Section 6 – Findings

6. Findings

6.1. Introduction

"Comparisons between streams of unknown characteristics must thus be of little help in understanding river process." Fahnstock and Bradley (1973)

This section presents the results of investigations performed to gather data for determination of physical conditions and problems with the stream corridor, and to provide guidance for future research and management recommendations. The geomorphic condition of the West Branch is the primary data group in these findings. Information on vegetation characteristics, public infrastructure, from public outreach efforts and a demonstration restoration project are also included in this section.

6.2. Geomorphic Condition of the West Branch

6.2.1. Introduction

A multiple objective *watershed* assessment protocol was followed to support the development of this plan. This watershed assessment protocol was prepared by Mark Vian with the NYCDEP stream management Program in 2001. These objectives, as modified through work during the Stoney Clove Stream Management Program were:

1. Provide the Stream Corridor Management Program (SCMPr) team with a general, baseline inventory of stream conditions on the West Branch main stem which included:
   - Conditions affecting hydraulic function, particularly *sediment* transport, including: cultural and natural grade controls, *berms*, riprap or other *revetment*;
   - Potential sources of water quality impairment, especially eroding banks, *clay exposures* or other hazards;
   - *Riparian* vegetation, including locations of functioning riparian communities, changes in riparian vegetation management, and occurrences of invasive exotic vegetation of significant consequence to stream *stability* and ecosystem function (primarily *Japanese Knotweed*);
   - Locations of *cross-sections* to be surveyed for characterization of channel *morphology*;
   - Infrastructure, including road crossings, bridges, *culverts* and outfalls and other features such as *tributary confluences*, springs or diversions.

2. The field protocol was meant to support the characterization of channel form, or *morphology*, throughout the West Branch main stem. Because sediment transport function and the stability of stream beds and banks is highly influenced by channel morphology, characterization of this morphology was key to the identification of *reaches* that were likely to present *erosion*, water quality or habitat problems, either in themselves or in the context of adjoining reaches and the system as a whole. The methods chosen for this characterization employed

Rosgen's natural channels classification system (Rosgen, 1996), described in **Section 5.9.2**. This classification system supports (but does not provide) general management interpretations regarding channel morphology on a watershed-wide basis. The morphological variables measured to classify reaches with the Rosgen approach can inform the interpretation of process beyond classification of Rosgen *stream types*.

3. To support analysis that would determine, for certain reaches and conditions identified during the stream feature inventory, the extent to which channel geometry and stream bank stability departs from a potential *stable* form[1]. This allowed determination of locations for which restoration of stable channel geometry was required, or alternatively where bioengineered bank stabilization would be sufficient to reasonably assure future stability. In this regard, the protocol represented a "first cut" to identify where further assessment is warranted, both of potential stable *reference reaches* and reaches where *instability* is indicated. Reference reaches will subsequently be surveyed in greater detail and over time to verify their stability and to provide data on the range of values they exhibit in variables such as facet dimensions, measures of bed *aggradation* and *degradation*, bank erosion rates, and substrate distribution. Stable channel geometry derived from these reaches can be used in the design of channel stability restoration projects. *Unstable* reaches will be subsequently surveyed in greater detail to allow comparison to the stable ranges of these same variables exhibited by reference reaches, and among themselves to characterize their relative severity and support the prioritization of their remediation.

The first step in the watershed assessment was production of a set of stream corridor maps which featured:

- Digital Orthographic Photography (Emerge, 2001)
- Identification of drainage area above and below each tributary confluence by using NYCDEP measuring watershed area and predicting hydraulic geometry protocol and at bridge crossing, and anticipated *bankfull* cross-sectional area at these points, using regional hydraulic geometry curves developed for the Catskills by NYCDEP.
- Contour lines (USGS, 20 foot contours, 1995 is from DEP GIS coverage).
- Property boundaries and owners names from 1993 Delaware County tax parcel data.
- Historical channel alignments, from 1938, 1963, 1971 and 1983 aerial photography.

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[1] This approach assumes that for any valley setting a variety of channel morphologies might be found, and that some of these forms, in that setting, convey the range of water and sediment discharges supplied by the landscape in a manner which allows them to maintain their morphology with relatively little change form year to year (stable forms), while others are less effective and are likely to evolve relatively rapidly though a sequence of channel forms due to vertical and/or lateral adjustments (unstable forms). For any valley setting, there is a discrete range of potentially stable forms.

Fieldwork proceeded in three passes over three years as follows: 2002 – 24.6 miles from Utsayantha Lake to above Delhi; 2003 – 17.5 miles from above Delhi to Oxbow Hollow; 2003 – 13.4 miles from above Oxbow Hollow to the NYS Route 10 bridge near the Cannonsville Reservoir. The first pass used a *Global Positioning System* (GPS) receiver to map locations of features identified in the stream inventory summarized below, Section 6.2.2). Photographs were taken of each feature, and upstream and downstream at cross-section locations. Selected eroding banks were later *monumented* and surveyed for the purpose of long-term *monitoring*. These were severely eroding banks randomly selected during the walkover as it progressed.

The second pass involved elevation survey of the longitudinal profile of current water surface and field identified bankfull *stage* at 47 selected cross-sections out of 73 identified cross sections, numbered sequentially downstream from the headwaters. Following this survey, a stream-specific hydraulic geometry curve was developed for 29 of these cross-sections (selection of these sections is further described below) to support determination of bankfull stage at other locations in the watershed. Modified Wolman pebble counts were conducted for each of the 47 cross-sections. These data were used to classify the stream reaches to Rosgen Level II, and to perform hydraulic calculations at these reaches.

A third pass involved the collection of bulk samples (stream bed particle analysis) at the 29 selected cross-sections. This information was used to validate sediment transport estimates and whether or not the stream reach is in an *aggrading*, *degrading* or stable condition.

The locations of features described in the tables and charts in this section are available as maps. However, due to the overwhelming number needed to cover the entire West Branch main stem, only a few maps are included in this plan for illustrative purposes (see **Section 7**). Upon request, maps can be provided for another section of the river not included here.

6.2.2. Data Collection/Analysis

Geomorphic data were collected as described above during the summers of 2002, 2003, and 2004 using a GPS receiver (see **Figure 6.1**). These data were incorporated into a *Geographic Information System* (GIS) and then located on aerial photos for mapping and analysis. The data collected included:

Figure 6.1 Using a hand held GPS receiver to locate a debris jam downstream of South Kortright.

- The location and surface area of eroded banks.
- The location of headcuts,

natural or cultural grade control, and other evidence of stream bed erosion.

- The location and extent of revetments, *rip-rap*, and other similar erosion control measures.
- The location and extent of unstable depositional features such as side bars and center bars. See **Table 6.2** below.

Rosgen Level II surveys were performed at 29 locations. Information collected included:

- Surveyed stream bed elevation.
- Pebble counts at the surveyed cross-sections.
- Documentation of bankfull indicators.
- *Thalweg* and water surface profiles.

Cross sections were chosen at locations where bankfull stage indicators were readily or reasonably identifiable, to create a localized hydraulic geometry curve to assist in the description of channel geometry. This is used to assist in determining stream hydraulic geometry properties where stream instability or other conditions obscure bankfull indicators. Since good indicators are required for development of a reliable hydraulic geometry curve, these 29 sections are at locations that are typically more stable than other sections in that particular reach. Thus, the data generated by the Level II analysis is reflective of a selection of cross-sections with characteristics that tend to be hydraulically and geomorphically more stable than the surrounding reaches and the river as a whole.

For mapped location of the 29 cross-sections see the Stream Segment maps in **Section 7**. No cross sections were taken below Hamden due to time constraints. The summers of 2003 and 2004 were extremely wet, and consequently the water depth in the river precluded any surveys being done.

Visual observation by trained DCSWCD personnel and GIS data were used to supplement the cross section data. Where no cross sections were surveyed, visual observation and GIS data form the basis of descriptions, conclusions and recommendations made in this report.

6.2.3. <u>Current Conditions of the West Branch</u>

Note: The scope of this project was limited to surveying, cataloging and analyzing the physical condition of the West Branch main stem, including the form and functions of its streambed and banks. In this section, perceived problems with the river will be limited to a discussion of the effects of erosion and deposition, and suggested strategies to effectively manage these concerns. Flood management issues are mentioned in **Sections 5.8.3** and **5.14**, but determining causes and solutions to flooding problems was largely beyond the scope of this project.

Figure 6.2 Measuring erosion loss using the bank-pin method at cross-section 53 just upstream of Delhi.

Anyone making a casual review of conditions along the West Branch of the Delaware River main stem might find the following:

- Widespread streambank erosion
- Widespread repairs along previously-eroding streambanks
- Widespread and common depositional features (i.e. *gravel* bars in various forms)

When stream surveys of the main stem were completed and GIS and Rosgen Level II data were analyzed, the above features were confirmed repeatedly. After careful documentation and review, the following problems became apparent:

- A general aggrading trend exists along the length of the river, that is, there are more sections aggrading than degrading.
- There are many eroding banks.
- Overly large Width/Depth ratios are common.
- Fine-textured sediments are being deposited in noticeably greater quantity at the downstream reaches near the Village of Walton.

Taken together, this pattern of erosion and deposition runs the length of the West Branch Delaware River, from its headwaters to the Cannonsville Reservoir.

The processes of stream erosion and deposition go together. If the stream cannot carry the available sediment load, then some sediment will drop out — *raising the streambed.* The stream widens in response to this — causing bank erosion — since it needs a certain cross sectional area to convey its *discharge*. As a result of aggradation and widening more of the stream bank is exposed to flood flows. Especially in the absence of riparian vegetation that could otherwise hold banks in place, this encourages further erosion and increases the sediment load that the stream must move. A spiral of events begin, the result of which is the destabilization of the stream. While in theory a stream will stabilize or reach a new *equilibrium* condition over time, the time required may be very long, and the stream will not stabilize if the disturbance that caused the destabilization persists.

The following human activities have an effect on streams and can initiate the erosion/deposition cycle. Evidence of all these activities can be found in the watershed.

- Deforestation. This increases peak *runoff*. For further discussion see **Section 5.10.5**.
- Building development. This increases impervious area, which increases peak runoff. This leads to an increase in erosion. For further discussion see **Section 5.10.3**.
- Agricultural practices. Certain agricultural practices can increase bank erosion and increase peak runoff. For example, the lack of a riparian buffer or cattle having direct access to the stream leads to an increase in erosion. For further discussion see **Section 5.10.3**.
- Stream realignment. Generally, when this happens the stream is straightened. This increases the slope of the stream, which in turn increases erosion. For further discussion see **Section 5.9.2**, especially **Figure 5.15**.
- Bulldozing streams. This is often done in conjunction with realignment. Usually the motive is to increase the capacity of the channel for purposes of flood control. If the stream channel is deepened this increases erosion. If it is widened it increases deposition. It frequently occurs in the vicinity of bridges in an attempt to achieve the desired capacity for floods or to align the stream at a right angle to the bridge.
- Bridges located on alluvial fans or at confluence areas. Typically, this means that the stream has been realigned, and the channel has usually been widened and deepened to get the capacity to pass the required design flood. The effect is the same as bulldozing streams.

