Section 9
Capital Improvement Projects

9.1 Problem Identification

The results of the hydrologic, hydraulic, and geomorphic evaluations discussed in the previous sections of this report formed the foundation for identifying problem areas in the watershed. Problem areas were classified as primary or secondary.

Primary problem areas are those that pose a serious public safety concern or include significant structural damage. In addition, primary problem areas include sites where the problem creates a clear influence elsewhere in the watershed. Secondary problem areas include sites where stream degradation or instability exists, but it is not likely to propagate to other areas in the near watershed. Secondary problem areas also include infrequent flooding of habitable buildings.

Three major categories were used to evaluate potential primary and secondary problem areas, including 1) drainage infrastructure, 2) habitable buildings, and 3) natural streams. For primary problem areas, a recommended improvement was developed and is presented in Section 9.2. The recommended improvements were then grouped and prioritized to form the basis of the capital improvement projects (CIPs), which are described in Section 9.3. Secondary problems are described in Section 9.4.

The following provides the methodology used to identify primary and secondary problems within each of the three major categories.

9.1.1 Drainage Infrastructure

Because of the rural nature of the watershed, a significant number of unimproved roads are located throughout the study area. As development continues in the watershed, it is anticipated that drainage infrastructure (e.g., culverts and bridges), will be replaced or retrofitted at the same time the road is improved. Therefore, for the purposes of this study, the approach was to provide the necessary design data for each modeled drainage structure, to be used during detailed design at the time the roadway is upgraded. The design data for each modeled drainage structure is provided in Appendix J located in Volume II of this report.

Drainage structures in need of immediate structural repair were considered a primary problem. Routine maintenance needs required to maintain the capacity of the drainage system were classified as secondary problems. Applying these criteria resulted in no primary or secondary problem areas under this category.

9.1.2 Habitable Buildings

The hydrologic and hydraulic analysis as described in Sections 3 and 4 of this report include the estimation of the 2-, 5-, 10-, 50-, 100-, and 500-year peak stormwater flow rates and resultant water surface elevations (WSEs). For the purposes of this study, habitable buildings being impacted from the 2- and 5-year design storms were

considered primary problems. Applying these criteria resulted in no primary habitable building problem areas in the watershed.

Habitable buildings being impacted from the 10-, 50-, and 100-year design storms occur much less frequently, and therefore were classified as secondary problems. Secondary problems are associated with deficiencies within the adjacent manmade drainage system, which is the primary cause of the flooding. However, habitable buildings located in the natural 100- and 500-year floodplains were not considered problem areas. Improvements designed to remove habitable buildings from the natural floodplain are cost-prohibitive. A total of five secondary problem areas were identified in the watershed and are described in Section 9.4.

9.1.3 Natural Streams

The geomorphic evaluation discussed in Section 8 was used to identify primary and secondary stream instability problems. Each stream instability problem was assigned a priority based on the descriptions below.

- Priority 1 – Hazard. These stream conditions pose a near-term threat to public safety or significant infrastructure and should be repaired promptly. Sites exhibiting clear evidence that a long delay in treatment will potentially lead to a permanent loss of property or a dramatic increase in the cost of treatment directly associated with the progression of the problem receive a priority of 1.

- Priority 2 – Systemic. These sites, while not posing an immediate public hazard, are fundamentally unstable with clear influence elsewhere in the watershed. The series of knick points mentioned above is an example of this case. While the knick points may pose no immediate threat, if left untreated, the incision migrating throughout the watershed will. As the bed elevation drops, bank heights increase and consequently so does the risk of mass wasting, the generation of massive sediment, and the risk of bridge and culvert sedimentation. Priority 2 projects are not emergencies but should be addressed as soon as funding permits.

- Priority 3 – Supporting. Like the Priority 2 problems, these sites include ongoing channel adjustment conditions. However, either because of location in the watershed or particularly robust channel conditions, propagation of the problem is less likely or is proceeding relatively slowly.

- Priority 4 – Localized. These problems are distinct from the two previous categories in that the cause is local rather than systemic. Examples of this type of problem include overbank drainage, removal of riparian corridor, and debris dumping.

- Priority 5 – Preservation. These are opportunities to protect the higher quality reaches of Stevens Creek. In addition to the aesthetic, water quality, and habitat benefits, protecting the better-functioning reaches provide a reference point for reclaiming the damaged areas. Moreover, the presence of self-managing reaches buffers some of the effects of stream degradation.

- Priority 6 – Enhancements. These are opportunities to prevent future problems, reduce water and sediment conveyance stress on the stream system, or to otherwise improve stream performance. This category includes improvements that increase infiltration, dissipate or direct energy, or re-establish a normal grade for streambanks.

Priorities 1, 2, and 3 are considered primary problems, while priorities 4, 5, and 6 are considered secondary problems. None of the problem areas were given a priority 1 designation, while 18 problem areas were assigned as priority 2 and 8 problem areas were assigned as priority 3, for a total of 26 primary problem areas. A total of 79 secondary problems were identified that received a priority of 4, 5, or 6.

9.1.4 Summary

Figure 9-1 shows the location of the primary and secondary problem areas. Primary problem areas are designated with a "star ★" symbol, while secondary problem areas are designated with a "filled in circle ●" symbol. All 26 primary problems were classified as stream instability problems. The secondary problems include 5 habitable building flooding problems and 79 stream instability problems.

9.2 Recommended Improvements

Conceptual recommended improvements were developed to address each primary problem area. For this study, only stream stability problem areas were identified as primary problems. The types of improvements to address these problems are referred to as stream interventions. A general description of the methodology followed by a detailed description of each stream intervention is provided below. Secondary problem areas are addressed in Section 9.4.

9.2.1 Methodology

The stream interventions recommended in this report generally comply with the principles of river engineering. This approach represents the integrated knowledge of fluvial geomorphology and civil engineering accumulated over the last half century. Much of this work is documented in USACE engineering reports and manuals (1994, 2001). Here project objectives such as flood or erosion protection are achieved by working *with*, rather than against, the forces shaping the stream. Preservation of complex channel form and process including native vegetation are central to this approach.

The recommendations that follow do not constitute a compendium of all problems in the watershed. Stevens Creek is systemically unstable and continuing to degrade watershed-wide. A program to repair all of the problem sites along this stream would easily top $100 million, excluding the cost of property acquisition, utility relocation, or infrastructure replacement. Instead, the recommended improvements are strategic, focusing on interrupting the cycle of degradation and moving the entire system closer to self-sustaining dynamic equilibrium.

Most of the stream interventions address systemic channel incision, the source of much of the erosion and mass wasting observed throughout the Stevens Creek Watershed.

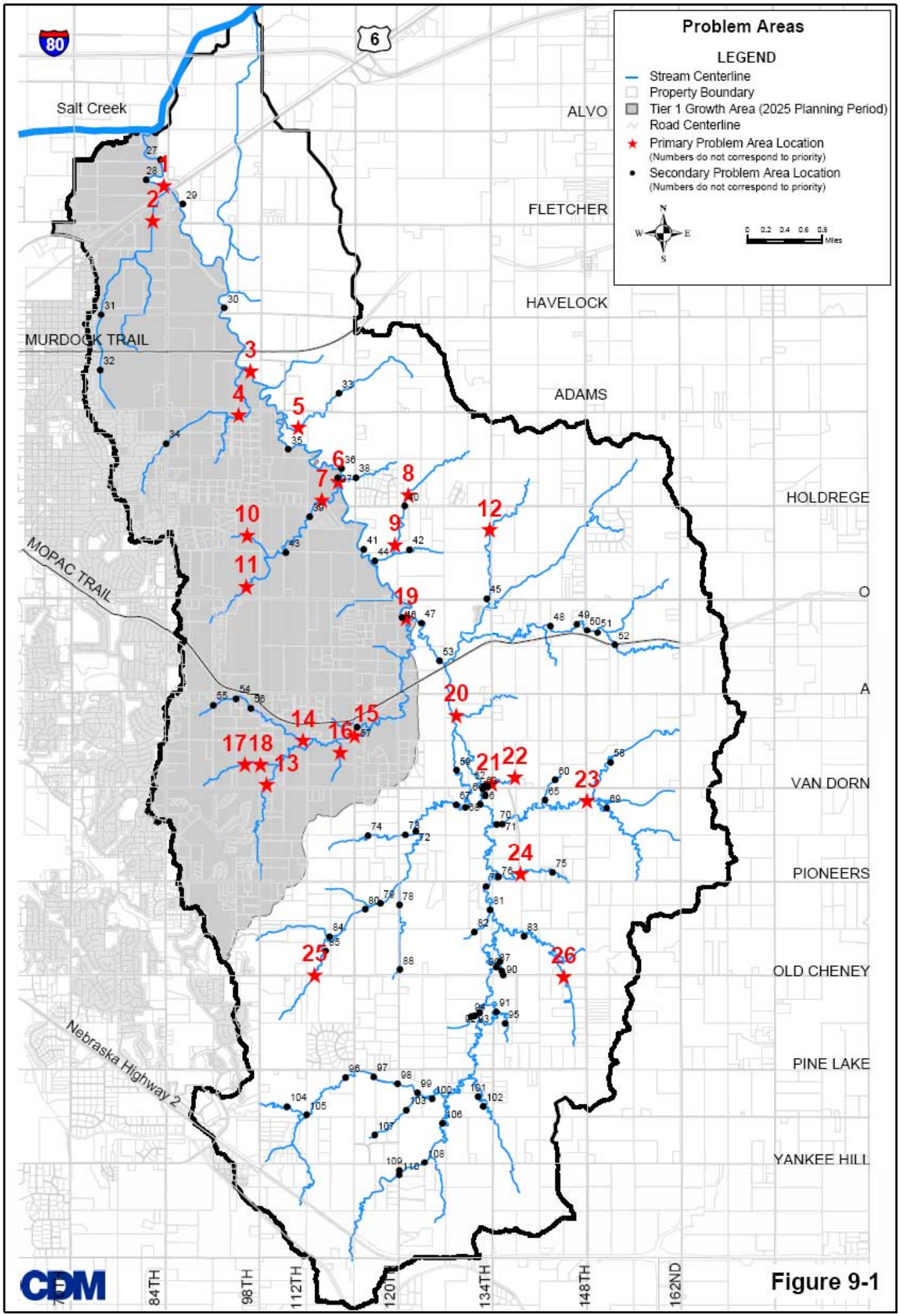

Problem Areas
LEGEND
Stream Centerline
Property Boundary
Tier 1 Growth Area (2025 Planning Period)
Road Centerline
Primary Problem Area Location
(Numbers do not correspond to priority)
Secondary Problem Area Location
(Numbers do not correspond to priority)
N
W
E
S
0 0.2 0.4 0.6 0.8
Miles
80
6
Salt Creek
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
VAN DORN
PIONEERS
OLD CHENEY
Nebraska Highway 2
PINE LAKE
YANKEE HILL
84TH
98TH
112TH
120TH
134TH
148TH
162ND
CDM

Figure 9-1

Early intervention in this stage of channel evolution minimizes widespread bank failures, mass wasting, and sediment generation. This approach enables construction of stable channel grade and cross section, thereby accelerating channel recovery and re-establishing dynamic equilibrium.

The natural feedback loop to limit incision in this system is the woody debris jam. Although rock grade controls would not normally occur in this watershed, they are easily constructed, flexible, adaptive to minor changes in channel form, flow of water and sediment, and dissipate energy over a long distance. In addition, rock grade controls do not deteriorate over time like large woody debris.

Where incision is not the focus, recommendations generally address either channel widening, the next phase in channel evolution, or localized erosion problems at culverts or outfall structures. Channel widening has occurred along reaches where the channel has already incised to a depth that exceeds critical bank height. Critical bank height is a function of a complex cross section expressed as bank height, angle, material and groundwater level that, when exceeded, results in a geotechnical failure of the slope. Grade controls are sometimes recommended to capture sediment, thereby raising the channel bed and decreasing bank height.

All of the stream intervention recommendations in this report share several common features. All are intended to remedy the cause of instability and not necessarily its most obvious symptom. All recommendations also rely heavily on measures that manage the distribution of energy through the project reach. Focusing flows, dissipating hydraulic energy and developing a gradual transition between native bed or bank and the installed structures are important design features. These are especially important in the erodible soils of Stevens Creek. For these reasons, drop structures, gabions, and other monolithic devices are not recommended.

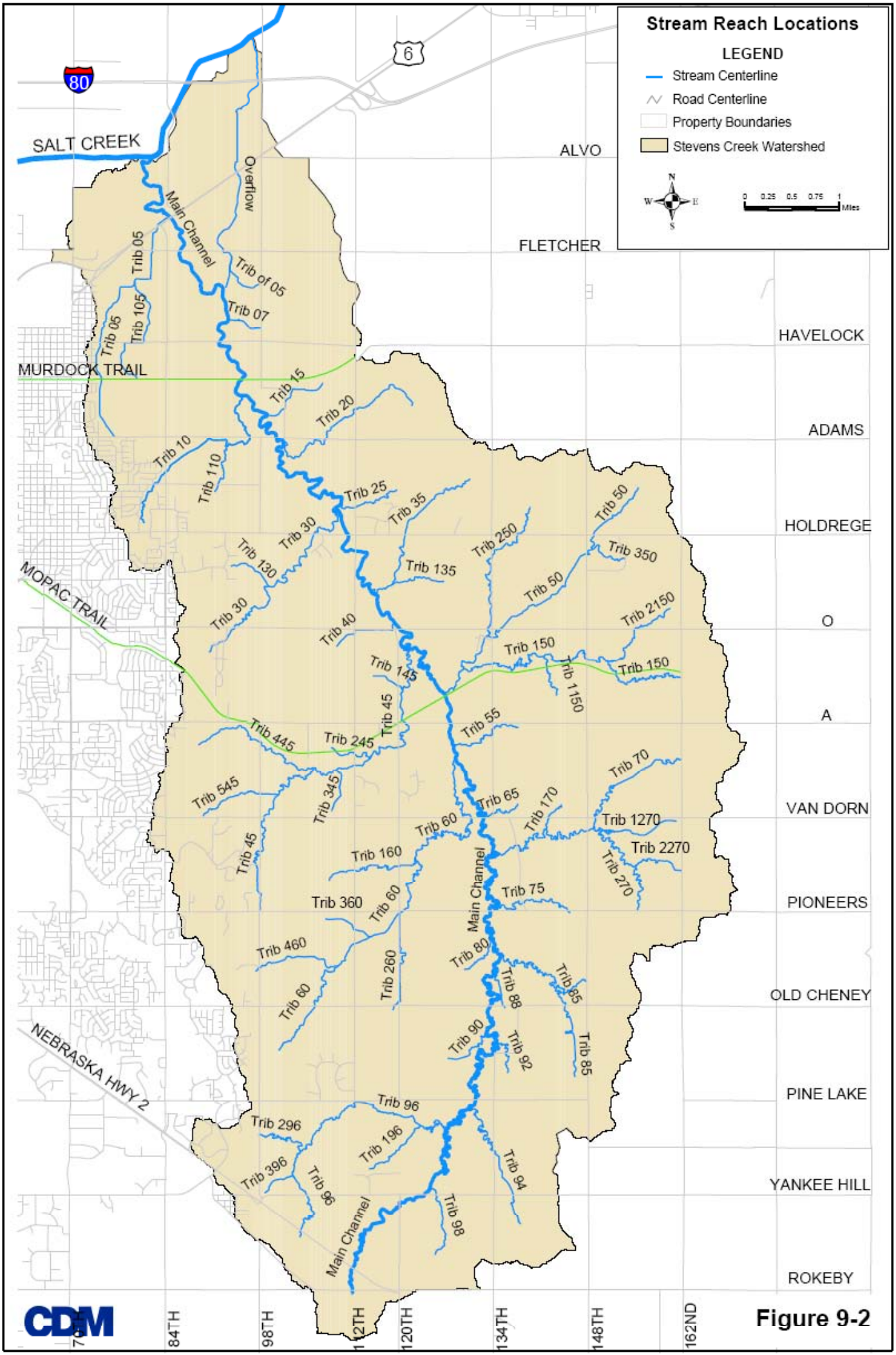
Bank failures are commonplace in this watershed and it is reasonable to question why bank stabilization is so rarely the focus of the recommendations. Stevens Creek is fundamentally unstable. The old truism regarding streambanks is as applicable here as anywhere in this region - *It is impossible to stabilize a streambank on an unstable stream*. Until some measure of equilibrium is regained, extensive bank stabilization efforts are wasteful and probably counterproductive. Critical infrastructure areas, where protection of a bridge or other crossing requires that the stream alignment be fixed, are the exceptions to this rule.

9.2.2 Stream Interventions

One recommendation is applicable throughout this watershed. The restoration and protection of the riparian forest is a vital aspect of sustainable watershed management. This is one of the most cost-effective methods to protect water quality, conserve wildlife habitat, support stream stability, and prevent loss of public and private property. The woody corridor should be wide, dense, and extend the length of the watershed including the headwater tributaries. The corridor should include a diverse selection of native trees, shrubs, and greases. Turf, crops, and pasture grasses do not provide the benefits of native species and should not be used as part of buffers.

While riparian buffers are vitally important, they are most effective when combined with grade stabilization and conservation land use practices throughout the watershed. Conservation farming practices and the improvements to stormwater management described in Section 7 manage hydrology to reduce the flashiness of storm flows. The combination of these three broad measures approximates the behavior of undisturbed systems and will reduce problems in the future.

Stream interventions were formulated for each of the 26 primary problem areas. These 26 interventions are described on the following pages and shown on Figure 9-1. Figure 9-2 shows the referenced stream reach locations.



CDM

Figure 9-2

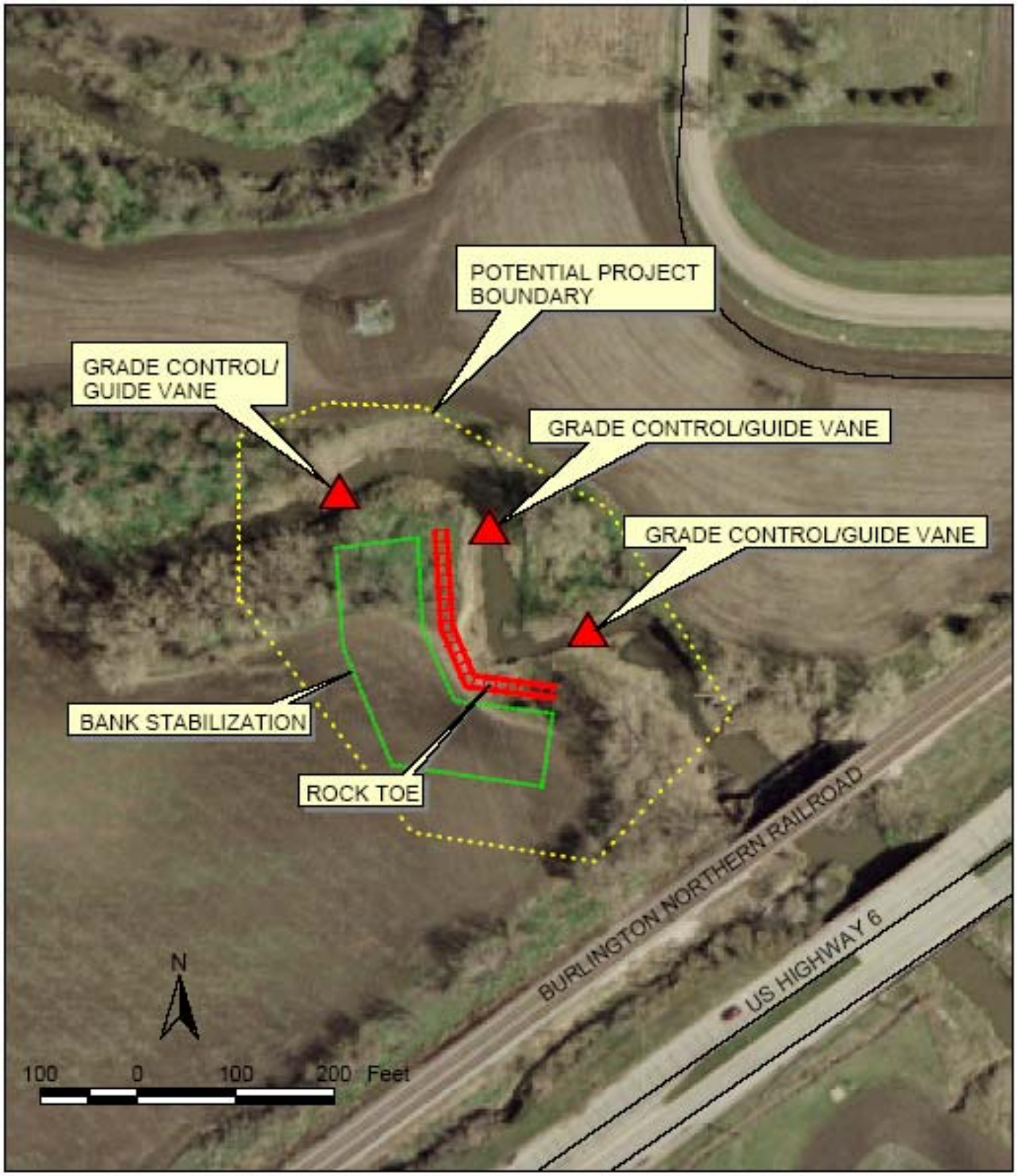
Intervention 1. Lower Main Stem, River Mile 1.222 to 1.167 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment is common along Stevens Creek Lower Main Stem, downstream of Nebraska Highway 6 and the Burlington Northern Railroad crossing. Adjustments in channel plan form have resulted in tall, alternating cutbanks, standing nearly 30 feet tall, between River Mile 1.222 and 1.167. Bank erosion continues to liberate large, toppled chunks of silty clay soils. The addition of such large amounts of sediment is troubling because it further degrades water quality and because the channel bars formed by the sediment aggravates the meander adjustment. This problem is not likely to resolve itself without substantial further damage.

