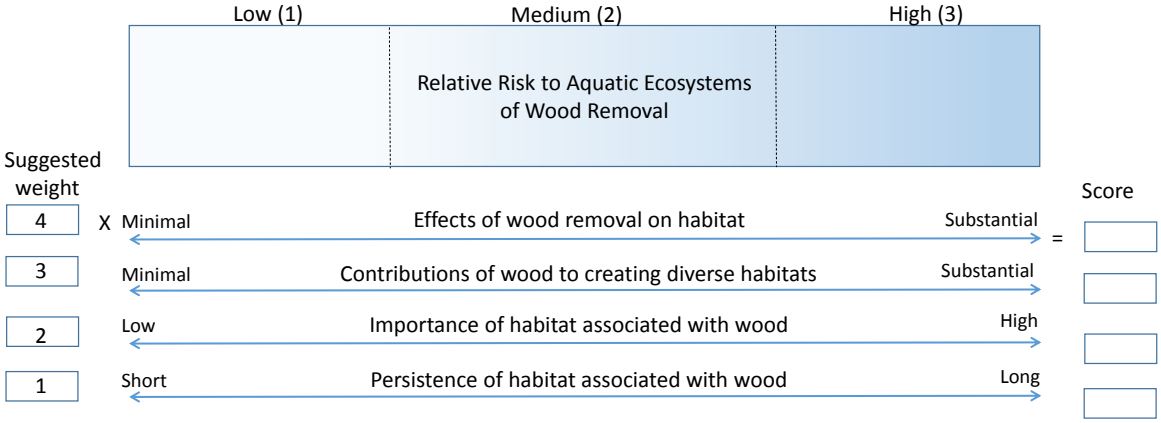
Tool 3. Decision Bands

The decision bands shown in Figure 3 are designed to assist field-based evaluation of the relative risk created by individual pieces of wood or logjams in a channel or on a floodplain. Individual bands focus on aquatic and riparian ecosystems, recreational users, and inhabitants and infrastructure. The suggested weights assigned to each row below the band, which can be altered by the user, can be used to create a weighted score for comparing different sources of risk. We emphasize that these decision bands represent a starting point for a complicated assessment process that is very context-specific. Some river reaches will have minimal recreational use or potential, for example, or no floodplain habitat. Although we briefly explain the characteristics that can be used to assign a score to each decision band, users who want to evaluate these characteristics in more depth are encouraged to consult the relevant technical

literature or disciplinary experts, and to use specific tools such as flow and habitat models (section III.2).

Figure 3. Decision bands for assessing the relative risk to different components of river systems associated with wood removal. Individual bands relate to (A) aquatic or in-channel ecosystems, (B) riparian or floodplain ecosystems, (C) recreational users, (D) water surface rise relative to adjacent floodplain, (E) wood stability and potential mobility, (F) downstream structures, facilities and infrastructure, (G) potential for unintended geomorphic consequences, and (H) a cumulative assessment for property, infrastructure, and public safety. For each band, the suggested weight in the box at the left in each row is multiplied by one of the numbers at the top of the band (1, 2, or 3) to create a score for that row, and these scores are then summed to create a total score for that decision band.

(A) Decision band for assessing the relative risk to aquatic ecosystems of wood removal.



Rationale:

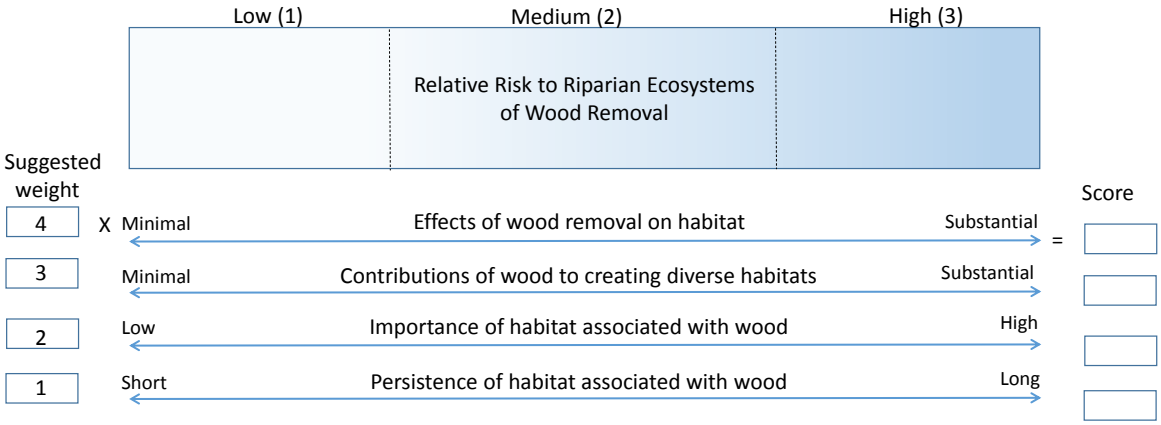
a. Effects of wood removal on habitat assesses whether habitat important to sustain fish or aquatic invertebrates, such as deep pools, is likely to decline as a result of wood removal (which would result in a low score), or is unlikely to be reduced by wood removal (a high score).

b. Contributions of wood to creating diverse habitats assesses whether the wood creates multiple types of habitat, such as pool scour and overhead cover for fish, diverse coarse and fine substrates for macroinvertebrates, perching habitat for birds, or backwater pools for fish and macroinvertebrates. Aquatic habitat diversity primarily requires a diversity of flow depth, flow velocity, streambed substrate, and complex physical structure created by wood.

c. Importance of habitat associated with wood includes considerations such as abundance of wood-related habitat at the reach scale, and the need for this habitat by key species. For example, pools are commonly critical habitats for many fish species, so if the wood creates the only pool habitat for fish within a particular stream reach, then the importance would be rated as high. In contrast, if the wood creates no pool or a very small pool, then the importance could be rated as low. Likewise, wood structures that create critical habitat for an at-risk or desired species equate to a higher score for the importance of habitat.

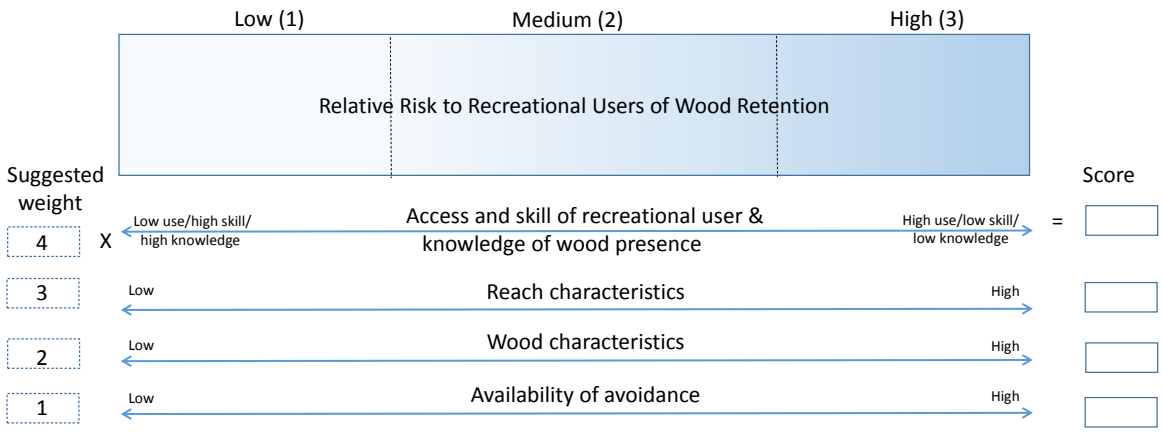
d. Persistence of habitat associated with wood assesses whether the wood-related habitat is likely to persist for a short period (< 5 years) or to persist for longer time periods (5-100 years or more).

(B) Decision band for assessing the relative risk to riparian ecosystems of wood removal.