Table 6.1, below, lists various physical properties of the West Branch as measured at 29 cross-sections along its 49.5-mile length. Cross-sections were taken from the top of the watershed down and are listed as such in the table. (Note: In the following text, use of adjectives such as “good”, “undesirable”, or “preferred” when referring to the river’s condition indicate comparisons to streams that are in balance or relatively stable ─ a goal for stream management purposes.)

Approximately 95% of the West Branch is a C stream type. Other reaches included type D, Type DA, and type F. Cross sections were not surveyed for these types because they were not considered stable reaches (note: DA is a stable type. Cross-sections were not taken in this reach due to time constraints). (For a description of stream types see **Section 5.9.2,** and **Figure 5.18**).

All of the surveyed cross sections are a Type C. The following description of a Type C4 also largely applies to a type C3 except that the C3 has a *cobble*-dominated bed. While no cross sections were taken south of Hamden, observation and GPS data indicate that the river is primarily a C type through out its entire length, excepting where multiple channels or highly *entrenched* conditions were observed.

> The C4 stream type is a slightly entrenched, *meandering*, gravel-dominated *riffle*/*pool* channel with a well developed *floodplain*. The C4 stream type is found in U-shaped glacial valleys; valleys bordered by glacial and Holocene terraces; and in very broad coarse alluvial valleys typical of the plains areas. Some of the C4 stream types occur in glacial outwash terrain, closer to the lobe where gravel material is present. The C4 stream channels are found in Valley Types IV, V, VI, VIII, IX, and X (the predominant valley type in the West Branch is Valley Type VIII). C4 stream channels have gentle gradients of less than 2%, display a high width/depth ratio, are slightly more sinuous and have a higher meander width ratio than the C1, C2, and C3 stream types. The riffle/pool sequence for the C4 stream type average 5-7 bankfull channel widths in length. **The stream banks are generally composed of unconsolidated, heterogenous, non-cohesive, alluvial materials that are finer than the gravel-dominated bed material. Consequently, the stream is susceptible to accelerated bank erosion. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation**. Sediment supply is moderate to high, unless stream banks are in a very low erodibility condition. **The C4 stream type** characterized by the presence of point bars and other depositional features, **is very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed**. (Rosgen, 1996) (Emphasis added).

Table 6.1 Summary of various physical properties for 29 cross-sections in the West Branch Delaware River

1	2	3	4	5	6	7	8	9	10	11	12	13
Cross-section #	Stream Type	Drainage Area (mi^2)	Bankfull Width W_{bf} (ft)	Bankfull Depth d_{bf} (ft)	Bankfull Area A_{bf} (ft^2)	Width/ Depth ratio (W_{bf}/d_{bf})	Entrenchment Ratio	D84 (mm)	Aggrading/De-grading/Stable	Sinuosity	Stream Slope (%)	Profile Length (ft)
2	C3	3.96	30.3	1.1	33.5	27.5	2.0	223	A	1.15	0.66	617
7.9	C4	8.35	20.2	1.7	33.5	11.9	14.8	142	D	1.20	1.13	746
8	C4	8.35	29.0	1.4	40.3	20.7	8.6	152	D	1.20	1.13	746
14	C4	9.13	46.0	1.7	76.9	27.1	1.3	158	A	1.15	0.44	1542
15	C4	9.19	44.8	1.5	67.9	29.9	2.3	169	A	1.15	0.78	1542
16	C4	9.36	31.8	1.8	58.2	17.7	8.0	136	A	1.15	0.52	1542
16.8	C4	9.61	52.4	1.3	65.8	40.3	4.8	233	A	1.15	1.16	1355
16.9	C4	9.61	31.3	1.8	55.4	17.4	7.5	172	A	1.15	1.02	1355
17	C4	9.61	74.1	1.1	78.0	67.4	2.0	155	A	1.20	0.90	1355
19.5	C4	13.54	96.8	1.1	107.8	88.0	2.6	173	A	1.15	0.80	719
20	C4	13.54	55.6	1.4	79.6	39.7	9.0	165	A	1.15	0.82	719
21	C3	13.85	46.9	2.0	94.2	23.5	2.3	198	A	1.20	0.57	1035
22	C3	13.85	48.0	2.0	96.2	24.0	3.6	154	A	1.20	0.50	1035
23	C3	13.85	51.0	2.1	105.0	24.3	2.7	207	A	1.20	0.44	1035
24	C4	31.97	57.3	2.2	121.2	26.0	8.7	138	D	1.20	0.68	970
26	C3	39.17	52.1	3.2	169.3	16.3	7.7	167	S	1.10	0.62	748
29	C4	44.33	80.2	2.8	222.4	28.6	6.2	198	A	1.15	0.55	1240
35	C4	75.23	58.6	4.3	254.2	13.6	4.2	137	A	1.15	0.43	622
38	C4	81.20	98.0	3.9	377.5	25.1	8.2	109	A	1.15	0.36	2073
38.5	C3	81.20	83.4	4.5	373.4	18.5	9.6	168	S	1.15	0.35	2073
40	C3	94.96	83.0	5.2	428.7	16.0	5.4	157	A	1.15	0.22	5914
41	C3	94.96	155.0	5.2	483.1	29.8	4.5	90	A	1.15	0.27	5914
41.2	C3	94.96	139.5	4.0	552.3	34.9	5.0	132	A	1.15	0.27	5914
42	C3	94.96	103.8	4.4	460.9	23.6	2.9	118	A	1.15	0.25	5914
46	C4	99.07	106.4	3.4	362.7	31.3	3.3	100	D	1.42	0.41	610
48	C4	106.81	83.0	5.1	424.0	16.3	3.4	62	D	1.42	0.21	992
56	C4	197.35	122.5	6.0	738.3	20.4	3.6	47	S	1.15	0.25	1302
61	C4	242.31	123.0	5.9	721.9	20.8	4.1	107	A	1.15	0.12	1205
63	C4	247.19	147.7	4.3	637.6	34.3	3.4	80	A	1.15	0.25	1690
▨	Gray hi-lighted cells indicate width/depth ratio exceeds 24											
🟨	Yellow hi-lighted cells indicate entrenchment ratio is less than 2.2											
🟥 🟩	Red/green hi-lighted cells indicate cross sections that are on the same profile (reach)											

- As a general rule a width/depth ratio of 24:1[2] is about the maximum that we would like to see on a stable Type C stream. However, as shown in column 7, 15 of the 29 cross sections have a width/depth ratio greater than 24. These cross sections are highlighted in the table. A width/depth ratio not over 20[3] would be preferable. In this case, 21 of the 29 cross sections would be too wide.

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[2] Class note, River Restoration and Natural Channel Design, Wildland Hydrology, 2001

[3] Class note, River Restoration and Natural Channel Design, Wildland Hydrology, 2001

While a large width/depth ratio does not by itself indicate an unstable stream, any stream that has a width/depth ratio wider than preferred should be considered to be at risk. Recall that C type streams are very sensitive to accelerated bank erosion especially if the riparian vegetation is inadequate. Note that just over 50% (15 of 29) cross sections have a width/depth ratio greater than 24. This indicates that while the stream is not over-wide everywhere it has tendency to become wider than should be expected to maintain stability. Also, referring to **Table 6.1,** the sum of the profile length of the shaded (wide) cross sections is 27,295 feet, the total length of all the profiles is 52,524 feet, so 52% of the surveyed profile exhibits signs of tending to be over-wide.

Two cross sections have a width/depth ratio between 30 and 40, while two others have ratios greater than 50. Any time the width/depth ratio exceeds 40- 50[4], channel braiding can occur (potentially becoming a D type). While factors besides width/depth ratio can influence a stream's tendency to braid, anywhere the ratio approaches 50 should serve as a "red flag" indicator.

Cross sections 2, 7.9, 8, 14, 15, 16, 16.8, 16.9, 21, 24, 38, 38.5, 41, 41.2, 42, 48, 61, and 63 had bulk (bar) samples taken from the stream bed. They were judged to be aggrading, degrading, or stable by calculating critical dimensionless shear stress and then determining if the existing mean depth and/or water surface slope at bankfull were sufficient to move the largest particle from the bar (bulk) sample. (See Entrainment Calculation Form in **Appendix 7**).

It was not possible to gather bulk samples at the other cross sections, due to persistent high water in the river during the summers of 2003 and 2004. For cross sections which had no bulk samples taken we compared the bankfull shear stress to that shear stress required to move the D84 and D90 of the surface particles in a riffle. If the shear stress fell between that required to move the D84 and D90 we judged the cross section to be stable. If it was not great enough to move the D84 we judged the section to be aggrading. If it was larger than the shear stress required to move the D90 we judged it to be degrading. This approach will yield only approximate results, but provided a useful measure of bed stability to compare with locations in which we were able to obtain bed samples.

Again referring to **Table 6.1**, 21 out of the 29 cross sections, or 72%, are listed as aggrading. Taking only the cross sections that were bulk sampled, 13 of the 18 were judged to be aggrading, also 72%.

Totaling up profile lengths for the 29 cross sections: 18,102 feet aggrading, 3,318 feet degrading, and 4,122 feet stable; for 71% aggrading. Totaling up profile lengths for the 18 cross sections that got bulk sampled: 15,431 feet aggrading, 2,708 feet degrading, 2,073 feet stable; for 76% aggrading. Note: 2,073 feet (cross sections 38 and 38.5) was included in both aggrading and stable summations because both sections are on the same reach and one section is aggrading and one is stable.

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[4] Rosgen 1996 especially Figure 5-3. And, Knighton 1998, pg 231.

Our initial survey indicates that the river has a tendency toward aggradation.

While no cross sections were surveyed below Hamden, observation and GIS indicate that this same tendency towards aggrading and widening appears to persist the length of the river to the Cannonsville reservoir as indicated by comparing historic aerial photographs with current images, observation, and conversations with longtime residents.

- The entrenchment ratio is good (consistent for a stable C type) for most of the stream (see **Table 6.1**, column 8). In only 3 locations is it below 2.2. This means that the stream is generally not *incised* and still has access to its floodplain. Two locations have an entrenchment ratio of 2.0 which is still at the low limit of acceptability for a type C stream. Only one cross section (14) exhibits signs of incision outside the acceptable range for a type C stream in an otherwise C type reach. If a reach on a type C stream has an entrenchment ratio of 2.0 or less. It should be observed closely and regularly. A low entrenchment ratio (< 2.0) could be indicative of the stream entrenching itself. This could be warning that the system is destabilizing.

- Sinuosity is generally about 1.15 (see **Table 6.1**, column 11). This is slightly less than the preferred value of 1.2 or greater for a C type stream with a stable meander pattern, but is within the acceptable range.