Recommended intervention: The primary function of this intervention is managing and dissipating hydraulic energy immediately downstream of the railroad bridge. Deflecting scouring flows away from the streambanks is an appropriate first step. A series of rock guide vanes or rock grade control structures placed to focus flow in the center of the stream will significantly reduce stress on the streambanks (Figure 9-3). Rock toe armor reinforced with woody vegetation along the left descending bank provides continuity of treatment. Critical design features here are maintenance of sufficient hydraulic roughness to dissipate scouring energy and careful alignment of the rock structures. These are erodible soils and an overly acute angle will induce excessive scour at the apex of the structure while an overly flat angle will induce scour at the root of the structure.

While reducing the stress on the streambank alleviates much of the driving force for bank failure, further treatment has merit. Flattening the slope of the left descending bank reduces the likelihood of bank failures whether geotechnical or fluvial in origin. Re-establishment of native vegetation provides additional stabilization.

Estimated Construction Cost: $434,000



INTUITION & LOGIC

Stevens Creek Intervention #1
Lower Main Stem – River Mile 1.222 to 1.167

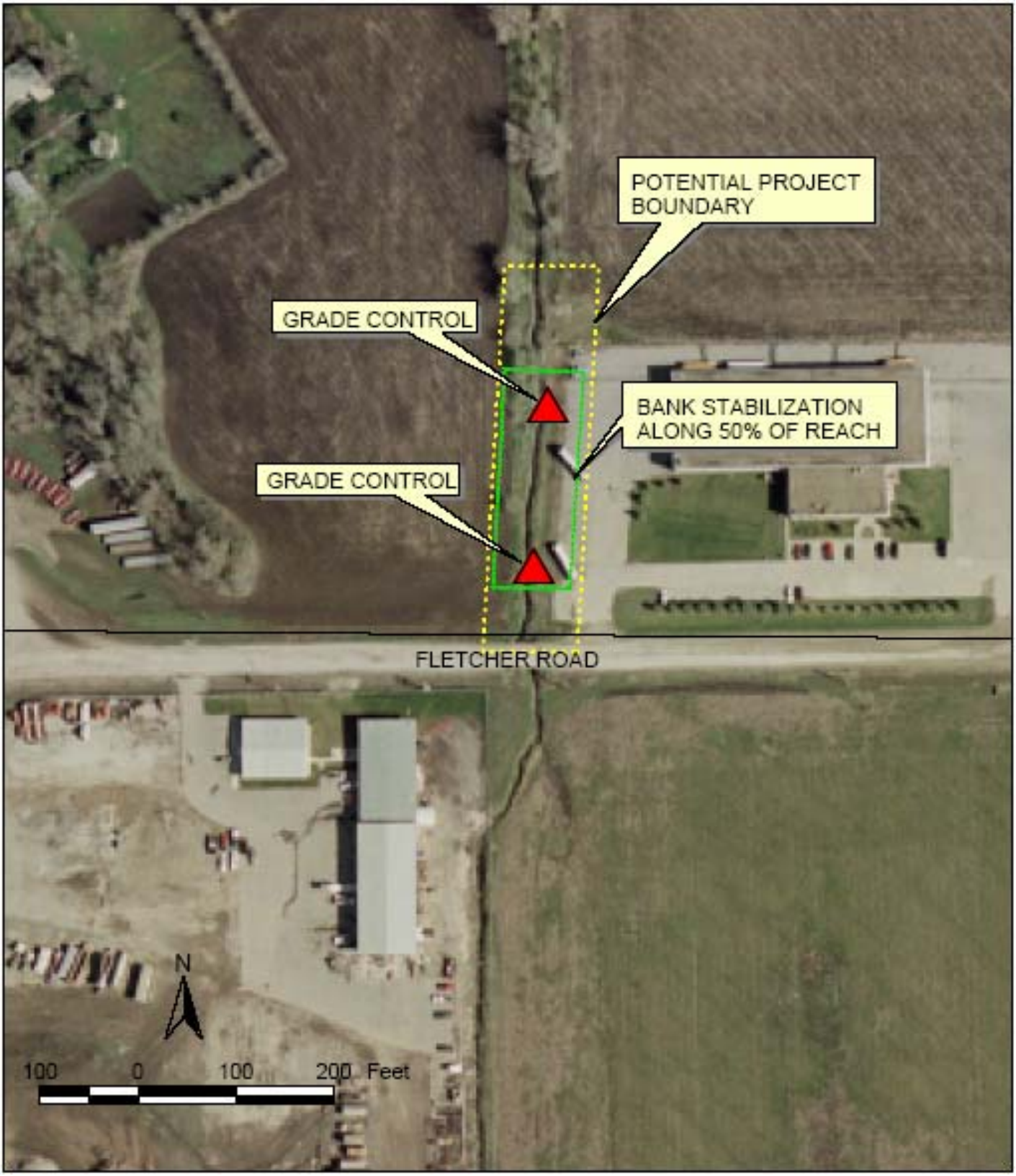
Figure 9-3

Intervention 2. Tributary 5, River Mile 1.708 to 1.689 – Grade control incising channel

Problem description: Channel incision and removal of woody vegetation along Tributary 5 has resulted in bank erosion downstream of the Fletcher Road Bridge. The two factors have reinforced each other; incision has increased the height and steepness of the banks, while the loss of trees and shrubs has reduced the shear strength of the soil. Left untended, this site will most likely continue to degrade until a stable channel slope is achieved. This process increases the likelihood of future bank failures.

Recommended intervention: A series of rock grade control structures immediately downstream of Fletcher Road will stop the incision (Figure 9-4). As with all in-stream structures, providing sufficient hydraulic roughness is an important design feature as is the shape of the upstream-facing arch and the depth of the key trenches. This recommendation does not include large-scale bank revegetation. However, where grade control installation has caused site disturbance, the streambanks should be restored by flattening the slopes and installing both degradable erosion control fabric and native vegetation.

Estimated Construction Cost: $98,000



Stevens Creek Intervention #2
Tributary 5 – River Mile 1.708 to 1.689

Figure 9-4

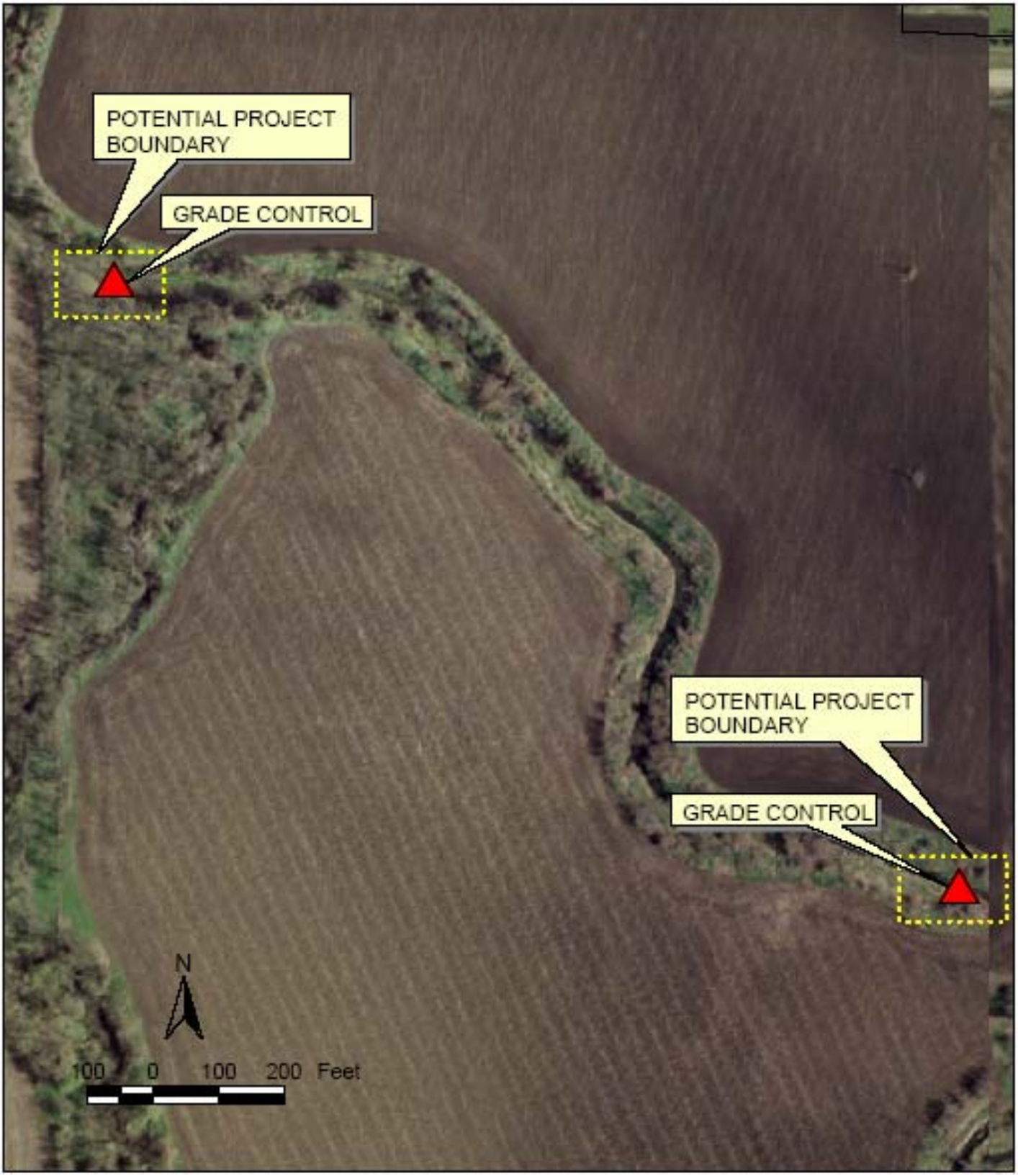
Intervention 3. Lower Main Stem, River Mile 4.545 to 3.839 - Grade control existing knickpoints

Problem description: An advancing headcut along Steven Creek Lower Main Stem has resulted in incision-induced bank failures and generation of toppled trees and woody debris.

No infrastructure or buildings are immediately threatened. However, headcuts in the lower part of any watershed are problematic because of their potential to migrate upstream. This migration eventually moves through all of the tributaries and up to the headwaters. This occurs because all tributaries must match grade with their receiving streams so a drop in grade at any point on the main stem has implications for all channels above it. Therefore the potential for serious future damage warrants immediate treatment. Construction of Intervention 3 should be coordinated with the construction of 98th Street, which is currently planned for this area.

Recommended intervention: Arresting the incision moving up the main stem requires a series of grade controls (Figure 9-5). Because of the relatively flat grade and erodible soils, Newbury-style grade controls are appropriate. Multiple grade controls at each knick point are preferable. Distributing the grade change over two or more structures lowers the stress on each and lowers the risk of a catastrophic failure. The structures should be rock, hydraulically rough and shaped in plan, section and profile to focus and dissipate hydraulic energy. Planting shrub species on the downstream edges of the structures will further dissipate energy and discourage raveling at the soil-rock interface.

Estimated Construction Cost: $229,000



INTUITION & LOGIC

Stevens Creek Intervention #3
Lower Main Stem – River Mile 4.545 to 3.839

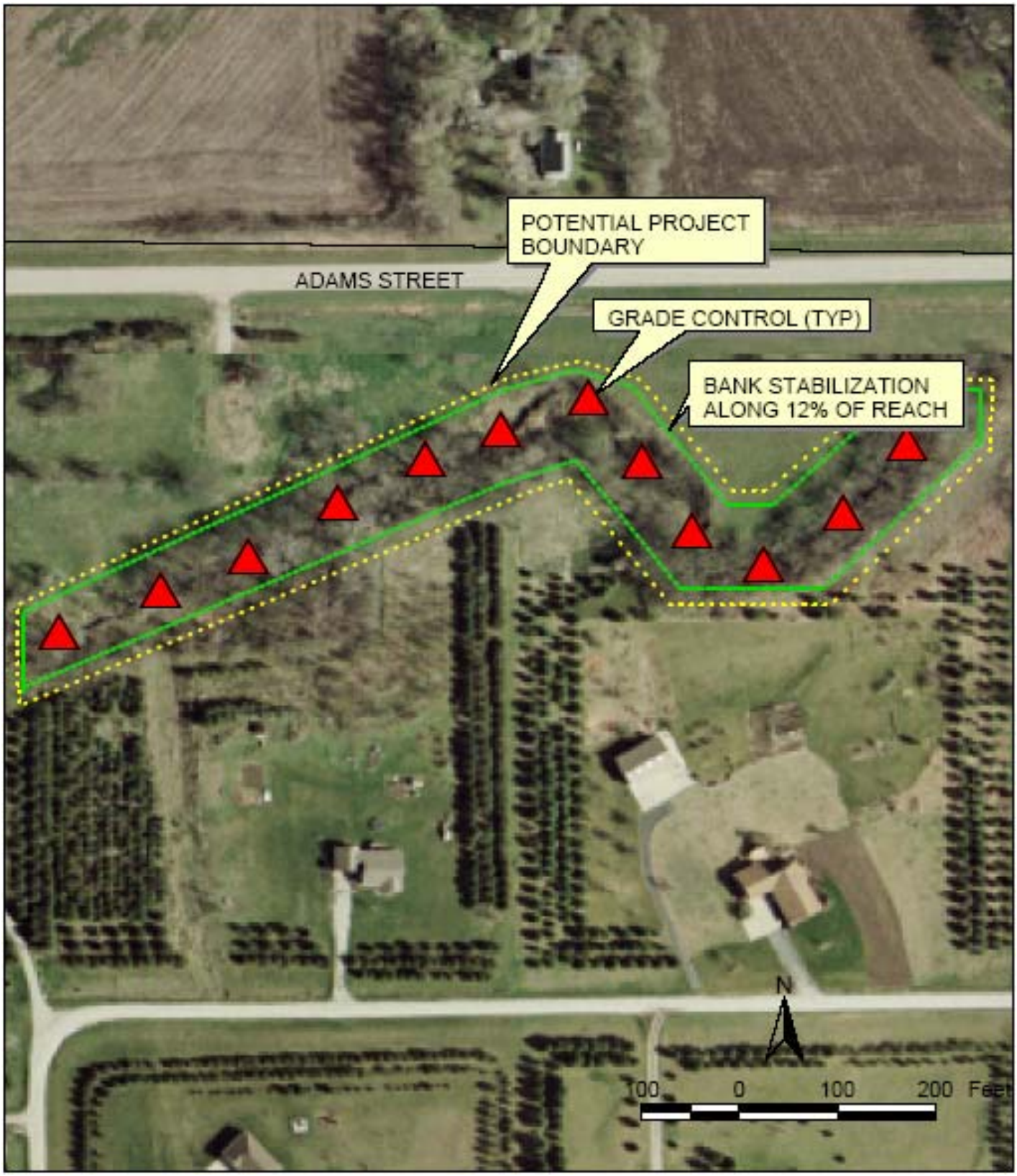
Figure 9-5

Intervention 4. Tributary 10, River Mile 5.043 to 4.191 - Grade control incising channel

Problem description: Channel incision along Tributary 10 has resulted in widespread bank scouring and erosion. The channel bed elevation has dropped approximately four feet based on the height of the exposed tree roots. The streambanks are approaching critical bank height. Further progress of the incision will likely lead to bank failures throughout this reach. In addition to liberating considerable sediment and degrading water quality, extensive bank failures will topple the trees lining the bank generating a series of woody debris jams. This last action is a natural response to incision and would eventually arrest it. However, the debris jams may also contribute to flooding and are not necessarily persistent structures.

Recommended intervention: Incision in erodible-soil streams is best managed with a series of Newbury-style grade controls (Figure 9-6). In Newbury series, grade changes in the reach can be distributed over the rock structures in small steps, sparing the softer bed and banks from scouring flows. The hydraulic roughness and shape of the structures dissipates stream energy. Although the streambanks are high and bank failures possible, the priority is to remove the driving force for continued downcutting. Here the recommended bank restoration is generally limited to areas disturbed during grade control construction.

Estimated Construction Cost: $805,000



INTUITION & LOGIC

Stevens Creek Intervention #4
Tributary 10 – River Mile 5.043 to 4.191

Figure 9-6

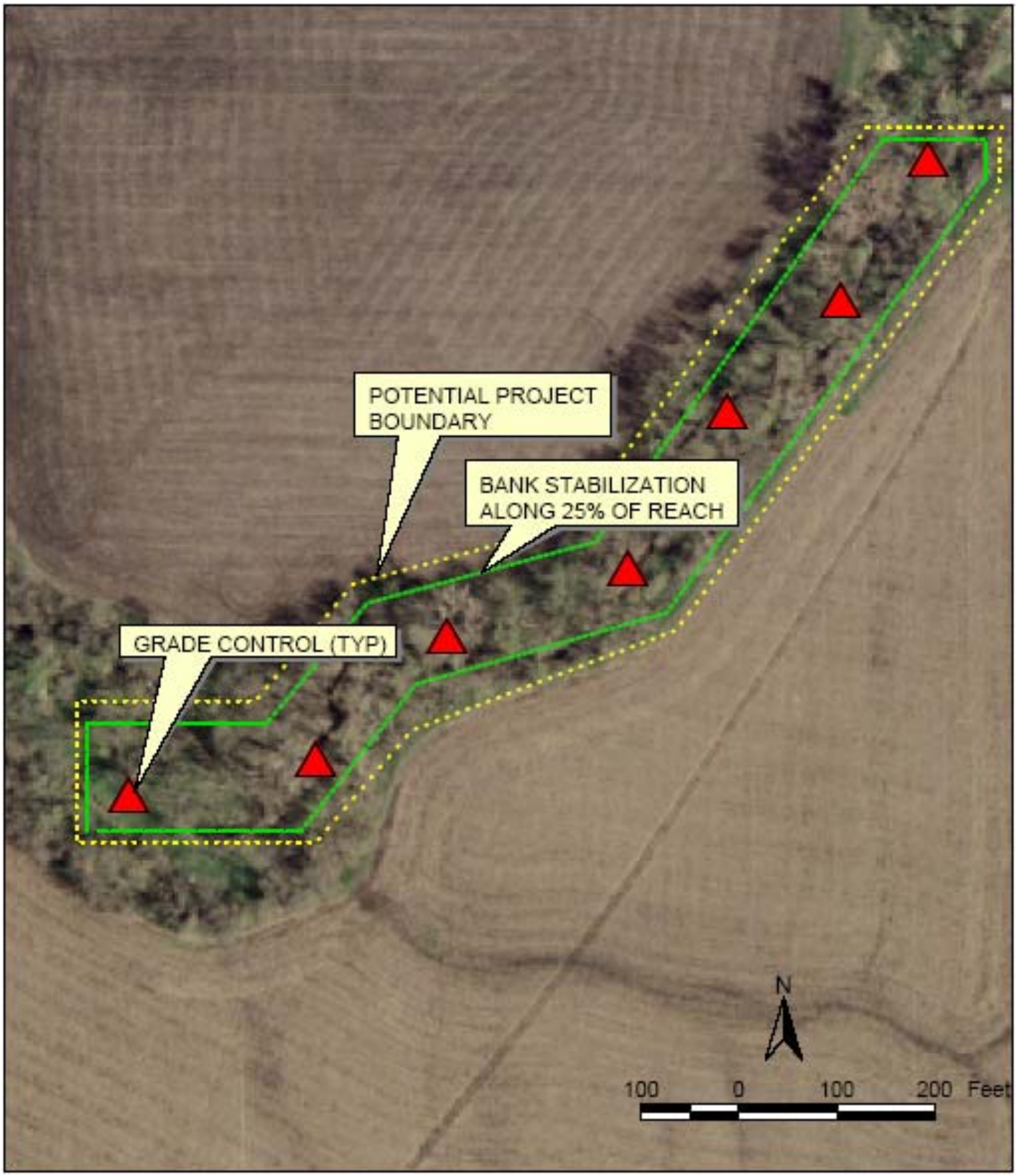
Intervention 5. Tributary 20, River Mile 5.627 to 5.399 - Grade control incising channel

Problem description: Channel incision upstream from the confluence with Stevens Creek Main Stem has resulted in widespread bank erosion. This reach illustrates the far-reaching effects of main channel incision. Here, a previous wave of incision moved up the main channel lowering its grade. In turn, the local change in slope at the mouth of Tributary 20 induced its own incision migrating up this channel and its sub-tributaries. The reach is characterized by steep, undercut banks with extensive undermining of stabilizing tree roots. Once the roots are undermined to this degree, their ability to reinforce the bank is severely compromised. Left untreated, the reach will continue to generate sediment. The excess sediment is detrimental to water quality and when deposited in the main stem in the form of channel bars may contribute to instability there as well.

