Natural Channel Design in a Legal Ditch System: Restoration of Lawndale Creek

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Problem Definition
Restoration Design Philosophy and Approach
Project Design
Project Construction

Channelization or “Channel Improvement”

27,000 miles of Minnesota’s 90,000 miles of watercourse are now ditches (Taft 1998), while thousands of miles more have been straightened or dredged.

Published Effects of “Channel Improvement”

Increased Peak Flows

Increased flooding downstream due to lost floodplain storage, aggradation, and decreased time of concentration resulting in higher flood peaks (Emerson 1971).

Channel Instability and Sedimentation

Headcutting (upstream incision), and downstream aggradation due to increases in slope and shear stress (Army Corps of Engineers 1994).

Sediment accumulation in Lake Pepin has increased by an order of magnitude since 1830 (Engstrom et al. 2009).

Water Quality Impairment

Greater turbidity, conductivity, pH, particulate loads, phosphorous, and nitrates than natural channels (Kuenzler et al. 1977).

Nitrate and phosphate concentrations in the Minnesota River are 15 times that of the early 1900s.

The Red River contributes only 8.2% of the inflow but 58% of the phosphorus load to Lake Winnipeg.

Reduced Biodiversity and Biomass

88% reduction in invertebrate drift (Morris et al 1968)

82% reduction in fish biomass, 49% reduction in biodiversity (Huggins and Moss 1974)

Loss of Biodiversity
(Anthropogenic Mass Extinction)

Freshwater extinction rates are 5 times that of terrestrial rates (Ricciardi and Rasmussen 1999)

71.7% of North American unionid mussel species are imperiled (Williams et al. 1993).
Half of the mussel species of the Minnesota River have been extirpated (Sietman 2008).

Over 85% of sturgeon species are at risk of extinction making it the most imperiled group of species (IUCN).

As native species decline from habitat loss and fragmentation, invasive species benefit from the altered habitat and unexploited niches.


RESTORE:
"TO BRING BACK TO AN ORIGINAL STATE"
- Webster's Dictionary

Restoration:

the act of **relaxing human constraints** on the development of natural patterns of diversity (Ebersole et al. 1997, and Frissell et al. 1997), where restoration measures should not focus on directly recreating natural structures or states but on identifying and **reestablishing the conditions under which natural states create themselves** (Frissell and Ralph 1998).

Stream Restoration Components

Hydrology and Hydraulics

Floodplain, wetland, and bank storage
Channel roughness, velocity distributions, helical flow patterns etc.
Groundwater interactions and water table

Fluvial Geomorphology

Channel geometry (dimension, pattern, and profile)
Channel stability and maintenance (sediment transport and competence)
Habitat formation and maintenance (riffles, runs, pool, glides, backwaters, hyporheic zone, riparian zone, flood plain)

Water Quality

Nutrient processes (allochthonous inputs, uptake, spiraling)
Vegetative stabilization of banks and sediment inputs
Metabolic breakdown of anthropogenic compounds
Life supporting gas exchange processes (Dissolved O_2, CO_2 etc.)

Connectivity

Longitudinal (access to upstream and downstream reaches)
Lateral (floodplain and riparian wetlands)
Vertical (hyporheic zone)

Biology / Biodiversity

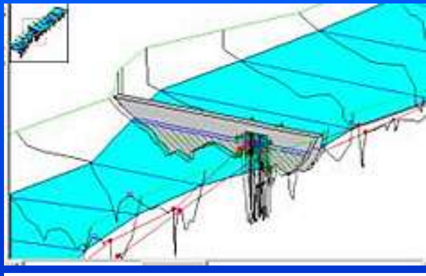
Species richness (fish, benthic invertebrates, reptiles, amphibians, birds, mammals, bacteria, plants, etc.)
Trophic structure (piscivores, herbivores, invertivores, scrapers, shredders, etc.)
Life history context (reproduction, growth, and survival, habitat type)
Riparian zone (plant diversity, root depth and density)

Web Search Images for “Stream Restoration”

River Models

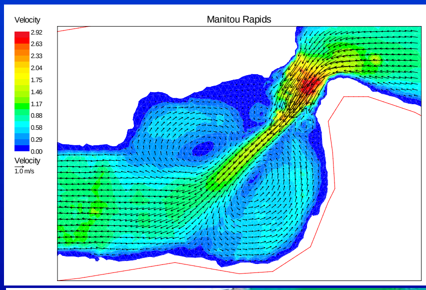
One-dimensional – steady state

Assumes uniform and steady flows
Relatively easy to use
Still the standard (required by FEMA for floodway analyses)
HECRAS – now has unsteady option



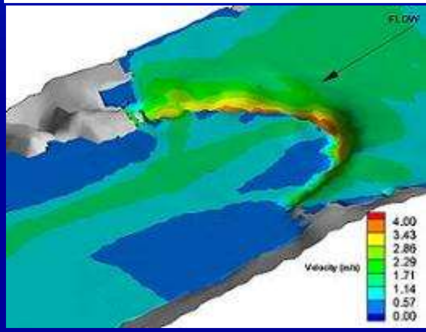
Two-dimensional

Available and in use for special applications
Requires detailed bathymetry



Three-dimensional unsteady state

Available but few practitioners, very data intensive
Realistic representation of flow



Physical

Downscaled models with real water and sediment
Allows limited assessment of sediment and erosion process
Lacks biological, water quality, and other ecological components