What is not apparent in **Table 6.1** is that the river has long reaches of planar bed, which came to be referred to as "long runs" by DCSWCD personnel (see **Figure 6.3**). The cause of these long runs is not known, but they have been observed by our personnel on other streams in the northeast where they appear to be quite common. They are devoid of features (riffles, pools), cross-sections tend to be nearly rectangular and the bed is usually flat and level. In this sense, they interrupt the pool-riffle sequence; they have been observed occupying a length that would normally be occupied in similar reaches by one or more pool-riffle sequences. They can be stable, especially if the riparian vegetative buffer is thick, with a good root mass to hold the banks in place (see **Figure 6.3**). Their significance is unclear. As a working hypothesis, since they do interrupt the normal pool-riffle sequence, it is assumed that they are most likely a response by the stream to a past disturbance, but it remains unclear whether long runs represent a current problem.

Figure 6.3 Example of a long run just below Bloomville at cross-section 43.

The location and surface area of eroded banks, and the location of unstable depositional features such as side bars, center bars, transverse bars and emergent gravel bars were located by GPS. For a summary of these features see **Table 6.2**, below. **Table 6.2** lists the number of erosional and depositional features per mile for each management unit. (See maps in **Section 7**).

Table 6.2 Erosion and depositional features per mile by Management Unit

Segment Number	Management Unit	Length (mi)	Linear Feet Erosion	Surface Area (sq.ft.)	# Erosion Features	# Deposition Features	Linear Feet Erosion per Mile	# Erosion Features per Mile	# Deposition Features per Mile
1	1	0.57	52	26	1	1	91.23	1.75	1.75
	2	0.70	255	951	6	4	364.29	8.57	5.71
	3	0.59	87	193	2	2	147.46	3.39	3.39
	4	0.37	140	729	2	0	378.38	5.41	0.00
2	5	2.55	905	1901	14	19	354.90	5.49	7.45
	6	0.76	417	2703	5	13	548.68	6.58	17.11
	7	0.38	0	0	0	0	0.00	0.00	0.00
	8	0.39	521	3502	5	7	1335.90	12.82	17.95
	9	1.99	1936	9498	18	12	972.86	9.05	6.03
	10	1.65	2562	10511	15	14	1552.73	9.09	8.48
	11	0.96	1131	7954	6	3	1178.13	6.25	3.13
	12	4.89	9054	47441	61	54	1851.53	12.47	11.04
	13	1.20	1433	7702	6	6	1194.17	5.00	5.00
3	14	4.60	8377	41689	50	32	1821.09	10.87	6.96
	15	1.67	3282	12718	10	6	1965.27	5.99	3.59
	16	1.27	3499	16548	23	18	2755.12	18.11	14.17
	17	0.87	1081	3998	7	4	1242.53	8.05	4.60
	18	1.12	3953	15705	19	11	3529.46	16.96	9.82
	19	2.84	7605	26247	32	22	2677.82	11.27	7.75
4	20	1.75	7739	31315	25	15	4422.29	14.29	8.57
	21	2.97	8307	27497	38	23	2796.97	12.79	7.74
	22	1.03	3234	7658	13	7	3139.81	12.62	6.80
	23	0.64	2236	9432	12	15	3493.75	18.75	23.44
	24	2.35	4970	19346	34	31	2114.89	14.47	13.19
5	25	2.21	3600	11054	26	5	1628.96	11.76	2.26
	26	0.84	2824	14770	14	15	3361.90	16.67	17.86
	27	1.58	2120	8283	24	13	1341.77	15.19	8.23
	28	1.86	6204	40272	31	10	3335.48	16.67	5.38
	29	4.44	9554	36808	54	46	2151.80	12.16	10.36
Total			**97078**	**416451**	**553**	**408**			

There are about 1,961 feet of eroded bank for each mile of stream. This works out to 18.5% of the stream banks being eroded. There are approximately 19 erosion features per mile of stream. There are approximately 8.2 depositional features per mile of stream.

Chart 6.1 below graphically illustrates the linear feet of erosion per mile per management unit. Note that there is less erosion in the upstream units. This is probably due to:

- The river being small and lacking erosive power, especially in reaches with low slope.
- The river is channelized and hardened within the Village of Stamford.
- A lack of West Branch and sub-basin development and agriculture in the upper portions of the watershed.
- Healthier riparian vegetative communities to hold stream banks in place.

Chart 6.1 Linear Feet of Erosion per Mile by Management Unit

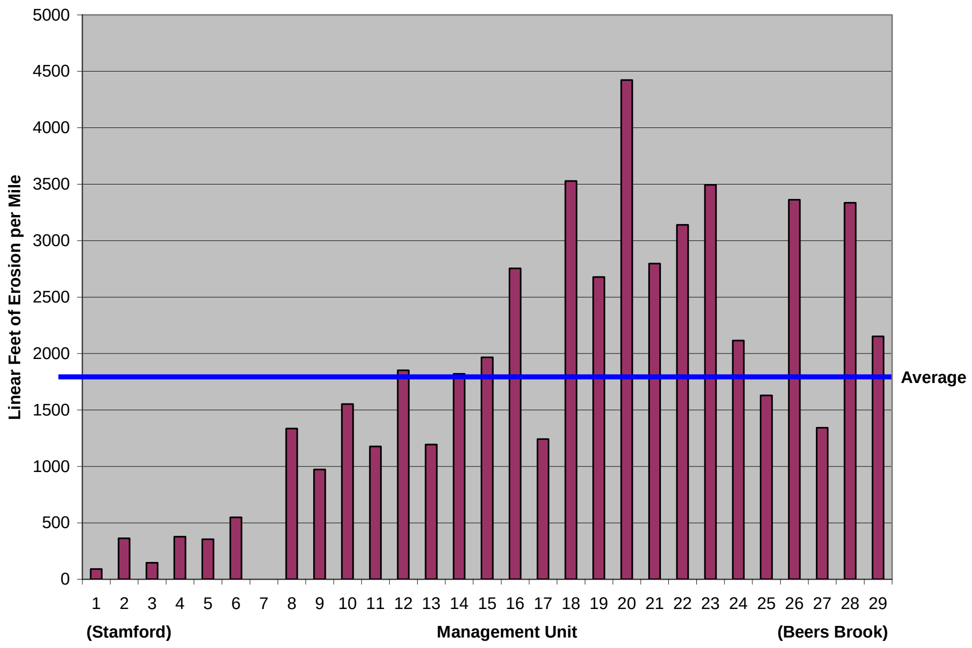


Chart 6.2, below, graphically illustrates the rate of depositional features per mile per management unit. Note that the rate of depositional features tends to increase in the downstream direction. This is particularly true from management unit 23 to management unit 29. This is probably due to:

- Excessive sediment load being contributed by the tributaries along the length of the main stem.
- The total sediment entering the stream from the upstream eroded banks being more than the stream can move.
- Stream slope decreasing to the point that it can no longer transport the sediment being made available to it.
- Stream depth decreasing and/or stream width increasing to the point that it can no longer transport the sediment being made available to it.
- Some combination of the above factors.

Chart 6.2 Depositional Features per Mile by Management Unit

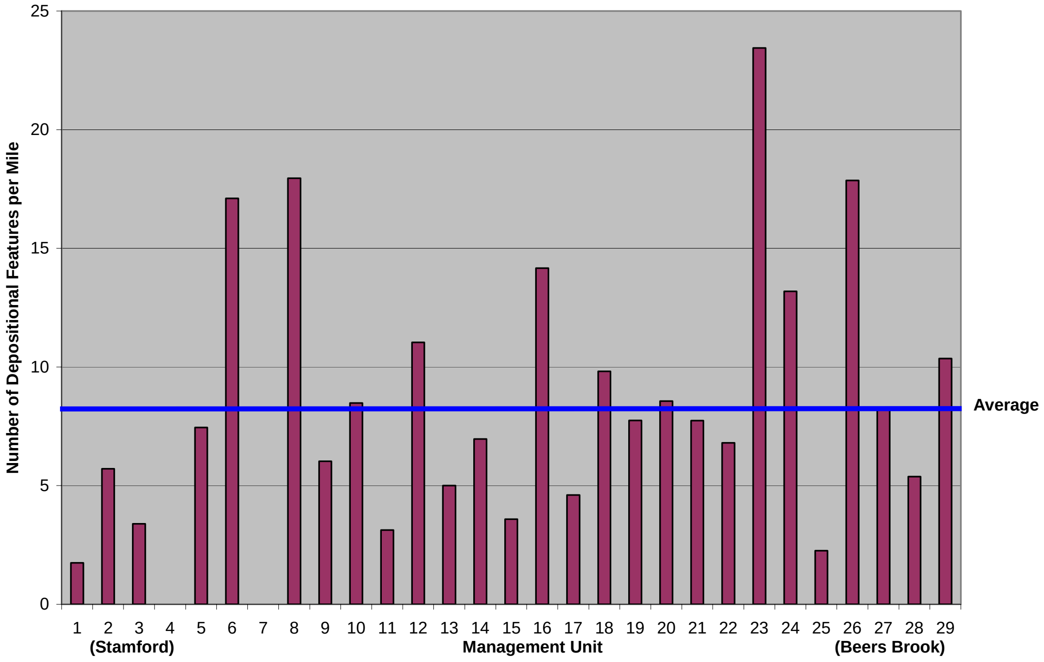
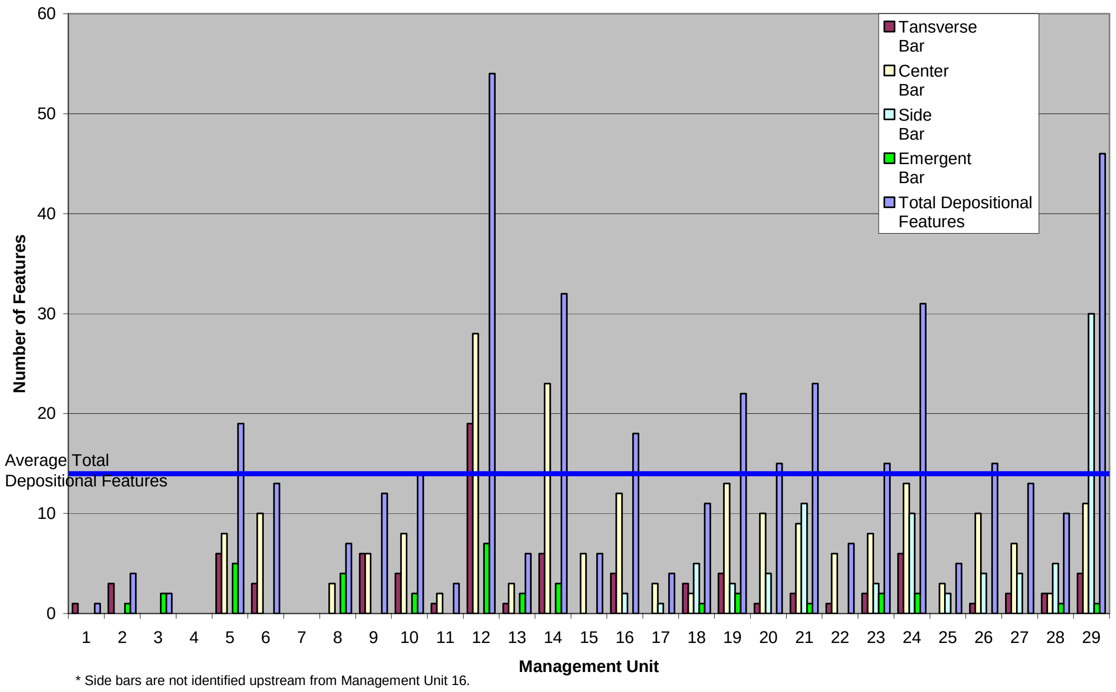


Chart 6.3, below, graphically illustrates the depositional features by type for each management unit. Note that center bars and side bars are the most common depositional features.