Recommended intervention: A series of Newbury-style grade controls is an effective treatment for incision. Distributing the grade change over two or more structures lowers the stress on each and lowers the risk of a catastrophic failure (Figure 9-7). The structures should be rock, hydraulically rough and shaped in plan, section and profile to focus and dissipate hydraulic energy. Planting shrub species on the downstream edges of the structures will further dissipate energy and discourage raveling at the soil-rock interface.

Although bank failures may occur on this reach, the treatment priority is arresting incision thereby removing the driving force for bank erosion. Because there are some riparian trees along this reach, the bank stabilization is generally limited to restoring areas disturbed by grade control installation.

Estimated Construction Cost: $311,000



INTUITION & LOGIC

Stevens Creek Intervention #5
Tributary 20 – River Mile 5.627 to 5.399

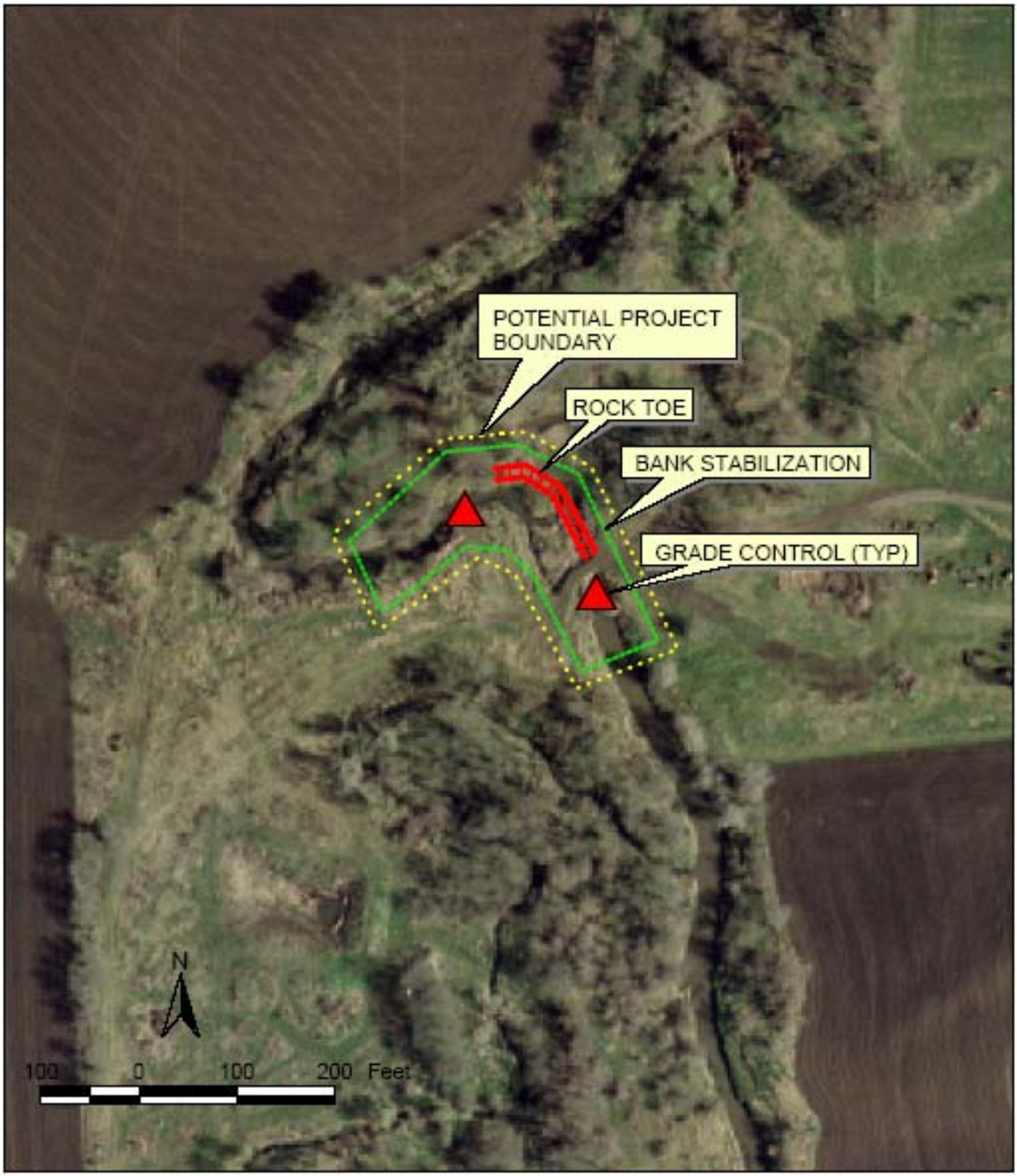
Figure 9-7

Intervention 6. Lower Main Stem, River Mile 7.172 to 7.134 - Restore stable channel geometry and grade control headcut

Problem description: The combined influence of in-stream excavation, failed cattle crossings, and concrete rubble dumping has induced the propagation of a headcut and localized channel widening along 200 feet of Stevens Creek Lower Main Stem. Along the failed crossing, the stream is drastically over-widened. Random actions including rubble dumping often worsen the problem they may have been intended to solve. The channel is severely degraded and aggravating the systemic channel adjustments downstream.

Recommended intervention: This project lies in a sharp meander bend with high stress downstream of the apex of the bend. In addition to a series of designed rock grade control structures, treatment includes rock toe armor along the outside bend and reshaping the channel to restore a more stable geometry (Figure 9-8). The radius of curvature should be slightly flattened. Concrete rubble with no exposed rebar may be broken up and used in the grade controls. In this badly damaged reach, it is also necessary to stabilize the streambank. This task requires reshaping the slopes, installing erosion control blanket and establishing a vigorous stand of woody vegetation.

Estimated Construction Cost: $379,000



INTUITION & LOGIC

Stevens Creek Intervention #6
Lower Main Stem – River Mile 7.172 to 7.134

Figure 9-8

Intervention 7. Tributary 30, River Mile 7.821 to 7.684 - Grade control incising channel

Problem description: Channel incision in the lower reach of Tributary 30 has resulted in widespread bank scouring and erosion upstream from the confluence with Stevens Creek Main Stem. Continued incision in this tributary threatens upstream reaches with further degradation of the channel bed. Bank failures will likely ensue when critical bank height is exceeded. The liberation and transport of the sediment generated by in-channel erosion is detrimental to both the water quality and the physical stability of the main stem. The removal of the woody riparian corridor from part of this reach further weakens the banks.

Recommended intervention: Rock grade control structures are an appropriate treatment for reducing the channel bed slope arresting channel incision. As is the case with the entire watershed, the structures should be of the Newbury style with gradual tail ramps and upstream-facing, arched head ramps. Minor bank stabilization is appropriate along the denuded area and to restore areas disturbed by grade control construction (Figure 9-9).

Estimated Construction Cost: $63,000

INTUITION & LOGIC

Stevens Creek Intervention #7
Tributary 30 – River Mile 7.821 to 7.684

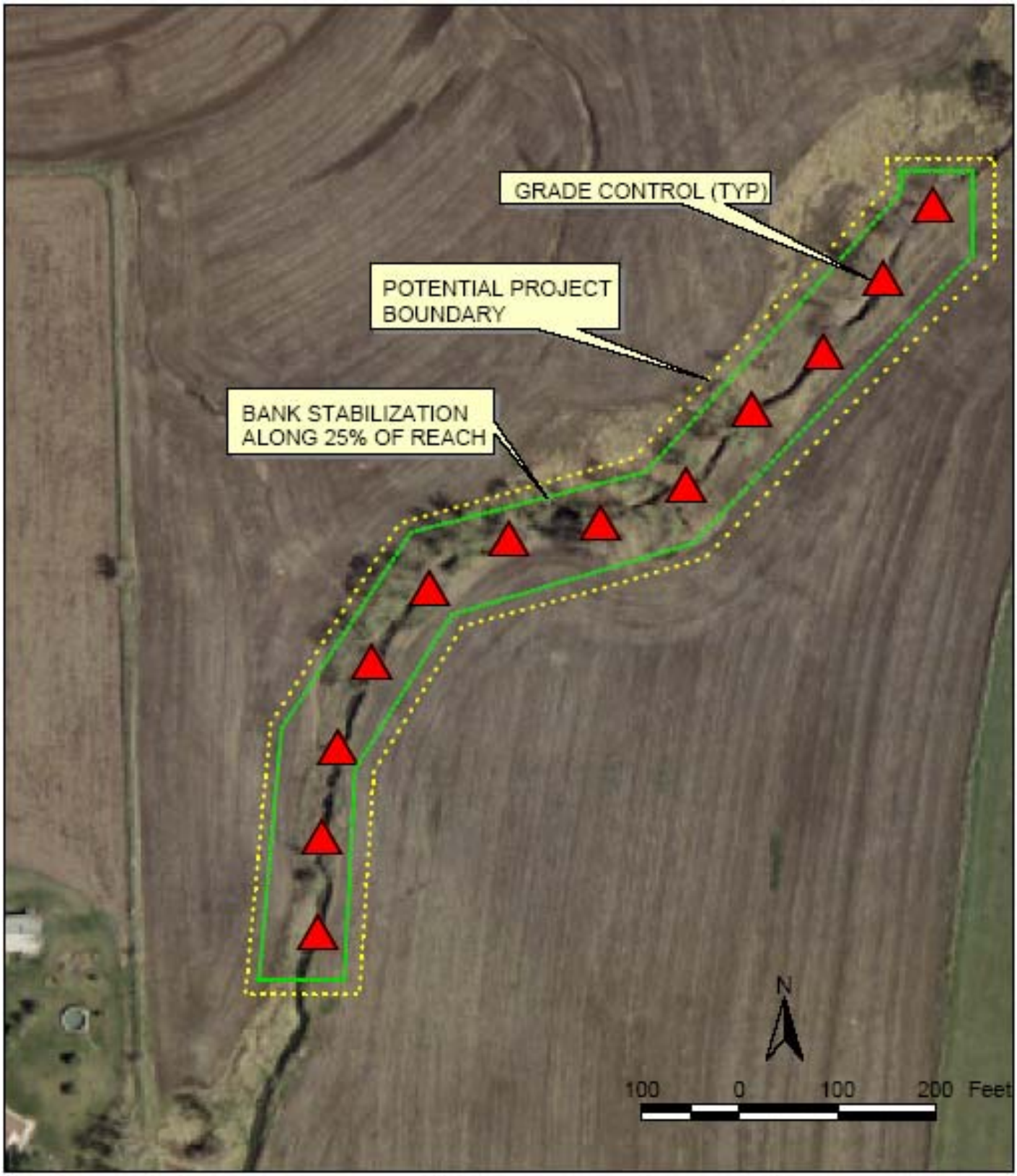
Figure 9-9

Intervention 8. Tributary 35, River Mile 9.878 to 9.575 - Grade control incising channel

Problem description: Channel incision along Tributary 35 has resulted in steep eroding banks and wedge failures. The reach appears to have been previously straightened, a possible contributor to the incision. Nine knickpoints occur along this project reach, each approximately 0.5 to 1 foot vertical drop through consolidated clay or silty clay. There is little in the way of woody riparian corridor and consequently little root reinforcement for the streambanks. No infrastructure or buildings lie along this reach. The threat to the basin lies in the continued generation of sediment damaging both water quality and physical stability of the receiving waters.

Recommended intervention: This is a straightforward application of grade stabilization. A drop of approximately one foot across each grade control is appropriate here. Small, Newbury-style rock structures should be designed to establish a stable slope for a channel bed of this strength. Vegetating the downstream edges of the rock structures is useful for additional energy dissipation and for managing the transition between structure and native channel material. Bank stabilization here is generally limited to restoring areas damaged by grade control installation (Figure 9-10).

Estimated Construction Cost: $309,000



INTUITION & LOGIC

Stevens Creek Intervention #8
Tributary 35 – River Mile 9.878 to 9.575

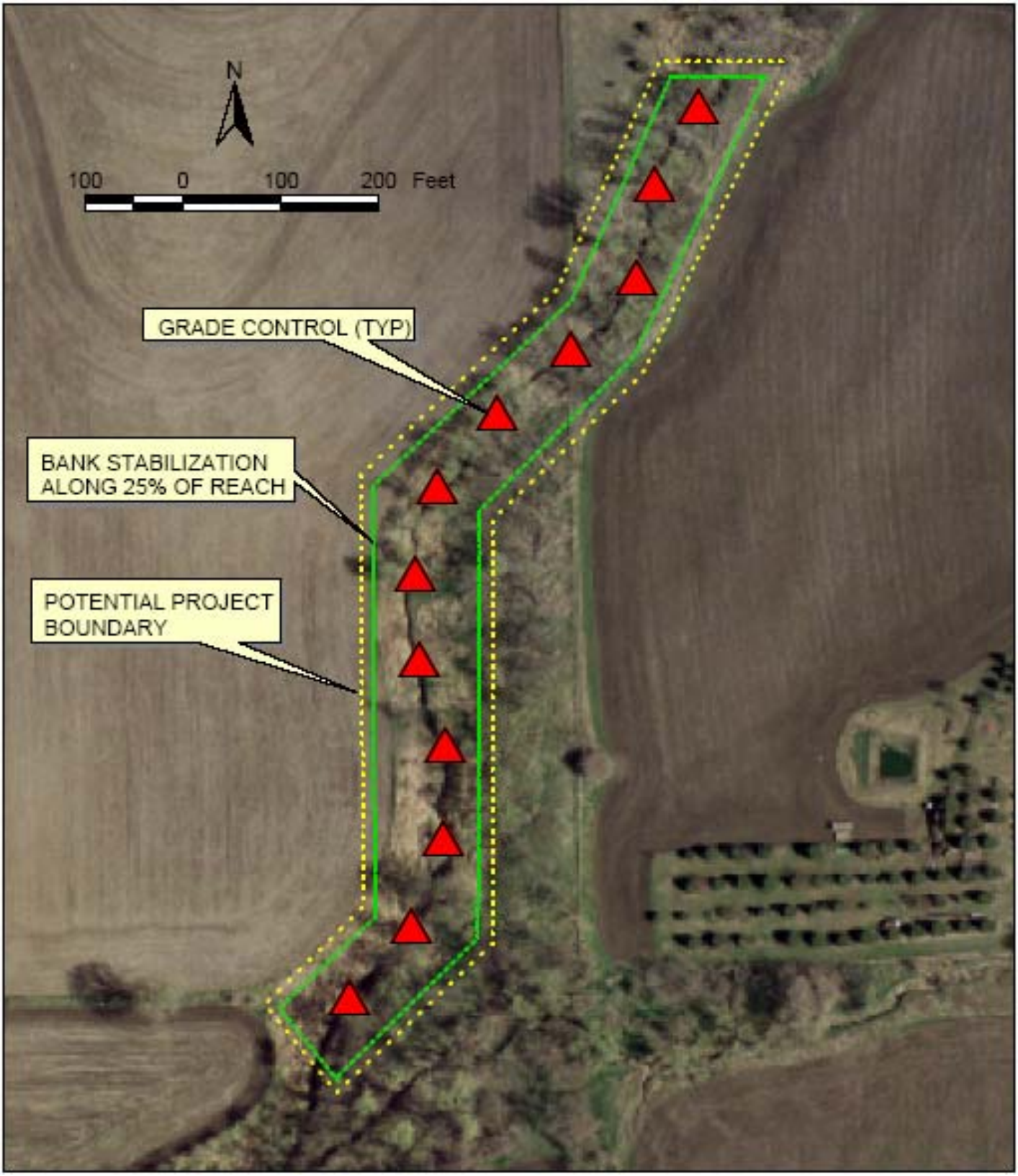
Figure 9-10

Intervention 9. Tributary 35, River Mile 9.239 to 8.844 - Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated steep eroding banks and frequent bank failures. Several knickpoints mark dramatic changes in channel bed elevation of more than one foot, including the 3-foot knickpoint immediately downstream of Tributary 35, River Mile 9.234 and an unarmored knickpoint in the clay bed at Tributary 35, River Mile 9.160. Wedge failures are common in this reach. The incision is progressing upstream unimpeded and unless arrested, will continue to liberate sediment damaging to water quality and downstream stability.

Recommended intervention: A series of rock grade control structures is an appropriate treatment here (Figure 9-11). The series, taken as a group, should re-establish a stable grade for the channel bed so that the upstream progress of incision is stopped. The drops at major knickpoints should be distributed over multiple rock structures. A drop of approximately one foot over each grade control should be sufficient. Although the banks are in generally poor condition, once incision is stopped, they may begin to self-heal. Most of the bank restoration effort is directed to repairing areas damaged by grade control construction.

Estimated Construction Cost: $356,000



INTUITION & LOGIC

Stevens Creek Intervention #9
Tributary 35 – River Mile 9.239 to 8.844

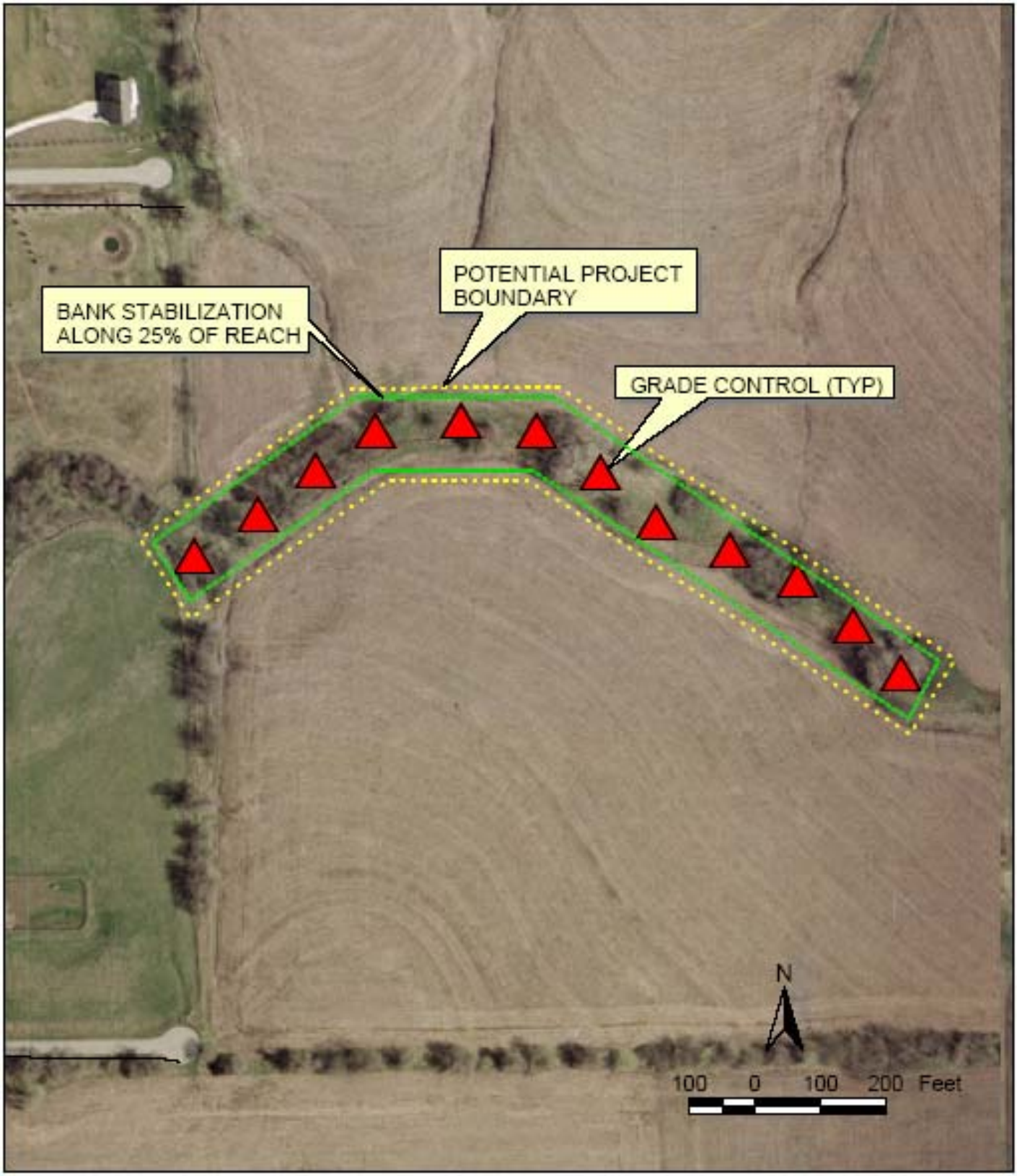
Figure 9-11

Intervention 10. Tributary 130, River Mile 7.754 to 7.489 - Grade control incising channel

Problem description: Tributary 130 is a narrow, entrenched channel with persistent incision-induced bank erosion along the upper 1,500 feet of channel. Bank failures are common throughout the reach. Occasionally the bank failures have doubled the top-of-bank width. The tributary continues to incise and has no existing structure in this reach that is likely to arrest the downcutting in the near future. In this lower reach of the tributary, the canopy cover is poor and there is little root reinforcement of the streambanks. The eroded banks contribute excessive sediment downstream where it impairs water quality. In addition the liberated sediment may contribute to physical instability in the receiving waters.

