

EVALUATION OF THE LONG-TERM IMPACTS OF URBANIZATION ON A PIEDMONT HEADWATER STREAM:

A Comparison of Physical, Biological and Chemical Indicators of Response

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Study Objectives

The objectives of the study are to measure and evaluate long-term changes in channel cross-sections, bank and channel scouring, streambed composition, longitudinal reach profiles, plan-form dimensions, biological habitats and communities, water chemistry, and land cover to determine the timing and response of the stream to urbanization within the watershed and compare with corresponding measurements of the developed watershed.

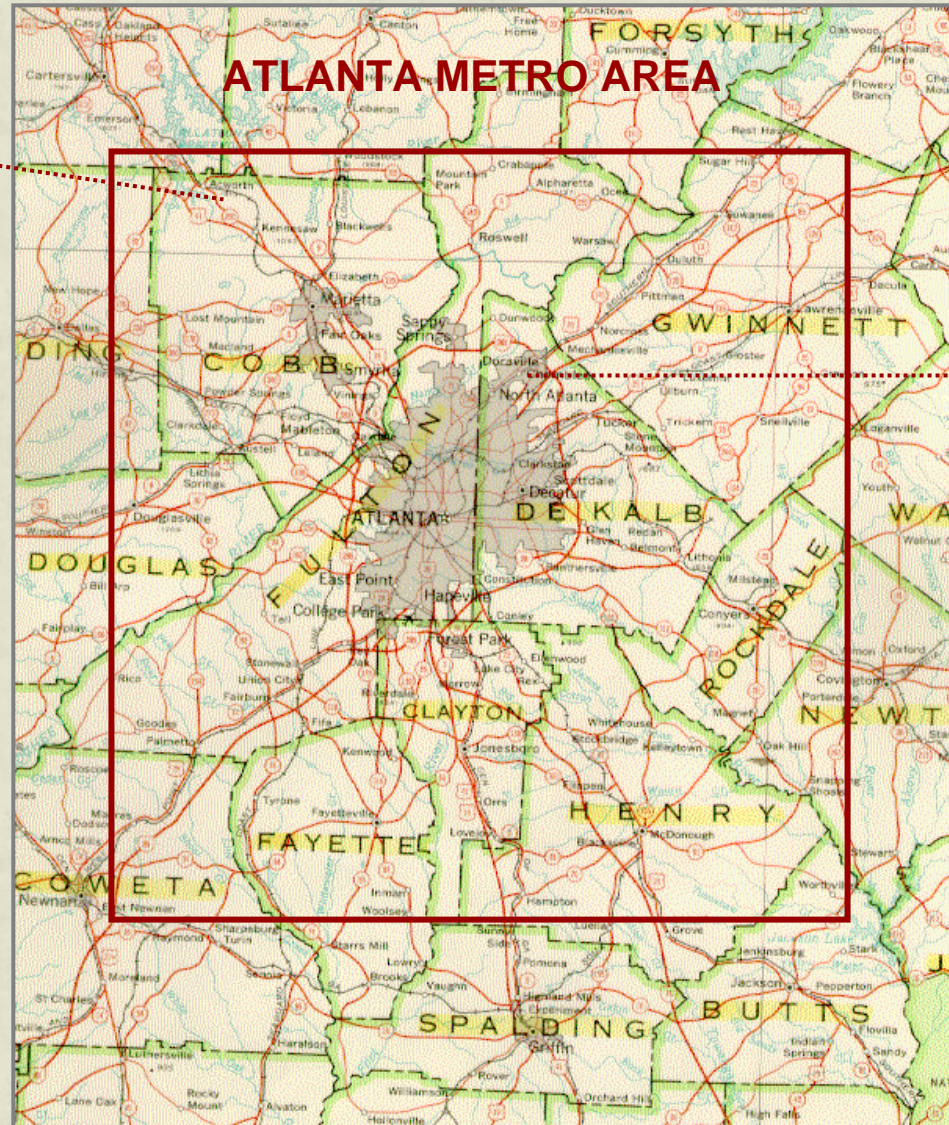


Purpose of the Study

A long-term field study was initiated in 1996 to evaluate the response of a 100 m reach of a tributary of Proctor Creek, a 3.1 km² watershed in the Atlanta metropolitan area, to the impact of rapid urbanization in the watershed over time and in comparison to a reach of a physically comparable, but almost fully developed urban watershed.

FIGURE 1: Study Location Map

Tributary to
Proctor Creek



Northwoods
Branch

FIGURE 2: Tributary to Proctor Creek Watershed

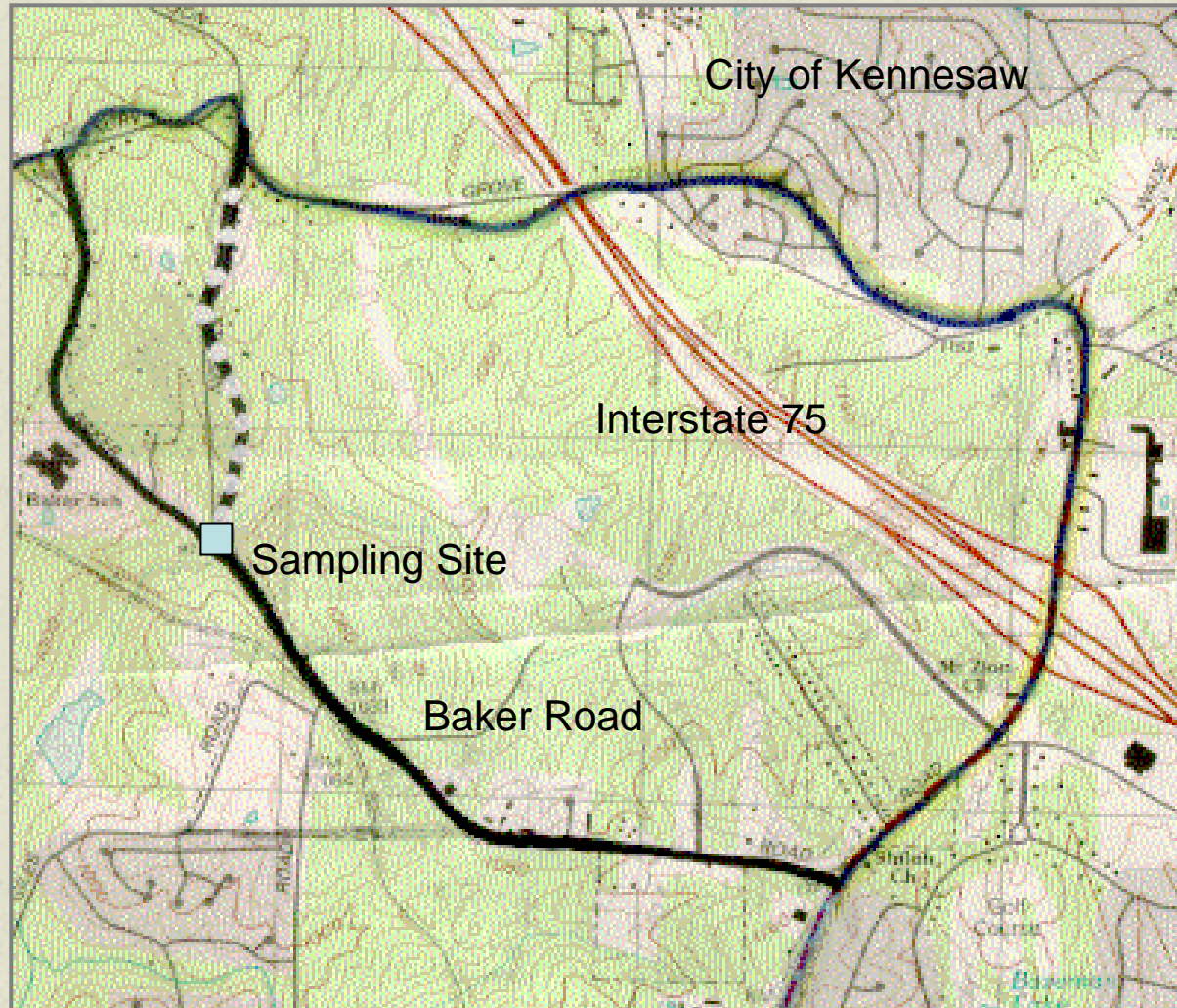


FIGURE 3: Northwoods Branch Watershed

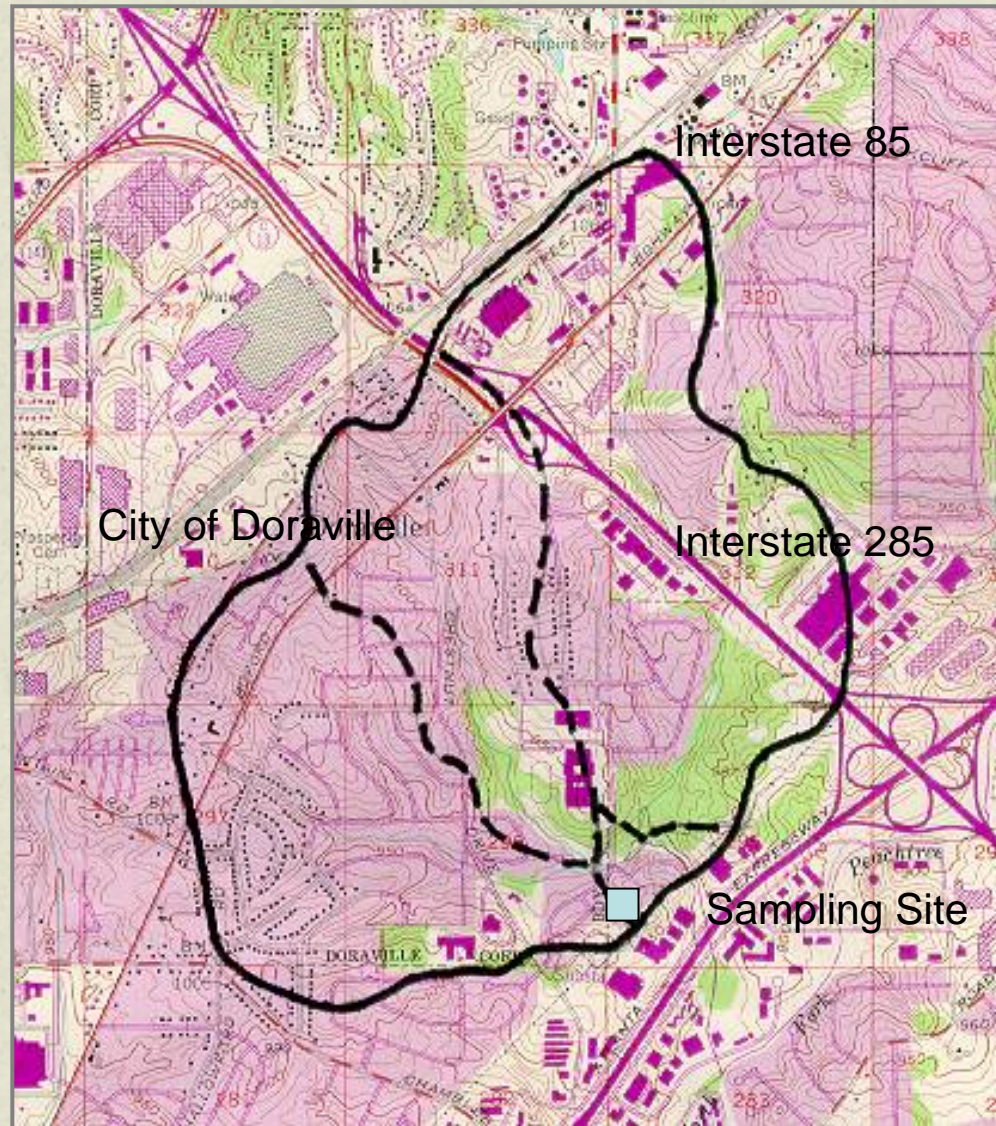


TABLE 1 Watershed Characteristics: Tributary to Proctor Creek and Northwoods Branch

Watershed Measurement	Proctor Creek Tributary	Northwoods Branch
	1995	1995
Area (ac/mi2)	984/1.54	1076/1.68
Horton Stream Order	1	2
Relief Difference (ft)	190	150
Main Channel Length (ft)	7800	7900
Main Channel Slope (ft/ft)	0.016	0.013
Dominant Upland Soil Type (1)	Gwinnett Clay Loam	Cecil Urban Land
Dominant Upland Soil Type (2)	Madison Clay & Sandy Loam	Pacolet Urban Land
Dominant Valley Soil Type (1)	Cartecay Soils	Toccoa Sandy Loam
Dominant Valley Soil Type (2)	Toccoa Soils	
Percent Forested/Parks	38.9	5.3
Percent Impervious (1995)	18.6	45.9
Dominant Land Use (1)	Low Density Residential (13%)	Med. Density Res. (41%)
Dominant Land Use (2)	Limited Access Highway (12%)	Commercial Services (22%)



**The Watershed
and Reach**

Assessment

TABLE 2: Assessment Methods/Sources & Data

Measurements	Method or Source
Land Cover	Cobb County Planning and Zoning 1993 Land Use Map. Atlanta Regional Commission (ARC) coverage.
% Impervious	Derived from ARC procedures for Big Haynes Creek Study, 3/19/99 letter from Tom Stanko.
Basin Physiography	Determined from USGS 1:24000 quadrangle sheets, using procedures described by Strahler (1964).
Rainfall	Cobb County NW Wastewater Treatment Plant Gage (1998- 2003) & Georgia Environmental Monitoring Dunwoody Gage (1996-1997)
Channel Cross-Sectional Area	Measurement techniques adapted from (Rosgen, 1996) and Harrelson, et al. (1994).
Bankfull Stage	Estimated using procedures described by Henson, et al. (undated) and Rosgen (1996).
Channel Dimensions	Determined using methods described by Rosgen (1996).

TABLE 2 (Continued) Assessment Methods

Measurements	Method or Source
Longitudinal Reach Profiles	Determined using methods described in Rosgen (1996).
Plan Form Dimensions	Determined using methods described in Rosgen (1996).
Pebble Counts	Counts taken at cross-sections using methods described by Georgia Environmental Protection Division (EPD, 2002).
Habitat Assessments	Evaluated by USGS, Georgia Wild Life Resources Division, Georgia EPD, and authors, using USGS and Georgia EPD (2002) protocol.
Macroinvertebrate Data & Indices	Collected by USGS, Georgia EPD, and Cobb County. Hilsenhoff index calculated in accordance with Georgia EPD (2002) protocol.
Water Quality Data	Collected & analyzed by Cobb County in accordance with Standard Methods.
Water Quality Index	Calculated by Cobb County in accordance with procedures described in ARC/USGS (1997).