Chart 6.3 Depositional Features by Management Unit



* Side bars are not identified upstream from Management Unit 16.

Table 6.3, below, lists the number and type of depositional features recorded during the river survey. The river averages 8.2 depositional features per mile. Note that point bars, being a normal feature of type C streams, are *not* counted as depositional features. The features that were noted in the table below are only those features which are or can be indicative of a high *bedload*.

Table 6.3 Depositional Features Found in the West Branch

Type of Deposition	Number
Center Bar	206
Side Bar	84
Transverse Bar	82
Emergent Gravel Bars	36
Total	**408**

Table 6.4, below, lists the erosion as measured at bank pins. There are 553 located erosion features on the West Branch. Their total length is 97,078 feet, and their total area is 416,451 square feet. Over the length of the river this equals about 1,961 linear feet of eroded bank per stream mile, or, about 18.5% of the length of the stream banks being eroded. Cubic yards (CY) is determined by measuring the eroded banks length, height and length of exposed bank pin.

Table 6.4 Measured Erosion at Bank Pins

Bank Pin Number	Installed	2003		2004		Notes
		Exposed (ft)	Soil Lost (CY)	Exposed (ft)	Soil Lost (CY)	
8.90	2004	-	-	-	-	New pin 2004
16.90	2004	-	-	-	-	New pin 2004
33.40	2004	-	-	-	-	New pin 2004
33.50	2004	-	-	-	-	New pin 2004
34.30	2002	2.75	125	2.2	150	
34.80	2003	-	-	5.1	188	New pin 2003
36.20	2002	0	0	2.3	43	Pin may have slumped with sod & was still flush with bank
38.50	2002	-	-	-	-	Not inventoried
44.40	2002	Assume 5	218			Bank pin 44.40 missing in 2003,
44.41	2003	-	-	4.5	115	New pin to replaced 44.40.
47.20	2002	1	21	1	21	
51.50	2002	0	0	0	0	Not inventoried
53.00	2002	1.55	3	3	32	
Total			367		549	
Average		2.57		3.02		Avg. for 2003-2004 = 2.80

*Note: (-) data has not been collected at this time.

Ongoing monitoring, of existing and new pins to represent additional erosion sites, will be required before any firm conclusion can be drawn regarding the rate of erosion along the West Branch. However, to get an idea of the magnitude of the total sediment eroded away each year, if only one foot of erosion occurs at each erosion feature, this equates to 23,946 tons of sediment entering the stream each year [416,451 sq. ft.[5] x 1 ft x 115 lbs/cu ft x (1T/2,000 lbs) = 23, 946 T]. The actual number could be higher or lower, and only monitoring over time will give us an accurate number.

The following is taken from the report entitled *Assessment and Conceptual Design: West Branch Delaware River, Walton New York*, by Fisch Engineering, November 12, 2003. (This report was prepared under a contract with Fisch Engineering to assess conditions and make recommendations for restoration of two significantly eroding streambanks in the Village of Walton where private property and public infrastructure are at risk).

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[5] See **Table 6.2**

> **“However, bank erosion in agricultural areas along the stream is likely higher than reference conditions, and areas devoid of good stands of riparian vegetation contribute a large amount of fine sediments to the stream.** (Emphasis added) These sediments are of concern not because they alter the channel stability, but because they contribute to water quality degradation for the system. Embeddedness is moderate and consists mainly of fine clays and *silts*[6]. **This condition is not unique to the mainstem of the West Branch of the Delaware, but was found to be true for virtually every tributary evaluated within the system, and is consistent with the glacial influence upon the landscape.”** (Emphasis added)
>
> “No explicit assessment of the environmental character of the West Branch of the Delaware was conducted, but observation of the fish and macro invertebrate communities suggest that the system is healthy. Algal and aquatic plant growth suggest a high *nutrient* content, and the Upper West Branch of the Delaware was listed as impaired by the State of New York due to high phosphorous levels. **Continued erosion of the banks along reaches of the stream lacking riparian vegetation appears to be the primary contributor to the input of fine sediments and phosphorous.”** (Emphasis added)

These remarks from Fisch Engineering’s report are consistent with the visual observations made by DCSWCD personnel as they located features using GPS along the stream. Fine sediment is noticeable throughout the West Branch of the Delaware, increasing in the downstream direction. This is logical, as one would expect the fines to drop out as the river slope decreases and sediment transport capacity is reduced. The sources of the fine sediment could include the exposed and eroded river banks, overland runoff, drainage ditches, and remobilized sediment from the stream bed itself. Tributaries could also be a significant source of fines.

Of all the West Branch main stem’s tributaries, only Town Brook was assessed. As was noted in the Geomorphic report for Town Brook (see **Section 6.6**), a conservative estimate would be 2,836 tons of gravel and sediment entering the main stem from this source each year. There are 18 identified tributary watersheds, which may be in better or worse condition than Town Brook. So, it is likely that these tributaries are also significant contributors of sediment and gravel, including the fines that were evident in the West Branch of the Delaware River. It cannot be definitively stated at the present time why there is a noticeable increase in fines coating the channel bottom on the reaches near Walton. However, this phenomenon is noticeable as one moves down the West Branch. The presence of fines coating the channel bottom not only adversely affects water quality but also negatively impacts fish propagation by smothering their eggs.

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[6] Editor’s note: Clay material in the West Branch system generally doesn’t settle out in the stream channel, and therefore does not significantly contribute to embeddedness of larger bed sediments. However, near Walton there is a noticeable increase of fines on the channel bottom. To date, the reason for this occurring has not been explained.

Another group of features that illustrate the erosion problem along this river is the amount of revetments that have been installed on its banks. **Table 6.5**, below, summarizes this information.

Table 6.5 Revetments/Repairs

Type	Number	Total Length (ft)
Stone Structures		
Dumped Stone	296	5262
Rip Rap	128	18110
Laid-up Stone	47	5364
Stacked Rock Wall	21	2963
Gabions	17	1730
Subtotal Stone Structures	509	33429
Berms	46	20722
Log Cribwall	30	4139
Concrete	23	1035
Sheet Piling	2	159
Other	8	1704
Log Deflectors	23	660
Total	**641**	**61848**

For the purpose of this assessment, revetments are considered to be maintenance and/or repair structures placed along the streambank to prevent erosion. Most revetments along the West Branch are of some sort of stone structure, with dumped stone predominating. This feature largely consists of field stone and cobbles dumped along the river bank; the intent is to decrease erosion. Rip rap is large stone that has been dumped or machine-placed. Laid-up stone is generally field stone that was hand-placed along the streambank, while *stacked rock walls* are larger rock, usually blockier in shape than ordinary field stone. *Gabions* are cuboid shaped wire baskets that are filled with stone, and the basket top wired shut. They are then stacked along the river bank.

Note that 46 berms have been constructed. Berms are ridge-like structures along streambanks, usually constructed of earth and stones. Their purpose is to raise the bank elevation to prevent the stream from overflowing. (They may also be called levees). These contribute to erosion because they deny the river access to its floodplain. Constraining flood waters increases the speed of flowing water, producing more shear stress and resulting streambank erosion. Since berms confine and increase floodwater velocities, they increase the damaging effects of floods downstream. This situation does not develop when the stream has access to its floodplain.

Log cribwalls are log structures constructed along the river bank and backfilled with stone. These structures were installed by the NYS Department of Environmental Conservation as part of a maintenance program over the last 40-50 years. The log deflectors were also installed during the same time period. These structures protrude into the stream channel and were designed to create streambed scour for fish habitat. Although technically not a revetment, they were inventoried as such for ease in assessment.

The remaining revetment or repair structures consist of concrete, both in the form of poured walls and concrete slabs dumped along the river bank. Sheet piling consists of long sheets of steel driven vertically into the riverbed along the bank. The remaining eight structures represent miscellaneous efforts at erosion control.

Stream length surveyed was 49.5 miles, or 99 miles of river bank. So, there has been an average of 6 structures made per mile of riverbank, which equals about one repair every 880 feet of riverbank or one repair approximately every 6 (average) bank full widths. The average revetment is 96.5 feet long, and 12% of the river bank has been revetted. This certainly illustrates the magnitude of the erosion problem that riverbank property owners have been trying to cope with. **Table 6.6**, below, shows the number of, type of, and length of revetment and repairs for each management unit.

Table 6.6 Revetment and Repair by Management Unit.

Segment	Management Units	Length (mi)	Dumped Stone	Rip Rap	Laid-up Stone	Stacked Rock Wall	Gabions	Log Cribwall	Concrete	Sheet Piling	Other	Log Deflectors	Total Revetment Length (ft)	Revetment Length per mile	Berms	Berm Length (ft)
1	1	0.57	-	-	2	-	-	-	-	-	-	-	58	102	1	146
	2	0.70	1	13	10	-	3	-	4	-	1	-	2663	3804	4	385
	3	0.59	-	3	2	-	-	-	-	-	-	-	107	181	-	-
	4	0.37	5	5	2	-	-	-	1	-	-	-	1485	4014	-	-
2	5	2.55	3	8	4	4	-	-	1	-	-	-	2438	956	-	-
	6	0.76	2	5	4	-	-	-	-	-	-	-	1154	1518	-	-
	7	0.38	-	3	3	-	13	-	2	-	-	-	2403	6324	-	-
	8	0.39	1	3	1	-	-	-	-	-	-	-	381	977	-	-
	9	1.99	10	26	2	-	-	4	2	-	-	10	5146	2586	9	3155
	10	1.65	7	12	3	-	-	5	-	-	-	10	3884	2354	3	2079
	11	0.96	4	3	4	-	1	1	-	1	-	-	1690	1760	1	105
	12	4.89	34	18	3	-	-	14	2	-	-	3	11124	2275	5	1211
	13	1.20	2	1	-	-	-	-	-	-	-	-	1413	1178	4	3464
3	14	4.60	33	3	1	-	-	3	-	-	-	-	8646	1880	8	4924
	15	1.67	10	5	1	-	-	-	-	1	-	-	3988	2388	3	1922
	16	1.27	6	2	-	1	-	-	1	-	-	-	794	625	-	-
	17	0.87	11	1	-	11	-	-	4	-	-	-	3118	3584	-	-
	18	1.12	10	3	-	-	-	-	-	-	-	-	1563	1396	1	448
	19	2.84	10	1	1	1	-	2	1	-	-	-	3271	1152	-	-
4	20	1.75	5	-	-	1	-	-	-	-	-	-	190	109	1	836
	21	2.97	29	5	-	1	-	1	2	-	1	-	6625	2231	3	980
	22	1.03	6	-	-	-	-	-	-	-	1	-	976	948	-	-
	23	0.64	10	-	-	-	-	-	-	-	-	-	1275	1992	-	-
	24	2.35	21	2	-	-	-	-	1	-	2	-	5433	2312	1	159
5	25	2.21	21	-	-	2	-	-	-	-	1	-	3772	1707	1	399
	26	0.84	10	-	-	-	-	-	-	-	-	-	1808	2152	-	-
	27	1.58	14	-	-	-	-	-	-	-	-	-	3272	2071	-	-
	28	1.86	11	5	-	3	-	-	-	-	-	-	5324	2862	-	-
	29	4.44	28	1	-	1	-	-	3	-	-	-	3681	829	1	509

Japanese knotweed may be a contributing factor to streambank erosion. Considered an undesirable and *invasive plant* species, knotweed colonizes river banks and grows in thick stands that out-compete indigenous riparian vegetation. Knotweed may facilitate erosion of stream banks, especially during winter months when it provides little or no soil surface protection. During the 2003 and 2004 field seasons 70,115 linear feet of knotweed stands were documented on both river banks over a distance along the river of 165,502 feet. Approximately 20,000 linear feet of erosion was noted at knotweed stands that were located at the water’s edge. Research is continuing, but at the present time it is not known if knotweed establishes itself at banks that are already eroded, or if it establishes itself and then erosion begins. What is known is that wherever knotweed is established, there is erosion. Japanese knotweed will not provide a sufficient vegetative barrier to prevent erosion and stabilize banks (see **Section 5.10.4** for additional information concerning Japanese knotweed).