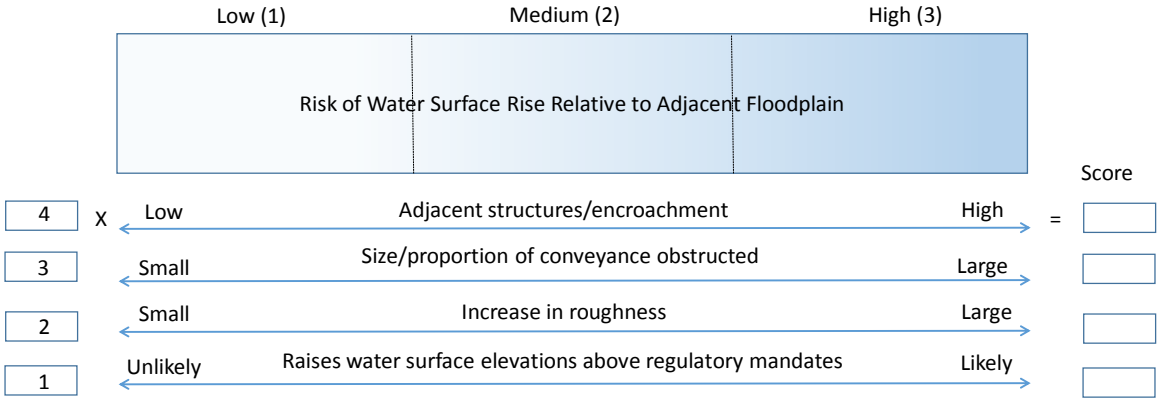
Rationale: The basic characteristics of the features (effects of wood removal, contributions of wood, importance of habitat, and persistence of habitat) are the same as described above for aquatic ecosystems, except they are applied to riparian organisms. As reviewed in section I.2, floodplain wood can create germination sites for riparian vegetation and provide habitat for invertebrates, amphibians, reptiles, small mammals, and birds. Where a long piece of wood spans both the channel and the floodplain, decision bands (A) and (B) should be used together to assess the wood.

(C) Decision band for assessing the relative risk to recreational users of wood retention.



Rationale:
The basic characteristics in this decision band relate to abilities and knowledge of the recreational user, the characteristics of the river reach in which the wood occurs (flow velocity), the characteristics of the wood (snagging potential, porosity of jams, horizontal and vertical placement, anchoring) and the availability of avoidance. Each of these characteristics is described in more detail in section II.3.

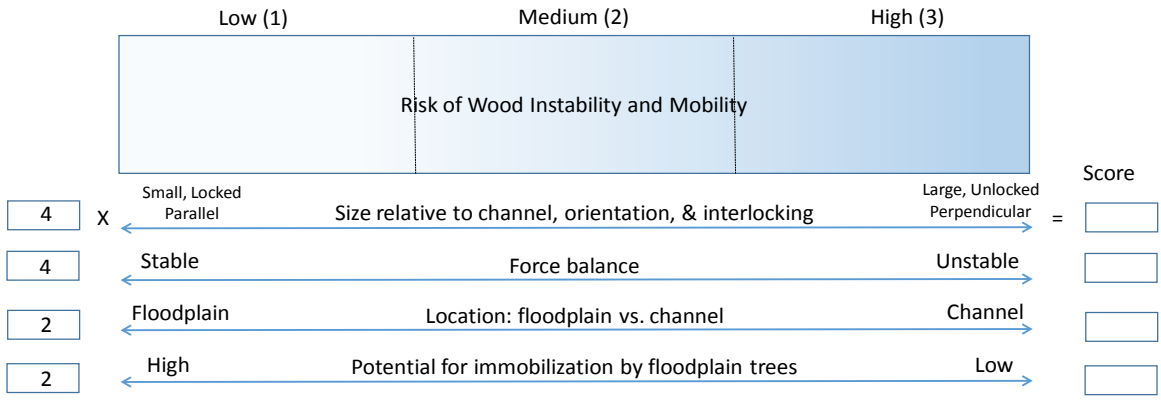
(D) Decision band for assessing the risk of water surface rise relative to the adjacent floodplain if wood is present.