Real World

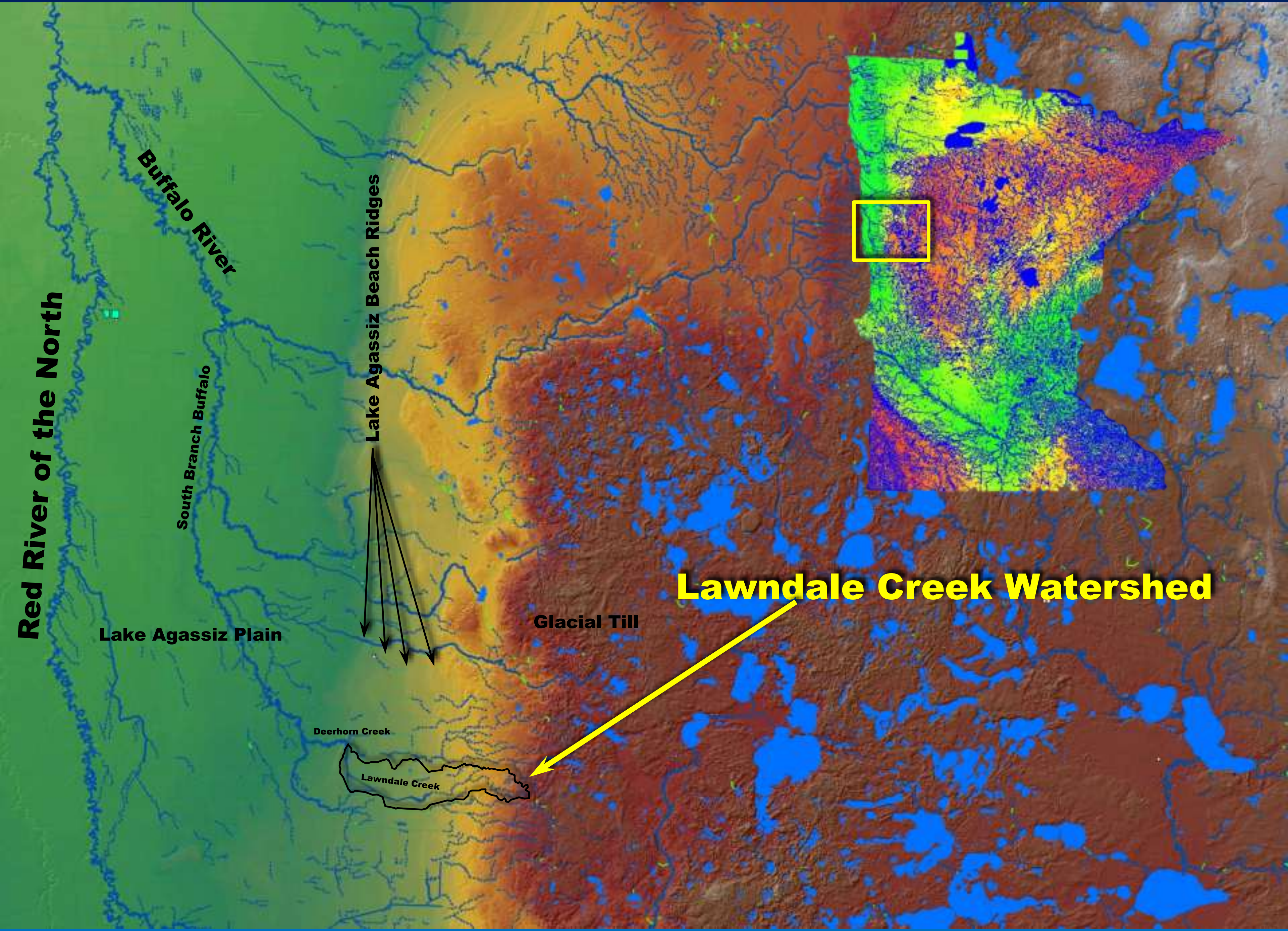
Allows observation of all parameters (hydraulic, geomorphic, biological, water quality, and connectivity) in situ. Only model that addresses ecological functions