Recommended intervention: Grade stabilization is the appropriate remedy for both the incision and the bank erosion (Figure 9-12). By re-establishing a stable channel grade, the driving force for continued bank failure is removed and some degree of self-healing can begin. As is the case throughout the basin, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. A drop of one foot or less across each rock structure and construction of a gently sloped tail ramp should be sufficient. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure.

Estimated Construction Cost: $217,000



INTUITION & LOGIC

Stevens Creek Intervention #10
Tributary 130 – River Mile 7.754 to 7.489

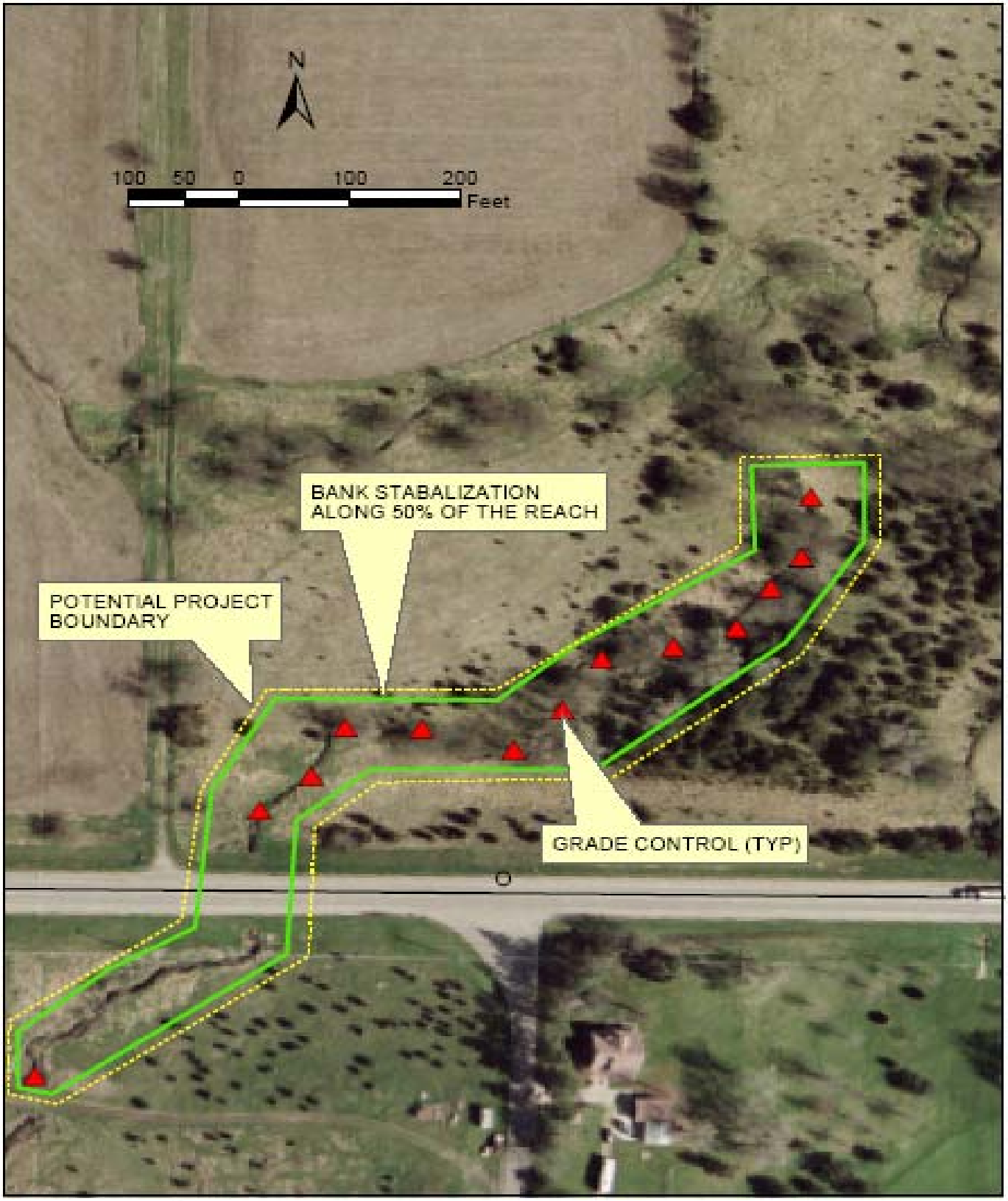
Figure 9-12

Intervention 11. Tributary 30, River Mile 9.972 to 9.364 - Grade control incising channel and armor plunge pool at culvert outfall

Problem description: This tributary has degraded throughout its length. Since the installation of the culvert illustrated at left (a private drive upstream of O Street), the channel has incised approximately 4.5 feet. The culvert provides no energy dissipation and the resulting scour of both bed and bank may eventually threaten the integrity of the crossing. North of the crossing, the woody riparian corridor is sparse and provides little bank protection.

Recommended intervention: Arresting the incision in this reach requires a series of rock grade controls (Figure 9-13). Newbury-style grade structures with gradually sloping tail ramps are appropriate here. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank. The downstream side of the culvert requires construction of a riprap lined scour pool to dissipate energy properly. The scour pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. The poor condition of the woody corridor and the extensive grade control required here also necessitates restoration of approximately 50% of the streambank. Most of this effort is concentrated at areas disturbed by grade control construction but also includes establishment of trees and shrubs along the denuded bank.

Estimated Construction Cost: $703,000



INTUITION & LOGIC

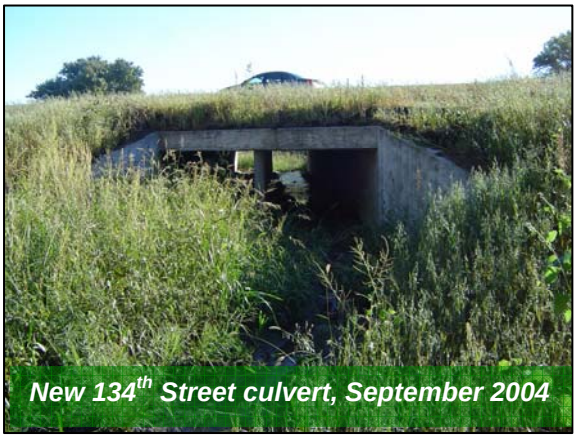
Stevens Creek Intervention #11
Tributary 30 – River Mile 9.972 to 9.364

Figure 9-13

Intervention 12. Tributary 250, River Mile 12.692 to 11.740 - Grade control channel

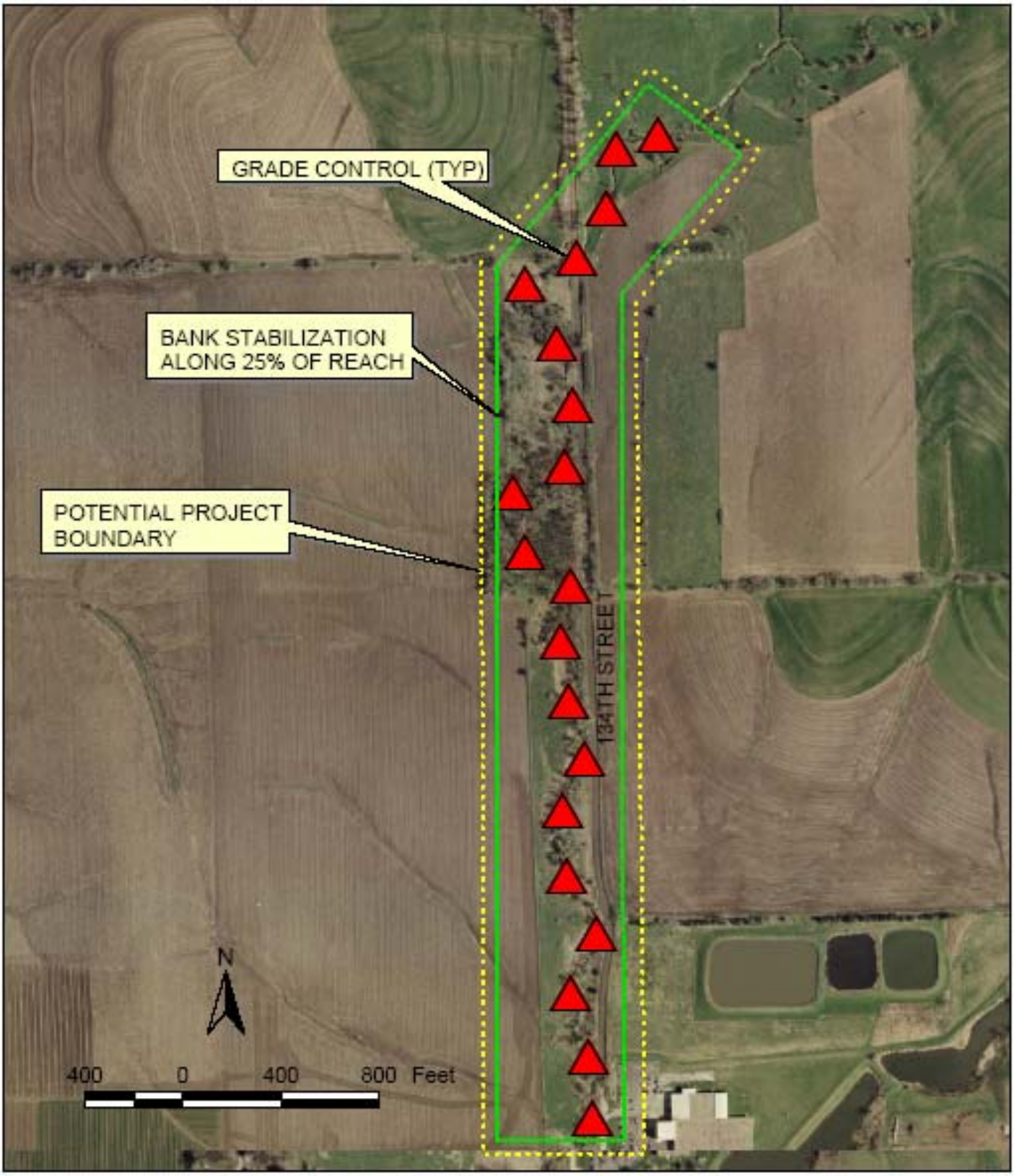
134 Street culvert, March 2004

Problem description: During the field reconnaissance of Tributary 250 in March 2004, the culvert under 134th Street had an invert 3 feet above pool elevation and both banks were severely eroded. The culvert has since been replaced with a double box culvert at channel grade, and local bank scouring in the vicinity of 134th Street has been repaired (see picture below). However, bank erosion extends downstream as a result of continued channel incision. The reach confined by the farm fields and 134th Street is distinctly less sinuous than the adjacent streams. The additional increase in channel slope caused by a presumed straightening has increased the driving force for incision. Knickpoints are common throughout the reach occurring roughly 500 feet apart. In addition to bank failures and threats to infrastructure, this tributary supplies excess sediment to the receiving waters degrading water quality and potentially decreasing physical instability. If left untreated, channel incision will progress upstream, posing a threat to the new culvert at 134th Street.


New 134th Street culvert, September 2004

Recommended intervention: Downstream of the culvert, a series of rock grade control structures will control channel grade and dissipate scouring energy. In addition, three grade controls upstream of 134th Street will mitigate a draw-down effect, resulting from the lower elevation of the new culvert, which could exacerbate existing erosion problems upstream. In this basin, relatively flat Newbury-style structures are appropriate. The grade change across each structure should be no more than 1 foot.

Estimated Construction Cost: $906,000



INTUITION & LOGIC

Stevens Creek Intervention #12
Tributary 250 – River Mile 12.692 to 11.740

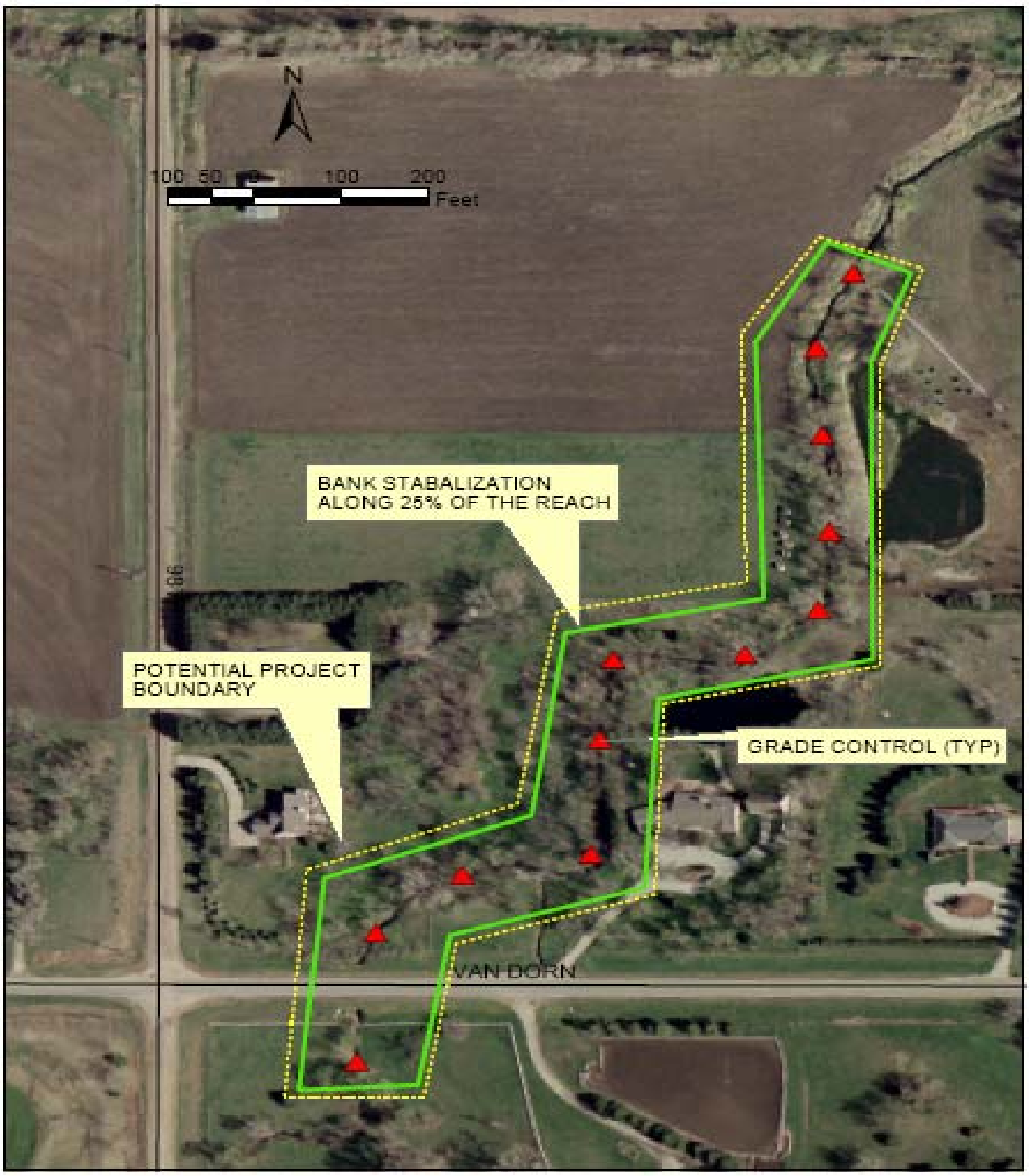
Figure 9-14

Intervention 13. Tributary 45, River Mile 13.762 to 13.468 - Grade control incising channel

Problem description: Extensive bank scouring and erosion caused by channel incision dominate this reach of Tributary 45. The knickpoints are relatively close together (five occur between 98th Street and Van Dorn) and are typically reinforced by woody debris jams. Natural streams in this region often self-manage incision by constructing grade controls from large woody debris. In undisturbed conditions, this may be sufficient to stabilize grade and re-acquire dynamic equilibrium. In this developing watershed, however, the risks associated with relying exclusively on debris jams for incision control outweigh the benefits. In addition to raising flood levels, the debris jams may fail under intense flows potentially blocking bridges or culverts.

Recommended intervention: A series of rock structures provides more persistent grade stabilization than debris jams. The structures should be hydraulically rough, shaped in plan, profile and section to direct flows to the center of the channel and relatively flat. Producing a stable, non-eroding channel grade removes most of the driving force for bank failures. For this reason, extensive bank stabilization is not warranted and most of the bank effort is focused on repairing the areas disturbed by grade control installation (Figure 9-15).

Estimated Construction Cost: $299,000



INTUITION & LOGIC

Stevens Creek Intervention #13
Tributary 45 – River Mile 13.762 to 13.468

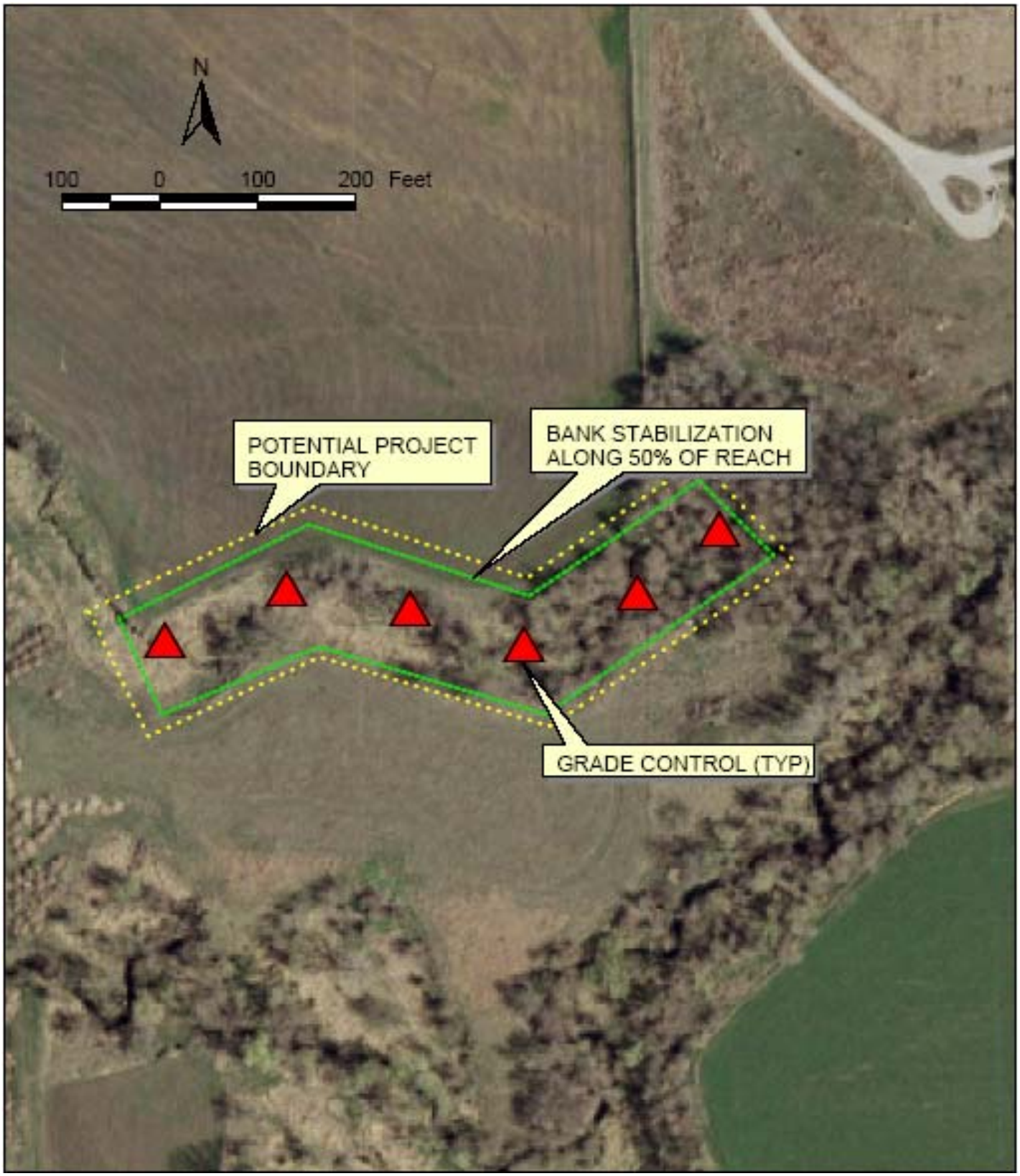
Figure 9-15

Intervention 14. Tributary 445, River Mile 12.802 to 12.656 - Grade control existing knickpoints

Problem description: Tributary 445 is an incising stream, with several knickpoints occurring between the confluence with Tributary 45 and the headwaters reach of the tributary. Although previous incision and occasional bank scour is apparent in the tributary, this stream also exhibits signs of recovery. Parts of the reach are now metastable and barring additional insult, should self-manage. However, the receiving waters, Tributary 45 is continuing to incise and a knickpoint in Tributary 445 indicates that this grade change is propagating up the sub-tributary. Unless arrested, another wave of incision will move through this sub-basin.