Rationale:
Potential costs and the risk of negative consequences associated with large wood retention and placement depend on site-specific channel and floodplain characteristics. Encroachment by human development, infrastructure, and other valuable assets tend to increase potential costs associated with floodplain inundation and river channel changes. Thus, local encroachment in the vicinity of large wood is a fundamental consideration. Assessing risk also requires an understanding of the physical factors that control flood conveyance. The local extent of channel blockage, flow obstruction, and reduced cross-sectional area that may result from large wood

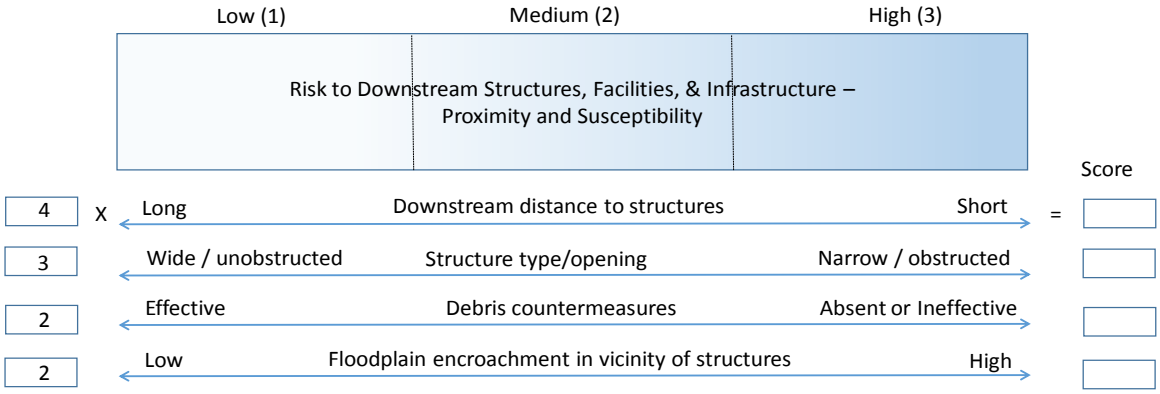
retention are fundamentally important. Flow conveyance is also proportional to flow resistance (a.k.a. roughness) as expressed by the widely used Manning *n*. Obstructions directly influence *n* values, but roughness is included as a separate factor to emphasize the importance of considering relative changes in flow resistance when assessing potential reductions in flood conveyance capacity. A final consideration is whether retention or emplacement of instream wood will alter water surface elevations to an extent that requires regulatory action such as generating a letter of map revision. The impact of such regulatory implications must be evaluated on a case-by-case basis by floodplain managers.

(E) Decision band for assessing the relative risk of wood instability and mobility.



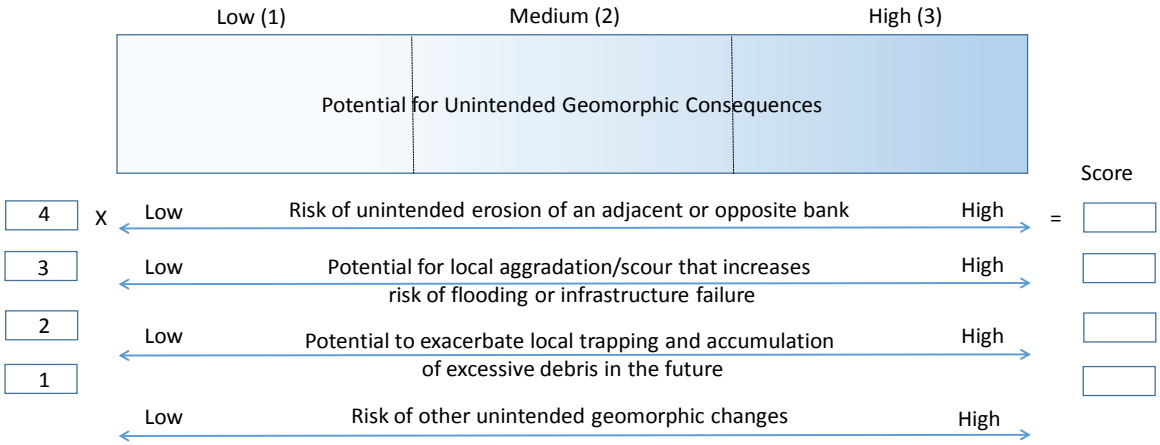
Rationale:
Large wood that presents little risk in its current location may nevertheless produce much greater risks if transported downstream to a location where it could exacerbate flooding and/or threaten property and infrastructure. This decision band is intended to address the likelihood of large wood being mobilized and transported downstream without reference to specific downstream conditions (addressed in decision band F). Individual pieces of wood that are large relative to channel width (e.g., spanning from top of bank to top of bank) may be inherently less mobile for a given amount of flow energy. Wood that is oriented lengthwise along a streambank in the flow direction is likely to be inherently more stable compared to a piece of wood oriented perpendicular to high velocity flow in the center of the channel. Physically-based models that explicitly account for the various forces acting on instream wood can be very useful and informative in assessing stability and the potential for downstream transport. To our knowledge, the spreadsheet-based force balance tool of Rafferty (2014) is the most rigorous and complete model of this type that is currently available. Wood mobility depends on the balance of stream power available to transport the wood versus the resistance of the wood to motion based on its weight, situation, and other factors. Floodplain flows, especially in unconfined valleys, typically have less erosive power than in-channel flows and thus less capacity to transport wood. In addition, forested floodplains may have a high capacity for trapping and immobilizing wood.