TABLE 3: Land Use/Activity Change Over Time

Land Use	Proctor Creek Tributary				Northwoods Branch
	1993	1995	1999	2003	1995
Forest/Parks (%)	56.5	38.9	37	23.3	6.3
Pasture (%)	8	8	0	0	0
Transitional (%)	4.5	9	1.4	3.4	0
Low Density Residential (%)	4.5	13.4	5.2	4.5	0
Medium Density Residential (%)	8.5	8.5	28.6	32	40.9
High Density Residential (%)	0	4.1	3.2	6.3	12.5
Industrial/Commercial (%)	0	0	6	12.1	7.6
Commercial (%)	4.6	4.6	7	7.4	22.1
Highway-Limited Access (%)	12.1	12.1	8.9	8.9	8.2
Urban Other (%)	1.3	1.3	1.4	1.4	2.4
Estimated Impervious (%)	14.6	18.6	28.6	34.3	45.9

**The Watershed
and Reach in**

1996



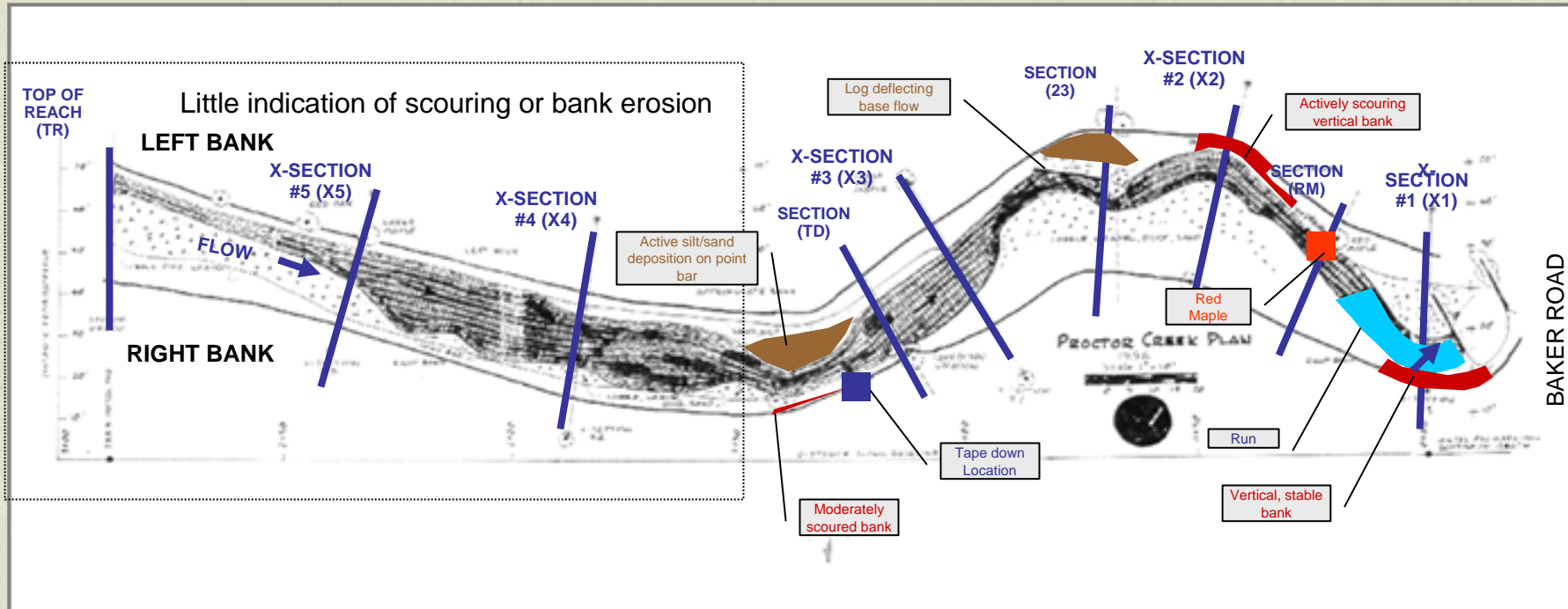
FIGURE 6: Proctor Creek Tributary

1996 Watershed
Development



- Residential development immediately upstream of sampling reach.
- Inadequate erosion and sediment controls and spotty to inadequate enforcement actions.
- Heavy sediment loading to stream.
- Percent impervious increases from 14.6% in 1993 to 18.6% in 1995.
- Slightly below normal rainfall in 1996.

FIGURE 8: 1996 Plan View of Proctor Creek Tributary Sampling Reach



- Flow over the 288.5' (measured on a baseline) is from L to R, with LB & RB labeled looking DS.
- Channel X-sections & pebble counts taken at 4 & later 5 locations.
- Other sections are top of reach (TR), tapedown (TD), Sec. (23) below X2, & a large maple (RM) below X2.
- Little indication of scouring/erosion in upper reach.
- Active silt/sand sand deposition on point bar @ TD.
- Log armoring bank at Sec. 23 is diverting base flow & promoting pooling & deposition at higher flows.
- Vertical, actively scouring bank, outside bend @ X2.
- Active sediment deposition observed over reach (24% of particles silt or sand, very light silt covering riffles & runs).
- The mean bankfull area of 4 X-sections in 1996 was 32 ft², vs. 29 ft² for basins of a similar size derived from regional curve of eastern basins.
- Mean riffle spacing of 52', with 46% of the reach in pools. Mean entrenchment ratio of 1.80, width/depth ratio of 12.04, sinuosity ratio of 1.21, & slope of 0.01 ft/ft indicate Rosgen type B stream (moderately entrenched, moderate gradient, riffle dominated stream, with infrequently spaced pools).

FIGURE 9: Proctor Creek Tributary 1996



Looking US at X-4, toward top of reach (TR)

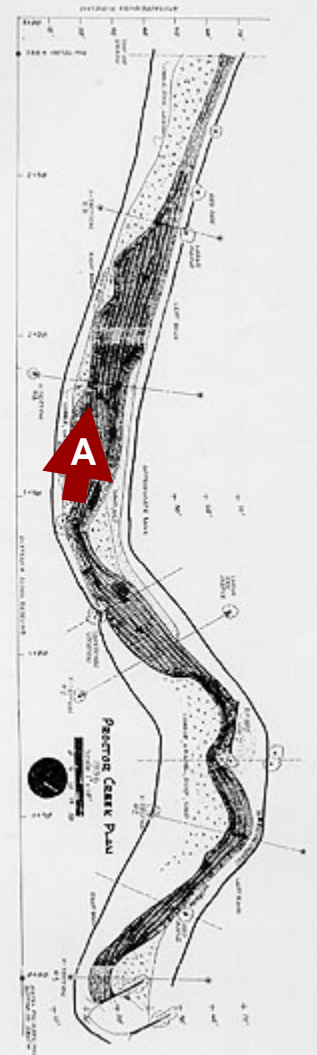


FIGURE 10: Proctor Creek Tributary 1996



A



B



C



D

- “A” Looking US past Sec. 2/3. Note transverse log and built up peninsular behind it.
- “C” Looking DS past X1. Note turbidity and run past X1.

- “B” Looking DS past X2 toward red maple (RM).
- “D” Looking DS at old Baker Road bridge. Note shallow run & pool above bridge.





**The Watershed
and Reach from**

1996

1998

FIGURE 11: Proctor Creek Tributary

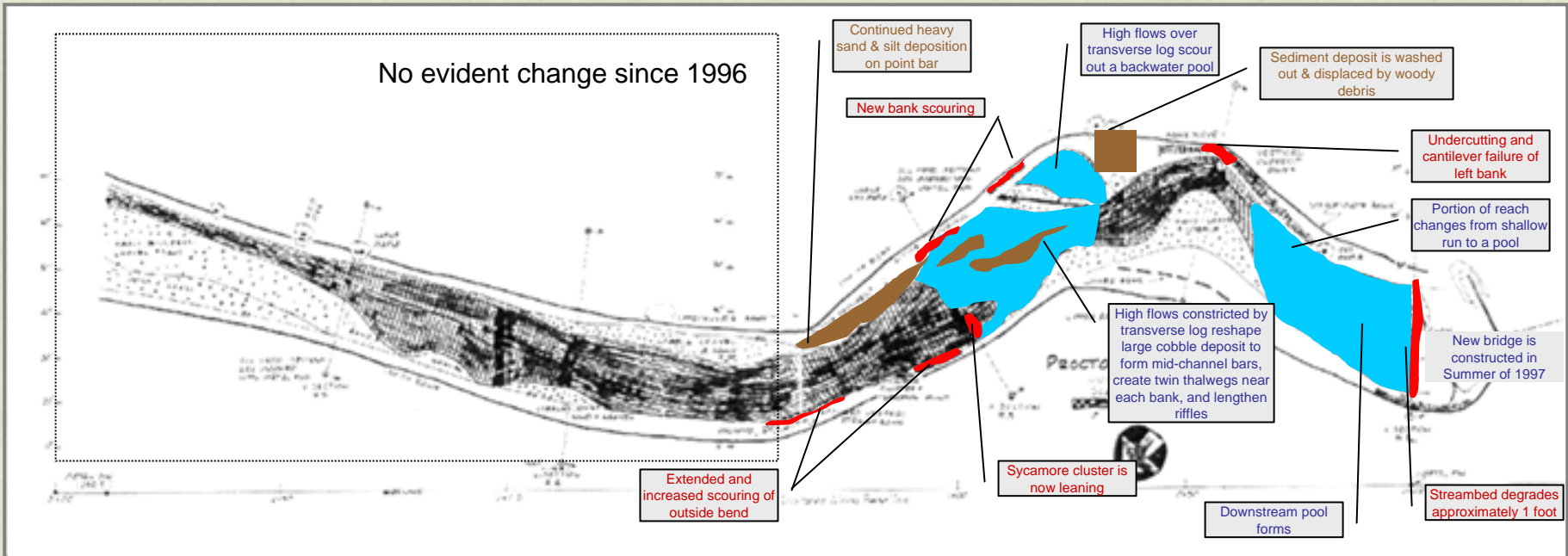
1998 Sediment
Sources



Major Changes in Watershed: 1996-98

- While the construction of medium density residential development and the commercial-industrial park continued, Cobb County issued no new building permits during 1997.
- Heavy sediment delivery from immediately upstream residential construction continued despite reporting problems responsible jurisdiction. Cobb County took enforcement actions against a residential development in the middle of the watershed.
- The estimated impervious area approached 25% of the watershed.
- Normal rainfall in 1997 & 1998.

FIGURE 12: 1998 Plan View of Proctor Creek Tributary Sampling Reach



- No evident changes in the upper, relatively straight portion of reach.
- Increased & extended scouring of outside bend near tapedown (TD) site & continued heavy sand & silt deposition on opposite point bar.
- Sycamore cluster (TD) on edge of bank site has leaned into the stream at a pronounced angle.
- High flows constricted by transverse log below X-3 reshape large cobble deposit to form mid-channel bars and create thalwegs near each bank, and lengthen riffles.
- Higher flows have begun scouring LB below X3, scoured out a pool behind the transverse log, and displaced the sediment peninsular at Section 23 with woody debris.
- The upper portion of the outside (LB) bank @ X2 receded approximately 2 feet due to undercutting and cantilever bank failure.
- Construction of new bridge @ Baker road resulted in upstream ponding & ponding of the former shallow run above X1.
- The streambed at X1 degraded approximately 1 foot.

TABLE 4: Changes in Plan Dimensions and Cross-Sections 1996-98

Measurement	Year		
	1996	1997	1998
Thalweg Length (ft)	348	-	327
Sinuosity (Thalweg/Valley Length)	1.21	-	1.13
Water Slope (ft/ft)	0.009	-	
Mean Riffle-Riffle Spacing (ft)	52	-	59.3
Percent of Reach as Pool	46	-	61
Mean Maximum Bankfull Depth (ft)	2	2.4	2.6
Mean Bankfull Area (ft ²)	32.0	36.7	41.2
Mean Channel Area (ft ²)	95.3	104	106.9
Mean Bankfull Width/Depth Ratio	12.04	9.73	8.97
Annual Rainfall (in)	52.8	58.5	57.0

TABLE 5: Changes in Habitat Assessments, Macro-invertebrate Population and Water Quality 1996-98

Measurements	Year	
	1996	1998
Habitat Assessment (0 - 200, best)	123	120
Embeddedness (0 - 20, best)	11	11
Sediment Deposition (0 - 20, best)	10	10
Median Particle Size (mm)	10	13
Percent Silt	9	18
Percent Sand	15	20
Number Taxa	29	-
Number Individuals	281	-
Hilsenhoff Score (0-10, lowest)	5.86	-
Mean Site WQ Index (0-10, lowest)	0.16	0.10
Mean Conductivity (us/cm ⁻¹)	61.1	61.4
Mean D.O. (% saturation)	94.5	100.1
Mean Turbidity (NTU)	3.7	5.2
Annual Rainfall	52.6	57.0

The background of the slide is a photograph of a forest. On the left side, there are several large, dark tree trunks. Sunlight filters through the green leaves in the upper part of the image, creating a dappled light effect. A large, semi-transparent, light-brown rectangular box covers the right two-thirds of the slide, serving as a background for the text.

**The Watershed
and Reach from**

**1998
2000**

TABLE 7: Changes in Habitat Assessments, Macroinvertebrate Population and Water Quality 1998-2000

Measurements	Year		
	1998	1999	2000
Habitat Assessment (0-20, best)	120	-	117
Embeddedness (0 -20, best)	11	-	12
Sediment Deposition (0 - 20, best)	10	-	12
Median Particle Size (mm)	13	12	-
Percent Silt	18	14	-
Percent Sand	20	22	-
Number Taxa	-	-	-
Number Individuals	-	-	-
Hilsenhoff Score (0 -10, lowest)	-	4.3	5.7
Mean Site WQ Index (0-1, low)	0.10	0.18	0.19
Mean Conductivity (us/cm-1)	61.4	-	78.6
Mean D.O. (% saturation)	100.1	88.8	85.9
Mean Turbidity (NTU)	5.2	3.6	15.2
Mean Annual Rainfall	57.0	47.1	50.3

The background of the slide is a photograph of a stream. The water is clear, revealing a bed of smooth, light-colored stones. The banks are covered with a thick layer of fallen autumn leaves in various shades of brown, orange, and yellow. The lighting is soft, suggesting a misty or overcast day.

**The Watershed
and Reach from**

**2000
2002**

**TABLE 8: Changes in Plan Dimensions and Cross-Sections
2000-2002**

Measurement	Year	
	2000/1999*	2002
Thalweg Length (ft)	339*	354
Sinuosity (Thalweg/Valley Length)	1.18*	1.23
Water Slope (ft/ft)	-	0.011
Mean Riffle-Riffle Spacing (ft)	65*	68.3
Percent Reach as Pool	67*	57
Mean Maximum Bankfull Depth (ft)	2.5	2.5
Mean Bankfull Area (ft ²)	44.2	44.3
Mean Channel Area (ft ²)	108.6	102.1
Mean Bankfull Width/Depth Ratio	9.48	9.37
Annual Rainfall (in)	50.3	69.3

TABLE 9: Changes in Habitat Assessments Macro invertebrate Population and Water Quality 2000-2002

Measurements	Year		
	2000	2001	2002
Habitat Assessment (0 - 200, best)	117	93	115
Embeddedness (0 - 20, best)	12	7	10
Sediment Deposition (0 - 20, best)	12	8	10
Median Particle Size (mm)	-	22	17
Percent Silt	-	9	12
Percent Sand	-	21	22
Number Taxa	-	-	10
Number Individuals	-	-	135
Hilsenhof Score (0 -10, lowest)	5.7	-	5.2
Mean Site WQ Index (0 -10, low)	0.19	0.24	0.21
Mean Conductivity (us/cm ⁻¹)	78.6	109.4	115.7
Mean D.O. (% saturation)	85.9	88.4	89.6
Mean Turbidity (NTU)	15.2	10.3	5.3
Annual Rainfall (in)	50.3	61.4	69.3