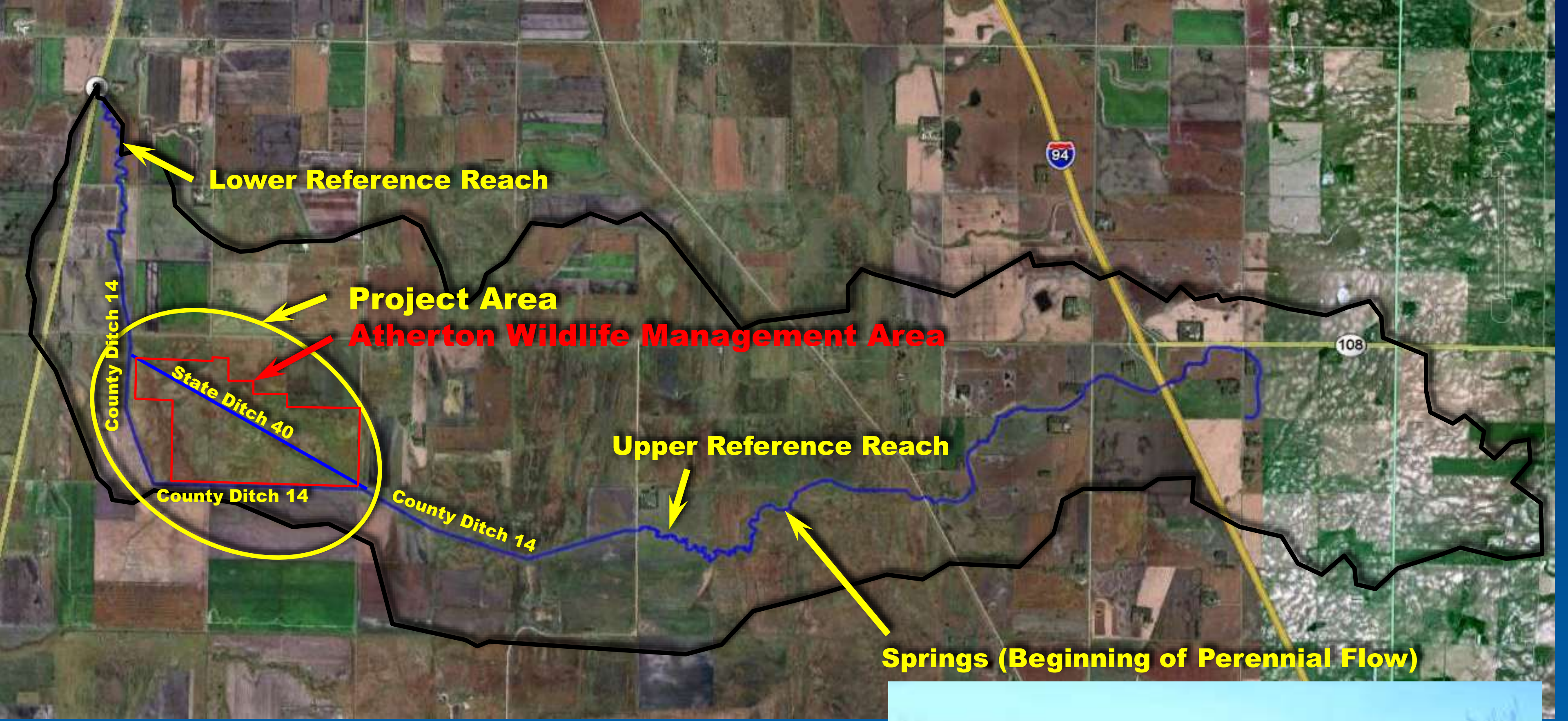
Natural Channel Design

Underlying logic:

The ideal model for a stream restoration is a stable reference reach of the same stream since it carries the water and sediment delivered by its watershed while providing diverse aquatic habitat and ecological functions.

If the restoration design is not based on natural channel morphology and ecology, it is NOT stream restoration!


Red River of the North
Buffalo River
South Branch Buffalo
Lake Agassiz Beach Ridges
Lake Agassiz Plain
Glacial Till
Lawndale Creek Watershed
Deerhorn Creek
Lawndale Creek

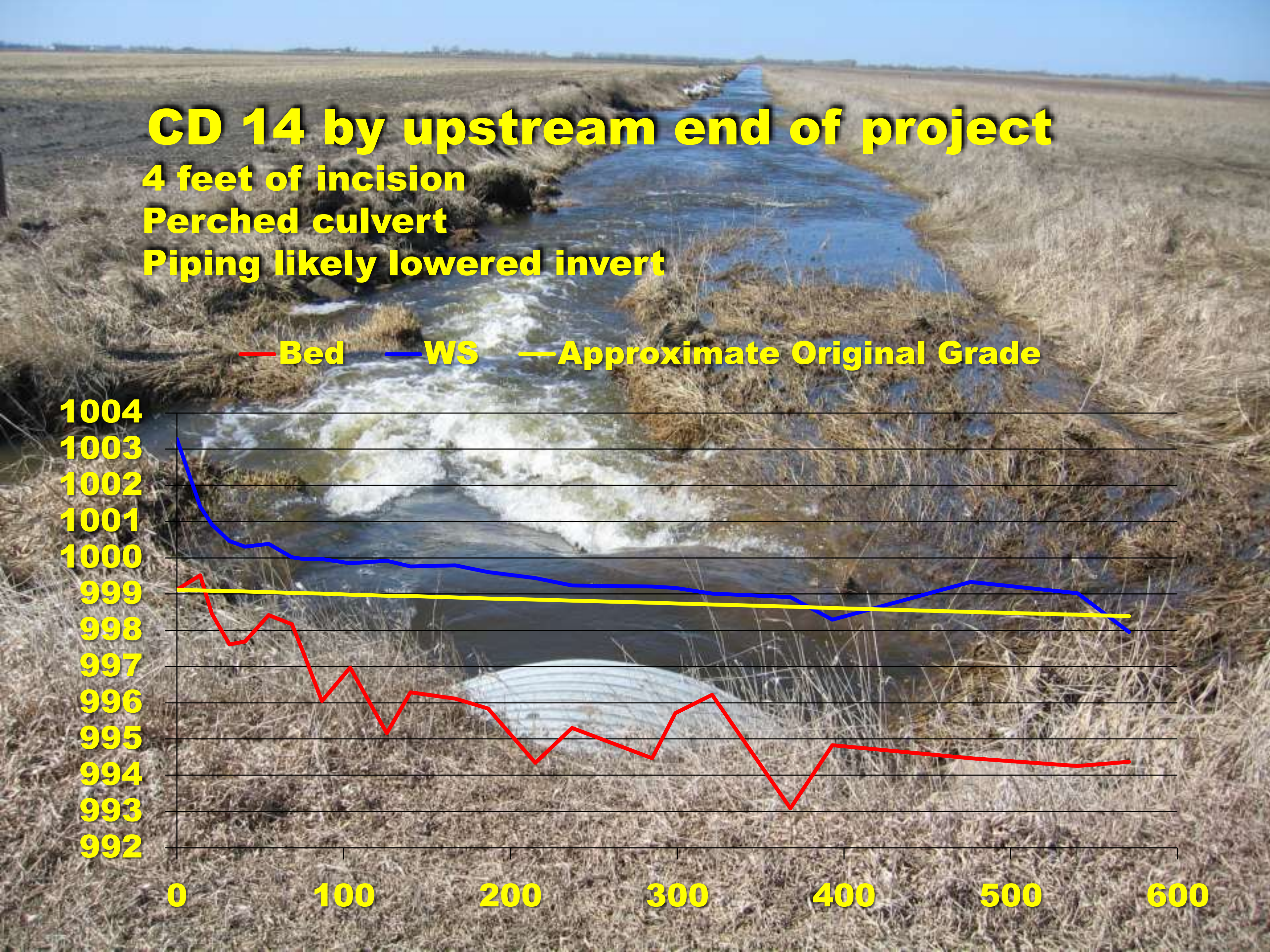


State Ditch 40 was dug in the 1890s

County Ditch 14 was dug in 1960 and carried all base flow and most flood flow due to channel incision