Recommended intervention: The active knickpoints should be arrested. A series of rock grade controls is an appropriate treatment (Figure 9-16). In the relatively erodible soils of the Stevens Creek Watershed, Newbury-style structures effectively manage grade changes without inducing scour. The change in grade should be distributed over a series of structures with no one grade control dropping more than approximately one foot. The structures should be hydraulically rough and should be shaped in plan, section and profile to focus the flow towards the center of the channel. The focus of the bank stabilization is repair of areas disturbed by grade control construction.

Estimated Construction Cost: $307,000



INTUITION & LOGIC

Stevens Creek Intervention #14
Tributary 445 – River Mile 12.802 to 12.656

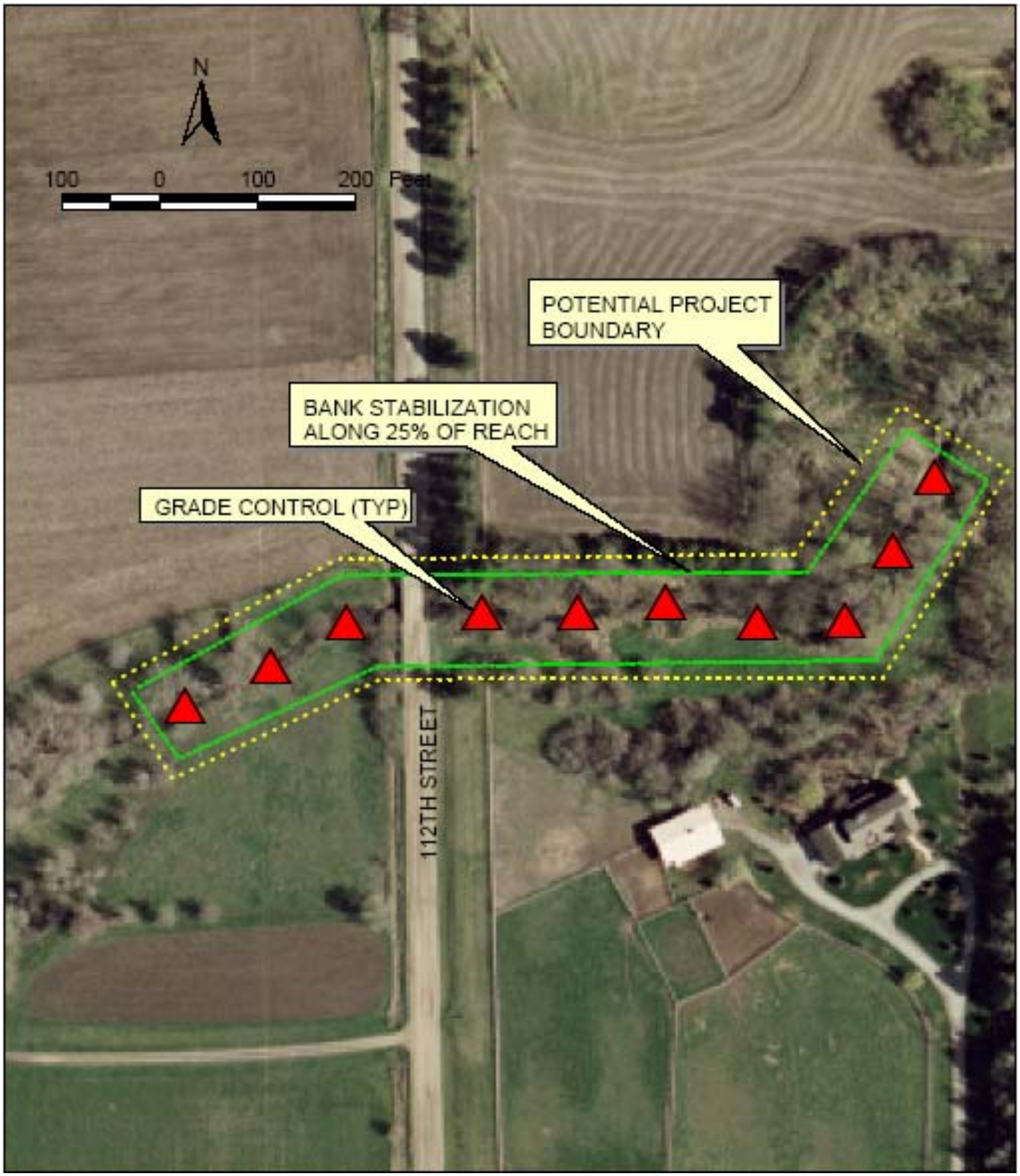
Figure 9-16

Intervention 15. Tributary 45, River Mile 12.114 to 11.641 - Grade control incising channel

Problem description: Channel incision has resulted in widespread bank scouring and erosion between Tributary 45, River Mile 2.727 and 2.254. Circular and wedge failures continue to introduce large volumes of sediment and woody debris into the channel. Several woody debris jams appear to have slowed the advance of incision. However, the effects of incision do not subside upstream, and continued damage to surrounding farm fields and riparian corridor is likely without intervention.

Recommended intervention: Constructing a series of rock grade controls is necessary to halt channel incision and prevent systemic bank erosion. As is the case throughout the watershed, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. A drop of one foot or less across each rock structure and construction of a gently sloped tail ramp should be sufficient. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure (Figure 9-17).

Estimated Construction Cost: $435,000



INTUITION & LOGIC

Stevens Creek Intervention #15
Tributary 45 – River Mile 12.114 to 11.641

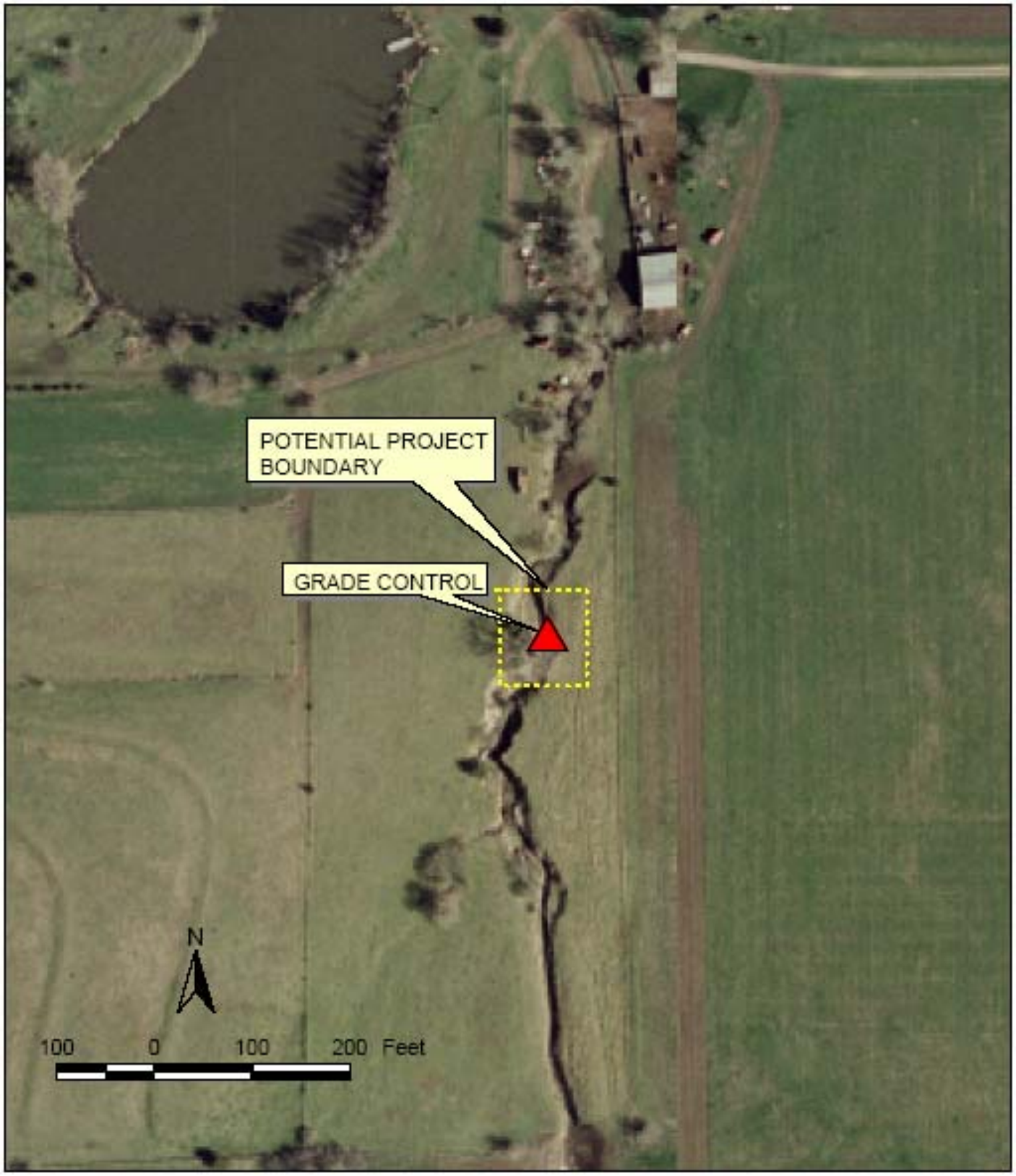
Figure 9-17

Intervention 16. Tributary 345, River Mile 12.406 to 12.403 - Grade control existing knickpoint

Problem description: A 3.5-foot headcut occurs in silty clay bed material along Tributary 345, near River Mile 12.406. The advancing headcut has precipitated widespread bank erosion downstream. Upstream of the headcut, past channel incision has resulted in a deep, "V"-shaped channel with banks very near critical bank height. Should the headcut continue to advance unimpeded, this would likely aggravate existing erosion problems upstream as banks exceeded critical bank height.

Recommended intervention: A rock grade control is recommended to halt the advancing headcut and maintain a stable channel grade upstream. A single, strategically placed grade control will alleviate the driving force for bank failure and avert an otherwise costly stream restoration effort in the future, as banks fail catastrophically once they have exceeded critical bank height (Figure 9-18).

Estimated Construction Cost: $35,000



INTUITION & LOGIC

Stevens Creek Intervention #16
Tributary 345 – River Mile 12.406 to 12.403

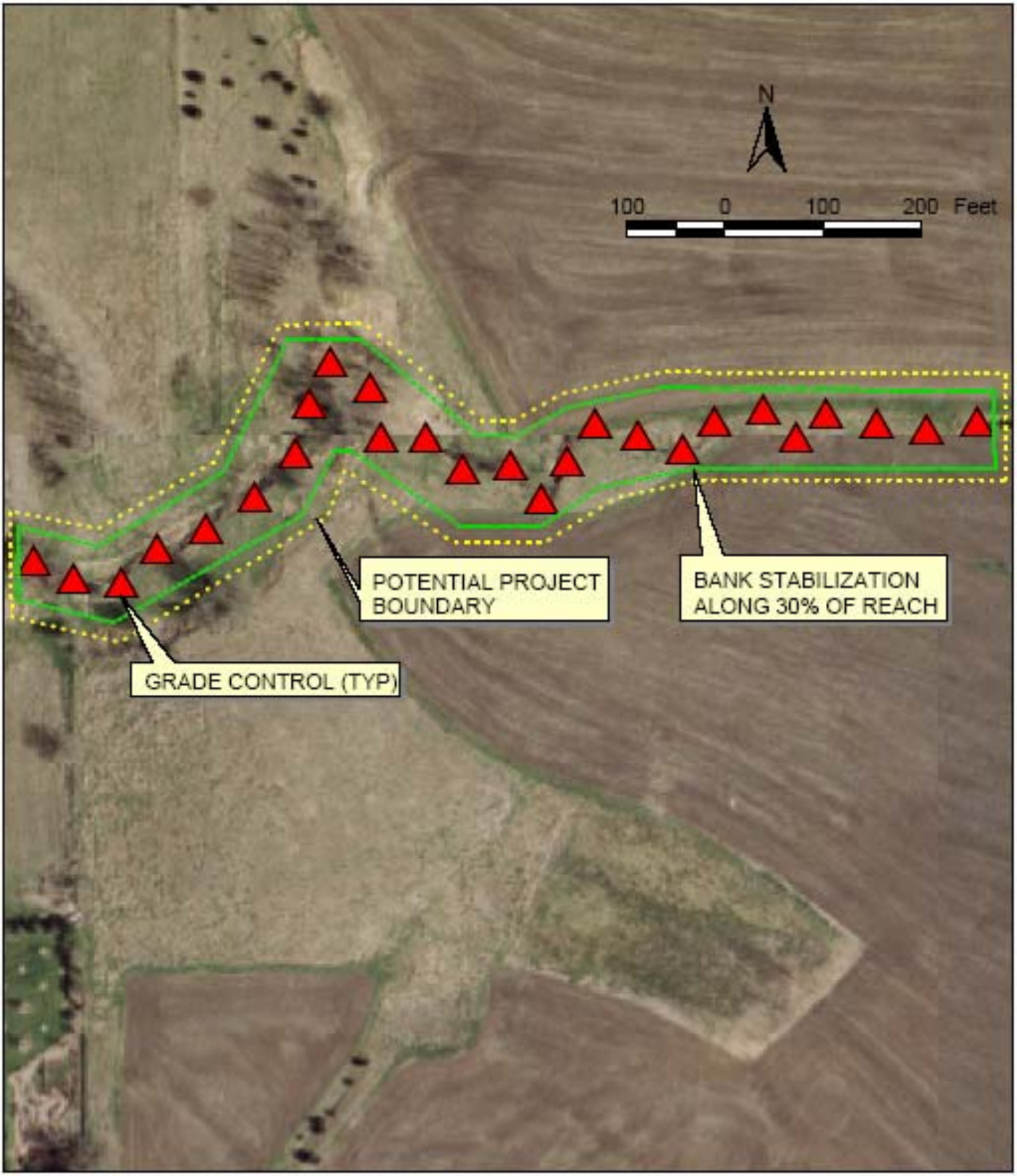
Figure 9-18

Intervention 17. Tributary 545, River Mile 13.579 - Grade control incising channel and restore streambanks

Problem description: Channel incision and subsequent widening along Tributary 545 has initiated severe bank erosion and mass wasting as banks exceeded critical bank height. While channel incision has been slowed by several large woody debris jams acting as *de facto* grade controls, widening occurring between knickpoints continues to liberate sediment from the streambanks and undermine trees, compromising channel stability and impairing water quality.

Recommended intervention: Constructing a series of rock grade controls is necessary to replace existing woody debris jams and stop systemic bank erosion (Figure 9-19). By re-establishing a stable channel grade, the driving force for continued bank failure is removed and some degree of self-healing can begin. As is the case throughout the watershed, relatively flat, Newbury-style rock structures effectively manage the grade change through the reach without inducing excessive scour downstream of the structure. Approximately 26 grade controls, each accommodating a 1-foot drop in channel bed elevation, are recommended to achieve a stable channel grade along the 3,000-foot reach. Vegetating the edges of the structures provides additional scour protection and manages the transition between native channel material and installed structure. Where the effects of mass wasting and erosion are particularly severe, regrading and vegetating the banks will be necessary to provide a stable bank shape and hydraulic roughness.

Estimated Construction Cost: $659,000

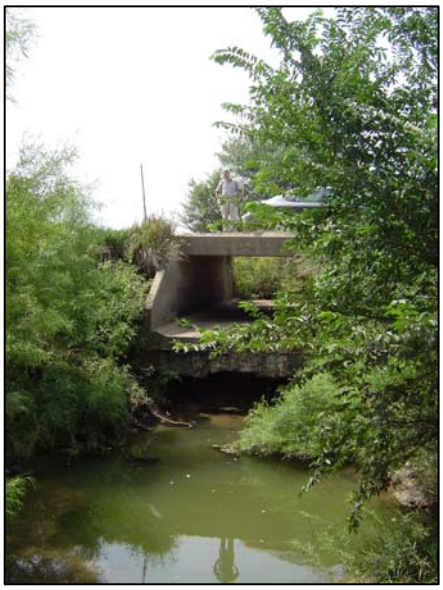


INTUITION & LOGIC

Stevens Creek Intervention #17
Tributary 545 – River Mile 13.579

Figure 9-19

Intervention 18. Tributary 545, River Mile 13.579 - Armored plunge pool downstream of 98th Street culvert



Problem description: Bed scouring downstream of 98th Street has produced a 2-foot drop at the culvert outfall. Due to a lack of bed armoring, localized scouring continues to undermine the lip of the concrete box, threatening the structural integrity of the culvert.

Recommended intervention: Due to the severity of localized erosion downstream of 98th Street, a riprap-armored plunge pool at the culvert outfall is necessary to dissipate energy and prevent continued bed scouring (Figure 9-20). The armored plunge pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Both banks are already well-vegetated and show no signs of fresh erosion. Therefore, additional bank stabilization is not needed.

Estimated Construction Cost: $137,000

INTUITION & LOGIC

Stevens Creek Intervention #18
Tributary 545 – River Mile 13.579

Figure 9-20

Intervention 19. Tributary 45, River Mile 0.042 to 0.008 - Grade control confluence

Problem description: A headcut occurs along Tributary 45, no more than 40 feet upstream from the confluence with Stevens Creek Lower Main Stem. Channel incision along Tributary 45 has resulted in widespread bank erosion and failures, and the upstream advance of yet another headcut would aggravate existing erosion problems along this tributary.

Recommended intervention: The active knickpoint upstream of the confluence should be arrested. A Newbury-style grade control structure will effectively manage grade changes in the lower reach of Tributary 45 without aggravating existing bank scour. The change in grade can be accommodated in a single structure with a grade change of approximately 1 foot (Figure 9-21). The structures should be hydraulically rough and should be shaped in plan, section and profile to focus the flow towards the center of the channel. The focus of the bank stabilization is repair of areas disturbed by grade control construction.