6.2.4. Summary of Geomorphic Condition of the West Branch

Overall, the following can be said about the main stem of the West Branch of the Delaware River:

- The stream exhibits a tendency to be wider than is desirable. This could be due to lateral erosion, excess sediment load, or a combination of management approaches that leads to erosion and a reduced sediment transport ability.

- The stream exhibits a tendency to aggrade. Sources of sediment include exposed and eroded river banks and the river's tributaries.

Fine sediment that coats the rocks on the channel bottom becomes particularly noticeable near Walton. Its exact cause is unknown, but it is probably due to some combination of fine sediments entering the stream from eroding banks, the upper main stem or tributaries, low energy gradients, and wide channels.

- Bank erosion is widespread throughout the whole length of the river. Recall that type C streams are susceptible to lateral erosion particularly if riparian vegetation is inadequate.

- Review of aerial photographs from 1938, 1961, 1971, and 1983 show that plan form has remained relatively unchanged since 1938. Over the entire length of the river, sinuosity is slightly low (1.15) for the stream type and valley setting but is not considered a problem. Straight stretches of stream do exist and are readily identifiable from aerial photographs. Presumably, some of these straight reaches are due to alteration to the stream's natural winding course. The stream at these locations was probably moved for the construction of railroads or highways, or to form contiguous acreage for planting or pasture. It appears that most stream relocation and straightening took place in the 19th to the early 20th century prior to 1938.

Figure 6.4 Severely eroding bank in the Village of Walton (December 2004).

6.3. West Branch Vegetation

6.3.1. Evaluation of Land Use and Riparian Vegetation Communities

Section 5.10.1 reviewed the importance of forest land in regulating the hydrology of a watershed, and the role of riparian vegetation in maintaining the stability of river as well as providing for *aquatic habitat*, and other benefits. This section provides a summary of the findings of two sets of analyses conducted to provide: an overview of land use/cover within the West Branch of the Delaware River and examine the structure of riparian vegetation along the river. The general analysis for the entire watershed was based on a land use classification derived largely from satellite imagery of the entire Cannonsville basin, while the analysis of riparian vegetation involved the mapping and classification of ecologic communities within a 300 foot buffer of the river between Stamford and the Cannonsville Reservoir.

Watershed Land Use/Land Cover Analysis

Section 5.7 generally describes the land use and land cover for the West Branch of the Delaware River watershed. **Map 5.8** provides a map of land cover based upon a classification of 1992 Landsat imagery for the project area. Recent efforts by the NYCDEP have produced updated maps and a set of statistics for the current land use/land cover in the basin under the New York City Watersheds 2001 Land Use/Land Cover Classification Project. The maps and underlying database for this project were derived by selectively merging data from various imagery and GIS datasets.[7]

As with the 1992 Land use classification and as shown in **Figure 6.5**, below, deciduous forests dominate the watershed landscape, comprising approximately 68 percent of the area. As shown in **Map 5.8**, the bulk of the forest land covers the higher elevations and steeper slopes. Brushland or successional land (11%) typically occurs in the mid-elevations to lower slopes, or upper portions of sub-watersheds. Agricultural land (10%) is commonly on the level flats of the river bottom lands. Urban or built up lands make up only about 6% of the watershed area, and are chiefly found on the alluvial fans and *terraces* along the mainstem and principal tributary valleys. The large proportion of successional land indicates a transition from agriculture to new forests, a trend over the last several decades.

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[7] These included: 2001 Landsat Enhanced Thematic Mapper Plus (ETM+) satellite imagery (5 April, 2001; 8 June, 2001; 10 July, 2001, and 12 September, 2001), April 2001 color infrared orthoimagery (NYS 1 foot resolution) and Emerge 0.3 meter resolution, Tax Parcel Data, and National Wetland Inventory polygon data. These data were used to produce a land use/land cover classification based upon a slightly modified version of the USGS Anderson Level II-IV standard. This is the result of a classification of land use using a modified version of Anderson land use classification system (Anderson et. al., 1976). The Anderson system was devised by the USGS to update existing widely used classification systems and provide Federal, State and local government agencies with a standard system of defining land use from remotely sensed imagery. The system allows the user the flexibility to define increasingly detailed categories of land use as it progresses from Level I through Level IV. For the purpose of this plan, the summary will provide the statistics in the more general categorization of the Anderson Level I and Level II standards.

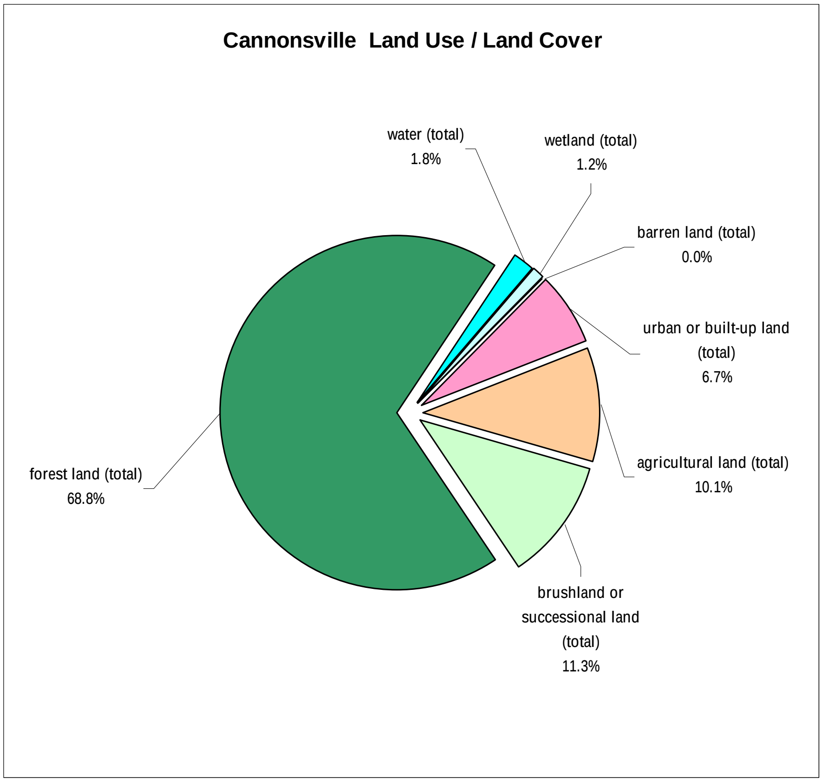

Figure 6.5 Cannonsville Land Use/Land Cover in percentages

When examining land cover in the valley along the river corridor (i.e., not the entire watershed), the intensity of land use increases; less land was left as forest while more land is actively farmed. For land use within 1000 feet of the river, the mix is approximately 33 percent forested, 23 percent agricultural and 14 percent shrubland or transitional. *Wetlands* (7%) also are a significant portion of the land cover in this principally riparian zone.

A Closer Look

The presence of riparian forest vegetation acts as a “buffer” or shock-absorbing feature, adding to stream corridor stability. As the streamside buffer lands were of primary concern, detailed mapping was performed on the riparian corridor and near adjoining upland areas within 300 feet of the main stem’s riverbanks. The purpose was to develop information on the condition of the riparian buffer and to identify locations where additional vegetation could be established to improve buffer function. A greater level of detail was needed to assess the condition of the riparian buffer, so high-resolution Digital Ortho Quarter Quadrangle (DOQQ) aerial photographs were used to produce a map. Mapping included the approximate delineation of ecological communities through the photo interpretation of “Emerge” digital orthophotography acquired by New York State in 2000.[8] Later, a similar assessment was made for the riparian zone along Town Brook.

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[8] The classification of the land cover by ecological community based upon the New York Natural Heritage Program’s (Reschke, et al. 2000) definitions was created as a GIS data layer using heads-up digitizing techniques with ESRI’s Arcview and Image Analyst softwares. Photo interpretation was field checked with class boundaries and classification amended based upon field observations. The classification was then translated in to an Anderson Level II land use/land cover classification comparison with other datasets and analysis for this report.

The land use/land cover maps resulting from this process accompany each management unit, but a summary table of land use/land cover is found below (**Table 6.6**), and a map of a portion of the main stem (**Figure 6.6**) is displayed on the following page.

The table below summarizes the land use/land cover distribution for lands within 300 feet of the mainstem between Lake Utsayantha and the Cannonsville Reservoir.

Table 6.6 Land Use/Land Cover within 300 ft. buffer width along West Branch main stem

Riparian Land Use/Land Cover Distribution

Anderson Level II	Acreage	%
Cropland and Pasture	1052.3	28.8%
Mixed Forest Land	661.7	18.1%
Herbaceous	447.1	12.2%
Mixed Brush	428.9	11.7%
Deciduous Forest Land	405.9	11.1%
Transportation, Communications and Utilities	129.3	3.5%
Residential	119.3	3.3%
Wetland	115.5	3.2%
Commercial and Services	72.3	2.0%
Shrub and Brush	64.5	1.8%
Water	63.4	1.7%
Coniferous Forest Land	54.6	1.5%
Strip Mine, Quarries and Gravel Pits	30.0	0.8%
Exposed Bare Rock	5.9	0.2%
Other Urban or Built Up Land	1.8	0.1%
Grand Total	**3652.5**	**100%**

Compared with the watershed-wide statistics, the amount of land in forest is significantly less (approximately 30%), with agriculture comprising approximately 40 % of the riparian zone.