**The Watershed
and Reach from**

**1996
2003**

FIGURE 24: Proctor Creek Tributary

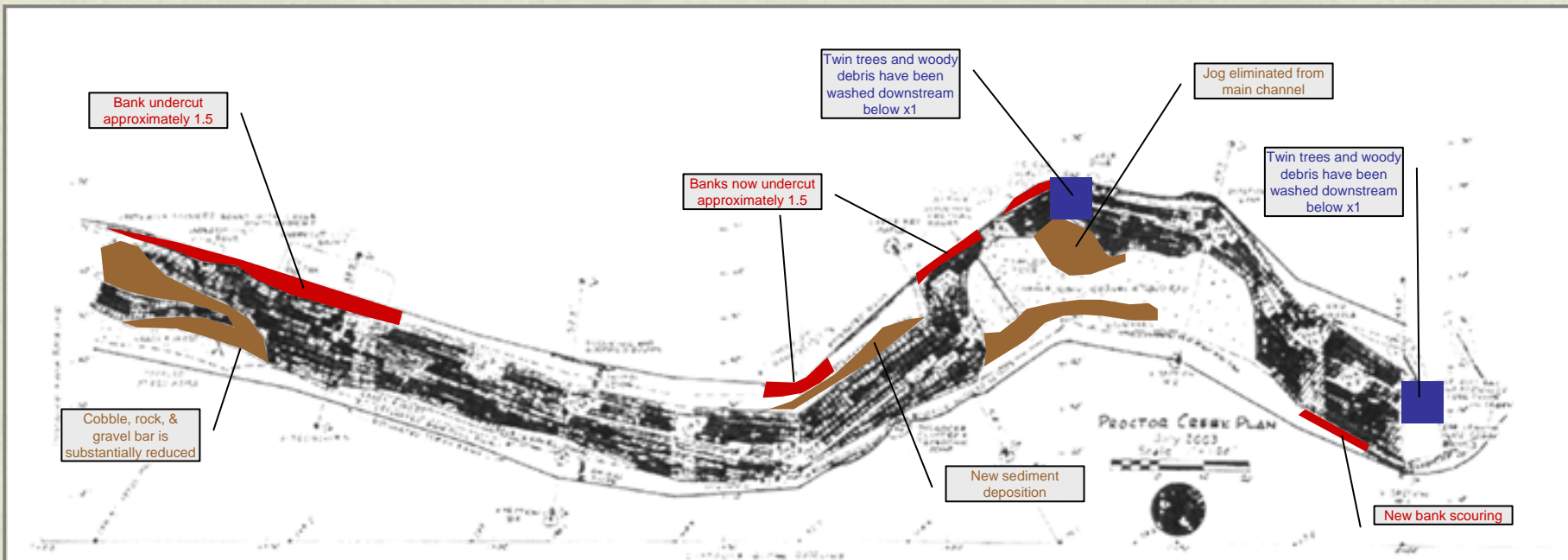
2003
Development



Major Changes 1996-2003

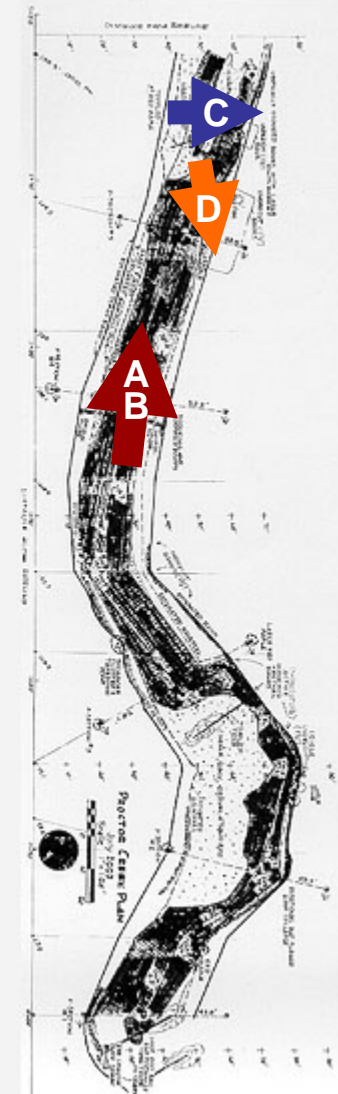
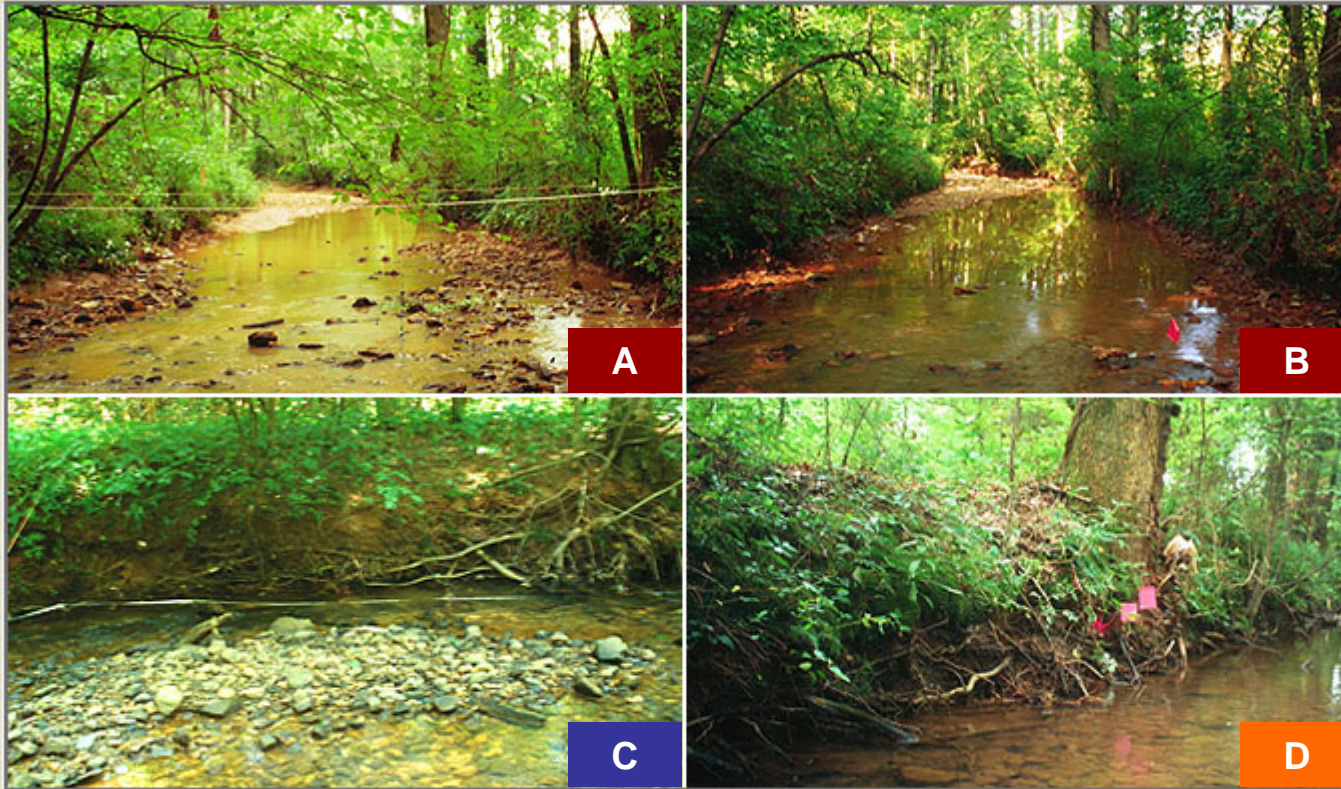
- By 2003, medium and high density residential development occupied over 53% of the watershed as compared to 23.3% remaining in forest.
- Estimated percent impervious increased from 14.6% in 1993 to 34% in 2003, vs the estimated 45.9% impervious for the fully developed Northwoods Branch watershed.

FIGURE 25: 2002-2003 Plan View of Proctor Creek Tributary Sampling Reach



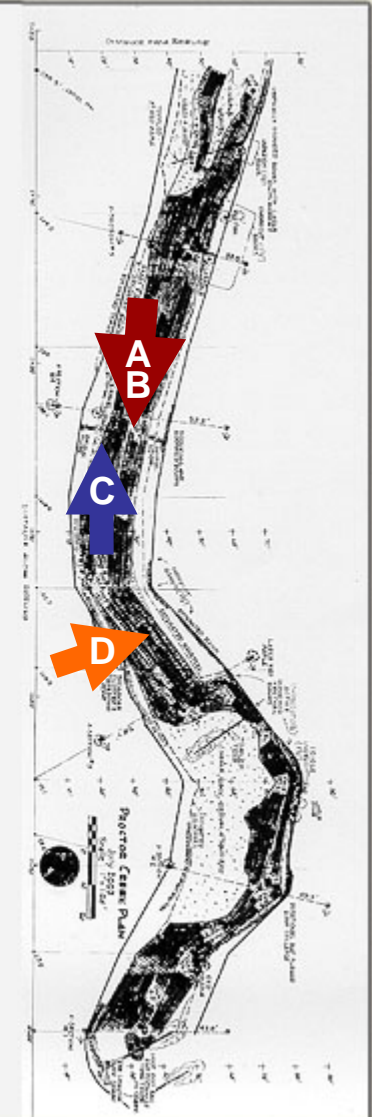
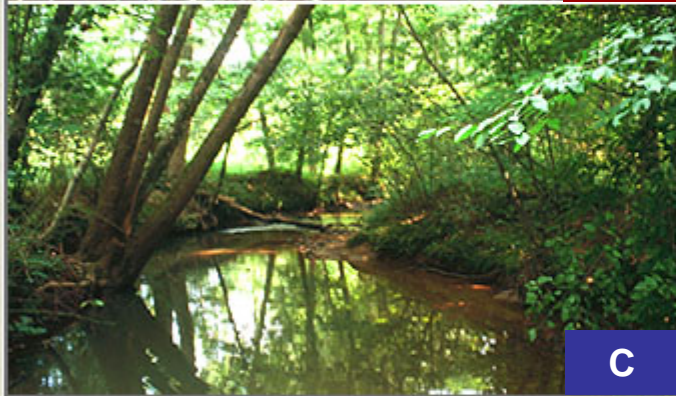
- Between 2002 & July, 2003, the heavily scoured LB from the TR to X4 was undercut approximately 1½ ft.
- The cobble & rock bar US X4 was greatly reduced..
- The X5 bankfull area increased from 33.8 to 36.3 ft².
- Scouring of RB (outside bend) US X3 continued.
- The heavily scoured & receding LB US & DS from X-3 was undercut approximately 1½ ft.
- The right of the twin channels below X3 was filled by an increased accumulation of cobbles which diverted even higher flows to the left channel.
- High flows continued to scour the upper LB @ Sec. 23, washed away the twin red maple trees & debris peninsular, & scoured the bank to vertical by 2003.
- The point cobble bar between X3 & X2 increased in area and height as the outside bend continued to suffer bank undercutting & cantilever, planar failure.
- Between 2002 and 2003 bank scouring increased substantially on the RB near X1.

FIGURE 27: Proctor Creek Tributary 1996-2003



- “A” 1996 looking US past X4.
- “B” 2003 looking US past X4.
- “C” 2003 Erosion of LB between TR & X5.
- “D” 2003 Erosion of LB between TR & X5.

FIGURE 28: Proctor Creek Tributary 1996-2003



- “A” 1997 looking DS past TD.
- “B” 2003 looking US past TD toward X4.

- “B” 2003 looking DS past TD. Note leaning trees.
- “D” 2003 Looking at LB above X3.

FIGURE 29: Proctor Creek Tributary 1996-2003



- “A” 2003 cobble, rock bed below X3.
- “B” 2003 looking DS @ LB above Sec. 23.
- “C” 2002 looking DS @ twin red maples & debris @ Sec 23.
- “D” 2003 looking US at former site of twin red maples shown in photo “C”.

FIGURE 30: Proctor Creek Tributary 1996-2003



- “A” 1996 looking US at traverse log on LB just below X3.
- “C” 1996 looking DS toward LB @ X2.

- “B” 2003 looking US at former site of traverse log shown in photo “A”.
- “D” 2003 looking US toward LB @ X2.

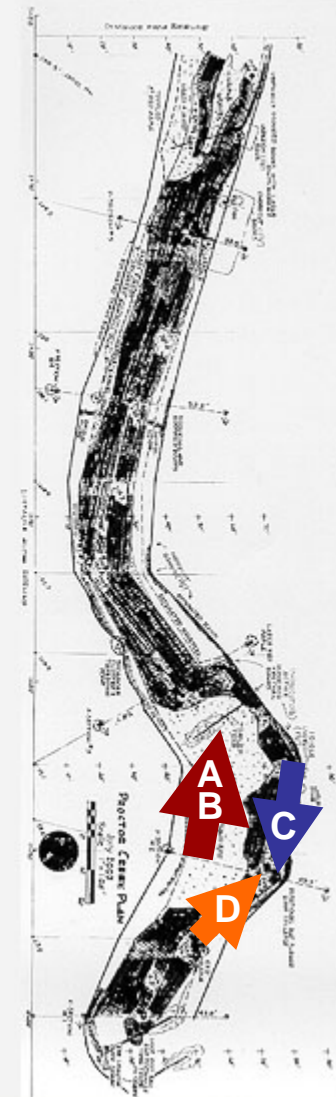
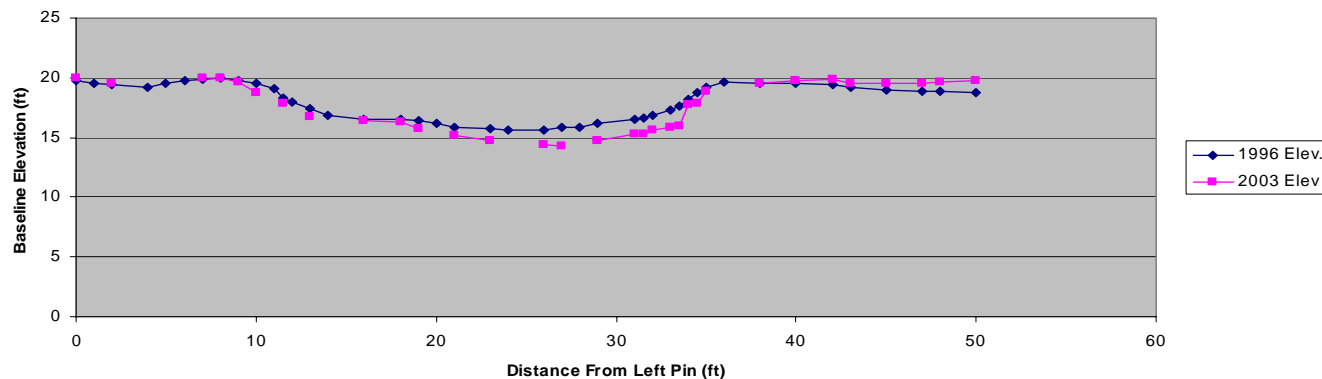


FIGURE 32: Proctor Creek Tributary 1996-2003



Cross-section 3 Changes: 1996-2003



- Photo "A" 1996 looking US past Red Maple on LB.
- Photo "B" 2003 looking US past Red Maple on LB.
- Major changes in X3 were an up to 1.5' degradation of the right channel bed (left on the map) & 72% increase in bankfull area from 28.5 to 49.1ft².