Estimated Construction Cost: $44,000

INTUITION & LOGIC

Stevens Creek Intervention #19
Tributary 45 – River Mile 9.429 to 9.395

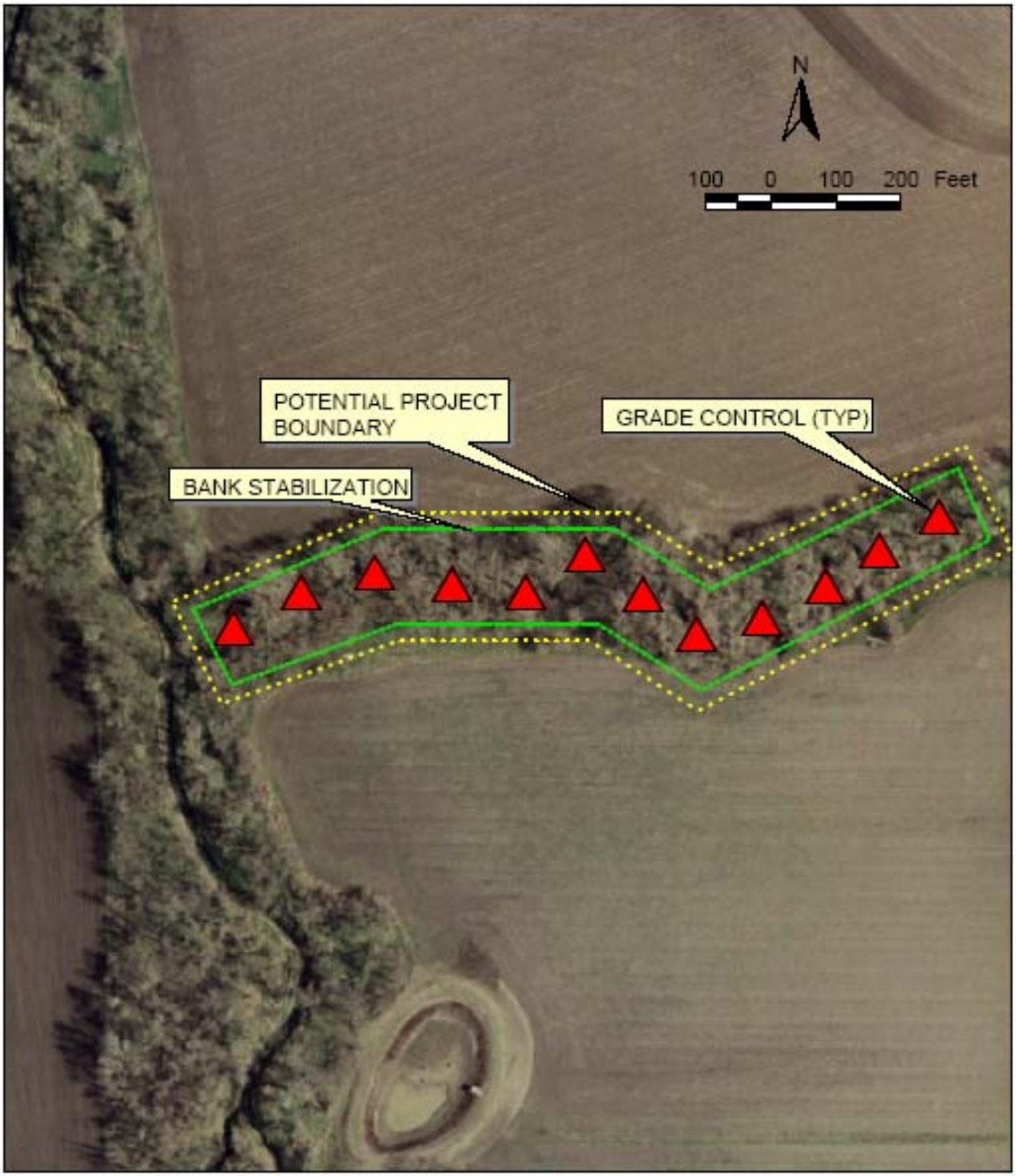
Figure 9-21

Intervention 20. Tributary 55, River Mile 11.472 to 11.245 - Grade control incising channel

Problem description: Tributary 55 is a deeply incised channel with several severe knickpoints occurring along the lower 1,400 feet of channel. The largest and most dramatic example is a 4-foot headcut in consolidated clay or till bed material near River Mile 11.472. In contrast to other incising reaches encountered in the Stevens Creek Watershed, woody debris and toppled trees have failed to slow incision along Tributary 55. It appears that incision will continue unimpeded, resulting in substantial damage to the stream, without additional interventions.

Recommended intervention: Arresting the incision in this reach requires a series of Newbury-style rock grade controls. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank (Figure 9-22). The poor condition of the woody corridor and the extensive grade control required along this reach also necessitates restoration of 100% of the streambank. This effort includes both areas disturbed by grade control construction as well as the establishment of trees and shrubs along the entire intervention reach.

Estimated Construction Cost: $460,000



INTUITION & LOGIC

Stevens Creek Intervention #20
Tributary 55 – River Mile 11.472 to 11.245

Figure 9-22

Intervention 21. Tributary 65, River Mile 12.547 to 12.536 - Armored plunge pool downstream of 134th Street culvert

Problem description: The 134th Street culvert has an exceptionally steep grade and, as a result, the bed and banks at the culvert outfall are severely scoured. In addition, incision up to the culvert outfall has aggravated bank erosion immediately downstream.

Recommended intervention: Constructing an armored plunge pool at the culvert outfall will dissipate hydraulic energy and prevent continued bank erosion at the culvert outfall (Figure 9-23). The armored plunge pool should be sized to release flows at shear stresses below the critical shear strength of the native channel material. A critical design feature of the armored plunge pool is the addition of a grade control outfall, keyed-in deep into the channel bed to prevent channel incision from potentially undermining the structure. The grade control outfall will also focus flow toward the center of the channel, thereby reducing stress along both banks.

Estimated Construction Cost: $137,000

INTUITION & LOGIC

Stevens Creek Intervention #21
Tributary 65 – River Mile 12.547 to 12.536

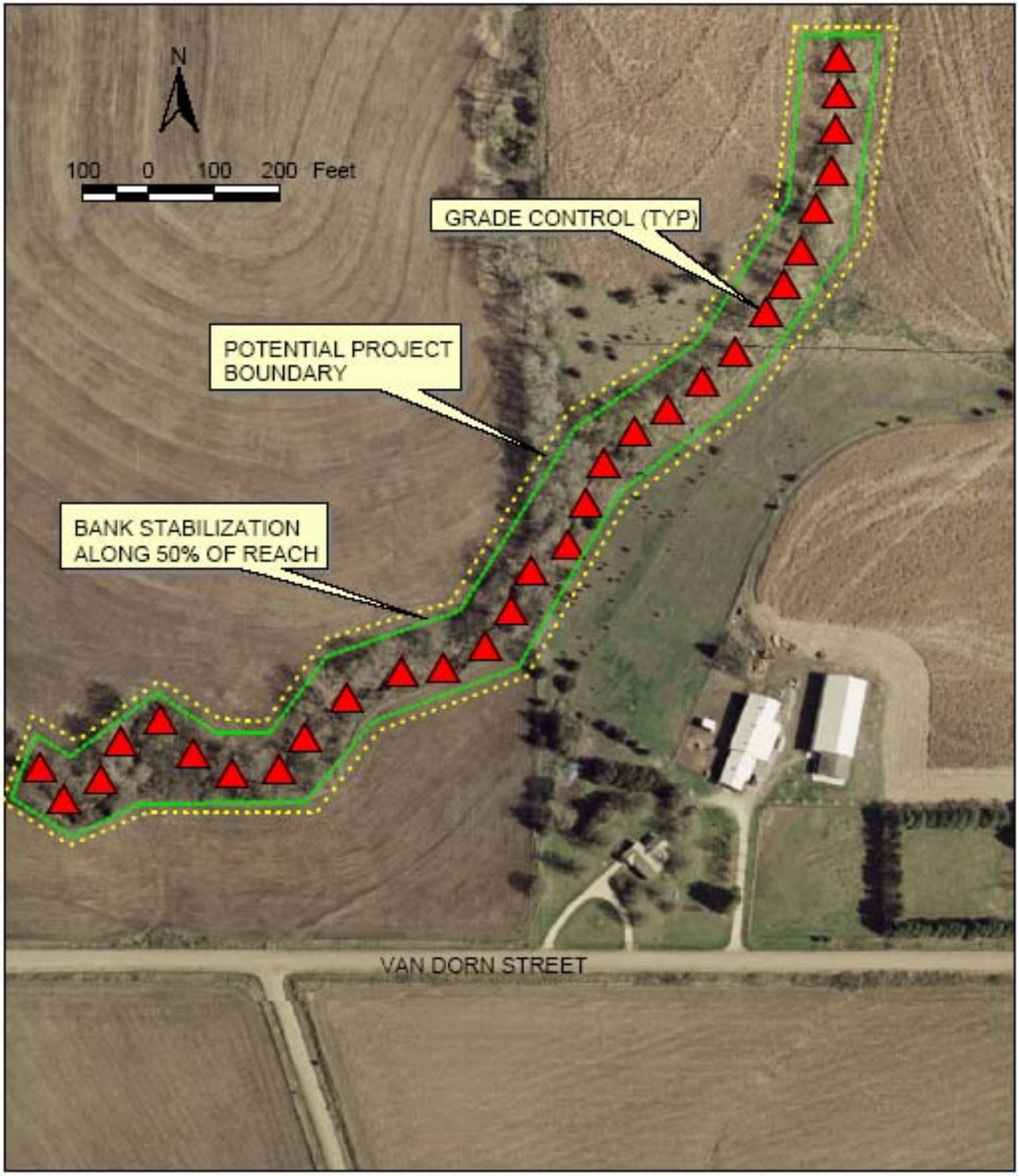
Figure 9-23

Intervention 22. Tributary 65, River Mile 12.945 to 12.547 – Grade control existing knickpoint

Problem description: The extent of channel incision along Tributary 65 is marked by a 5-foot headcut near Tributary 65, River Mile 12.949. The upstream advance of the headcut appears to have been temporarily slowed by dumped concrete slabs and debris acting as a *de facto* grade control. Continued incision along this reach will eventually undermine the concrete slabs and debris that are currently supporting a stable channel grade upstream, liberating additional sediment, and posing a threat to channel stability and water quality.

Recommended intervention: The existing concrete rubble and debris should be removed and replaced with a series of grade controls extending downstream to Tributary 65, River Mile 12.911 (Figure 9-24). Small, Newbury-style rock structures should be designed to establish a stable slope. The drops at major knickpoints should be distributed over multiple rock structures. Although the banks along Tributary 65 are in poor condition, once incision is stopped, they may begin to self-heal.

Estimated Construction Cost: $332,000



INTUITION & LOGIC

Stevens Creek Intervention #22
Tributary 65 – River Mile 12.949 to 12.911

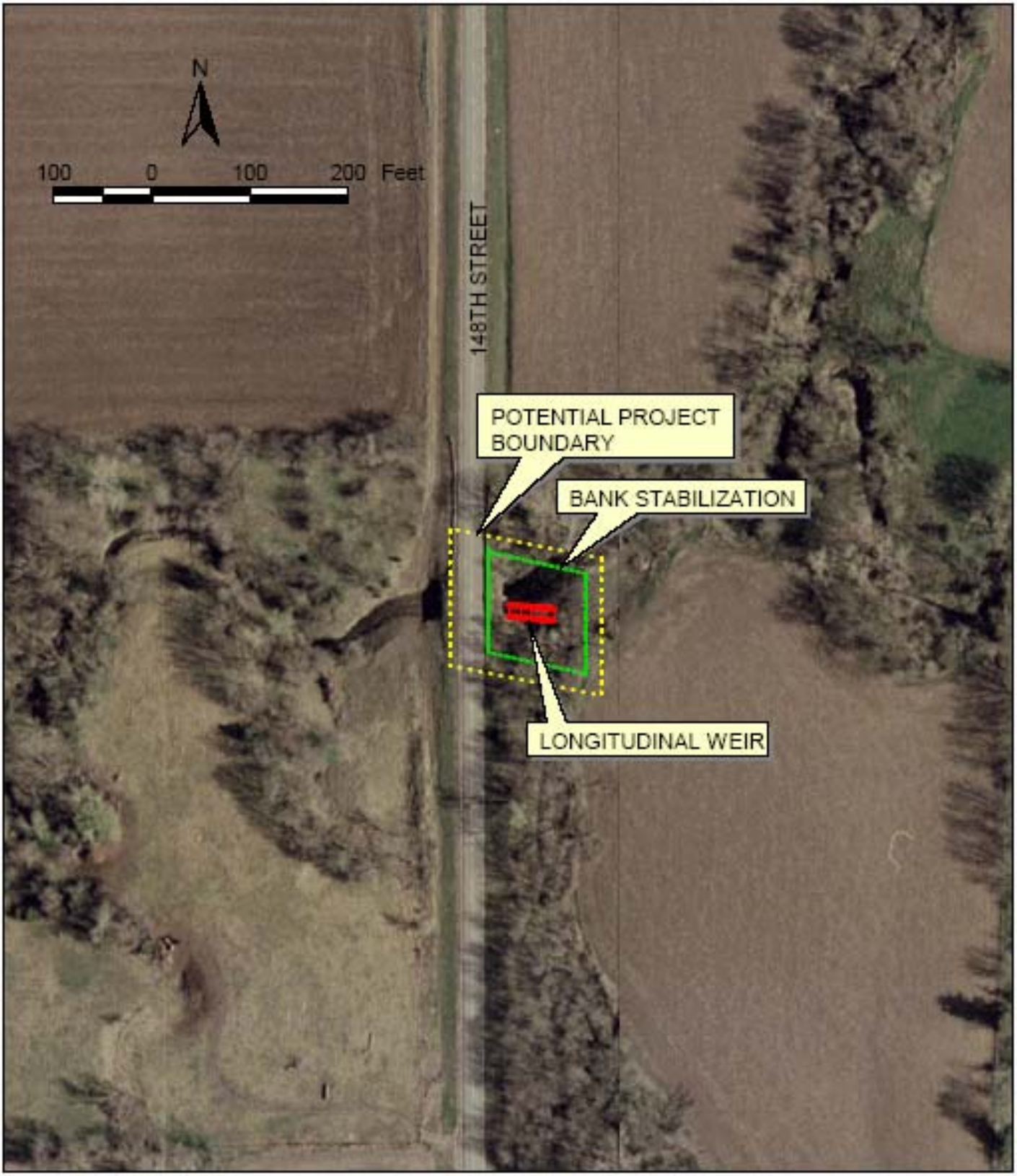
Figure 9-24

Intervention 23. Tributary 70, River Mile 15.283 – Longitudinal weir upstream of culvert

Problem description: Deposition and accumulation of large woody debris in the right descending box of the 148th Street culvert has reduced hydraulic capacity and poses an increased flood risk. While simply removing the deposition and debris may temporarily increase capacity through the culvert, it would also induce upstream erosion as the stream re-establishes a stable hydraulic grade, and eventually replace the removed material with freshly eroded sediment and debris.

Recommended intervention: The long-term solution is to remove the accumulated debris upstream of the culvert and to replace it with a longitudinal weir (Figure 9-25). The weir would be designed to direct low flow through a single box, maintaining sediment transport continuity during stream-forming flow, but allowing for additional flow capacity through the second box during higher flood flows.

Estimated Construction Cost: $71,000



INTUITION & LOGIC

Stevens Creek Intervention #23
Tributary 70 – River Mile 15.283

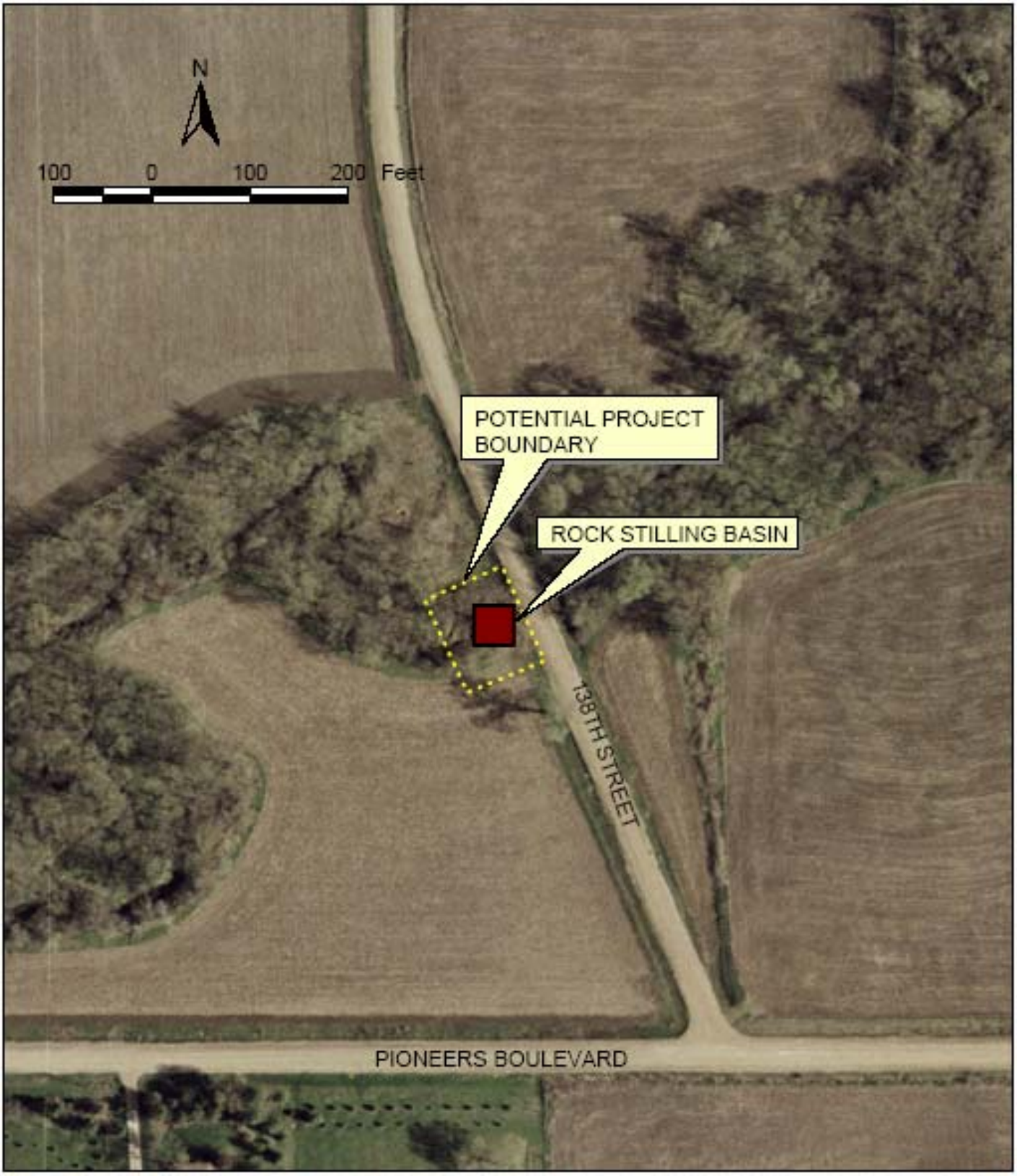
Figure 9-25

Intervention 24. Tributary 75, River Mile 15.056 – Stilling basin with grade control outfall

Problem description: Past incision has scoured the channel bed along Tributary 75, leaving the 138th Street culvert outfall perched 4.5 feet above the channel bed. In addition, a series of knickpoints downstream of the culvert, near the confluence with Stevens Creek Upper Main Stem, indicates more recent channel incision advancing upstream, posing an added threat to the already undermined culvert.

Recommended intervention: Constructing an armored stilling basin at the culvert outfall will dissipate hydraulic energy and protect the bed and banks from the effects of localized scour (Figure 9-26). The stilling basin should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Similar to previously described outfall protection, a key design element of the stilling basin is the addition of a grade control outfall. The grade control outfall must be keyed-in deep into the channel bed to prevent channel incision from undermining the structure.

Estimated Construction Cost: $137,000



INTUITION & LOGIC

Stevens Creek Intervention #24
Tributary 75 – River Mile 15.056

Figure 9-26

Intervention 25. Tributary 60, River Mile 11.320 to 11.314 – Stilling basin with grade control outfall

Problem description: Tributary 60 is currently widening subsequent to channel incision. The extent of past incision is indicated by the 4-foot culvert invert at Old Cheney Road. Localized scouring at the culvert outfall and a lack of hydraulic roughness along both banks has left both the bed and banks severely eroded.

Recommended intervention: Constructing an armored stilling basin at the culvert outfall will dissipate hydraulic energy and reduce the driving force for localized widening downstream of the culvert (Figure 9-27). The stilling basin should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed. Vegetating the riprap along the banks and at the downstream end of the proposed stilling basin will provide additional hydraulic roughness and reduce shear stress along the banks and at the downstream end of the basin.