The Atherton became a WMA in 1960

LAWNDALE FISH SPECIES



CD 14 by upstream end of project
4 feet of incision
Perched culvert
Piping likely lowered invert
Bed
WS
Approximate Original Grade
1004
1003
1002
1001
1000
999
998
997
996
995
994
993
992
0
100
200
300
400
500
600


CD 14 at downstream end of project
2 feet of aggradation since last ditch maintenance

Problems in Ditched Reach of Lawndale Creek

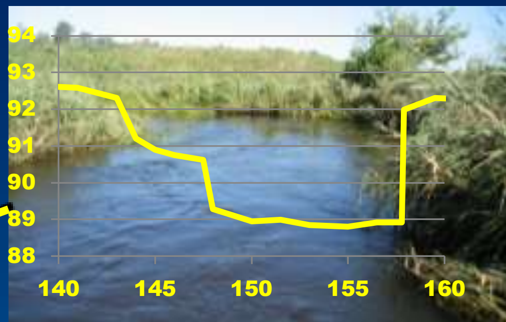

HYDROLOGY and HYDRAULICS
Steepened slope, high velocities and conveyance, drained wetlands, limited storage. Irrigation permit for 2 cfs (entire base flow) from ditch

FLUVIAL GEOMORPHOLOGY
Unstable, incised or aggraded reaches with poor quality homogenous habitat (no riffles or pools)

WATER QUALITY
Turbidity impaired

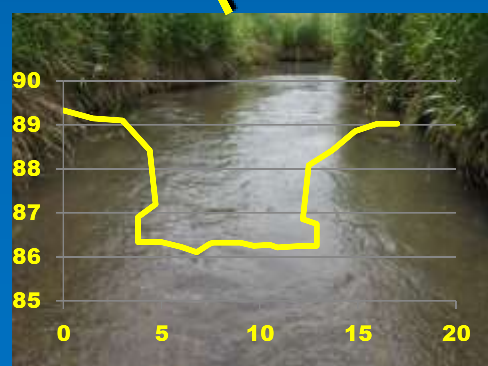
CONNECTIVITY
Incision caused perched culvert, separation from floodplain and wetlands, and sedimentation filled hyporheic zone.

BIOLOGY / BIODIVERSITY
Fish community dominated by cyprinids (no deep pools)



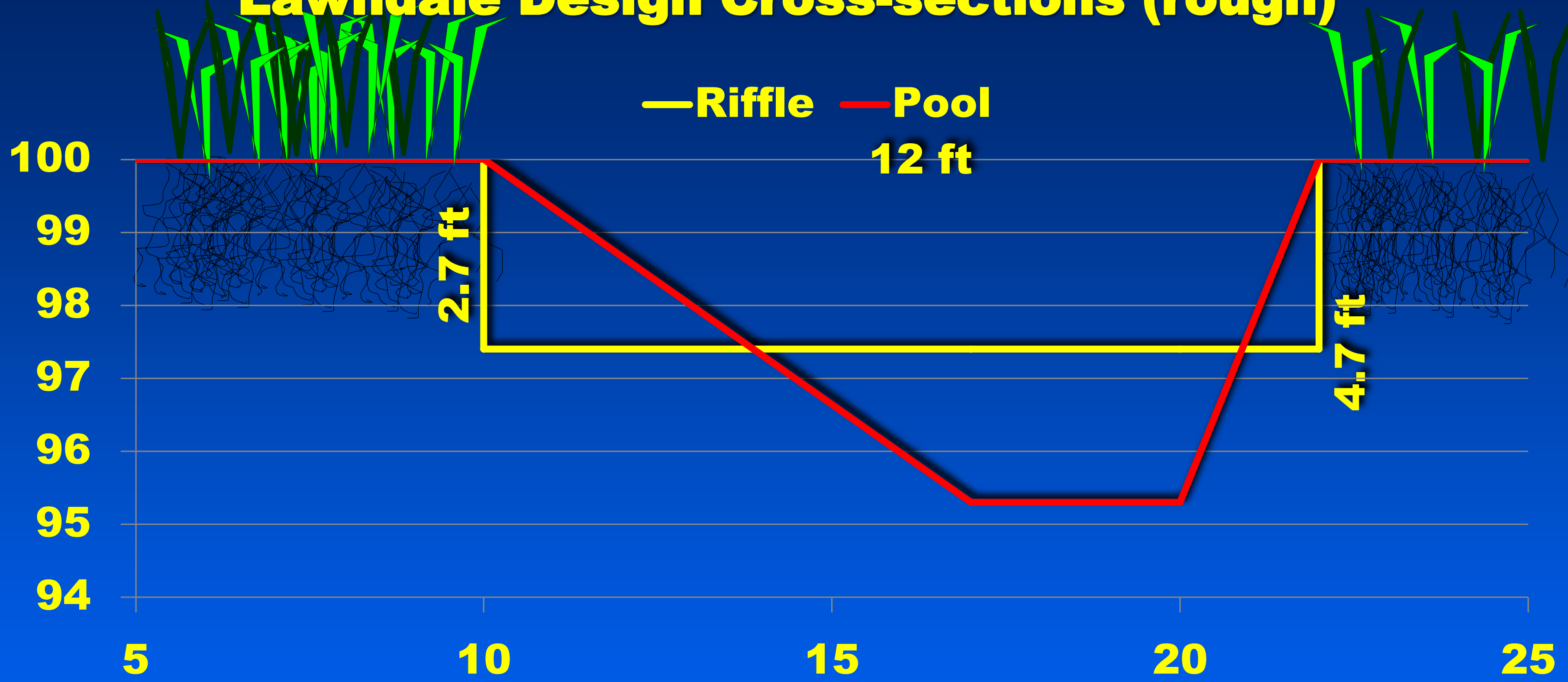
Lower Reference Channel (1.7 miles)
Drainage Area = 19 mi^2
14 - foot Bankfull Width
"E5" channel
Slope = 0.009%
Bankfull discharge = 100 cfs