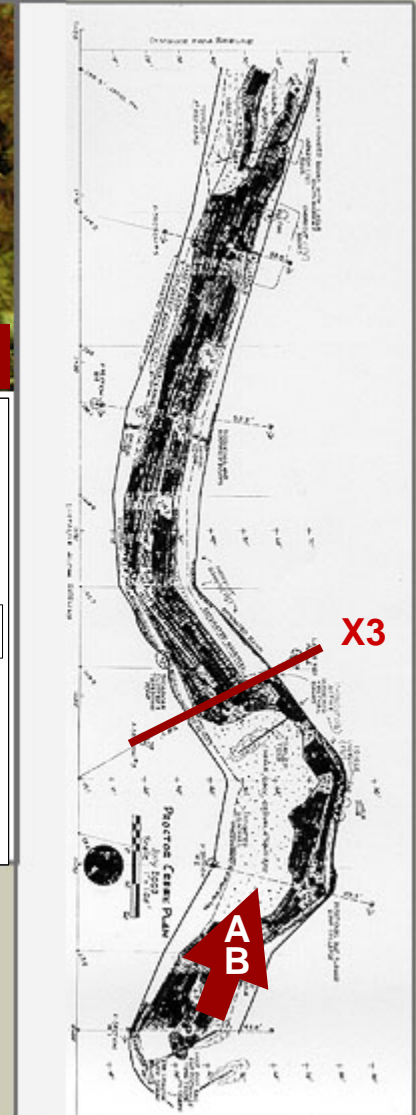
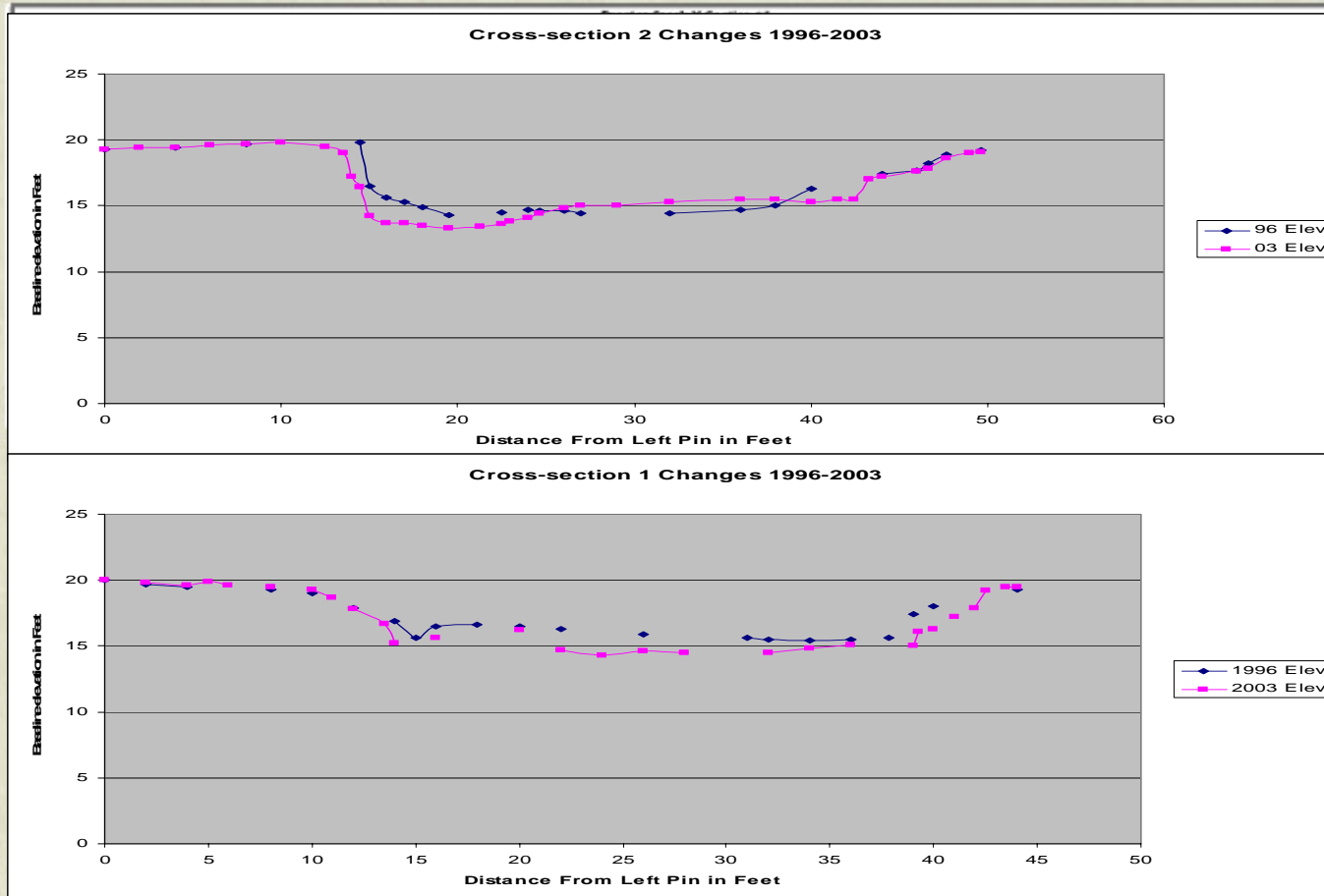


FIGURE 33: Proctor Creek Tributary 1996-2003



Major changes in X2 were a 1'+ recession of the LB, excavation of a scour pool below the LB, up to 1' build-up of the cobble & rock and cobble bed on right side, and a 2'+ recession of the lower RB. Bankfull area increased 105% from 31.9 to 65.4ft². Major changes in X1 an up to 2' degradation of the stream bed and the expansion of the RB by 3 + feet. Bankfull area increased 72% from 29.8 to 51.3ft².

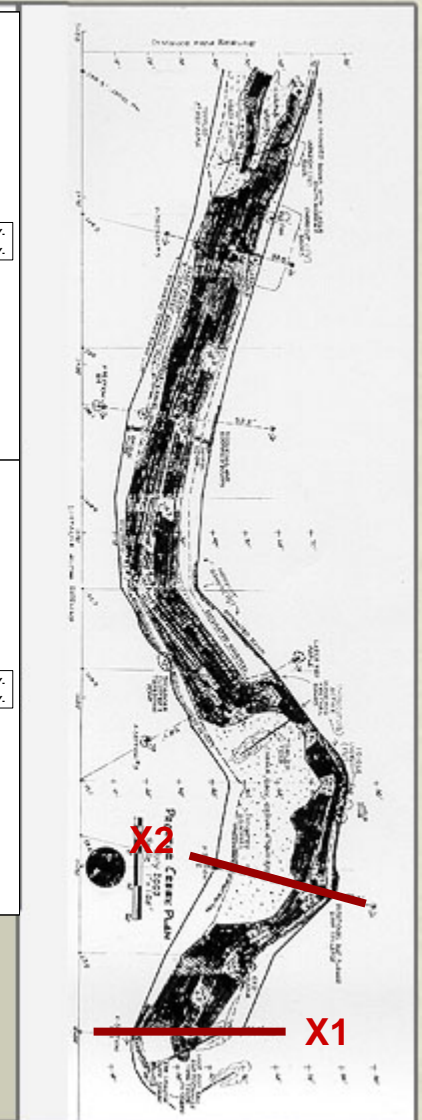


TABLE 10: Changes in Plan Dimension and Cross-Sections

Measurement	Year		
	1996	2002	2003
Thalweg Length (ft)	348	354	352.5
Sinuosity (Thalweg/Valley Length)	1.21	1.23	1.22
Water Slope (ft/ft)	0.009		
Mean Riffle-Riffle Spacing (ft)	52	68.3	64
Percent Reach as Pool	46	57	40
Mean Maximum Bankfull Depth (ft)	2	2.5	3.1
Mean Bankfull Area (ft ²)	32	44.3	52.4
Mean Channel Area (ft ²)	95.3	102.1	105.2
Mean Bankfull Width/Depth Ratio	12.04	9.37	7.65

**TABLE 11: Changes in Habitat Assessments,
Macroinvertebrate Population and Water Quality**

Measurements	Year		
	1996	2002	2003
Habitat Assessment (0 - 200, best)	123	115	
Embeddedness (0 -10, best)	11	10	
Sediment Deposition (0 - 10,best)	10	10	
Median Particle Size (mm)	10	17	10
Percent Silt	9	12	17
Percent Sand	15	22	30
Number Taxa	29	10	
Number Individuals	281	135	
Hilsenhoff Score (0 -10, low)	5.86	5.2	
Mean Site WQ Index (0 -1, lowest)	0.16	0.21	
Mean Conductivity (us/cm ⁻¹)	61.1	115.7	
Mean D.O. (% saturation)	94.5	89.6	
Mean Turbidity (NTU)	3.7	5.3	

FIGURE 34: Water Quality Indices (WQI) Over Time

Proctor Creek Tributary Water Quality Index Values Over Time

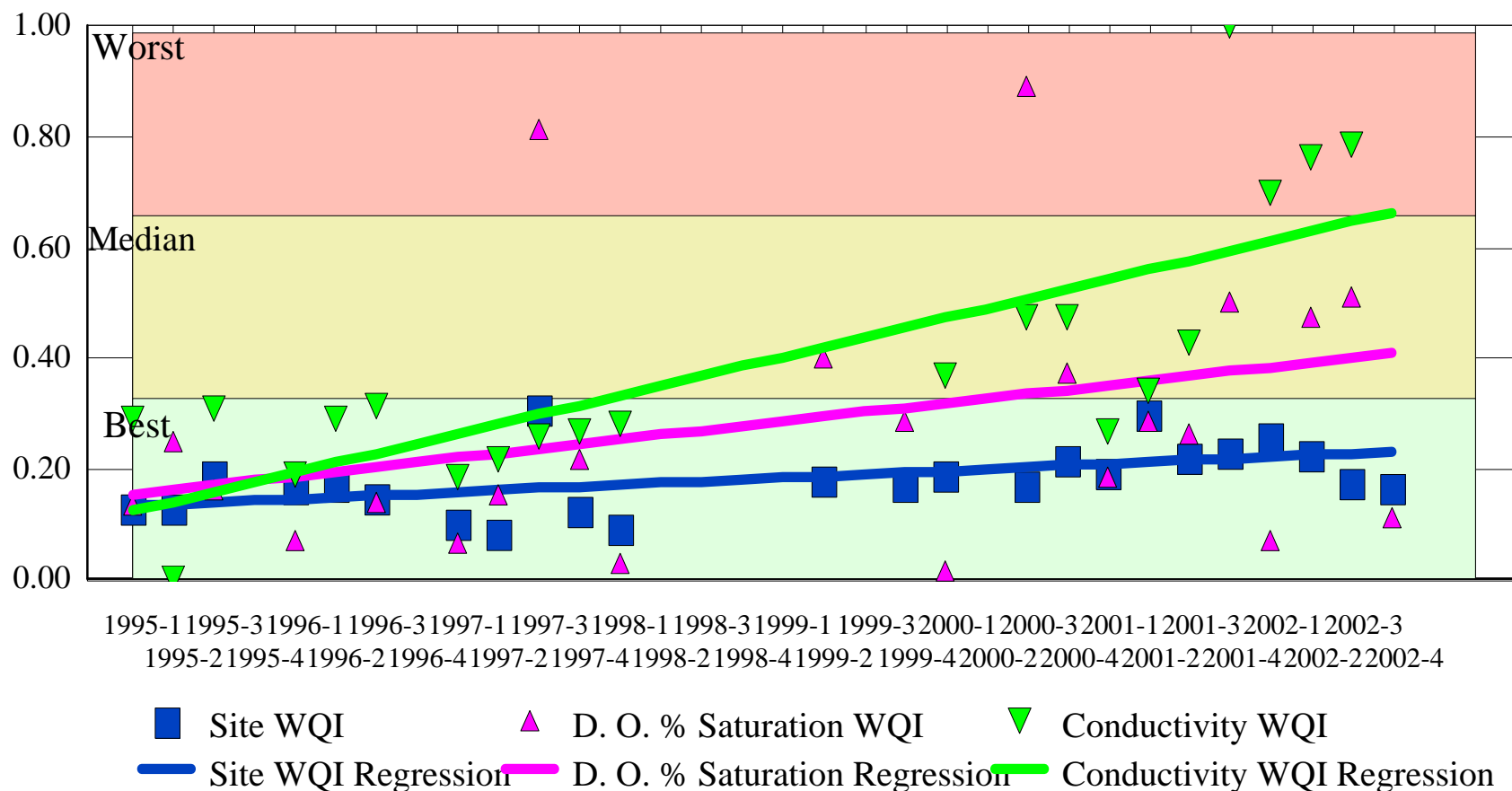
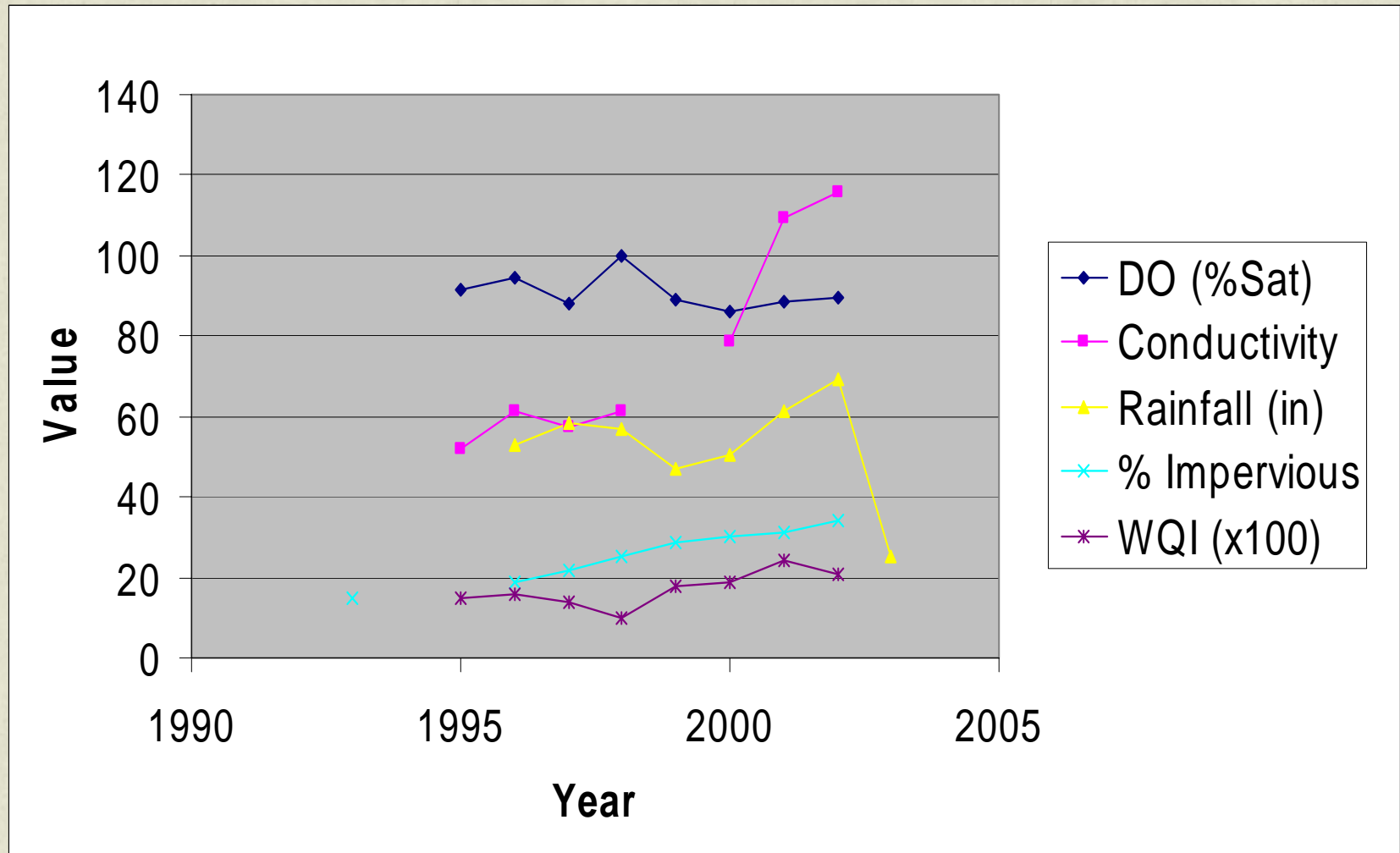