Estimated Construction Cost: $90,000

INTUITION & LOGIC

Stevens Creek Intervention #25
Tributary 60 – River Mile 11.320 to 11.314

Figure 9-27

Intervention 26. Tributary 85, River Mile 17.810 to 17.582 – Grade control incising reach and protect culvert outfall

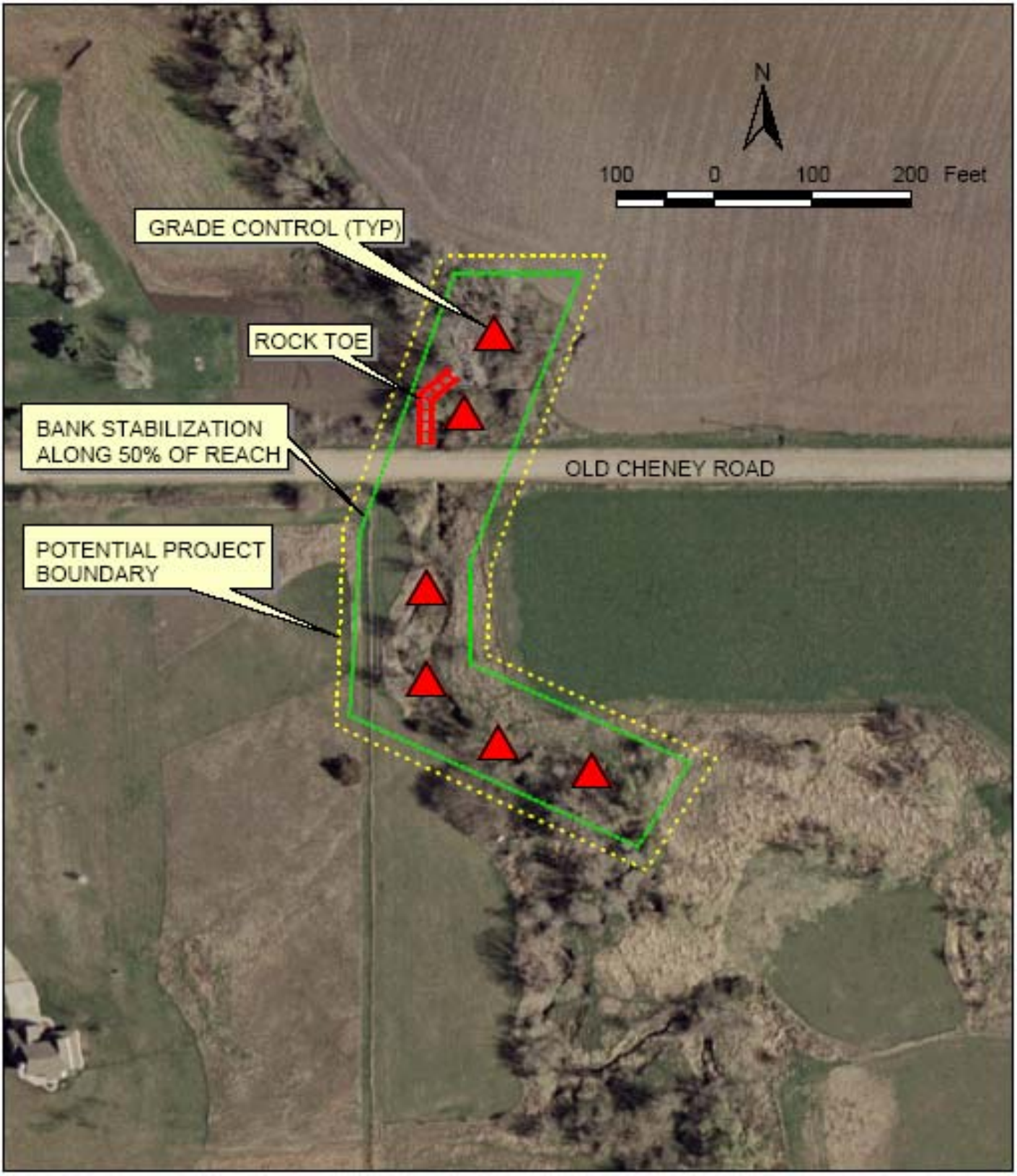
Problem description: Channel incision upstream of Old Cheney Road has resulted in extensive bank failures between Tributary 85, River Mile 17.810 and 17.852. Bank erosion is particularly severe immediately upstream from the Old Cheney culvert, where wedge failures continue to erode the bank no more than 8 feet from a fence along the top of the right descending bank.

Downstream of Old Cheney culvert both banks are eroded as a result of localized scouring and a lack of hydraulic roughness at the culvert outfall.

Recommended intervention: Arresting channel incision upstream of Old Cheney requires a series of rock grade controls (Figure 9-28). Newbury-style grade structures with gradually sloping tail ramps are appropriate here. Vegetating the downstream edges of the rock structures provides additional energy dissipation and protection for the interface between rock and native bank. Additional bank stabilization includes streambanks immediately upstream of Old Cheney. Rock toe armor along the right descending bank will deflect flow away from the bank and reduce stress at the bank toe.

Downstream of the Old Cheney culvert requires construction of a riprap-lined scour pool and grade controls to dissipate energy properly. The scour pool should be sized so that the applied shear stress at the downstream edge does not exceed the critical shear strength of the bed.

Estimated Construction Cost: $203,000



INTUITION & LOGIC

Stevens Creek Intervention #26
Tributary 85 – River Mile 17.810 to 17.582

Figure 9-28

9.3 Capital Improvement Projects

A priority scheme was used to develop a CIP list to address the 26 primary problem areas. After the interventions are rated by priority, each intervention is ranked as low, medium and high based on its location in the watershed and its potential to affect other reaches. Interventions are ranked high if they are in the bottom of the watershed or possess other characteristics that potentially affect larger amounts of stream than other interventions of the same priority. For example, an intervention may be ranked high because it is a single headcut with the potential to propagate up an entire reach.

Interventions are ranked low if they have the potential to effect less amounts of stream or propagation of the problem is limited by physical characteristics such as culverts or large amounts of woody debris. For example, an intervention may be ranked low because it is a single headcut in the headwaters of the sub-basin, has a small cross section and high debris jam potential.

Those interventions that are located in the mid portion of the watershed or subarea and possess no distinguishing characteristics that would qualify as a high or low rating, are rated medium. A construction sequence was developed based on the priority and ranking assigned to each intervention. The 18 priority 2 projects should be constructed before the 8 priority 3 projects.

Ten of the 18 priority 2 interventions are ranked high; therefore, these 10 projects are proposed for construction first. Four of the priority 2 interventions are ranked medium and these projects are proposed for construction second. Four priority 2 interventions are ranked low. These interventions are proposed for construction third. And finally, the priority 3 interventions all have a ranking of 4 and are proposed for construction last.

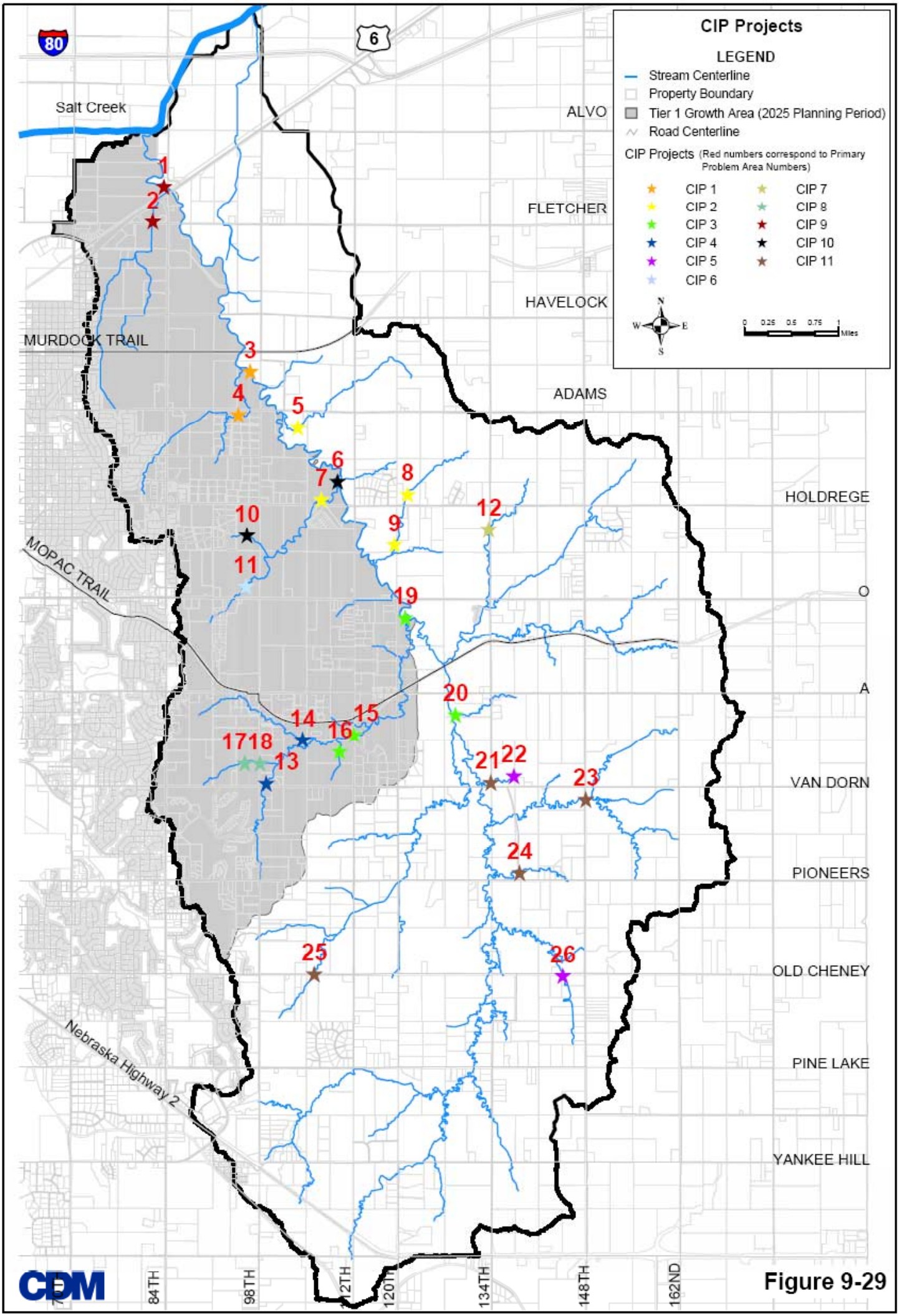
The next step was to define CIPs by grouping stream interventions by location and construction cost. Combining multiple stream interventions to form a CIP reduces overall project design costs for construction documents and engineering services. The target project cost for each CIP is $1,000,000.

Stream interventions 2 and 18 were each paired with another intervention of a higher construction sequence. These groupings are reasonable because the interventions are located close to those with which they were paired. The final groupings resulted in 11 CIPs as shown in Table 9-1 and illustrated on Figure 9-29. Surveying, engineering and construction management costs were estimated for each CIP as shown in Table 9-2. The total estimated cost for the 11 CIPs was $10.3 Million.

Detailed cost information is presented in Appendix K, located in Volume II of this report. Appendix K summarizes typical costs. All costs are in 2004 dollars and do not include land acquisition, hazardous waste remediation, utility relocation, or rehabilitation.

Table 9-1
Capital Improvement Project List

Capital Improvement Project	*Intervention Number*	*Tributary*	*Priority*	*Ranking*	*Construction Sequence*
1	**3**	ML	2	1-high	1
	4	10	2	1	1
2	**5**	20	2	1	1
	7	30	2	1	1
	9	35	2	1	1
	8	35	2	1	1
3	**19**	45	2	1	1
	15	45	2	1	1
	16	345	2	1	1
	20	55	2	1	1
4	**14**	445	2	2-medium	2
	13	45	2	2	2
5	**22**	65	2	2	2
	26	85	2	2	2
6	**11**	30	2	3-low	3
7	**12**	250	2	3	3
8	**17**	545	2	3	3
	18	545	3	4	4
9	**1**	ML	2	3	3
	2	5	3	4	4
10	**6**	ML	3	4	4
	10	130	3	4	4
11	**21**	65	3	4	4
	23	70	3	4	4
	24	75	3	4	4
	25	60	3	4	4


CIP Projects
LEGEND
Stream Centerline
Property Boundary
Tier 1 Growth Area (2025 Planning Period)
Road Centerline
CIP Projects (Red numbers correspond to Primary Problem Area Numbers)
CIP 1
CIP 2
CIP 3
CIP 4
CIP 5
CIP 6
CIP 7
CIP 8
CIP 9
CIP 10
CIP 11
N
W
E
S
0 0.25 0.5 0.75 1 Miles
80
6
Salt Creek
ALVO
FLETCHER
HAVELOCK
MURDOCK TRAIL
ADAMS
HOLDREGE
MOPAC TRAIL
O
A
VAN DORN
PIONEERS
OLD CHENEY
PINE LAKE
YANKEE HILL
Nebraska Highway 2
84TH
98TH
112TH
120TH
134TH
148TH
162ND
1
2
3
4
5
6
7
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26
CDM

Figure 9-29

Table 9-2
Capital Improvement Project Cost Estimate

CIP 1	
Construction:	
Intervention 3:	$229,000
Intervention 4:	$805,000
Surveying:	$57,000
Engineering:	$117,000
Construction Management:	$48,000
TOTAL	**$1,256,000**
CIP 3	
Construction:	
Intervention 15:	$435,000
Intervention 16:	$35,000
Intervention 19:	$44,000
Intervention 20:	$460,000
Surveying:	$52,000
Engineering:	$115,000
Construction Management:	$60,000
TOTAL	**$1,201,000**
CIP 5	
Construction:	
Intervention 22:	$332,000
Intervention 26:	$203,000
Surveying:	$37,000
Engineering:	$105,000
Construction Management:	$48,000
TOTAL	**$725,000**
CIP 7	
Construction:	
Intervention 12:	$906,000
Surveying:	$57,000
Engineering:	$107,000
Construction Management:	$48,000
TOTAL	**$1,118,000**
CIP 9	
Construction:	
Intervention 1:	$434,000
Intervention 2:	$98,000
Surveying:	$9,000
Engineering:	$80,000
Construction Management:	$36,000
TOTAL	**$657,000**
CIP 11	
Construction:	
Intervention 21:	$137,000
Intervention 23:	$71,000
Intervention 24:	$137,000
Intervention 25:	$90,000
Surveying:	$26,000
Engineering:	$97,000
Construction Management:	$36,000
TOTAL	**$594,000**

CIP 2	
Construction:	$311,000
Intervention 5:	$63,000
Intervention 7:	$309,000
Intervention 8:	$356,000
Surveying:	$64,000
Engineering:	$139,000
Construction Management:	$94,000
TOTAL	**$1,336,000**
CIP 4	
Construction:	
Intervention 13:	$299,000
Intervention 14:	$307,000
Surveying:	$28,000
Engineering:	$94,000
Construction Management:	$48,000
TOTAL	**$776,000**
CIP 6	
Construction:	
Intervention 11:	$703,000
Surveying:	$36,000
Engineering:	$88,000
Construction Management:	$36,000
TOTAL	**$863,000**
CIP 8	
Construction:	
Intervention 17:	$659,000
Intervention 18:	$137,000
Surveying:	$49,000
Engineering:	$113,000
Construction Management:	$48,000
TOTAL	**$1,006,000**
CIP 10	
Construction:	
Intervention 6:	$379,000
Intervention 10:	$217,000
Surveying:	
Engineering:	$86,000
Construction Management:	$48,000
TOTAL	**$748,000**
Total for All CIPs	**$10.3 M**

9.4 Other Areas of Concern

The secondary problem area locations are illustrated on Figure 9-1 and summarized below. These problem areas are not as serious as the primary problems, but should be addressed in conjunction with other infrastructure projects occurring in the watershed. For example, many of the secondary problems could be addressed at the same time roadways are improved and water and wastewater pipelines are installed, if they are located in the same general vicinity. In addition, many of these secondary problems could be combined with routine maintenance activities.

Location 27. Lower Main Stem, River Mile 0.580 to 0.557 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment along Stevens Creek Lower Main Stem has resulted in tall, alternating cutbanks and severe bank erosion.

Recommended intervention: Protect the banks from erosion by deflecting flow with rock wing dikes and rock toe armor.

Location 28. Lower Main Stem, River Mile 0.955 to 0.922 - Wing dikes and rock toe along eroding streambank

Problem description: Meander adjustment along Stevens Creek Lower Main Stem has resulted in tall, alternating cutbanks and severe bank erosion.

Recommended intervention: Protect the banks from erosion by deflecting flow with rock wing dikes and rock toe armor.

Location 29. Lower Main Stem, River Mile 1.500 to 1.447 – Remove dumped rubble and restore eroding streambank

Problem description: Concrete and asphalt rubble has been dumped along the right descending bank, aggravating localized bank erosion.

Recommended intervention: Remove the rubble and restore the degraded bank by regrading, fabric, and planting.

Location 30. Lower Main Stem, River Mile 3.231 to 3.152 – Composite revetment bank protection to restore eroded streambank

Problem description: Channel widening along Stevens Creek Main Stem has prompted severe bank erosion along the right descending bank downstream of Havelock Avenue, threatening a fenceline and farm building at the top of the bank. A lack of woody vegetation and a narrow riparian corridor has allowed erosion to proceed unimpeded.

Recommended intervention: Construct composite revetment bank protection along approximately 400 feet of streambank to halt bank erosion, restore a stable slope, and protect the property along the top of the bank.

Location 31. Tributary 5, River Mile 3.074 – Flood mitigation at Havelock Street

Problem description: Three habitable buildings are affected by the existing 100-year floodplain, per the model near the intersection at Havelock Street and 73rd Street. This may be due to insufficient conveyance capacity of the channel and drainage structure under Havelock Street. The culvert is causing backwater, which affects the houses approximately 500 feet upstream.

Recommended improvement: Resizing and replacing the culvert with a two-stage, conservation culvert may decrease the water surface elevation and mitigate the effects of the floodplain 500 feet upstream from Havelock. However, one of the houses, located east of 73rd Street on Morril Street, appears to be within the natural floodplain. Potential solutions, in conjunction with culvert resizing, could include adding a berm or channel modification to address flooding at this property.

Location 32. Tributary 5, River Mile 3.695 – Flood mitigation near Fremont Street

Problem description: Two habitable buildings are affected by the existing 100-year floodplain, per the model near Fremont Street, east of 70th Street. This may be due to insufficient conveyance capacity of the drainage structure under Havelock Street and the grading of a sidewalk that passes over the tributary near the effected houses. The culvert is causing backwater, which affects the houses approximately 250 feet upstream. In addition, three habitable buildings are affected by the existing 100-year floodplain. While structural improvements may lower the water surface elevation at the culvert, effects will still exist immediately upstream of the culvert after improvements. The houses appear to be within the natural floodplain.

Recommended improvement: Possible solutions include structure improvements, berm installation, or channel modifications.

Location 33. Tributary 20, River Mile 6.511 to 6.006 – Grade control incising channel

Problem description: Channel incision along Tributary 20 has resulted in extensive bank scouring and erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 34. Tributary 10, River Mile 5.903 – Flood mitigation at 98th Street

Problem description: Three habitable buildings are affected by the existing 100-year floodplain, per the model near 84th Street, south of Adams Street. This may be due to insufficient conveyance capacity of the drainage structure under 98th Street. The culvert is causing backwater, which affects the houses west of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, channel modifications, and detention upstream of the flood location.

Location 35. Lower Main Stem, River Mile 5.913 to 5.663 – Grade control existing knickpoints

Problem description: Channel incision along the Lower Main Stem of Stevens Creek has resulted in systemic bank erosion and the generation of sediment and woody debris.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 36. Lower Main Stem, River Mile 6.909 to 6.890 – Remove dumped rubble and restore eroding streambank

Problem description: Concrete and asphalt rubble has been dumped along the right descending bank, aggravating localized bank erosion.

Recommended intervention: Remove the rubble and restore the degraded bank with composite revetment bank protection.

Location 37. Lower Main Stem, River Mile 7.055 to 6.924 – Grade control incising channel

Problem description: Channel incision along the Lower Main Stem has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 38. Tributary 25, River Mile 7.197 to 7.183 – Turning vane upstream of culvert to direct flow

Problem description: The culvert under 112th Street is being flanked by localized bank erosion along the left descending bank.

Recommended intervention: Construct a rock turning vane to direct flow through the box culvert and maintain sediment transport continuity. Additional rock toe protection along the left descending bank is necessary to reduce localized erosion and protect the turning vane.

Location 39. Tributary 30, River Mile 7.987 to 7.959 – Grade control existing knickpoints

Problem description: Channel incision along Tributary 30 has resulted in systemic bank erosion.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 40. Tributary 35, River Mile 9.493 – Flood mitigation at Holdrege Street

Problem description: One habitable building is affected by the existing 100-year floodplain, per the model near Holdrege Street, east of 112th Street. This may be due to insufficient conveyance capacity of the drainage structure under Holdrege Street. The culvert is causing backwater, which affects the house west of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, and channel modifications.