Project Reach
Drainage Area = 14 mi^2
Slope = 0.1%
Bedload = fine gravel < 1 cm

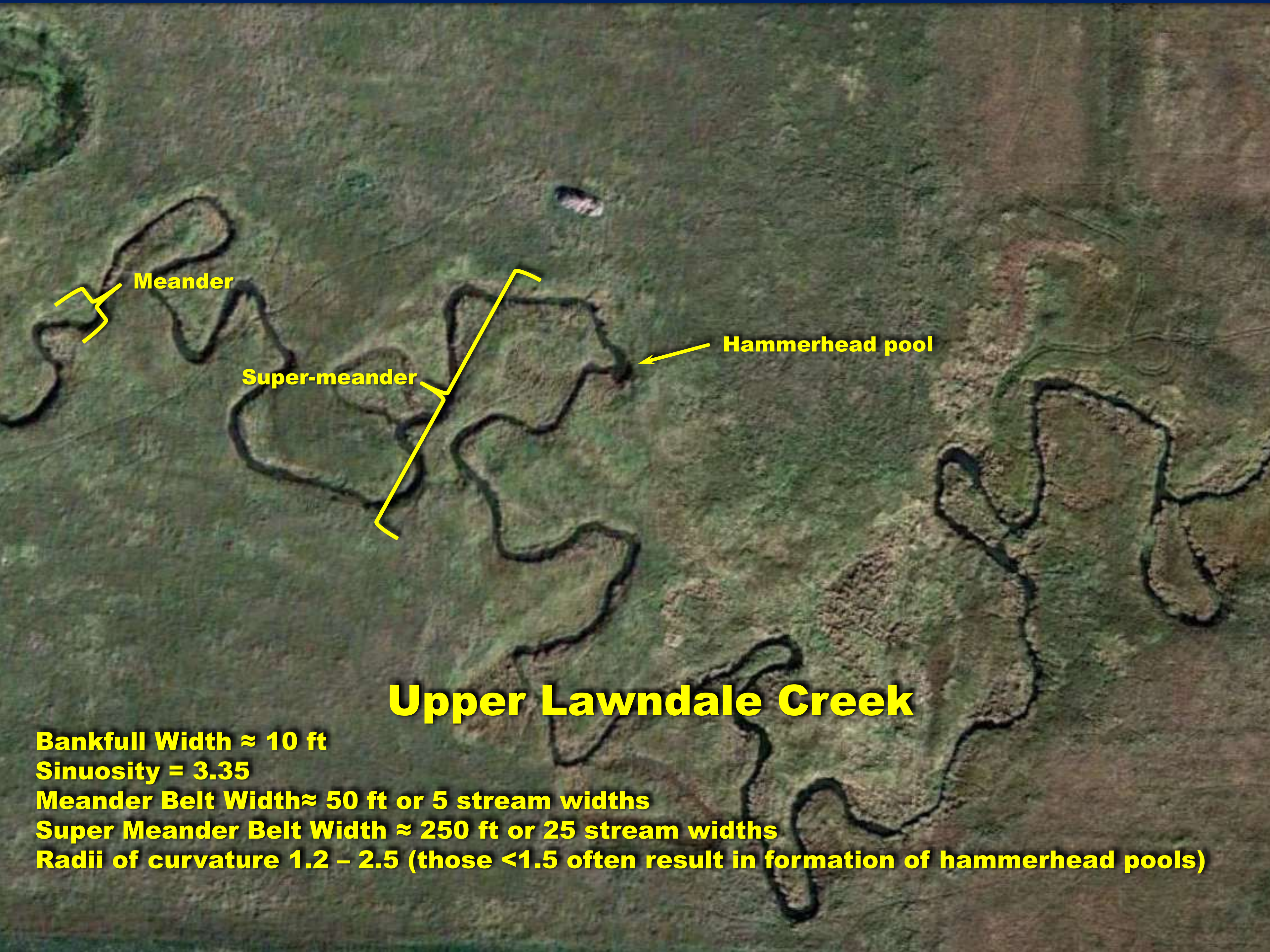


Upper Reference Reach (2.6 miles)
Drainage Area = 7 mi^2
Bankfull Width 6 – 10 ft
"E5" channel
Slope = 0.2%
Mannings N = .056 (backcalculated)
Bankfull discharge = 9 - 20 cfs
Tau = 0.7 kg/m^2