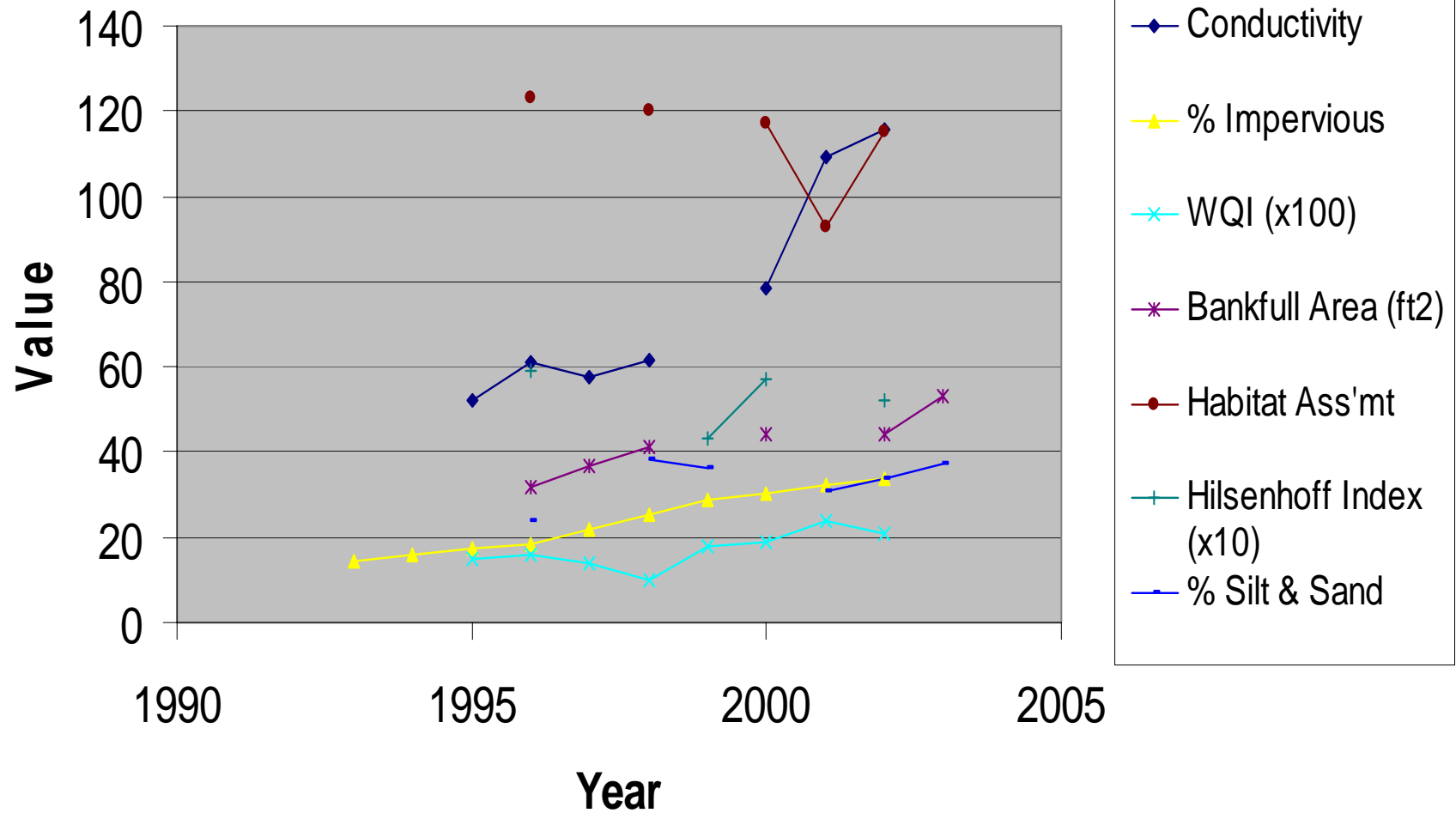
FIGURE 39: Relationship Between Watershed Imperviousness, Water Quality Index (WQI) & Conductivity



The Response of Water Quality Measures to Watershed Development

- The trend in the Water Quality Index developed for Georgia EPD by USGS/Atlanta Regional Commission (1994) closely tracks the increase in impervious area in the Proctor Creek watershed.
- Conductivity appears to be a promising and sensitive measure of the impacts of development on the Proctor Creek.
- M. J. Paul, et al. (2001) concluded that: “The strongest chemical response to urbanization was specific conductance”.

FIGURE 40: Comparison of Water Quality, Physical, and Biological Measurements Over Time



The Response of Physical and Biological Measures to Watershed Development

- Habitat assessment has not been adequately sensitive to declining conditions in the stream.
- Sand and silt bed composition probably more related to more direct influences than percent impervious.
- The mean increase in bankfull area follows increases in impervious areas, with largest increase between 2002-03, when rainfall was , exceptionally high.
- The Hilsenhoff index has not adequately reflected the loss of sensitive species and reduction of taxa and individuals in the creek.

TABLE 12: Proctor Creek vs. Northwoods Branch Measurements

Measurement	Year		
	Proctor Creek (1996)	Proctor Creek (2002)	Northwoods Branch (1999)
% Impervious	18.6	34.0	45.9
Sinuosity Ratio	1.21	1.22	1.25
Surface Slope (ft/ft)	0.009	.011	.005
Mean Bankfull Width/Depth Ratio	12.0	9.4	17.3
Mean Entrenchment Ratio	1.8	1.9	1.1
Rosgen Stream Type	B	W/D < 12 Like "G" Type	F
Mean Riffle Spacing (ft)	52	68.3	84.6
% Reach as Pools	46	57	66
Mean Maximum Bankfull Depth (ft)	2	2.5	2.2
Mean Bankfull Area (ft ²)	32	44.3	47.2
Mean Channel Area (ft ²)	95.3	102.1	176.0

TABLE 12: Proctor Creek vs. Northwoods Branch Measurements

Measurement	Year		
	Proctor Creek (1996)	Proctor Creek (2002)	Northwoods Branch (1999)
Habitat Assessment	123	115	67
% Sand & Silt	24	34	39
Mean Particle Size (mm)	10	17	14
Benthic Index Score		34 (Poor)	37(Poor)
Number Taxa	29	10	12
Number Individuals	281	135	58
Hilsenhoff Index	5.9	5.2	6.45
Mean Water Quality Index	0.16	0.21	-



Thank You:

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General Conclusions

- Conductivity . . . It's a good thing
- Bullet two
- Bullet three
 - Other stuff kdjfadjfkdf
 - Djdkjfkdf kjfdkjfdjfkdf
 - Kdjfkdfk djfjdkj
- Bullet four
- Bullet five
 - Djdkjfkdf kjfdkjfdjfkdf
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Comparison of Developing with a Fully Developed Urban Watershed

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FIGURE 5: Northwoods Branch Land Use 1995

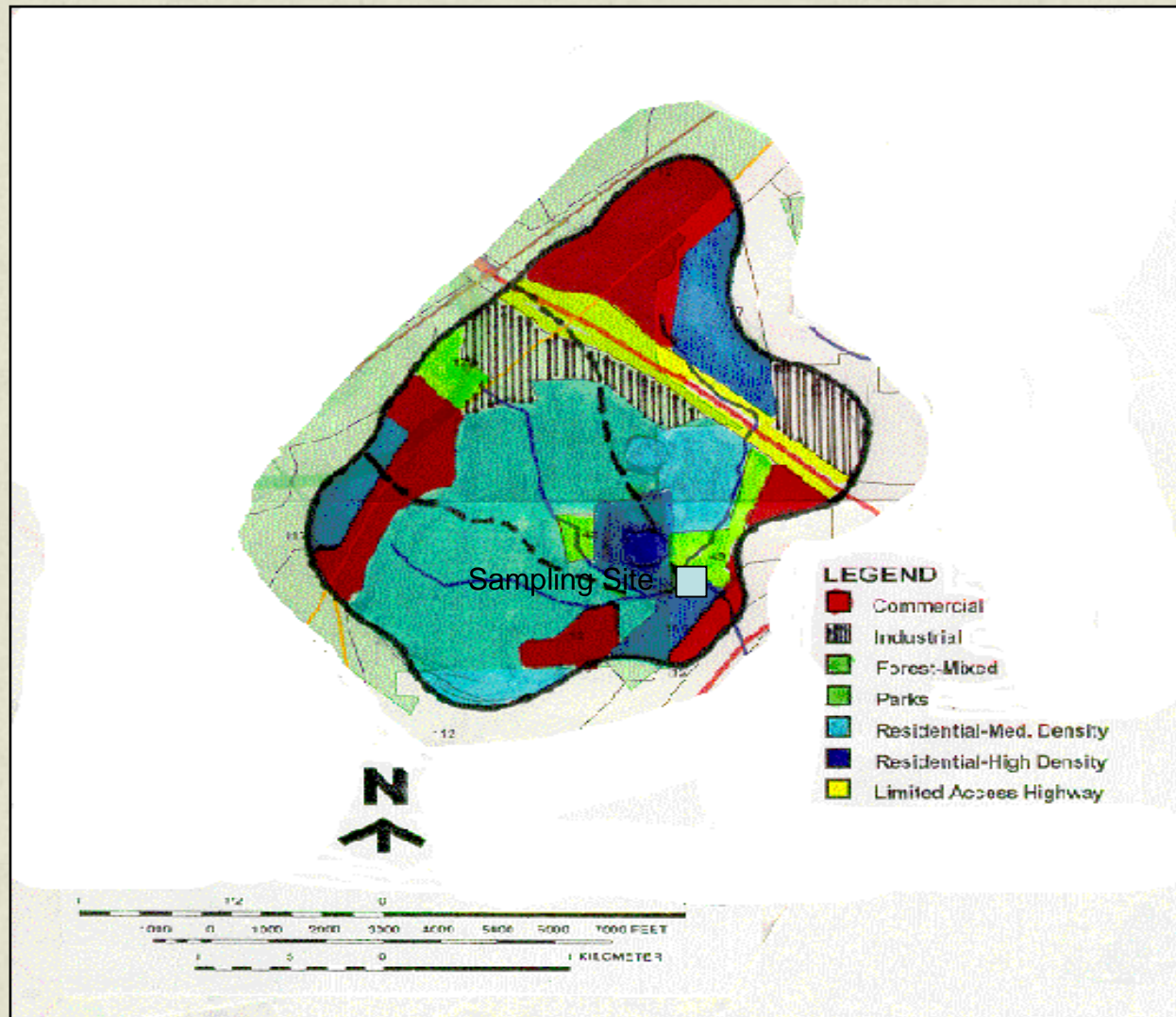


FIGURE 7: Proctor Creek Tributary

1996 Sediment
Sources



FIGURE 13: 1998 Plan View of Proctor Creek Tributary Sampling Reach

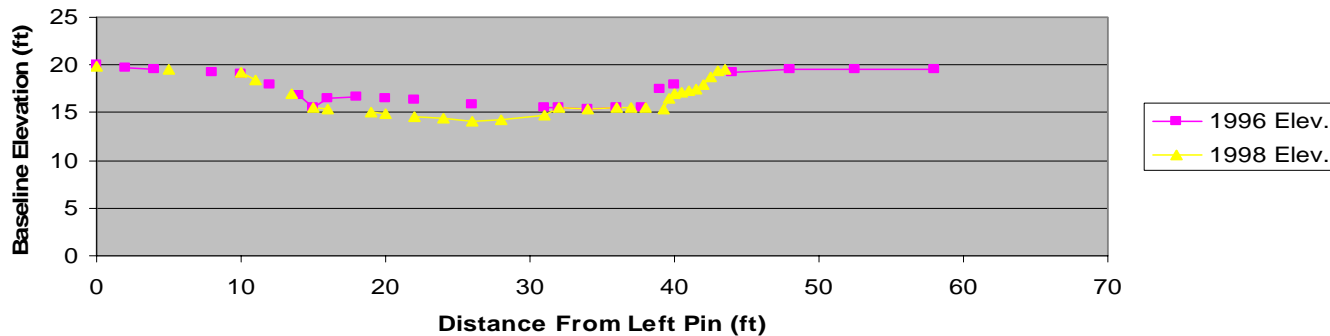


- "A" Looking US past X4 toward TR.
- "B" Construction of new bridge @ Baker Rd. Note ponding.
- "C" Silt deposition on LB opposite TD.
- "D" sycamore cluster @ TD leaning into stream, indicating undercutting.

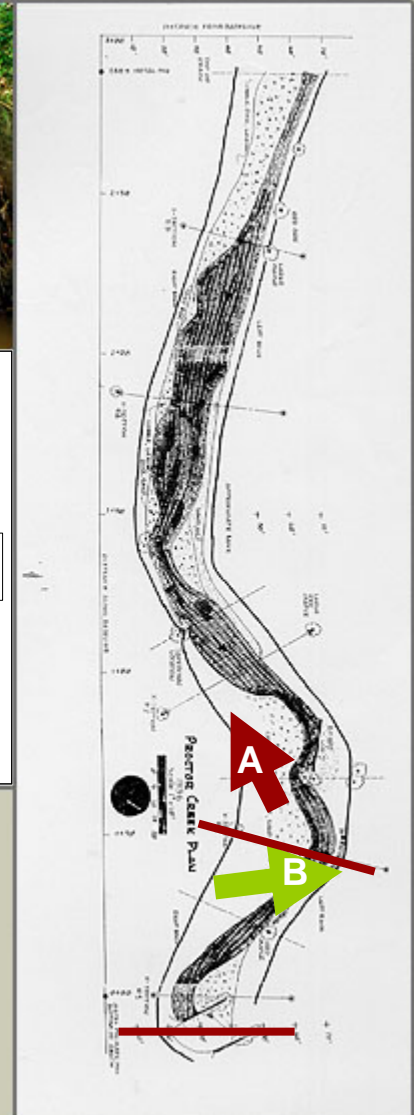
FIGURE 14: Proctor Creek Tributary 1996-98



Cross-section X1: 1996-98



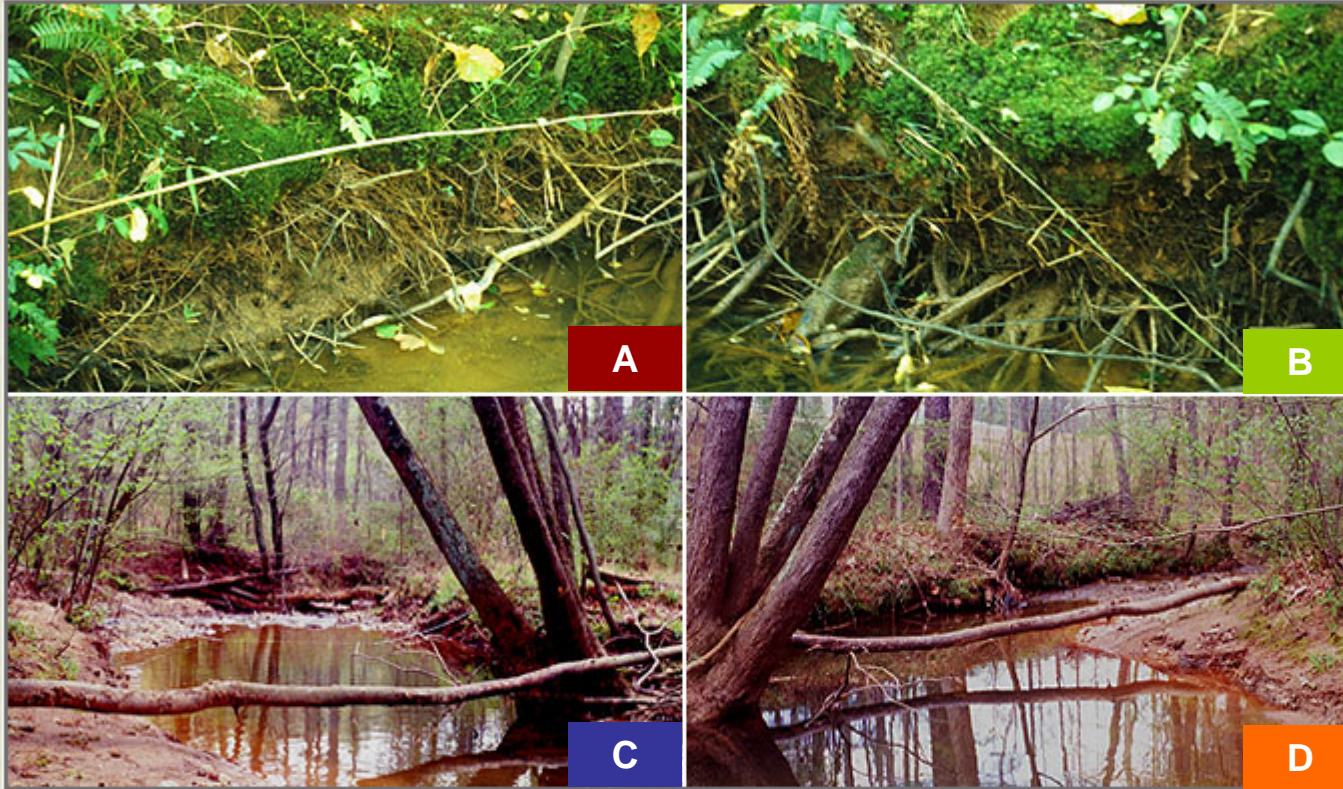
- The mean bankfull area of the four cross-sections increased 32 ft² to 41.2 ft² (29%) from 1996-98.
- The largest increases were for X1 and X2, respectively, 74% & 36%.
- The increase in the area of X1 (above) due primarily to bed degradation.
- The increase at X2 (Photo "B" above) due primarily to bank erosion & excavation of a deep scour pool below the outside (LB) bank.