Location 41. Lower Main Stem, River Mile 8.979 to 8.127 – Grade control existing knickpoints

Problem description: Channel incision along the Lower Main Stem has resulted in systemic bank erosion.

Recommended intervention: Grade control existing knickpoints to reduce channel bed slope and halt channel incision.

Location 42. Tributary 135, River Mile 9.106 to 8.917 – Grade control incising channel

Problem description: Channel incision along Tributary 135 has resulted in severe bank erosion and frequent wedge failures.

Recommended intervention: Install a series of rock grade controls to raise the channel bed and prevent continued mass wasting.

Location 43. Tributary 30, River Mile 8.779 to 8.756 – Grade control existing knickzone

Problem description: The upstream advance of a single knickzone along Tributary 30 has precipitated systemic bank erosion.

Recommended intervention: Grade control the existing knickzone to halt channel incision and maintain a stable channel grade.

Location 44. Tributary 35, River Mile 8.550 to 8.533 – Composite revetment bank protection to restore eroded streambank

Problem description: A tall, near vertical cutbank has resulted from high shear stress on the outside of a meander and the removal of trees and woody vegetation along the right descending bank, thereby reducing shear resistance.

Recommended intervention: Construct composite revetment bank protection along 100 feet of streambank to halt bank erosion and restore a stable channel cross section.

Location 45. Tributary 250, River Mile 11.741 to 11.707 – Longitudinal weirs upstream of culvert to direct flow

Problem description: A poorly aligned culvert under O Street has induced erosion upstream and downstream of the culvert.

Recommended intervention: Construct longitudinal weirs and rock toe protection to direct flow away from eroding streambanks and center the flow through the culvert.

Location 46. Lower Main Stem, River Mile 9.492 to 9.426 – Composite revetment bank protection to restore eroded streambank

Problem description: Channel widening has resulted in recurrent wedge failures along the Lower Main Stem.

Recommended intervention: Restore and protect eroding streambanks with composite revetment bank protection along roughly 350 feet of channel.

Location 47. Upper Main Stem, River Mile 9.845 to 9.780 – Grade control incising channel

Problem description: Channel incision has resulted in severe bank erosion and frequent bank failures.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 48. Tributary 150, River Mile 12.735 to 12.701 – Replace existing culvert

Problem description: A driveway culvert on Tributary 150 is misaligned and the wooden headwalls upstream of the culvert are in general disrepair, failing in toward the channel.

Recommended intervention: Replace the existing culvert with a two-stage conservation culvert, or a bridge with a rock or concrete headwall.

Location 49. Tributary 150, River Mile 13.242 to 12.962 – Grade control incising channel

Problem description: Channel incision and subsequent widening along Tributary 150 has resulted in widespread bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel incision, and restore a stable channel shape downstream with rock toe protection and regrading, fabric, and planting eroded streambanks.

Location 50. Tributary 150, River Mile 13.418 to 13.388 – Replace existing culvert

Problem description: The culvert under 148th Street appears to be undersized and inducing sediment deposition upstream.

Recommended intervention: Replace the existing culvert with a two-stage conservation culvert.

Location 51. Tributary 150, River Mile 13.918 to 13.415 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation combined with cattle access to the tributary has resulted in severe, localized bank erosion or poaching between the MOPAC trail and 148th Street.

Recommended intervention: Limit cattle access to the tributary and restore the riparian corridor with a mix of native trees and woody vegetation to mechanically stabilize eroding banks and increase shear resistance.

Location 52. Tributary 150, River Mile 13.949 – Longitudinal weirs upstream of culvert to direct flow

Problem description: A poorly aligned approach to the culvert under the MOPAC trail has resulted in bank scouring upstream of the culvert.

Recommended intervention: Construct a longitudinal weir upstream to direct flow away from the banks and through the culvert.

Location 53. Upper Main Stem, River Mile 10.976 to 10.218 – Grade control incising channel

Problem description: Channel incision along the Upper Main Stem has resulted in persistent toe scour and a frequent occurrence of debris jams.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 54. Tributary 445, River Mile 13.847 – Flood mitigation near A Street and 94th Street

Problem description: One habitable building is affected by the existing 100-year floodplain, per the model near A Street, east of 94th Street. This may be due to insufficient conveyance capacity of the drainage structure under a private drive. The culvert is causing backwater, which impacts the house south of the tributary.

Recommended improvement: Possible solutions include structure improvements, berm installation, and channel modifications.

Location 55. Tributary 445, River Mile 14.129 to 14.112 – New pond outfall with stilling basin

Problem description: An old concrete pond outfall is in deteriorating condition, with dumped rubble at angle of repose.

Recommended intervention: Repair or replace the pond outfall and add a riprap-armored stilling basin downstream.

Location 56. Tributary 445, River Mile 13.565 – Grade control existing knickpoint downstream of pond outfall

Problem description: Haphazardly placed riprap appears to have been undermined by an advancing headcut, threatening a detention pond outfall upstream.

Recommended intervention: Install a grade control at the existing knickpoint to maintain a stable channel grade downstream of the pond outfall.

Location 57. Tributary 245, River Mile 12.049 to 11.964 – Restore riparian corridor

Problem description: Systematic clearing of trees and woody vegetation from the riparian corridor has prompted overbank erosion and gullying of bare soil banks along Tributary 245.

Recommended intervention: Grade, fabric, and plant the banks to restore the riparian corridor and prevent continued overbank erosion.

Location 58. Tributary 70, River Mile 16.213 to 15.497 – Grade control incising channel

Problem description: Incision-induced bank erosion occurs from Van Dorn Street to a cattle crossing at Tributary 70, River Mile 16.213.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 59. Tributary 60, River Mile 6.964 to 6.149 – Grade control incising channel

Problem description: Channel incision has resulted in systemic bank erosion from the confluence with an unnamed tributary to Van Dorn Street.

Recommended intervention: install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 60. Tributary 170, River Mile 14.611 to 14.592 – Grade control existing knickpoint

Problem description: Bank failures along Tributary 170 occur in the vicinity of an existing debris jam-reinforced knickpoint.

Recommended intervention: Replace the existing debris jam with an engineered rock grade control to halt channel incision, and restore failed streambanks to a stable slope and shape.

Location 61. Tributary 65, River Mile 12.458 to 12.453 – Grade control existing knickpoint

Problem description: An advancing headcut upstream from the confluence with Stevens Creek Upper Main Stem has resulted in systemic bank erosion along Tributary 65.

Recommended intervention: Install a grade control at the existing knickpoint to maintain a stable channel grade upstream from the confluence with Stevens Creek Upper Main Stem.

Location 62. Tributary 65, River Mile 12.491 to 12.466 – Composite revetment bank protection to restore eroded streambank

Problem description: An existing cutbank appears to be advancing in the direction of Van Dorn Street.

Recommended intervention: Construct composite revetment bank protection along approximately 150 feet of streambank to halt advancing erosion.

Location 63. Upper Main Stem, River Mile 12.517 to 12.495 – Grade control existing knickpoint

Problem description: Channel incision along the Upper Main Stem has generated large volumes of sediment and woody debris. Woody debris and toppled trees have accumulated upstream of the Van Dorn bridge, reinforcing an existing knickpoint.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 64. Upper Main Stem, River Mile 12.654 to 12.631 – Composite revetment bank protection to restore eroded streambank

Problem description: Severe bank erosion along the right descending bank has resulted in a near-vertical cutbank and gullying through the farm field at the top of the bank.

Recommended intervention: Restore and protect the eroding streambank with composite revetment bank protection along approximately 120 feet of channel.

Location 65. Tributary 70, River Mile 14.350 to 14.312 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation combined with cattle access to Tributary 70 has resulted in severe bank poaching.

Recommended intervention: Limit cattle access to the tributary and restore the riparian corridor with a mix of native trees and woody vegetation.

Location 66. Upper Main Stem, River Mile 12.864 to 12.769 – Grade control incising channel

Problem description: Channel incision has resulted in systemic bank erosion along the Upper Main Stem.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 67. Tributary 60, River Mile 9.151 to 7.323 – Regrade, fabric, and plant banks with rock toe armor

Problem description: Channel widening along Tributary 60 has resulted in severe channel degradation and widespread mass wasting between Pioneers Street and a 48-inch CMP culvert under a private drive.

Recommended intervention: Repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 68. Tributary 60, River Mile 7.323 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 60 has been temporarily halted by a large woody debris jam immediately upstream from a 48-inch CMP culvert under a private drive.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 69. Tributary 270, River Mile 16.556 to 15.372 – Grade control incising channel

Problem description: Channel incision along Tributary 270 has resulted in widespread bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 70. Upper Main Stem, River Mile 13.250 to 13.182 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion and frequent bank failures.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 71. Tributary 70, River Mile 13.367 to 13.196 – Grade control incising channel

Problem description: Channel incision along Tributary 70 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 72. Tributary 160, River Mile 14.086 to 14.083 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 160 has been temporarily halted by a large woody debris jam acting as a *de facto* grade control.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 73. Tributary 160, River Mile 14.287 to 14.153 – Grade control incising channel and restore corridor

Problem description: Channel incision along Tributary 160 has resulted in severe erosion and mass wasting. Removal of trees and woody vegetation along the streambanks has accelerated systemic erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore the riparian corridor and increase shear resistance.

Location 74. Tributary 160, River Mile 15.026 to 14.391 – Grade control existing knickpoint and restore corridor

Problem description: The upstream advance of a knickpoint has precipitated bank erosion and frequent bank failures. Cattle access to the tributary has accelerated bank erosion, resulting in reaches of severe, localized bank erosion or poaching.

Recommended intervention: Grade control the existing knickpoint to halt channel incision and limit cattle access to the tributary.

Location 75. Tributary 75, River Mile 15.772 to 15.450 – Grade control incising channel

Problem description: Channel incision along Tributary 75 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 76. Tributary 75, River Mile 14.602 to 14.586 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 75 has been temporarily halted by a debris jam of dumped hay bales and woody debris acting as a *de facto* grade control.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 77. Upper Main Stem, River Mile 14.843 to 14.834 – Grade control existing knickpoint

Problem description: A woody debris jam acting as a *de facto* grade control has temporarily halted the advance of an existing knickpoint on the Upper Main Stem.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 78. Tributary 260, River Mile 15.474 to 15.015 – Grade control incising channel

Problem description: Channel incision along Tributary 260 has resulted in severe bank erosion in the near 120th Street.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 79. Tributary 60, River Mile 10.234 to 9.642 –Restore riparian corridor

Problem description: A lack of riparian trees and woody vegetation along Tributary 60 has resulted in overbank erosion and mass wasting between 112th and 120th Streets.

Recommended intervention: Grade, fabric, and plant the banks to restore the riparian corridor and prevent continued erosion.

Location 80. Tributary 60, River Mile 9.928 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 60 is eroding both banks and undermining a concrete low-water crossing.

Recommended intervention: Reinforce the low-water crossing with an engineered rock grade control immediately downstream to halt channel incision and protect the existing structure.

Location 81. Tributary 80, River Mile 15.321 to 15.317 - Armor plunge pool at pond outfall

Problem description: A 36-inch CMP pond outfall is focusing flow against the right descending bank, resulting in bed and bank scouring.

Recommended intervention: Construct a riprap armored plunge pool to dissipate the scouring energy at the pond outfall.

Location 82. Tributary 80, River Mile 15.757 to 15.647 – Grade control incising channel

Problem description: Channel incision along Tributary 80 has resulted in severe bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 83. Tributary 85, River Mile 16.490 to 16.158 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion and frequent bank failures.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 84. Tributary 460, River Mile 16.041 to 16.003 – Grade control existing knickpoint

Problem description: The upstream advance of a 2-foot knickpoint has precipitated systemic bank erosion and threatens channel stability upstream.

Recommended intervention: Grade control the existing knickpoint to halt channel incision and maintain a stable channel grade upstream.

Location 85. Tributary 60, River Mile 11.314 to 10.734 – Composite revetment bank protection and guide vanes

Problem description: Channel widening along Tributary 60 has resulted in severe channel degradation and widespread mass wasting.

Recommended intervention: Repair eroded streambanks and protect them from continued erosion with composite revetment bank protection along approximately 3,000 feet of channel. In addition, construct a series of rock guide vanes to deflect flow away from the banks and toward the center of the channel.

Location 86. Tributary 88, River Mile 16.430 to 16.203 – Grade control incising channel

Problem description: Tributary 88 is an entrenched channel with frequent, incision-induced bank failures.

Recommended intervention: Install a series of rock grade controls to halt channel incision, raise the channel bed, and establish a stable bed slope.

Location 87. Upper Main Stem, River Mile 16.752 to 16.695 – Grade control existing knickpoint

Problem description: Channel incision along the Upper Main Stem has generated large volumes of sediment and woody debris. Woody debris has formed a large debris jam, reinforcing an existing knickpoint.

Recommended intervention: Remove the debris jam and replace it with an engineered rock grade control to maintain a stable channel grade.

Location 88. Tributary 260, River Mile 16.091 to 16.082 - Armor right descending bank at culvert outfall

Problem description: Twin 48-inch CMP outfalls downstream of the 120th Street culvert are directing flow against the right descending bank, resulting in bank scouring.

Recommended intervention: Add vegetated rock toe armor along approximately 50 feet of the right descending bank to dissipate scouring energy at the culvert outfall.

Location 89. Tributary 88, River Mile 16.458 to 16.430 – Grade control existing knickpoints and regrade, fabric, and plant banks with rock toe armor

Problem description: Channel incision along Tributary 88 has resulted in severe bank erosion. However, the advance of incision has been slowed by a series of woody debris jams acting as a *de facto* grade controls.

Recommended intervention: Remove the debris jams and replace them with engineered rock grade controls to maintain a stable channel grade. In addition, repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 90. Tributary 88, River Mile unknown - Stilling basin with grade control outfall

Problem description: Channel incision along Tributary 88 has scoured the channel bed, leaving the 138th Street culvert outfall perched 1 foot above channel bed.

Recommended intervention: Construct a stilling basin downstream of the culvert with a grade control outfall to dissipate the scouring energy from the culvert and to halt channel incision.

Location 91. Tributary 92, River Mile 17.677 to 17.658 – Grade control incising channel

Problem description: Channel incision along Tributary 92 has resulted in severe bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 92. Tributary 90, River Mile 17.551 to 17.547 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 90 has been slowed by a large woody debris jam at an existing 3-foot tall knickpoint.

Recommended intervention: Remove the debris jam and replace it with a series of rock grade controls or a single drop structure to prevent the advance of the knickpoint and to maintain a stable channel grade.

Location 93. Tributary 90, River Mile 17.670 to 17.615 – Composite revetment bank protection to restore eroded streambank

Problem description: Severe bank scouring and wedge failures have resulted from high shear stress on the outside of a meander and the removal of trees and woody vegetation along the left descending bank.

Recommended intervention: Construct composite revetment bank protection along approximately 300 feet of streambank to halt bank erosion and restore a stable channel cross section.

Location 94. Tributary 90, River Mile 17.727 to 17.670 – Grade control incising channel

Problem description: Channel incision along Tributary 90 has resulted in systemic bank erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 95. Tributary 92, River Mile 17.962 to 17.941 - Armor plunge pool at culvert outfall

Problem description: An unarmored 60-inch CMP outfall at the Pleasant Hill culvert has resulted in bed and bank scouring.

Recommended intervention: Construct a riprap armored plunge pool to dissipate the scouring energy at the culvert outfall.

Location 96. Tributary 96, River Mile 21.894 to 21.889 - Armor plunge pool at pond outfall

Problem description: A 36-inch CMP pond outfall is focusing flow against the left descending bank, resulting in bed and bank scouring.

Recommended Location: Construct a riprap armored plunge pool to dissipate the scouring energy at the pond outfall.

Intervention 97. Tributary 96, River Mile 21.542, 21.459, 21.379, & 21.294 – Grade control existing knickpoints

Problem description: A series of beaver dams are reinforcing several 1 to 3-foot knickpoints along Tributary 96.

Recommended intervention: Replace or reinforce each of the beaver dams with an engineered rock grade control to maintain a stable channel grade.

Location 98. Tributary 96, River Mile 21.150 to 21.131 – Grade control existing knickpoint

Problem description: Channel incision along Tributary 96 has undermined a *de facto* grade control of dumped concrete and asphalt rubble.

Recommended intervention: Replace the concrete and asphalt with an engineered rock grade control to halt channel incision.

Location 99. Tributary 96, River Mile 20.964 to 20.839 – Grade control incising channel and replace low –water crossing

Problem description: Channel incision along Tributary 96 has resulted in systemic bank erosion between the confluence with Tributary 196 and a low-water crossing at River Mile 20.964.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, replace the existing low-water crossing with a bridge or appropriately sized CMP culvert.

Location 100. Tributary 96, River Mile 20.801 to 20.139 – Conservation easement along meandering reach

Problem description: Meander adjustment along the lower reach of Tributary 96 has resulted in alternating cutbanks and mass wasting.

Recommended intervention: Because the existing corridor is wide enough to accommodate meander adjustment, provide a conservation easement along the top of both banks to allow for continued planform adjustment until equilibrium is achieved.

Location 101. Tributary 94, River Mile 20.092 to 19.524 – Regrade, fabric, and plant banks with rock toe armor

Problem description: Channel widening along Tributary 94 has resulted in severe bank erosion and widespread mass wasting occurring on the outside of meanders.

Recommended intervention: Repair eroded streambanks and restore a stable channel cross section shape by regrading, fabric and planting with rock toe armor.

Location 102. Tributary 94, River Mile 20.149 to 20.092 – Grade control existing knickpoints

Problem description: The upstream advance of several knickpoints has precipitated bank erosion, frequent bank failures, and channel widening further downstream.

Recommended intervention: Grade control each of the existing knickpoints to halt channel incision.

Location 103. Tributary 196, River Mile 21.358 to 20.843 – Grade control incising channel

Problem description: Channel incision along Tributary 196 has resulted in systemic bank erosion and mass wasting downstream of a pond outfall.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 104. Tributary 296, River Mile 23.591 to 22.891 – Grade control incising channel and restore corridor

Problem description: Channel incision along Tributary 296 has resulted in severe erosion and mass wasting. Cattle access to the tributary and the removal of trees and woody vegetation along the streambanks has accelerated erosion.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore the riparian corridor and increase shear resistance.

Location 105. Tributary 96, River Mile 22.904 to 22.438 - Grade control incising reach and protect culvert outfall

Problem description: Channel incision downstream of a pond outfall has resulted in extensive bank failures. Downstream of the culvert the channel is scoured along both banks.

Recommended intervention: Arrest channel incision downstream of the pond outfall with a series of grade controls and armor the pond outfall with a rock armored plunge pool or stilling basin.

Location 106. Tributary Upper Main Stem, River Mile 21.576 to 20.564– Grade control incising channel and restore corridor

Problem description: Channel incision along the Upper Main Stem has resulted in severe erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision. In addition, grade, fabric, and plant the banks to restore a stable channel cross section and increase shear resistance.

Location 107. Tributary 196, River Mile 21.597 to 21.593 - Armor plunge pool and right descending bank at culvert outfall

Problem description: Triple 36-inch CMP outfalls downstream of a private drive off of Middlefork Road are directing flow against the right descending bank, resulting in bank scouring.

Recommended intervention: Construct a riprap armored plunge pool and add rock toe armor along approximately 20 feet of the right descending bank to dissipate the scouring energy at the culvert outfall.

Location 108. Upper Main Stem, River Mile 21.898 to 21.627 – Grade control incising channel

Problem description: Channel incision along the Upper Main Stem has resulted in systemic bank erosion and mass wasting.

Recommended intervention: Install a series of rock grade controls to reduce channel bed slope and halt channel incision.

Location 109. Upper Main Stem, River Mile 22.046 to 22.036 - Armor left descending bank near confluence

Problem description: Bank scouring continues to erode the left descending bank near the confluence with a gully.

Recommended intervention: Add a rock turning vane and vegetated rock toe armor along approximately 50 feet of the left descending bank to deflect flow away from the bank and toward the center of the channel.

Location 110. Upper Main Stem, River Mile 22.089 to 22.072 - Armor right descending bank at culvert outfall

Problem description: Bank scouring continues to erode the right descending bank downstream of the 120th Street culvert outfall.

Recommended intervention: Add a rock turning vane and vegetated rock toe armor along approximately 100 feet of the right descending bank to deflect flow away from the bank and toward the center of the channel.