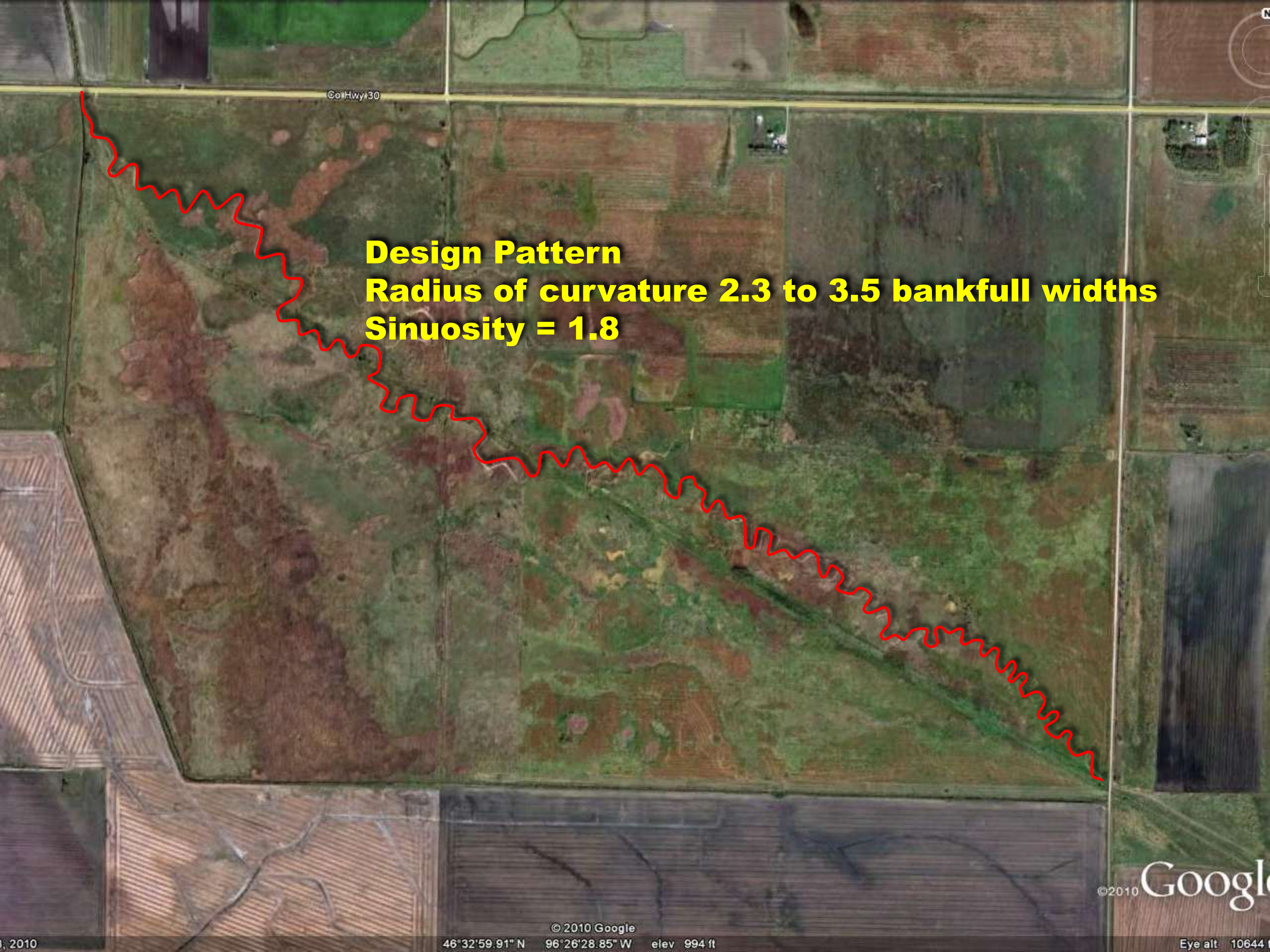
Lawndale Design Cross-sections (rough)



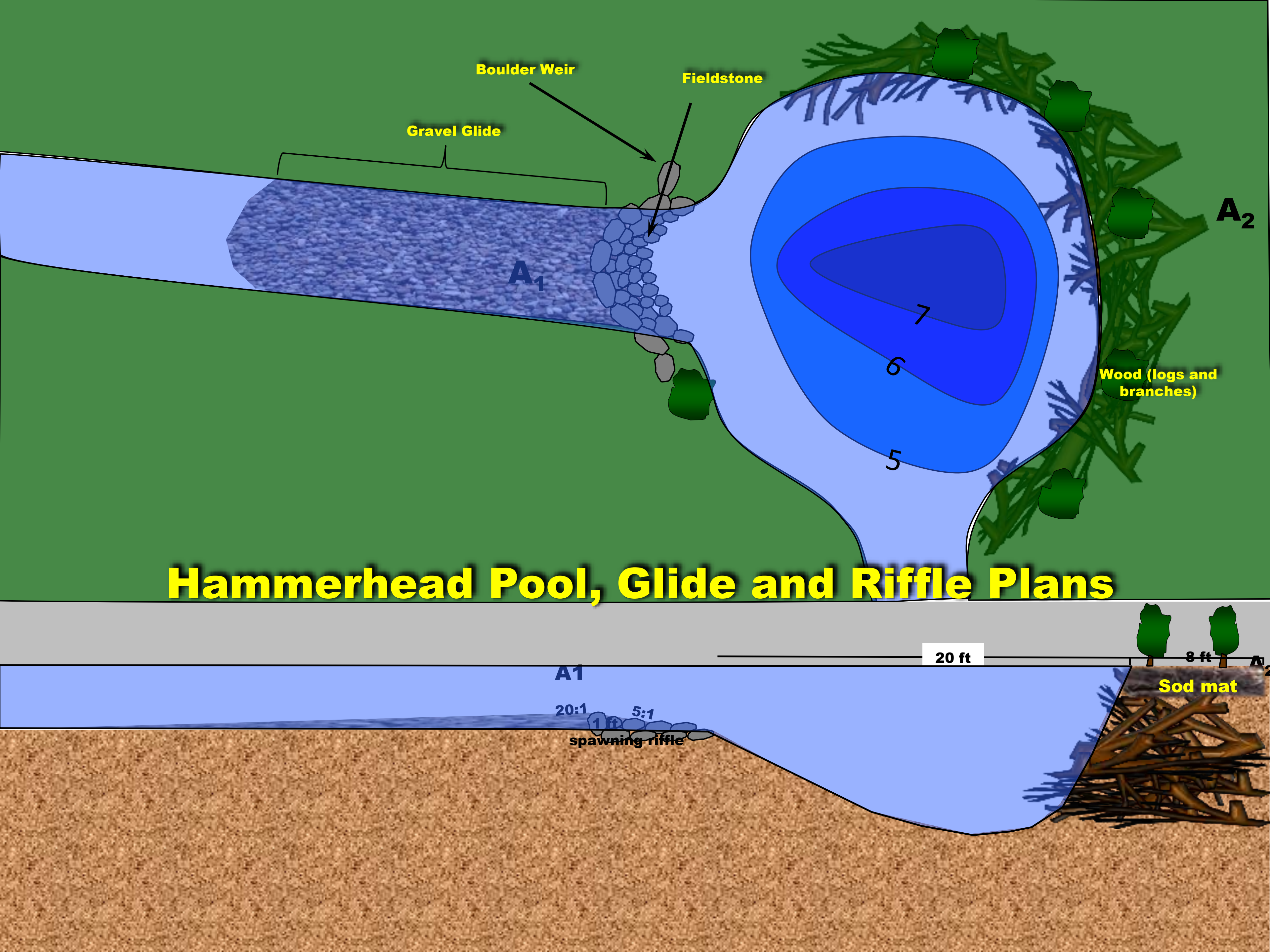
Bankfull discharge = 50 cfs
Bankfull shear stress = 0.8 kg/m^2