**TABLE 6: Changes in Plan Dimensions and Cross-Sections
1998-2000**

Measurement	Year		
	1998	1999	2000
Thalweg Length (ft)	327	339	-
Sinuosity (Thalweg/Valley Length)	1.13	1.18	-
Water Slope (ft/ft)		0.010	0.011
Mean Riffle-Riffle Spacing (ft)	59.3	65	-
Percent Reach as Pool	61	67	
Mean Maximum Bankfull Depth (ft)	2.6	-	2.5
Mean Bankfull Area (ft ²)	41.2	-	44.2
Mean Channel Area (ft ²)	106.9	-	108.6
Mean Bankfull Width/Depth Ratio	8.97		9.48
Mean Annual Rainfall (in)	57.0	47.1	50.3

FIGURE 17: Proctor Creek Tributary 1998-2000



- “A” new scouring of LB between TR & X4. Note exposed white roots.
- “C” looking DS past TD toward X3 and cobble bar.
- “A” new scouring of LB between TR & X4.
- “D” looking US past TD @ leaning sycamore cluster. Note sediment deposition on right.

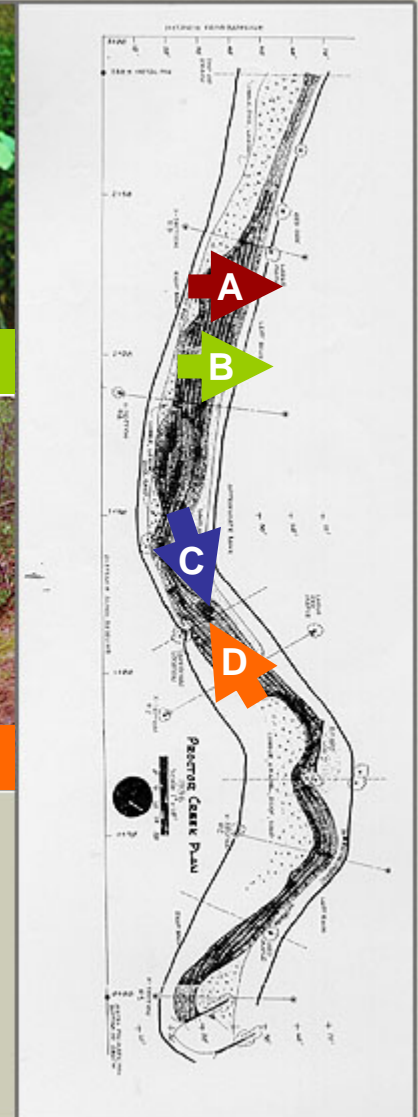


FIGURE 18: Proctor Creek Tributary 1998-2000



- Bullet one
- Bullet two
- Bullet three
- Bullet four

- Bullet one
- Bullet two
- Bullet three
- Bullet four

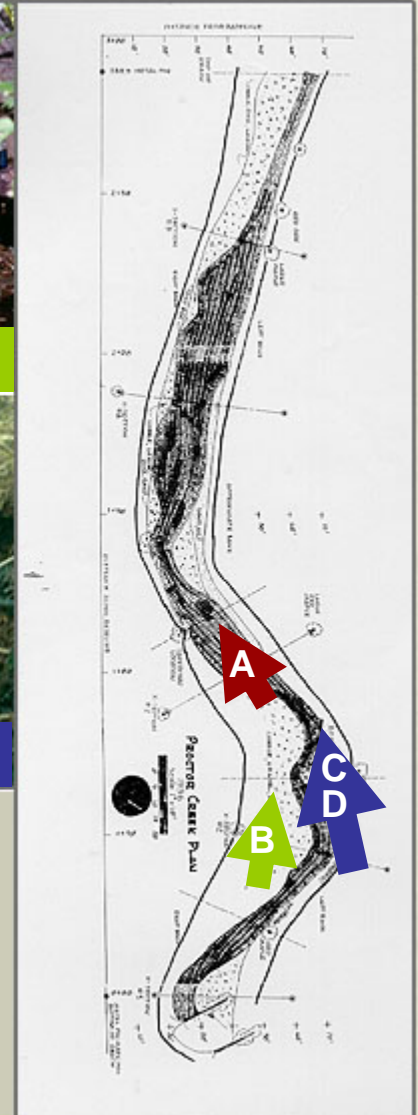
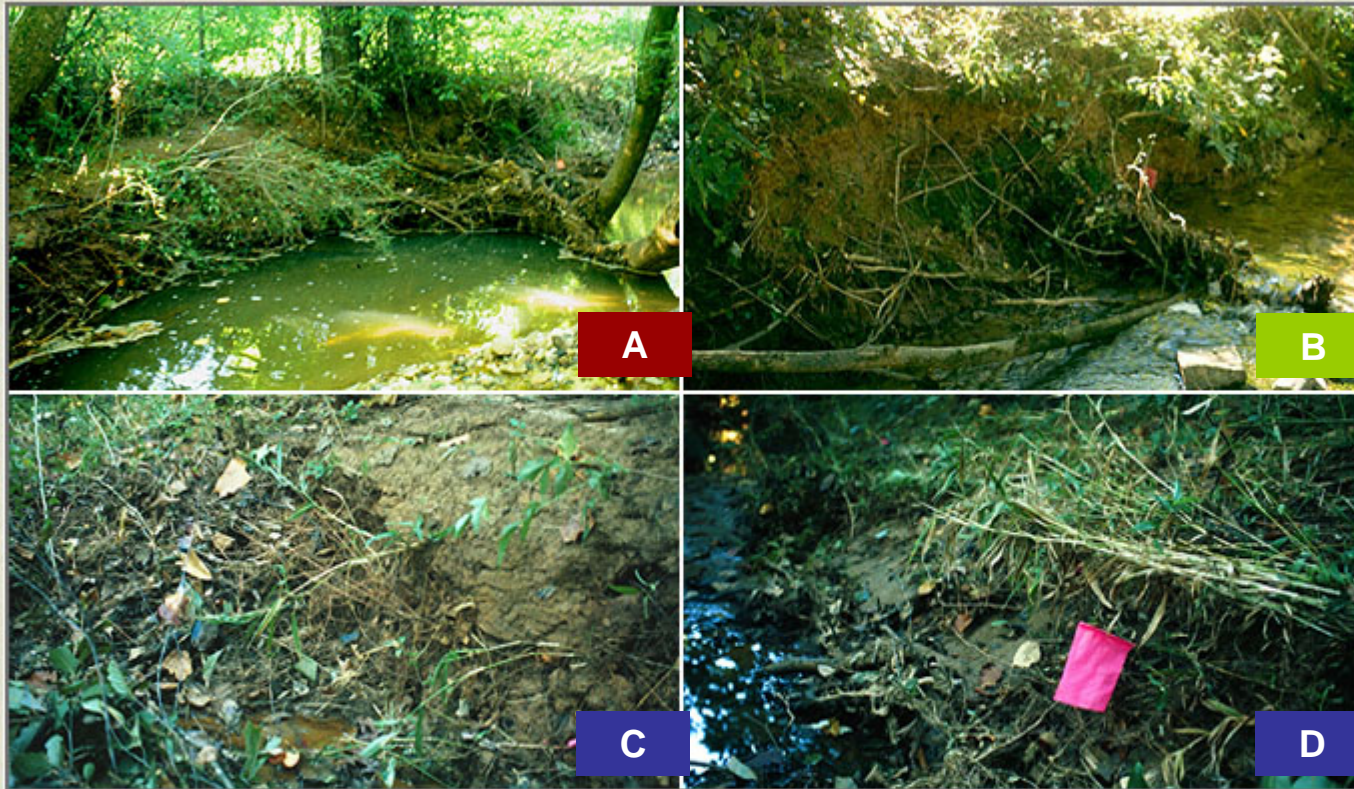


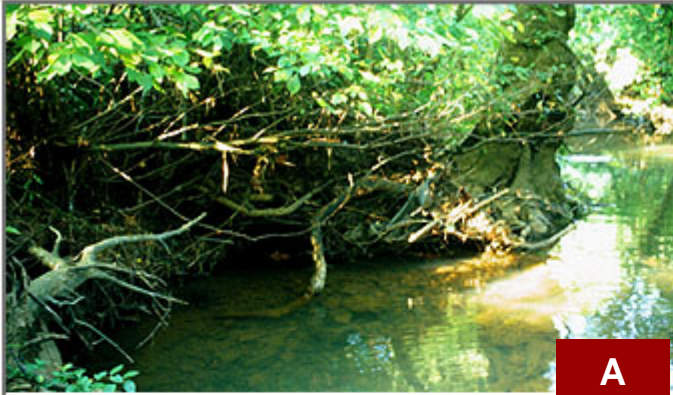
FIGURE 19: Proctor Creek Tributary 1998-2000



- “A” looking DS @ debris pile behind twin red maples.
- “B” undercutting & bank failure @ X2
- “C” Sediment deposition & lower bank scouring of RB @ X2.
- “D” Sediment deposition & lower bank scouring of RB @ X2.



FIGURE 20: Proctor Creek Tributary 1998-2000

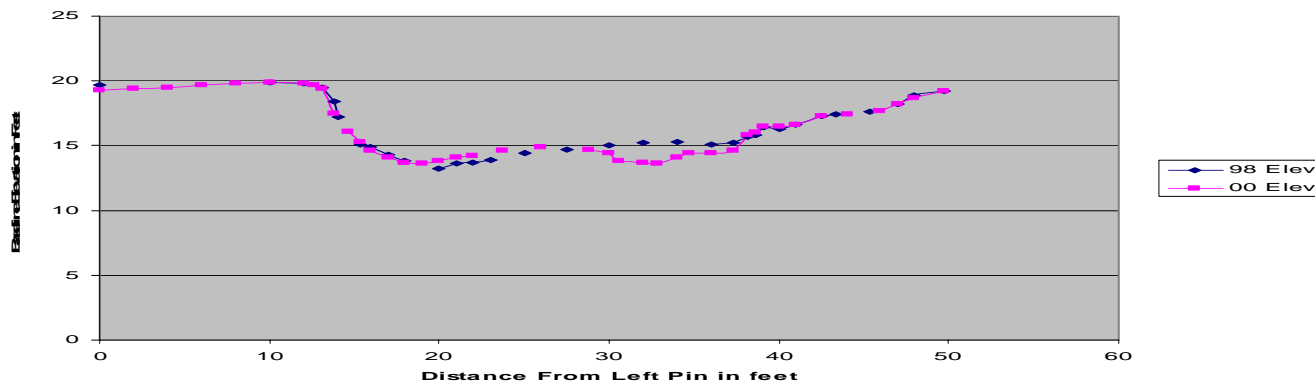


A



B

Changes in Cross-section 2: 1996-2000



- Photos "A" & "B" show upstream ponding caused by new bridge @ Baker Rd.
- While the mean bankfull area of the four cross-sections increased but 7% from 1998 to 2000, X1 & X2 both increased by 17%.
- The increase in X2 above was due primarily to a gully in the rock & cobble bar on right side of the stream bed & an increase in the estimated bankfull stage elevation.

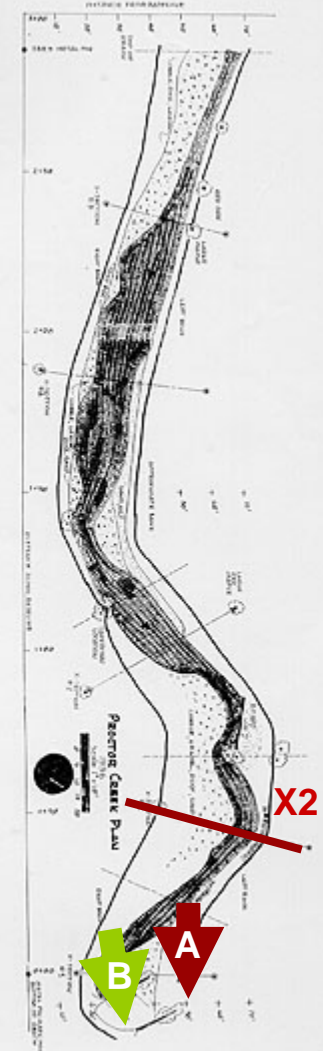


FIGURE 22: Proctor Creek Tributary 2000-2002

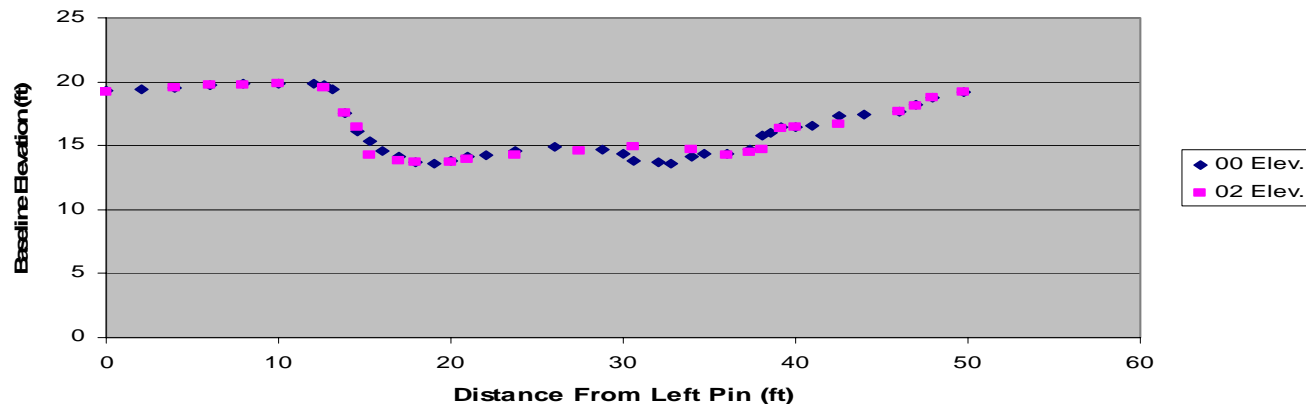


- “A” looking US at newly established X-5 & TR.
- “B” looking DS past TD & X3 toward cobble bar.
- “C” looking DS past twin red maples (@ Sec 23) toward bottom of reach (Sec. RM).
- Heavily scoured & undercut LB above twin red maples (on right side of photo).