(F) Decision band for assessing the relative risk to downstream structures, facilities, and infrastructure resulting from the presence of instream wood.



Rationale:
Once wood is mobilized downstream from the location where it enters a river or stream, its potential for creating hazards depends on the types of hydraulic structures and infrastructure it encounters. The greater the distance wood must be transported before encountering vulnerable structures, the more likely the wood is to be immobilized and thus provide opportunities for re-stabilization or removal. The inherent susceptibility of hydraulic structures to loss of conveyance, damage, and failure is highly variable (FHWA 2005). Factors that affect a structure's capacity to safely convey wood include opening width(s) and height(s) relative to wood size, pier spacing, shape, and orientation, backwater effects, and the presence of debris countermeasures. There are many types of structural and non-structural debris countermeasures for bridges and culverts (FWHA 2005). Assessing structure vulnerability and the potential effectiveness of debris countermeasures requires extensive knowledge of both structures and hydraulic engineering and should be performed by a Professional Engineer. As described above, encroachment by human development, infrastructure, and other valuable assets tends to increase potential costs associated with floodplain inundation and river channel changes. Decision band D focuses on floodplain land use and encroachment in the immediate vicinity of instream wood without consideration of potential downstream effects. Accordingly, this decision band requires an evaluation of the potential consequences of reduced flood conveyance and damage to structures if wood is transported to vulnerable downstream locations.

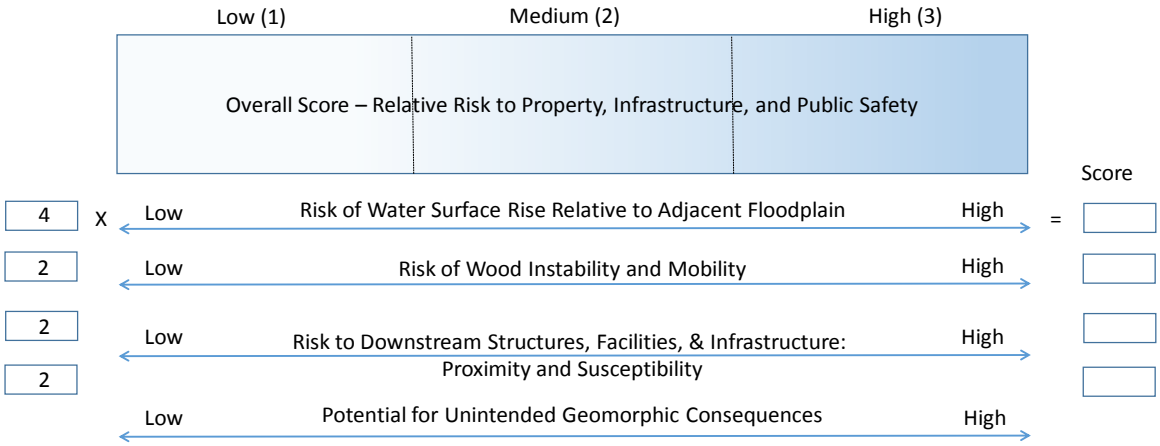
(G) Decision band for assessing the potential for unintended geomorphic consequences as a result of the presence of wood.