Meander
Super-meander
Hammerhead pool
Upper Lawndale Creek
Bankfull Width ≈ 10 ft
Sinuosity = 3.35
Meander Belt Width≈ 50 ft or 5 stream widths
Super Meander Belt Width ≈ 250 ft or 25 stream widths
Radii of curvature 1.2 – 2.5 (those <1.5 often result in formation of hammerhead pools)

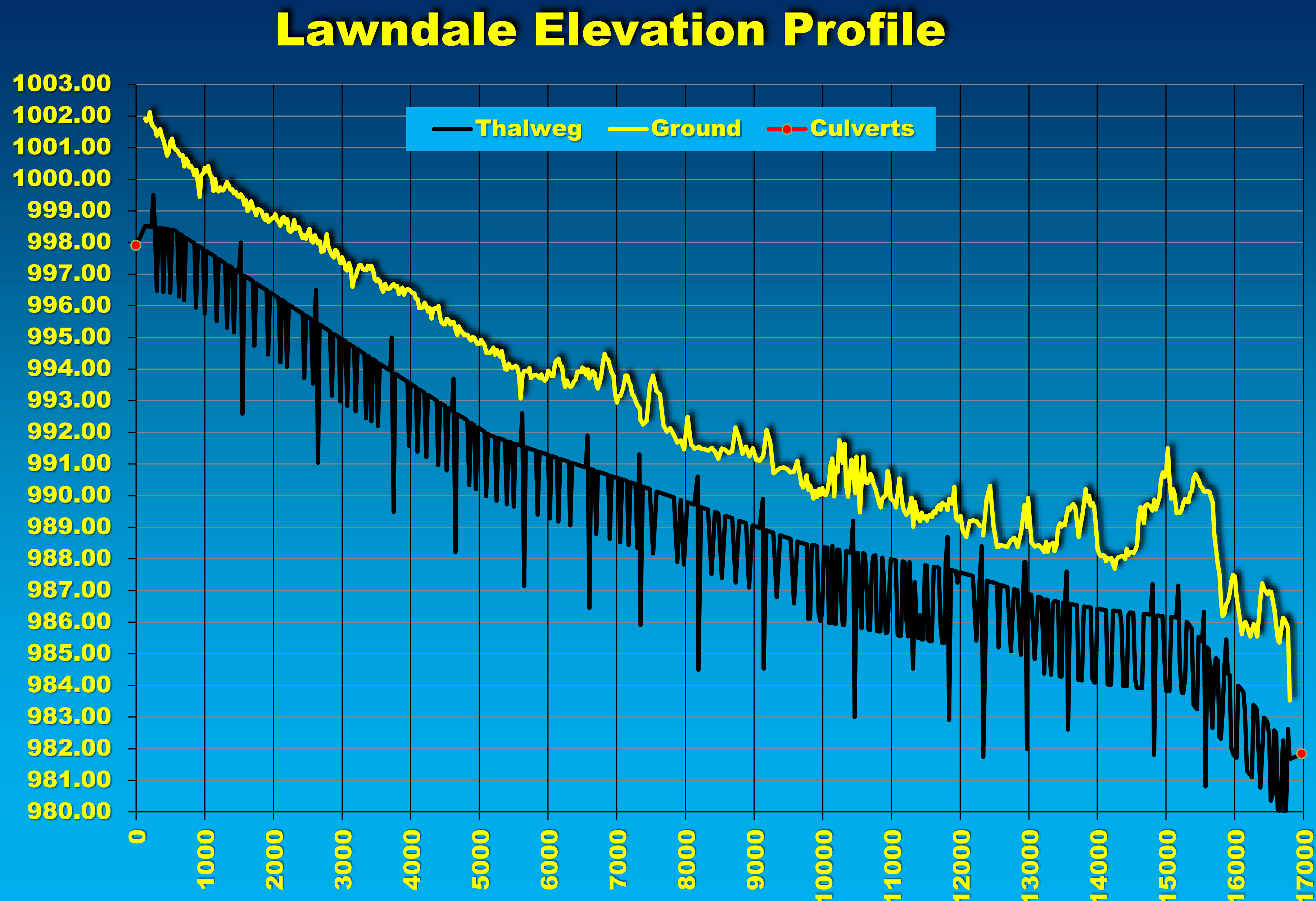

Lower Lawndale Creek
Bankfull Width 14 ft
Sinuosity = 1.63
Meander Belt Width≈ 50 ft or 3.6 stream widths
Super Meander Belt Width ≈ 250 ft or 18 stream widths
Meander
Hammerhead pool
Super-meander


Design Pattern
Radius of curvature 2.3 to 3.5 bankfull widths
Sinuosity = 1.8
Co Hwy 30
© 2010 Google
46°32'59.91" N
96°26'28.85" W
elev 994 ft
Eye alt

Hammerhead pools – key habitat


Hammerhead Pool, Glide and Riffle Plans
Boulder Weir
Fieldstone
Gravel Glide
A1
A2
7
6
5
Wood (logs and branches)
20 ft
8 ft
A1
20:1
5:1
1 ft
spawning riffle
Sod mat


Hammerhead Pool, Glide and Riffle
About 1 every 1000 ft of channel



Lawndale Elevation Profile
Thalweg
Ground
Culverts
1003.00
1002.00
1001.00
1000.00
999.00
998.00
997.00
996.00
995.00
994.00
993.00
992.00
991.00
990.00
989.00
988.00
987.00
986.00
985.00
984.00
983.00
982.00
981.00
980.00
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000