The most serious issue with the riparian buffer for the West Branch of the Delaware appears to be its structure. A functional riparian buffer needs to be both sufficiently wide and continuous to minimize channel migration, and to insure adequate capacity for trapping nutrients, pollutants and sediment from surface runoff. A narrow buffer or a buffer with gaps is easily breached by the river during flood events. The river then scours out high flow channels and erodes open land behind the buffer. A narrow buffer allows bank erosion to strip away whole chunks of the bank along with individual trees and shrubs. A narrow vegetative buffer also does not adequately trap nutrients or meet cover requirements of aquatic life.

Along the West Branch Delaware where agriculture is most intense, the riparian buffer is especially narrow, and in many places is absent. Where it does exist, its width is commonly about 50 feet wide. Areas where it is wider are typically either not tillable, subject to inundation, or include steep slopes that preclude development.

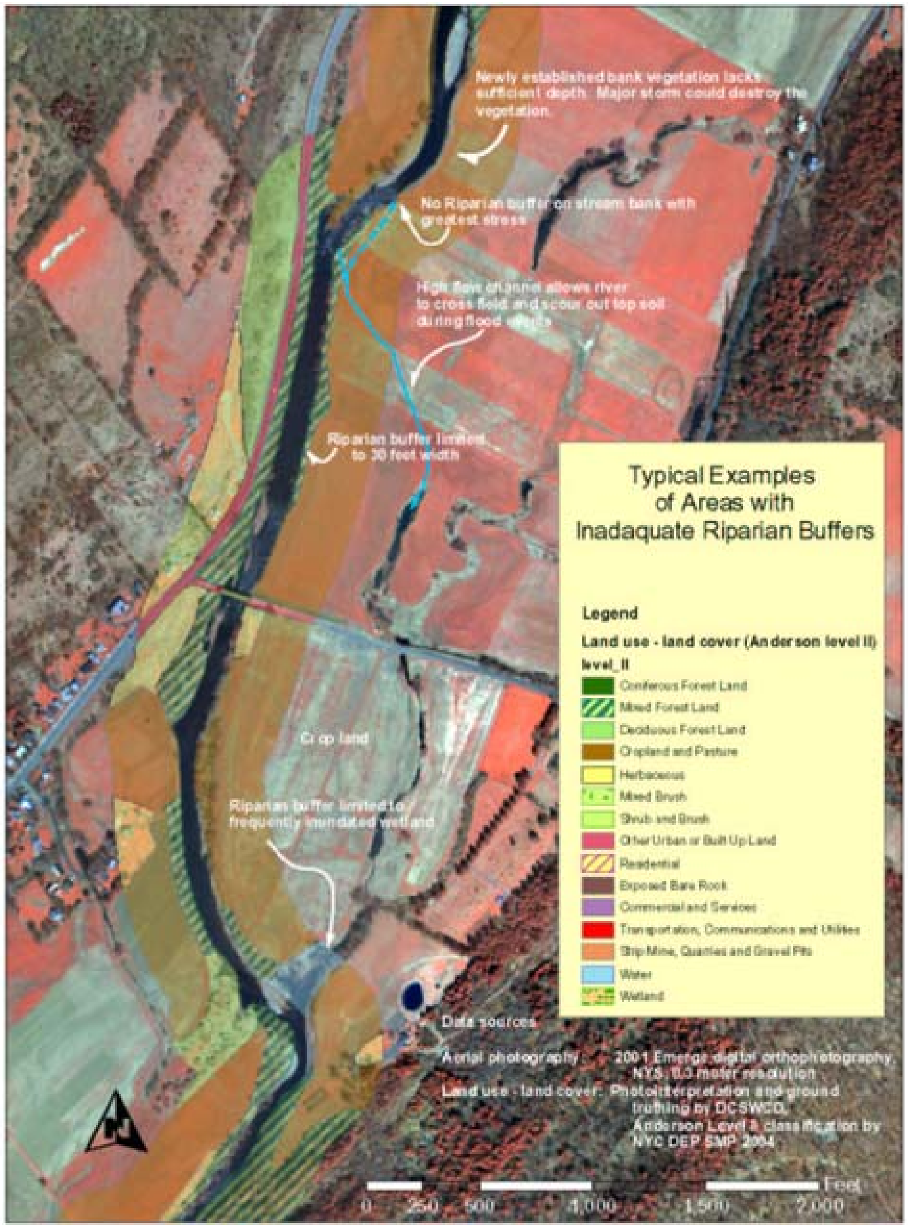

Figure 6.6 Photo of portion of West Branch main stem showing various land use/land cover characteristics.

NYCDEP's minimum recommended width for riparian forest buffers should be 100 feet, with wider buffers established where the river has historically attempted to utilize secondary channels or where stress and *erosion potential* on meander bends would warrant additional protection.

Using the 2000 high resolution aerial photography for the watershed, a map was created to indicate locations that would benefit from riparian forest buffer establishment or where additional land should be set aside and reforested to augment existing buffers. This review identifies areas where either no buffer exists or the existing buffer is inadequate. Relative adequacy was defined by width of the riparian buffer (< 100 ft = inadequate), type and density of vegetation (herbaceous or sparse tree and shrub cover = inadequate). The maps shown in **Section 7** are simply a cursory review of the buffer condition. **Table 6.7**, below, provides an estimate of the length of land fronting on the river that should receive consideration for riparian buffer establishment, enhancement or protection. Given that the total length exceeds 10 miles, it is clear that the size of the task is enormous and that additional prioritization based upon erosion threat, channel and floodplain considerations, runoff and nutrient sequestration concerns is required. From this cursory review, active agricultural land, which constitutes 44% of the inadequately buffered land, should be the primary target for riparian buffer establishment efforts –as under the Conservation Reserve Enhancement Program (CREP, see **Section 6.3.2**). Land that is already in a successional shrub stage or floodplain forest (30% of the inadequately buffered land) should also be considered for buffer enhancement/protection efforts. Landowners with mowed lawns (11% of the total) typically associated with residential property should be included as a target audience for riparian buffer efforts.

Figure 6.7 Natural riparian forest buffer near the Village of Stamford. Note abundance of vegetation and lack of erosion. Stream also has noticeable natural riffle-pool sequence.

Table 6.7 Estimated length of riparian buffer requiring establishment or enhancement (un-prioritized)

Ecological Community	Length ft.	Percentage
Cropland/field crops	15935	28%
Floodplain Forest	8783	15%
Successional Old Field	7070	12%
Cropland/row crops	5417	9%
Pastureland	4268	7%
Mowed Lawn	4121	7%
Shrub Swamp	2575	5%
Successional Shrubland	1883	3%
C.R.E.P.	1847	3%
Mowed Lawn w/ trees	1020	2%
Residential	889	2%
Closed Northern Hardwood	794	1%
Hemlock-Northern Hardwood	646	1%
Successional Northern Hardwood	495	1%
Shallow Emergent Marsh	430	1%
Open Northern Hardwood	305	1%
Commercial	194	0%
Unpaved road/path	174	0%
Conifer Plantation	75	0%
Paved road/path	59	0%
Brushy Cleared Land	43	0%
Gravel Mine	33	0%
Mixed Open Tree Canopy	30	0%
Riprap/erosion control roadside	30	0%
Backwater Slough	13	0%
Pine-Northern Hardwood	10	0%
Grand Total	57139	100%

Although CREP is making a significant contribution to improving riparian buffers in the watershed, additional programs that address non-agricultural land or abandoned agricultural land should be considered as possible outcomes of this planning process.

6.3.2. Conservation Reserve Enhancement Program

On August 26, 1998, New York City entered into a Memorandum of Agreement (MOA) with the United States Department of Agriculture (USDA) and New York State to implement a Conservation Reserve Enhancement Program in the Catskill and Delaware Watersheds. This MOA allows watershed landowners to enter into 10 to 15 year contracts with the USDA to retire environmentally-sensitive agricultural lands from production. CREP helps establish forested or grass riparian buffers adjacent to watercourses and provides for fencing watercourses to exclude livestock. The USDA pays the producer an annual rental rate per acre of retired land and 50 percent of the cost of all CREP Best Management Practices (BMPs) associated with establishing the riparian buffers, permanent grass and/or exclusionary livestock fencing, (which usually include alternative water systems). USDA also provides for signup incentive and practice incentive payments. New York City pays the remaining 50 percent of BMP costs for participating farms and technical and administrative assistance costs through its agreement with the Watershed Agricultural Council (WAC)[9] located in Walton, New York.

Figure 6.8 CREP buffer with fencing. Note brush mats and tree tubes (lower right) to protect seedlings and facilitate growth.

Most CREP implementation in the West Branch watershed consists of the establishment of riparian forest buffers through tree and shrub plantings and exclusionary livestock fencing, both of which are CREP priorities (**Figure 6.8**). Riparian forest buffers of sufficient width intercept sediment, nutrients, pesticides and other materials in surface runoff and reduce nutrients and other pollutants in shallow subsurface flow. Woody vegetation in buffers provides food and cover for upland wildlife, helps lower water temperatures by shading the stream, and slows out-of-bank flows. The vegetation closest to the stream provides litter fall and large woody debris important to aquatic organisms. Woody roots also increase the resistance of streambanks to erosion. A riparian forest buffer consists of 2 or 3 vegetation zones as shown and described in **Figure 6.9** below.

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[9] The WAC is a non-profit organization funded by New York City, USDA Forest Service and other federal and foundation sources. Their mission is to support the economic viability of agricultural and forestry through the protection of water quality and the promotion of land conservation in the New York City watershed region through various conversation programs. See **Section 4.5** for additional information.

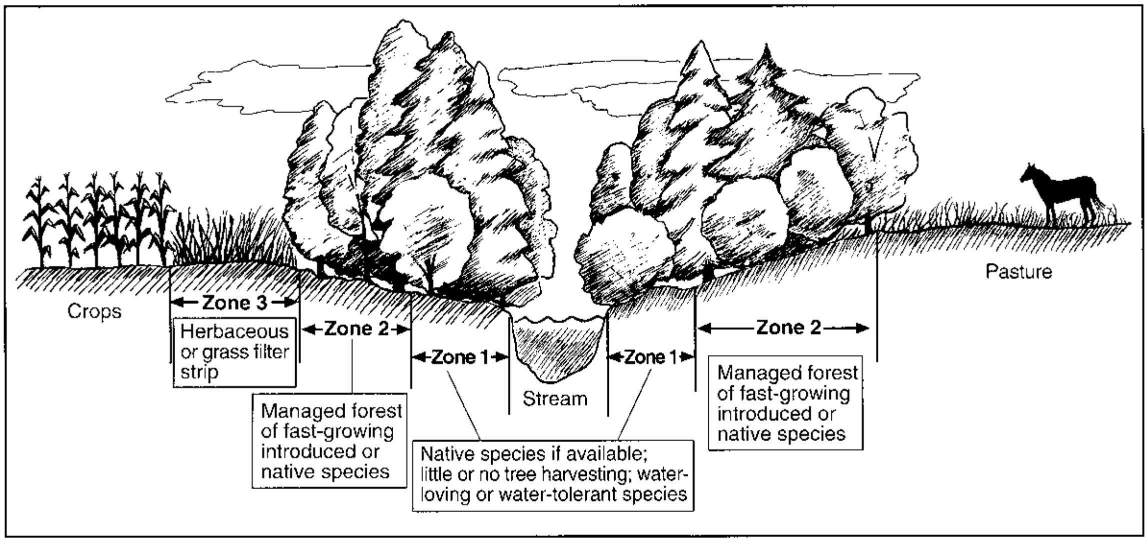

Figure 6.9 Illustration of riparian forest buffer zones

A riparian forest buffer zone includes zone 1, the area closet to the stream, and zone 2 the area adjacent to and up gradient of zone 1. Trees (67%) and shrubs (33%) in zone 1 help stabilize streambanks and provide habitat and shading. Shrubs (67%) and trees (33%) in zone 2 intercept sediment, nutrients and other pollutants. A third zone, zone 3, is established if periodic and excessive water flows, erosion, and sediment from upslope fields are anticipated. Zone 3 is usually herbaceous plants or grass. This zone provides a "first defense" to assure proper functioning of zones 1 and 2. The allowable minimum buffer width is 35 feet from the top of the streambank.