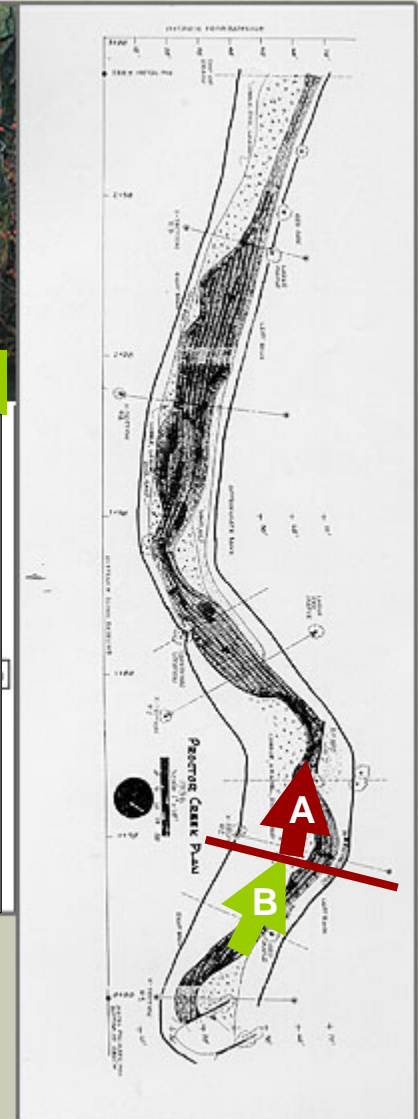
FIGURE 23: Proctor Creek Tributary 2000-2002



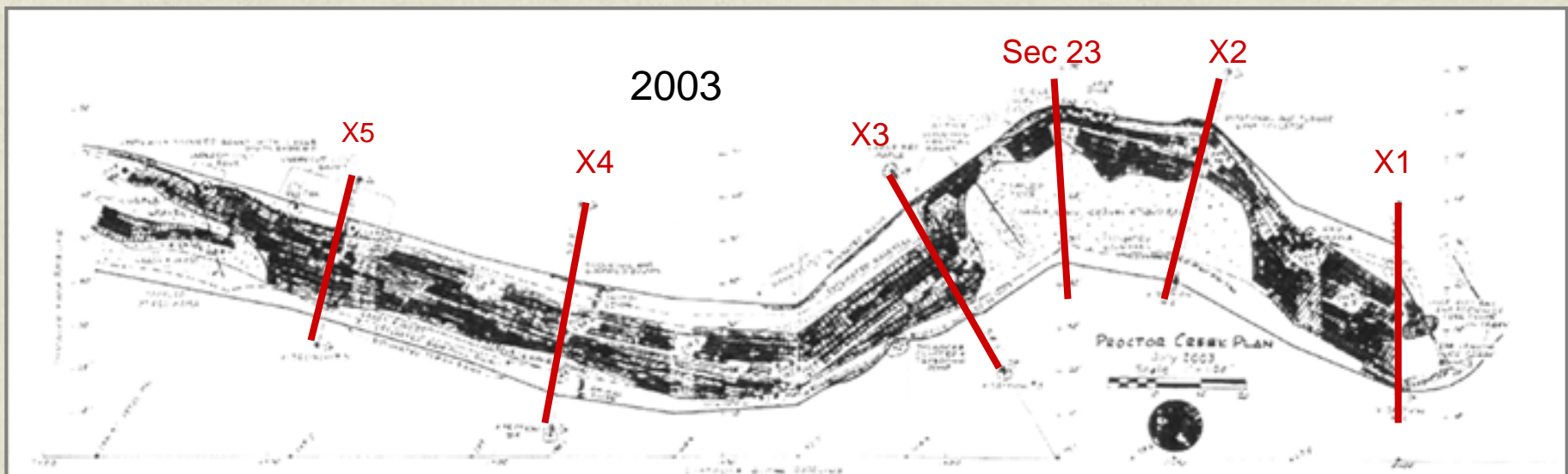
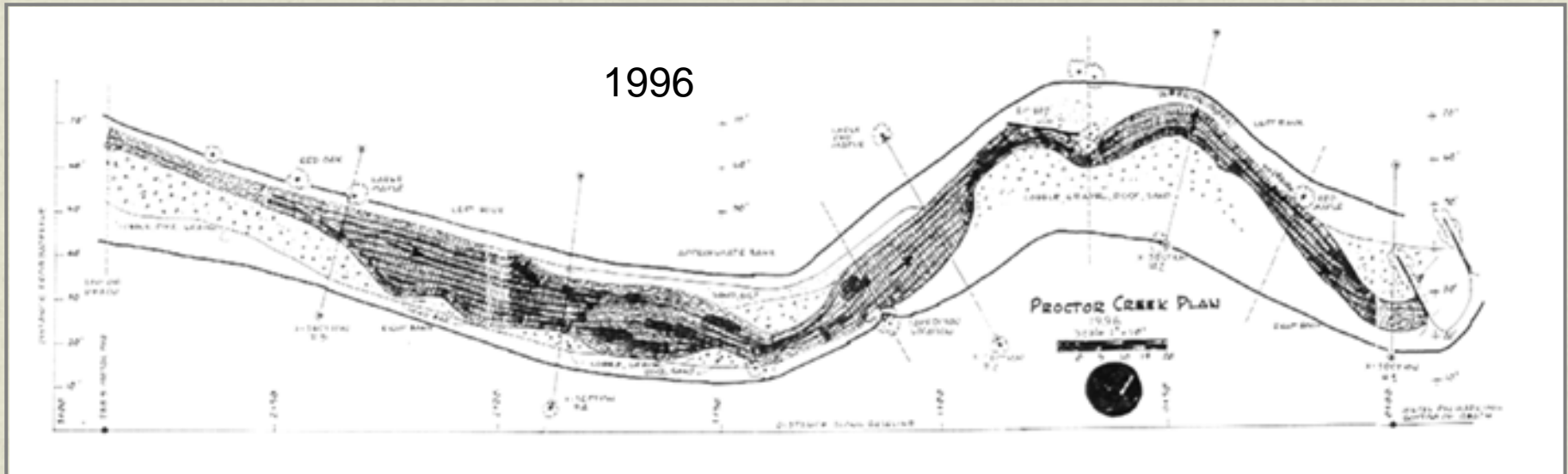
Cross-section 2 Changes: 2000-2002



- Photo "A" shows remaining debris behind twin red maples, which had diverted moderate flow. Photo "B" shows building rock and cobble bed below X2.
- While little change in the mean bankfull area from 2000-02, X2 did incur a 10 sq. ft. increase in bankfull area, due to continued erosion of the outside bank, the scour pool, & erosion of inside bank.



**FIGURE 26: 1996-2003 Plan View of Proctor Creek
Tributary Sampling Reach**



**FIGURE 35: Annual Rainfall Northwest WWT
(1998-03); Dunwoody 1996-98**

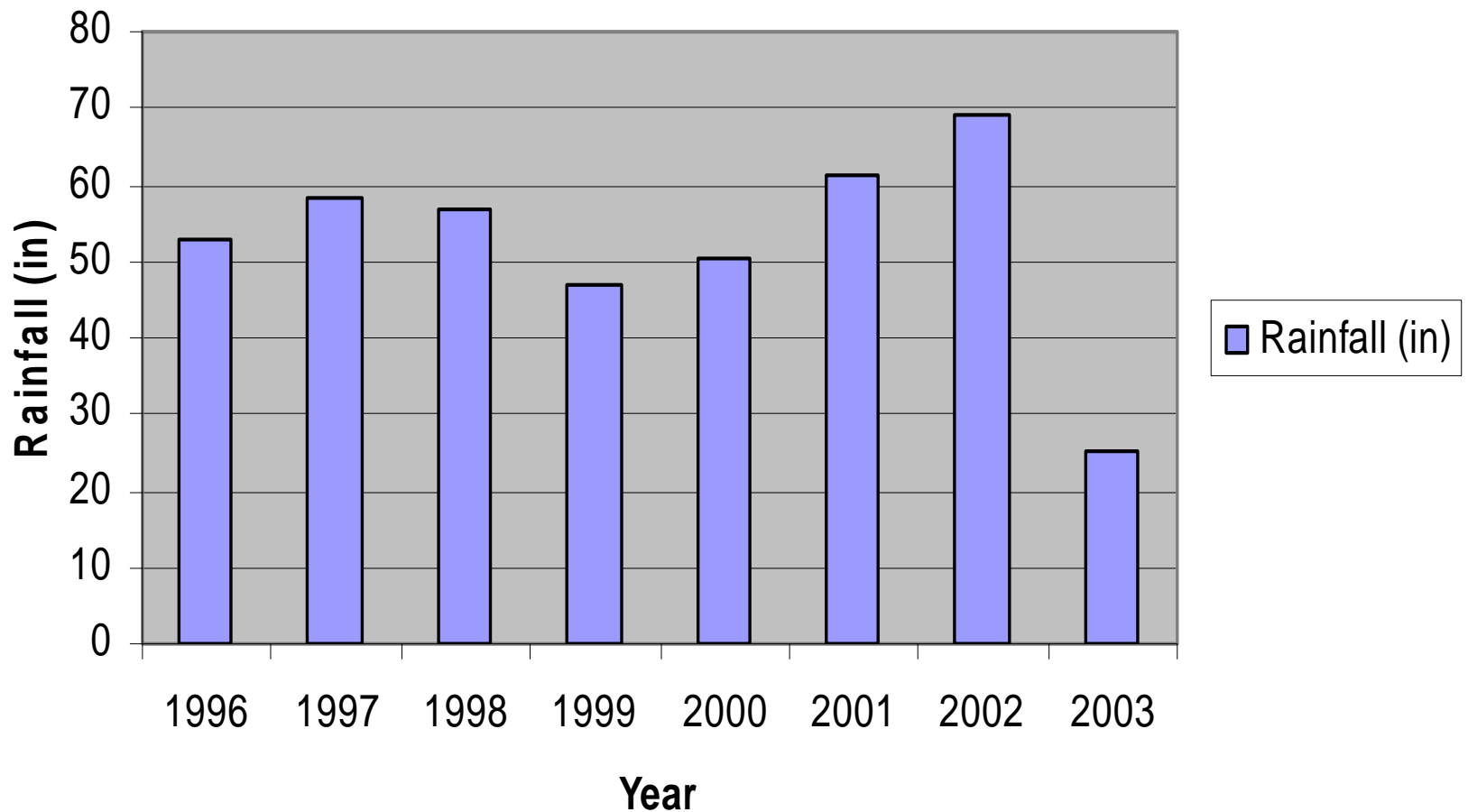


FIGURE 15: Proctor Creek Tributary 1998-2000 Development



- By 1999, the medium density residential development upstream from the sampling reach had been completed.
- Residential and commercial-industrial office park development in the middle and upper portion of the watershed continued and now occupied 28.6 & 13% of the watershed, respectively. .
- The estimated percent impervious had increased to 28.6%.

Major Changes in Watershed: 2000-2002

- Construction of medium and high density residential development and commercial-industrial office park development in the middle and upper portion of the watershed continued.
- By 2002, medium density residential development occupied approximately the same 30% of the watershed that remained in forest lands.

FIGURE 36: Dissolved Oxygen Saturation (%)

Proctor Creek Tributary D. O. % Saturation

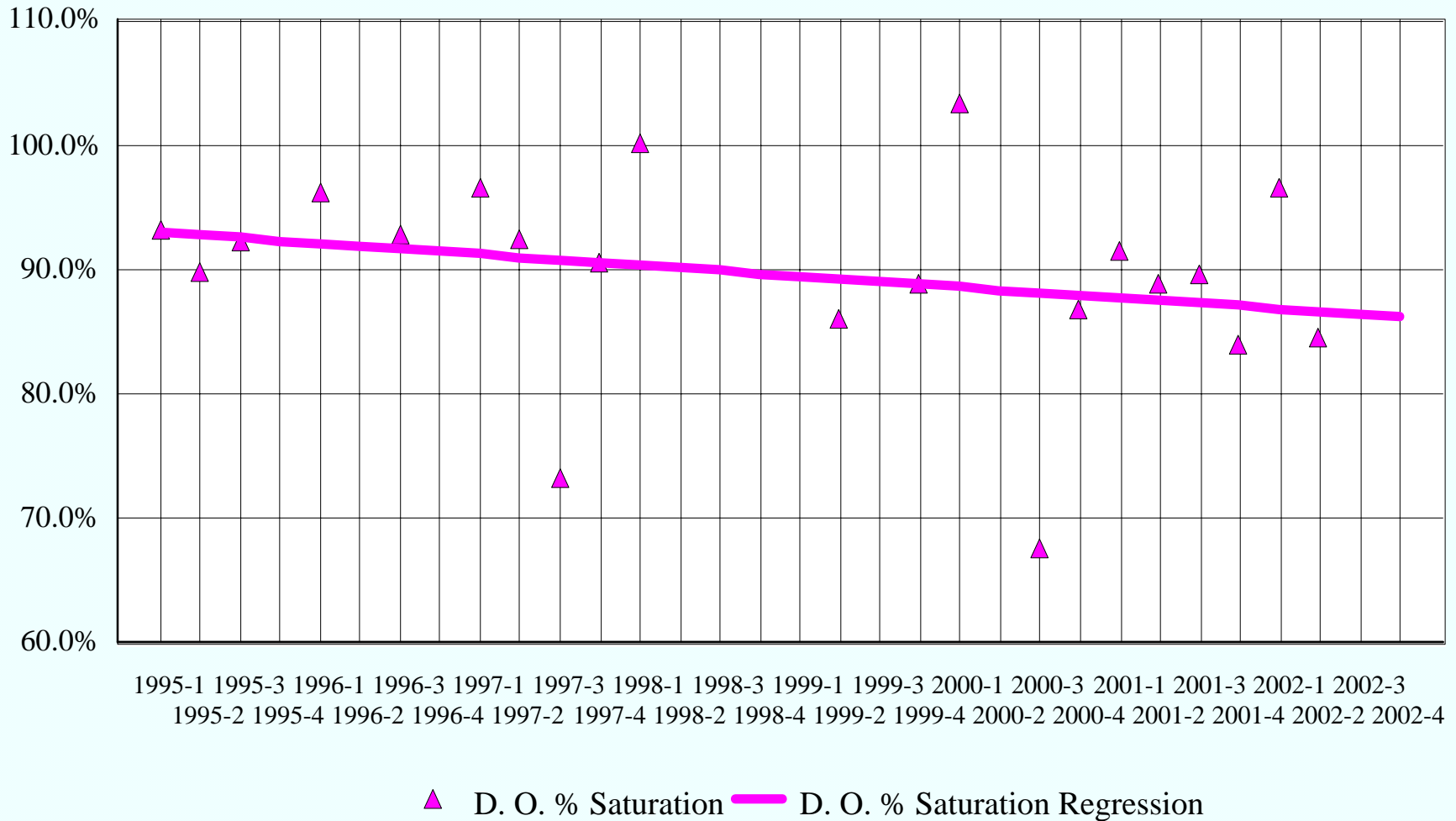


FIGURE 37: Turbidity (NTU)