Rationale:

Instream wood is widely recognized by river scientists for its capacity to create habitat diversity and channel changes that benefit aquatic ecosystems. However, dynamic channel adjustments are commonly socially unacceptable in river corridors that are highly constrained by human encroachment. In such situations, it is important to evaluate the potential for instream wood to produce channel adjustments that conflict with adjacent property values and floodplain management objectives. Potential responses to inputs of large wood include accelerated bank erosion as a result of increased velocities and/or flow redirection, ongoing accumulation of wood and loss of conveyance, backwater effects, and altered sediment transport capacity and downstream supply that affect patterns of sediment scour and deposition. Such channel responses to instream wood can be difficult to predict, even for experienced fluvial geomorphologists and river engineers. Therefore, evaluations of potential geomorphic consequences are best performed by interdisciplinary teams of experts with direct experience in managing instream wood.

(H) Decision band for assessing the relative risk to property, infrastructure, and public safety associated with the presence of wood.



Rationale:

Decision band H integrates the results of decision bands D through G into an overall assessment score for relative risk to property, infrastructure, and public saftety.

Applying Decision Band scores

Decision band scores consistently in the medium-high range of decision bands A and B (risk to aquatic and riparian ecosystems of wood removal), and in the low range of decision bands C to G suggest options of no action, monitoring, stabilization, or signage (Figure 2). Scores in the low range of decision bands A and B and the medium-high range of the other decision bands suggest options of remedial pruning, closing the reach or moving the wood (Figure 2). Table 1 provides further information on the implications of choosing one of the options within the oval in Figure 2.

Table 1. Implications of individual options in Figure 2

No action	• can help to ensure continued beneficial habitat effects of wood • low risk to recreational users
Monitor	• can help to ensure continued beneficial habitat effects of wood • facilitates evaluating how interactions among discharge, sediment and wood influence habitat through time • recreational moderate-high risk wood in a low use or high-skill reach • recreational low risk wood in a high use reach
Stabilization	• can help to ensure continued beneficial habitat effects of wood • can reduce risks to infrastructure • to reduce recreational risk of unstable pieces moving to high-risk locations after assessment • reduce recreational risk by using natural stabilization techniques such as burial rather than cables and ropes
Signage/Outreach	• can reduce risks to recreational users; inform recreational users of new wood & educate recreational users to avoid public protest
Remedial pruning	• can reduce risks to recreational users by reducing snagging potential & making avoidance easier • may reduce beneficial effects to habitat
Close reach	• can help to ensure continued beneficial habitat effects of wood • can reduce risks to recreational users
Move wood	• may reduce beneficial habitat effects of wood • can reduce risks to infrastructure & recreational users for moderate-high risk wood in moderate-high use areas

V. Concluding Remarks

Figure 2 provides an overview of the sequence of steps that we suggest for assessing the benefits and risks posed by wood in stream channels and on floodplains. This sequence starts with the relatively short Checklist for Initial Assessment of Wood (Tool 1), followed by the Large Wood Structure Stability Analysis (Tool 2), the Decision Bands (Tool 3), and/or the Multi-Criterion Decision Analysis (Tool 4). We suggest that any decision to retain wood should be coupled with ongoing monitoring. Monitoring can be used to re-evaluate wood benefits and risks if conditions at a site, such as bed elevation or channel cross-sectional, change as part of the natural dynamics of a river. Monitoring can also be a key component of ongoing refinement of risk assessment. The procedures outlined in this report should be implemented by experienced, interdisciplinary teams. The weights that we suggest in the decision bands can also be adjusted based on stakeholder preferences.