Figure 6.10 Fenced livestock crossing with animal walkway.

Since streams have long been the primary source of water for livestock, alternative water supplies, usually from on-site springs, are developed where streams are fenced out. In many instances, a dedicated livestock crossing is constructed with a fenced animal walkway through the CREP area. Crossings usually consist of specially designed concrete slabs placed at grade in the streambed, which provides a stable base for livestock traffic (**Figure 6.10**). Animal walkways usually consist of a gravel surface placed over filter fabric material. All CREP BMP's are planned, designed and constructed by New York City's Watershed Agricultural Program (WAP)[10] and according to USDA Natural Resources Conservation Service (NRCS) standards and

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[10] This program is responsible for Whole Farm Planning on volunteer farms in the West Branch and surrounding New York City water supply watersheds. See **Section 4.5** for additional WAP information.

have operation and maintenance requirements. Other requirements include a sixty percent survival rate of planted woody vegetation after the first year. This is to ensure that the remaining tree and shrub vegetation will meet the intent of the riparian forest buffer standard as designed to enhance water quality.

To date, approximately 1100 acres of CREP have been implemented on 79 farms in the West Branch basin. It is important to note CREP cannot be implemented on unstable streambanks. Consequently, there are areas identified and prioritized in the watershed that require some form of bank stabilization to facilitate CREP implementation. The current CREP authorization expires September 30, 2007. Currently, the Stream Corridor Management Program and the WAP are working together to further prioritize and plan bank stabilization projects for areas in greatest need of CREP implementation. See **Section 2, Recommendations**, for future recommendations.

Figure 6.11 Newly implemented riparian forest buffer system, with exclusionary fencing, and newly planted trees in brush mats.

6.4. Public Infrastructure[11]

Within the boundaries of the West Branch basin exists a network of highways and bridges under three separate ownership and maintenance categories: New York State, Delaware County, and townships. They are all part of an infrastructure system on an inventory maintained by the New York State Department of Transportation (NYSDOT). Highways are inventoried according to political jurisdiction with subcategories including pavement type. All bridge structures with a span of 20 feet and greater are inventoried, numbered, rated, and periodically inspected for condition and safety by NYSDOT. In Delaware County, bridges on town highways with a 20 foot span and greater are inventoried, numbered (in addition to the NYSDOT inventory and numbering system), maintained, and periodically inspected for maintenance or repair scheduling by the county. On county highways, all structures with a span of 5 feet or greater are managed as bridge structures. Structures on town highways with less than 20 feet of span are the individual town's responsibility and are not inventoried by the county or state.

Note: **Map 6.1,** a map of the highway system in the watershed, is included at the end of this section. Following is a brief description of this highway system.

The three state highways are NYS Route 10, which parallels the West Branch main stem on the north for the entire length of the watershed; NYS Route 28, which runs in a general north-south direction through the towns of Meredith, Delhi and Bovina, intersecting NYS Route 10 in the Village of Delhi; and NYS Route 23, which runs in a general northwest-southeast direction through the towns of Kortright, Harpersfield and Stamford, intersecting NYS Route 10 in the Village of Stamford. These are major routes in the watershed and are constructed and maintained according to strict NYSDOT standards. State highways are owned in fee by the State of New York.

Portions of nine county highways traverse the watershed and three lie completely within the basin. County Route 18 runs from the Village of Delhi to the Village of Stamford and parallels the West Branch main stem to the south. The remaining county highways are located along tributary streams and with the exception of County Routes 5 and 22, traverse into neighboring watersheds. County highways are all paved, most with oil and stone surface and a few with bituminous concrete (blacktop). Some county highways have been constructed to NYSDOT standards. Some county highway mileage is owned in fee by the County of Delaware and some is public right-of-way by usage according the New York State Highway Law.

Most of the highway mileage in the watershed is divided among the jurisdictions of nine townships (the Town of Andes has negligible mileage in the basin and Roxbury has none). These roads run along streams, over mountaintops and connect with each other and the state and county highways. The roads that parallel the West Branch main stem to the south between Delhi and Hamden, and Hawleys' Station and Walton are town roads (there are no roads along the river between Hamden and Hawley's Station). Town highways are constructed to various standards, with many having been constructed or rehabilitated to the Erwin and Donovan standards developed and financially supplemented by New York State from the period of 1952 through 1982. Town highways feature a variety of surfaces including improved dirt, gravel, or oil and stone. Most town highway mileage is public right-of-way by usage according the NYS Highway Law.

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[11] This section has been contributed to in part by Phil Pierce, P.E., Deputy Public Works Commissioner and John Reynolds, Senior Engineer, both with the Delaware County Department of Public Works.

Many of these highways are in close proximity to streams and rivers, often crossing them. Highway maintenance can affect stream dynamics and water quality as a result of roadside drainage management, road surface repairs, bridge rehabilitation or replacement, snow and ice removal, and bank stabilization (which may be between the road and the stream).

Many reaches of streambanks in proximity to roads have been stabilized primarily with dumped stone or riprap. Stacked rock walls and gabion baskets filled with stone are also fairly common along highway streambanks. Although there are 641 revetments along the West Branch main stem (see **Table 6.5, Section 6.2.2**), many of them are not the result of highway maintenance since highways paralleling the West Branch are generally not close to the river. Most highway related revetments are in the narrower tributary valleys along town highways or where streams (including the West Branch main stem) flow through villages. Most revetments along county highways are associated with bridge crossings. It is important to note that many revetments where streams and roads share a common slope were constructed or repaired during the aftermath of the January 1996 flood event.

Along some reaches, roadside drainage management impacts stream dynamics and water quality. Ditching practices and culvert sizing, placement and outfall protection all have drawn recent attention to highway and stream managers. The Delaware County Action Plan (DCAP) is currently developing and implementing programs for better management of highway infrastructure related to drainage and stormwater management (see **Section 4.6**).

Bridges are perhaps the key management issue between highway infrastructure and stream management. Of the 117 bridges in the West Branch watershed, thirty-one are on state highways (22 on NYS Route10, 3 on NYS Route 28 and 1 on NYS Route 23). Forty-six are county bridges on county roads, thirty-four are county bridges on town roads, and six are county bridges on village streets. Fifteen of these structures cross the West Branch main stem: five state bridges and ten county bridges (3 on county roads, 5 on town roads, and 2 on village streets).

Figure 6.12 Wide and shallow flow around a gravel bar downstream of county bridge 33-1 on County Route 33, just north of Bloomville

Stream flow through many bridges during periods of low flow exhibit the characteristics of a stream that is too wide and too shallow, resulting in lack of adequate energy to effectively transport its sediment (see **Section 5.9.2** for description of width/depth relationship and sediment transport). This can result in deposition downstream of or inside the structure, which in turn creates further flow issues (**Figure 6.12** above). Other bridges exhibit deposition upstream of the structure which is indicative of a backwater effect. Woody debris accumulations are another common concern at bridge crossings.

At some bridge crossings the highway approaches are elevated above the floodplain elevation. This creates an obstruction to floodplain flow, forces overbank flows under the bridge, and can create flood debris accumulation under the bridge. One solution that is being evaluated is the placement of culverts under the approaches to allow for some continuity of flood flow across the floodplain. This method has been applied where County Route 2 crosses the West Branch in Delancey (County Bridge 2-1, **Figure 6.13**). Although this application has met with some success, the practice is still being evaluated to determine its effectiveness.

Figure 6.13 Floodplain relief culverts installed at County Bridge 2-1 in Delancey. Photo taken looking upstream, March 21, 2003

On the town level, common concerns focus on culvert design and permitting to work within streams that are close to the roads. Most towns have some sort of ditch maintenance policy in place. There is interest in financial and technical assistance with drainage maintenance, and protection of roads close to streams.

6.5. Public Outreach

Outreach efforts consisted of a series of presentations and tours outlining the program goals, objectives and status updates of our ongoing research. The initial informational meeting was held on January 18, 2001 to introduce prospective Project Advisory Committee members to the program. A series of presentations were made to various agencies and organizations throughout the remainder of 2001.

In 2002 and 2003 a number of presentations were made in each of the major towns along the West Branch main stem and to the Delaware County Board of Supervisors. An additional presentation was made to a contingent of watershed farmers in November, 2002. This meeting was especially valuable because it featured a Pennsylvania farmer who had developed a good understanding of stream processes and the geomorphic approach and changed many management practices on his farm accordingly, with positive results.

In addition to presentations to agencies and organizations, efforts in 2004 included two tours of the David Post *demonstration project* site, further described in **Section 6.7** below.

A list of presentations and tours follows:

Program Outreach Efforts
(Presentations unless otherwise noted)

Date	Audience
2001	
January 18	Program introduction meeting, invited attendees
March 7	Delaware County Phosphorus Study Group (includes Delaware County Board of Supervisors)
March 14	Trout Unlimited, Susquehanna Chapter
April 4	Cornell University class field trip to Richard Latourette project (restoration project done through the Watershed Agricultural Program prior to inception of the Stream Corridor Management Program)
July 11	US Army Corps of Engineers representatives
July 19	NYS Attorney General:s office representatives
September 21	NYS Departments Health and Environmental Conservation (DEC) US Environmental Protection Agency (EPA), and NYC Department of Environmental Protection (NYCDEP) (the Stream Corridor Management Program was a venue on Cannonsville watershed tour hosted by Delaware County Department of Watershed Affairs)
December 20	NYS DEC Division of Water representatives
2002	
April 1	Town of Harpersfield board
April 15	Town of Kortright board
April 30	Board of Cooperative Educational Services class - Masonville campus
May 9	Town of Stamford board
July 2	Town of Middletown board (East Branch basin, requested by supervisor)
October 8	Delaware County Phosphorus Study Group
November 6	Watershed farmers

2003	
May 7	Town of Hamden board
May 13	Town of Delhi board
May 21	Delaware County Board of Supervisors
November 13	Cannonsville watershed tour for NYCDEP Stream Program Advisory Board, West Branch Project Advisory Committee (PAC), and neighboring Soil and Water Conservation Districts

Date	**Audience**
2004	
January 29	Hobart Rotary Club
March 5	Delaware County Board of Supervisors
July 7	US EPA representatives
August 5	Watershed Agricultural Program staff
August 18	David Post project site tour (PAC and agencies)
September 2	O'Connor Foundation (local funding entity)
October 20	David Post project site tour (DEC Division of Water Representatives)

Education on the Importance of Floodplain Function

During the development of this plan, it has become apparent that further education is necessary on the importance of floodplain function (see **Section 2, Recommendations**). Following is a brief discussion on floodplain function.