Proctor Creek Tributary Turbidity

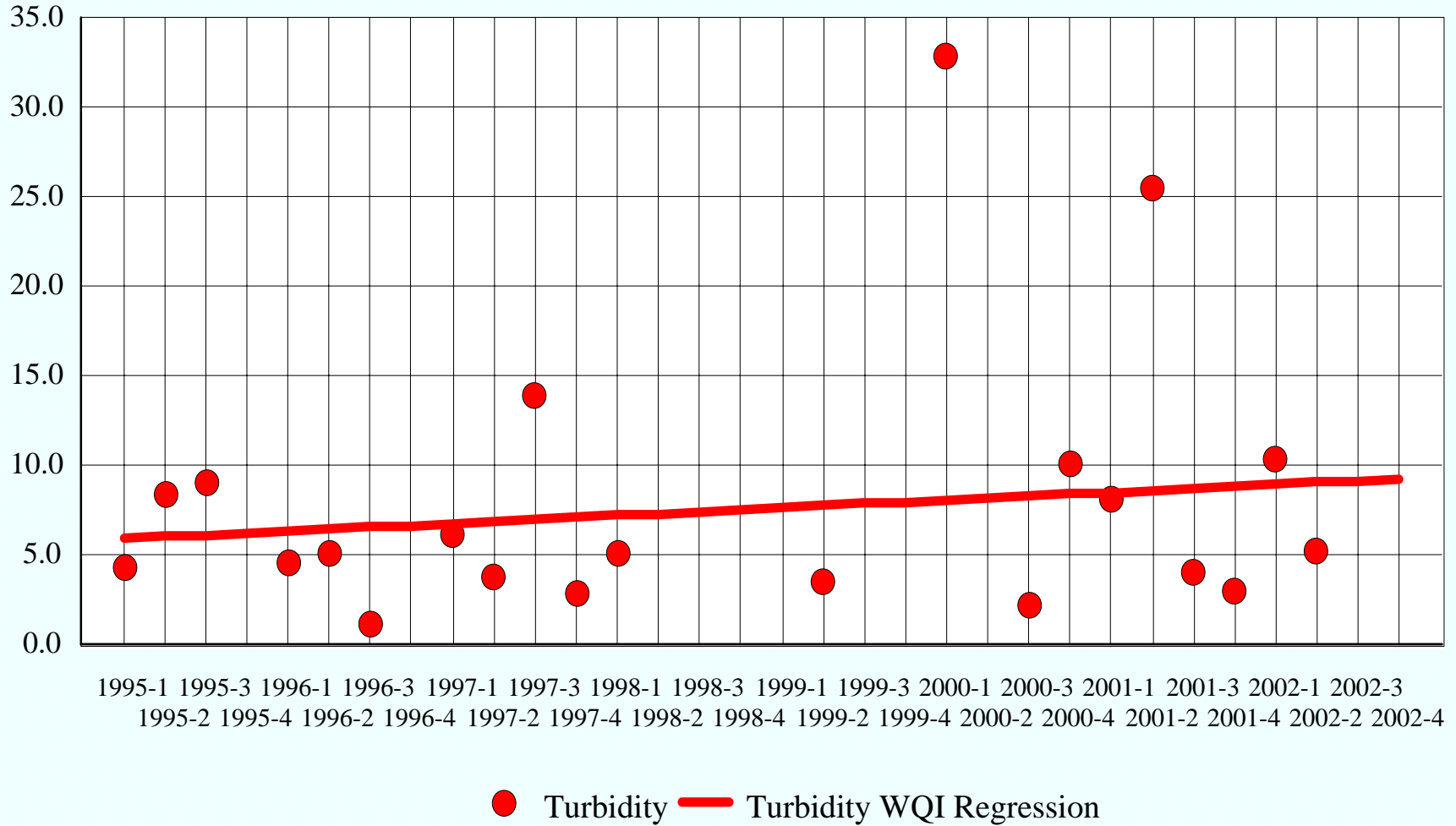
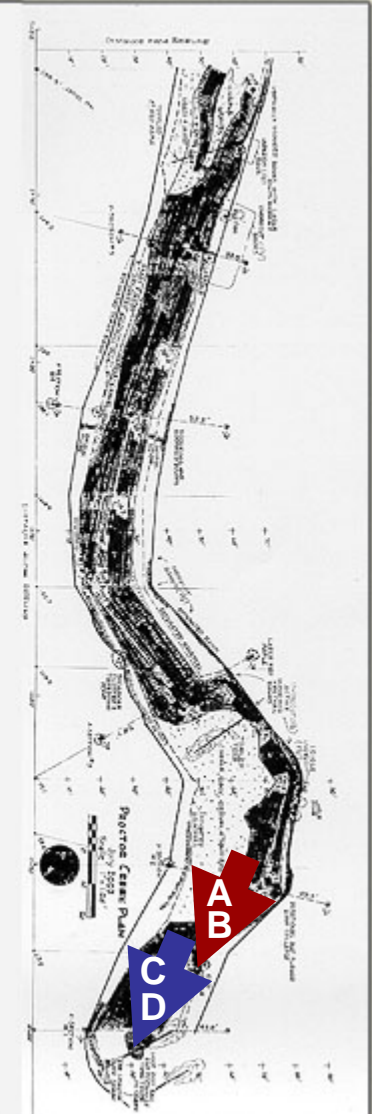


FIGURE 31: Proctor Creek Tributary 1996-2003



- “A” 1996 looking DS past Red maple on LB toward X1.
- “B” 1996 looking DS at X1.

- “B” 2003 looking DS past red maple on LB toward X1.
- “D” 2003 looking DS at X1. Note ponding.



Land Use 1993, 1995, 1999



- Initial residential development occurs just above the above sampling reach.
- By 1999, residential development continues to expand, commercial industrial park develops in middle, and commercial uses expand on ridgelines.
- After 1999, high density residential continues to develop in upper watershed

FIGURE 38: Conductivity (us/cm⁻¹)

Proctor Creek Tributary Conductivity

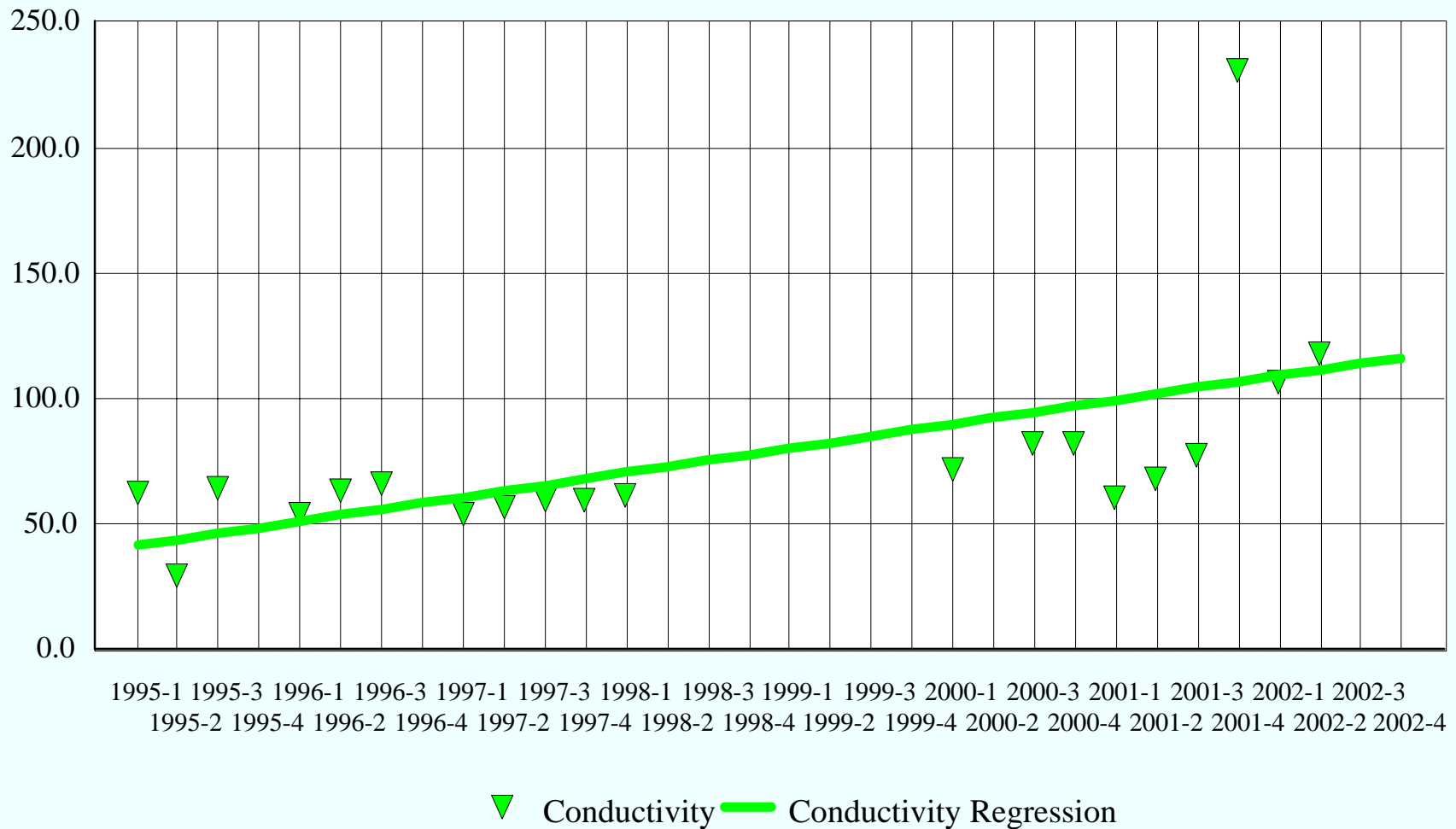
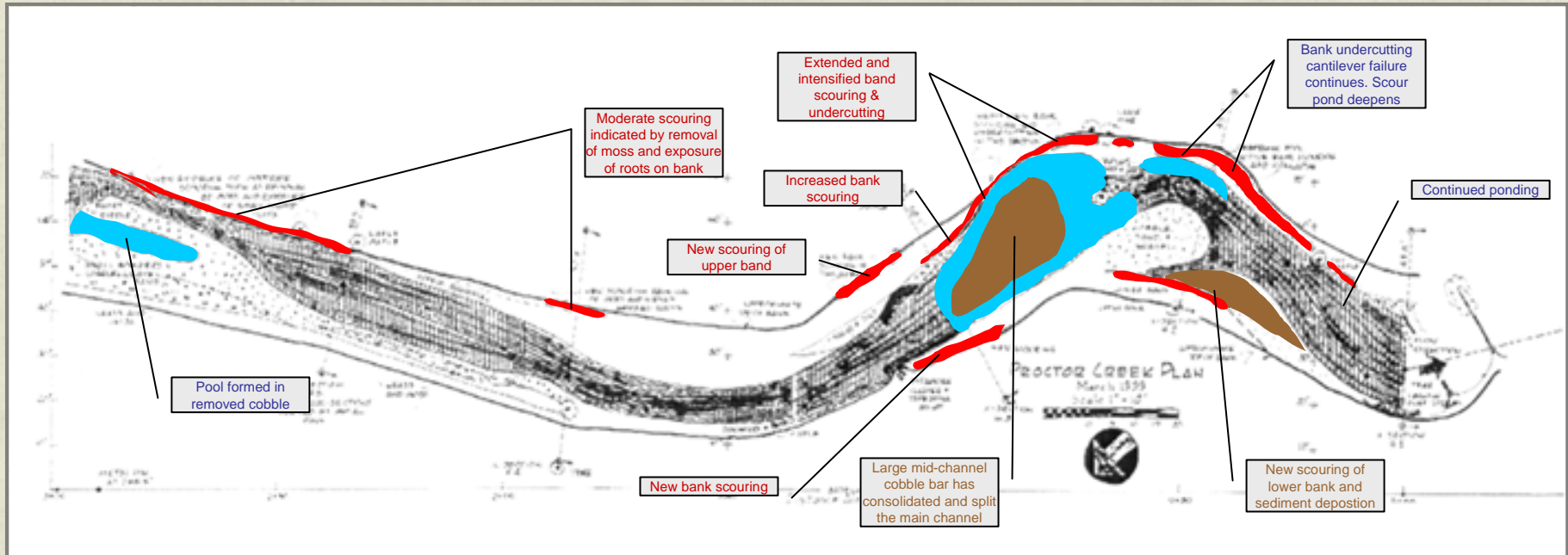
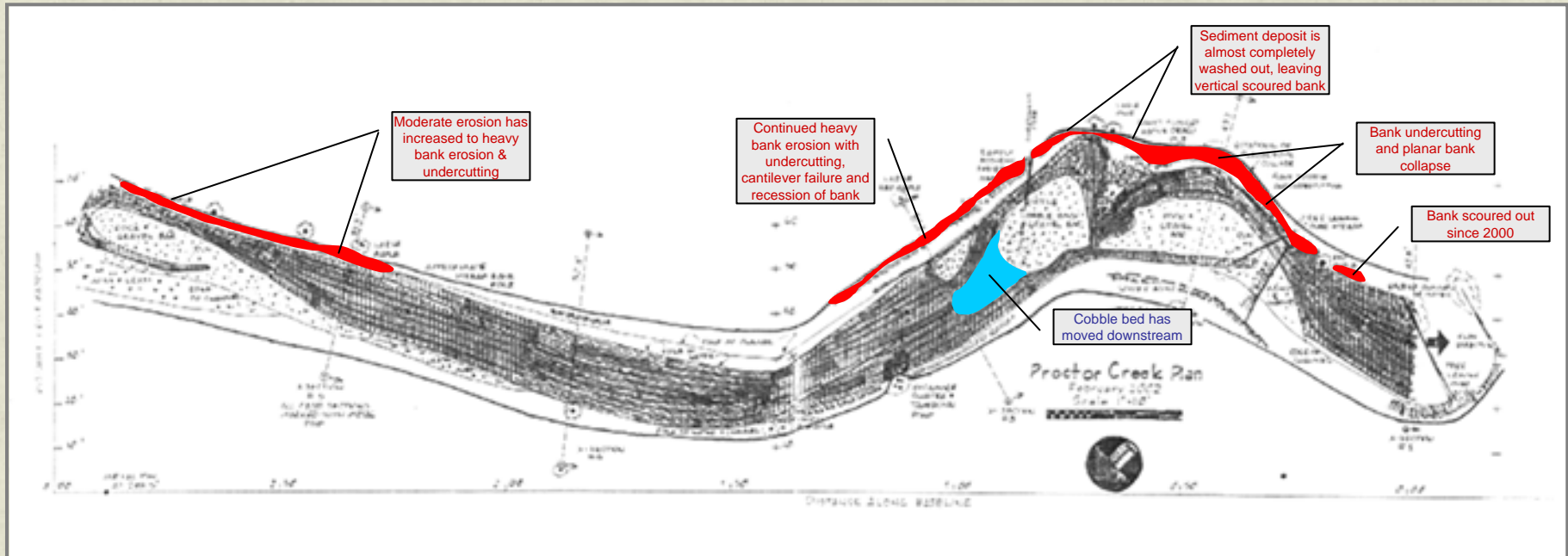


FIGURE 16: 1999 Plan View of Proctor Creek Tributary Sampling Reach



- Moderate bank scouring (indicated by removed moss and exposed roots) began on LB from TR to X4.
- Moderate bank scouring on both banks above X3.
- A large mid-channel cobble bar consolidated below X3 and diverted main channel flow through riffles adjacent to the LBb & RB.
- The LB below X3 & adjacent to cobble bar has been heavily scoured and undercut. (3 of 4 bank pins installed in 1998 washed away . Remaining pin reveals 0.45 ft erosion of the bank.
- Transverse log above Sec. 23 was removed & high flows scoured the upper bank behind the protruding twin red maple trees. The peninsular behind twin red maple trees has been reduced to a narrow pile of woody debris.
- Undercutting and cantilever bank failure continue on the LB at X2 & scour pool has deepened.
- The lower RB above and below X2 has been heavily scoured & new sediment is accumulating below X2.

FIGURE 21: 2002 Plan View of Proctor Creek Tributary Sampling Reach



- The moderately scoured LB above X5 was now become heavily scoured and undercut.
- The moderately scoured LB above and below X3 was now receding due to undercutting & bank collapse.
- The mid-channel cobble bar below X3 had migrated DS.
- The LB at Sec. 23 has been scoured to vertical. The tip of the peninsular behind the protruding twin red maples remained a narrow pile of woody debris.
- Severe bank erosion, undercutting, and cantilever failure continued on the outside bend (B) above and below X2.
- The LB below the Red Maple was scoured out.