The procedures outlined in this report represent a more nuanced approach to managing wood in river systems than automatically removing all wood. However, managers in some regions of the country are being more proactive than simply considering retaining naturally recruited instream wood. Managers in the U.S. Pacific Northwest, in particular, are now actively adding individual wood pieces and engineered logjams to channels because of the recognized physical and ecological benefits of wood. Jones et al. (2014) review some of these restoration projects and the success of the projects in achieving desired restoration of fish habitat.

An example of a large engineered logjam built by the Washington State Department of Transportation on the bank of the Hoh River along U.S. Highway 101.

Photo from Herrera Environmental Consultants, Inc (http://www.fhwa.dot.gov/publications/publicroads/06jan/05.cfm)

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VIII. Appendix: Definitions

bankfull channel: bankfull can be defined as the portion of the channel that contains relatively frequent floods occurring every 1-2 years, or as the portion of the channel below the inflection point at the top of the bank – above bankfull, flow moves beyond the channel and into the floodplain

biomass: the mass of living organisms within an area

channel morphology: the cross-sectional shape, downstream slope, bedforms (e.g., pools, riffles, steps, dunes), and planform (e.g., straight, meandering, braided) of a channel

debris: word sometimes used to refer to instream wood

floodplain: floodplain can be defined based on flood recurrence interval (e.g., 100-year floodplain), or as the portion of the valley bottom that would be inundated relatively frequently (every 1-2 years) under a natural flow regime

floodplain wood: large wood outside of the channel but within the floodplain

foot entrapment: when someone's foot becomes entrapped on the bottom of a shallow stream and the current pushes the person over, such that the individual can no longer stand or extract themselves without help; this usually occurs when someone is trying to stand or wade in shallow, swift moving water.

habitat heterogeneity: variation in physical environmental features (e.g., water depth, flow velocity, substrate) within an area

hyporheic: the portion of unconfined, near-stream aquifers where stream water is present; can also be defined as a flow-through subsurface region containing flowpaths that originate and terminate at the stream

instream wood: large wood that is at least partially within the bankfull channel

large wood: typically defined as wood pieces greater than 10 cm in diameter and 1 m in length
lateral migration: lateral movement of a channel, either via gradual erosion of one bank, or via abrupt shifting (avulsion) across the valley bottom during a flood

LWD: large woody debris, sometimes used to refer to instream wood

longitudinal: the downstream direction

macroinvertebrates: an invertebrate large enough to be seen without a microscopic; in streams, these are typically the juvenile stage of insects such as mayflies or caddisflies, and are typically bottom-dwellers (benthic)

multi-thread channels: a channel planform that includes multiple flow paths; these can shift laterally relatively rapidly between unvegetated bars (braided channel) or individual sub-channels can be more persistent features with forested islands between them (anastomosing channel)

natural flow regime: the hydrograph that would occur in the absence of human alteration of flow via dams, diversions, groundwater withdrawal, construction of levees, etc

organic matter: composed of organic compounds that have come from once-living organisms and their waste products in the environment (e.g., leaves, twigs, pine needles, frass)

periphyton: a community of algae, bacteria, microbes and fine detritus that is attached to cobbles and wood in the streambed

reach: any length of stream of interest for a particular study or concern; a reach is often defined as some multiple of the width of the channel at bankfull

riparian: the valley bottom outside of the channel, typically similar to the floodplain, but characterized by hydrophilic (water-loving) plants tolerant of inundation and mechanical damage during floods

risk: the probability of something happening multiplied by the resulting cost or benefit if it does

species richness: the number of different species represented in an ecological community

stability: the presence or absence of changes in channel morphology, flow regime, biomass, habitat heterogeneity, and other characteristics of rivers is highly dependent on the timespan being considered – what might appear to be a substantial change and evidence of instability when considered over relatively short time intervals, may appear as part of regular fluctuations within a generally stable state when considered over longer time periods

strainer: an obstacle in the river that is porous, such that items or people pushed up against it by the current cannot pass or swim through

uncertainty: limited knowledge makes it impossible to exactly describe the existing state, a future outcome, or more than one possible outcome