Handling Fill and Disturbance

Segments with Diverse Prairie

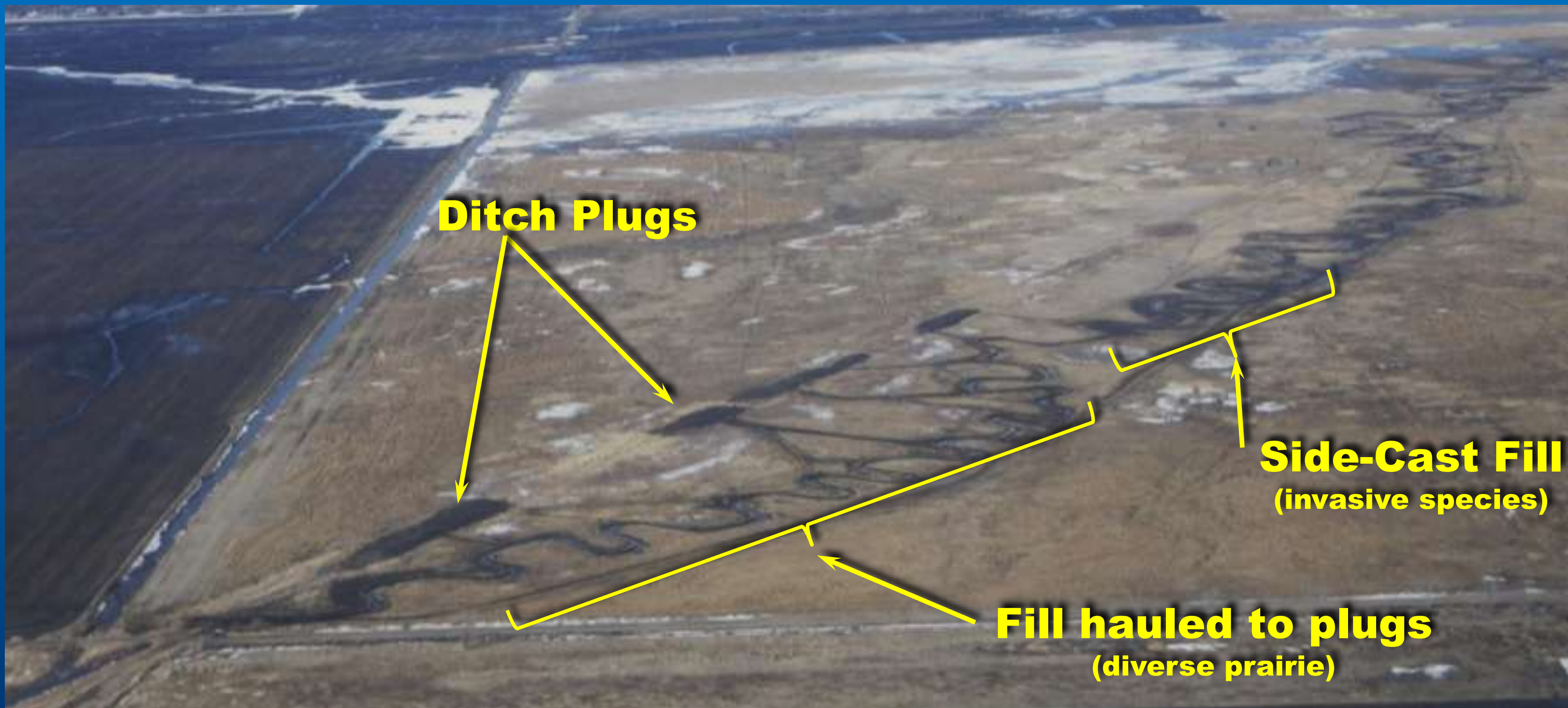
Fill hauled to ditch plugs, minimum impact



Segments with Invasive Species Monocultures

(reed canary grass, narrow leaf cattail)

Fill sidecast and seeded with native grasses and wildflowers



Ditch Plugs
Side-Cast Fill
(invasive species)
Fill hauled to plugs
(diverse prairie)


Wetland restored by plugging State Ditch 40


Excavated channel prior to flow diversion


Final Channel Excavation and Diversion of Flow
August 19, 2011

Hammerhead Pool after Flow introduction

Riffle for grade control and habitat

About 1 fieldstone riffle every 1000 feet (about 1 out of 12 riffles)
Grade control until natural grade control is established by:
Bedload recruitment into reach
Sorting of bed materials
Establishment of submergent vegetation
Increased channel roughness due to bank vegetation

575 brook trout brood stock released on 1/26/2012

Followed 3-years of major floods in 2009, 2010, and 2011(2009 was 120-year record at Fargo, 2011 was second highest).

No documented recruitment or sampled trout after 2008…reproduction was last documented in 2008.

Brook trout are short-lived; reproduction and adult survival are adversely affected by large floods


Photo courtesy of Vern Whitman Photography

Project Manager: Arlin Schalekamp
Design:
Project Engineers: Geoff Griffin and John Filardo
Geomorphic Design: Luther Aadland
Drawings: Kevin Zytkovicz and Mike Oren

Lawndale Creek Restoration Effects

HYDROLOGY and HYDRAULICS

Increased time of concentration and floodwater storage in channel, floodplain, water table, and off-channel wetlands. Decreased slope, velocity and peak flow. Re-established velocity distributions and helical flow. Irrigation withdrawals ceased.

FLUVIAL GEOMORPHOLOGY

Channel stability should increase due to slope reduction, re-established morphology, and riparian vegetation. Diversified habitat (riffles, pools, runs, glides, and backwaters).

WATER QUALITY

Should benefit from increased retention time and nutrient uptake by riparian vegetation, nutrient processing by microbial and invertebrate fauna

CONNECTIVITY

Reconnected floodplain and restored riparian wetlands. Longitudinal connectivity regained (no perched culvert) re-established hyporheic zone.

BIODIVERSITY

Should benefit from all of the above. Early indications support this

Construction is complete but the restoration is NOT; natural processes will complete project