"The floodplain is defined as the flat area bordering a stream, constructed by the river in the present climate and inundated during periods of high flow." (Leopold, 1997). The floodplain has key roles in stream function, perhaps the most important being energy dissipation during overbank flows. The normal elevation for the floodplain is the bankfull elevation. Water flows that are higher than bankfull will flow across the floodplain with a much lower velocity than in the main channel in a properly functioning riverine system (**Figure 6.14**). The floodplain also acts as a storage area for floodwaters. Another important function of the floodplain is for deposition of fine sediments during high flows – in other words, a sediment trap. These sediments facilitate seed generation on the floodplain. Another way to state the relationship between the channel and floodplain is that the floodplain, like the channel, ***is part of*** the stream.

Figure 6.14 Photo of overbank flow taken just downstream of the Village of Stamford, March 21, 2003.

Assessments identified numerous locations where attempts to protect lands along the stream through the construction of berms and walls limited the river's access to its floodplain. Other channel modifications that are commonly advocated, but can disconnect the floodplain or reduce its function include deepening the channel and widening the channel

Development within the floodplain also restricts its function. Constructing buildings in the floodplain, especially large complexes, reduce the capacity of the floodplain. Further, flow around floodplain obstructions causes scour, which in turn introduces additional sediment into the system. Aside from damage to the floodplain and the structure, this additional sediment becomes deposition further downstream.

Misunderstanding or ignoring the importance of the floodplain can result in actions which reduce sediment transport capacity, accelerate erosion or shifts problems from one location to other sections of the river system. An education effort highlighting the importance of preserving floodplain function will promote expanded stewardship of the river and ultimately result in greater stream stability.

6.6. Geomorphic Condition of Town Brook

6.6.1. Introduction and Overview of Drainage Basin

The summer of 2003 was extremely wet. Unseasonably high water levels in the West Branch prevented much Rosgen Level II work from being performed but it did seem possible to assess a tributary stream instead. Since NYCDEP, NYSDEC, Cornell University and the Watershed Agricultural Program had various research projects ongoing in the Town Brook sub-basin, a Global Positioning System (GPS) walkover and Rosgen Level II surveys were performed during the 2003 field season.

Town Brook is 7.58 miles long with a drainage area, upstream of the gage near Hobart, of 14.3 square miles. The stream begins at an elevation of 2400 feet and joins the West Branch Delaware River at 1600 feet. The overall stream slope is 0.02 ft/ft (2.0%). The valley that it runs through is a Type V valley. The uppermost 0.9 miles of town Brook is a Type B stream, and where it crosses under Davis road it begins to transition to a Type C stream. Ten tributaries to Town Brook are identified on USGS topographic maps. There are also numerous intermittent swales that direct flow to the stream during rainstorms, but are not mapped as streams. The watershed is primarily used for farming, and about 20% is forested. There is very little urbanization, and what there is tends to be concentrated in the Village of Hobart at the lowest end of the watershed. Some residential development is occurring along Town Brook Road between the Village of Hobart and the upstream reaches of the watershed.

6.6.2. Data Collection

Geomorphic data were collected along 6.2 miles of stream during 2003 using a Global Positioning System receiver. The data was incorporated into a Geographic Information system (GIS) and then located on aerial photos for mapping and analysis. No data were collected along one reach near the midpoint of Town Brook, because we were denied access by the landowner. The data collected included:

- The location of and the degree of severity of eroded banks.
- The location of *head-cuts* and other evidence of erosion.
- The location of revetments, rip-rap, and other similar erosion control measures.
- The location of depositional features such as side bars and center bars.

Rosgen Level II surveys were performed at selected locations. Information collected included:

- Surveyed stream cross sections.
- Pebble counts at the surveyed cross sections.
- Documentation of bankfull indicators.
- Bulk gravel samples (bar samples).

6.6.3. Current Conditions of Town Brook

When the GIS and Rosgen Level II data were analyzed, the following problems became apparent:

- Un-vegetated and clearly eroded banks.
- High banks, which indicate that the stream is incised.
- Existing revetments and erosion repairs.
- Head cuts.
- Transverse bars.
- Mid-channel bars and side bars.
- Channel widths that are too wide for their depth.

As described in **Section 6.2.2**, the processes of stream erosion and deposition go together. A spiral of erosional and depositional events can occur, the result of which is the destabilization of the stream.

Figure 6.15 High eroding bank on Town Brook just below cross-section 10.

Table 6.8 Summary of various physical properties for 14 cross-sections in Town Brook

1	2	3	4	5	6	7	8	9	10	11	12	13
Cross-section #	**Stream Type**	**Drainage Area (mi^2)**	**Bankfull Width W_{bf} (ft)**	**Bankfull Depth d_{bf} (ft)**	**Bankfull Area A_{bf} (ft^2)**	**Width/Depth Ratio (W_{bf}/d_{bf})**	**Entrenchment Ratio**	**D84 (mm)**	**Aggrading/ Degrading/Stable**	**Sinuosity**	**Stream Slope (%)**	**Profile Length (ft)**
1	B4	1.30	12.1	0.8	10.0	15.1	1.65	146	A	1.1	2.50	225
2	B4	1.60	18.4	1.0	17.8	18.4	1.58	152	A	1.1	2.90	1317
3	C4	3.12	37.9	0.9	33.2	42.1	1.16	142	D	1.2	1.75	432
3.1	C4	3.12	30.1	0.8	25.3	37.6	1.63	140	A	1.2	1.47	432
4	C4	3.20	35.1	0.8	29.8	43.9	8.55	109	A	1.1	1.30	494
4.1	C4	3.20	29.4	1.1	30.9	26.7	10.20	125	A	1.1	1.30	494
5	C4	7.80	22.4	1.4	32.3	16.0	13.39	140	A	1.2	0.97	482
6	C4	7.80	30.8	1.3	40.6	23.7	8.12	108	A	1.2	0.42	482
7	C4	9.18	43.5	1.0	43.8	43.5	4.14	156		1.1	1.82	484
8	C4	9.18	37.4	2.9	60.1	12.9	5.35	175		1.1	1.56	484
9	C3	12.50	35.4	1.9	66.3	18.6	5.08	237		1.1	1.25	735
10	C3	12.50	30.9	1.8	56.2	17.2	5.82	180		1.1	1.30	735
11	C4	13.50	27.3	2.0	55.9	13.7	4.21	176		1.1	0.93	935
12	C4	13.50	47.0	2.0	94.3	23.5	6.38	195	A	1.1	0.93	935
🟨	Shaded cells exceed acceptable width/depth ratio 24											
🟥 🟩	Red/green hi-lighted cells indicate cross sections that are on the same profile (reach)											

*Note: No bulk samples were taken at X-sections 7, 8,9,10 and 11. However comparison of shear stress to D84 suggests that they are all aggrading.

Reference to **Table 6.8** above shows that Town Brook is aggrading. Note that 7 of the 14 cross sections exceed the allowable width depth ratio for a stream in regime. This commonly happens when a steam is aggrading and is further evidence of excessive bedload. While sediment is eroded away and must be transported downstream by Town Brook, the tributaries were not surveyed; yet it was noted that many of them tend to be steep and show obvious signs of erosion (severe down cutting, exposed banks, bars at their mouth). They are a major source of sediment that overloads the system.

Table 6.9, below, summarizes the eroded bank data. The worst location is the Lamport farm site, as almost the entire reach there is badly eroded. Approximately 20% of the *bank* length of Town Brook (inclusive of both sides) is eroded. Assuming that one foot of earth is eroded each year (a *very* conservative estimate) in one year's time 2826 tons of gravel and sediment is eroded and must be transported downstream by Town Brook, where it then enters the West Branch main stem.

Table 6.9 Eroding Bank Summary

Number	**Total Length (ft)**	**Total Area (Sq. Ft.)**
166	12,928	49,400

This high bedload should show up as depositional features. **Table 6.10**, below, summarizes the depositional features found.

Table 6.10 Depositional Features found in Town Brook

Type of Deposition	Number
Transverse Bar	31
Center Bar	18
Emergent Gravel Bar	27
Side Bar	9
Total	**85**

There are a considerable number of features. 85 features over 6.2 miles of stream works out to one feature every 385 feet or approximately one feature every 12 *bankfull widths*. This is further proof that the stream carries an excessive bedload.

Table 6.11 summarizes the number and types of revetments and erosion repair features. Each site has probably experienced previous erosion. Thus, erosion problems are and have been wide spread along Town Brook. We also noted the presence of berms. As was explained in **Section 6.2.2**, berms prevent the stream from accessing its floodplain and they increase erosion.

Table 6.11 Revetments/Repairs along Town Brook

Type	Number	Total Length (ft)
Stone Structures		
Dumped Stone	34	3073
Rip Rap	15	1489
Stacked Rock Wall	4	250
Subtotal Stone Structures	53	4812
Berms	14	5918
Concrete	1	81
Other	1	97
Total	**69**	**10908**

6.6.4. Summary of Geomorphic Condition of Town Brook

Overall Town Brook exhibits the following characteristics:

- The stream is or should be a type C stream over most of its length; it is or should be a Type B stream in its upper reaches.
- The stream tends to too wide for its depth.
- It exhibits symptoms of both erosion and deposition.
- Its defects are due to excessive bedload.

6.7. Demonstration Project

6.7.1. Introduction

The Contract Scope required the design and construction of a natural stream channel (or fluvial geomorphic) demonstration restoration project. Many sites along the West Branch main stem were originally given consideration. However, *reference reach* information was not obtainable for the larger watersheds of main stem project sites. Subsequently, the decision was made to implement the initial demonstration project on a reach with a watershed size compatible with the limits of available stable reach information. Further discussion led to a decision to prioritize three potential sites in the Town Brook sub-basin. This decision was based on 1) a geomorphic assessment had been performed in the sub-basin and a reference reach had been located, as well as a "sister" reference reach in a watershed of similar characteristics (Pettis Brook in the Town of Hamden), 2) erosion at these sites was significant, and 3) two of the three sites were currently ineligible for CREP due to unstable streambank conditions.

The merits of these three sites were compared by developing a *matrix* (a table with varying weights given to characteristics) to prioritize potential sites in the West Branch watershed (see **Appendix 4**)[12]. The project selected was a 1200 foot long reach on the David Post farm, located just below the point where Town Brook crosses Davis Road in the Town of Stamford (see **Map 6.2** attached at the end of this section).

The project was let to public bid and a contract was awarded to T. C. Briggs Construction and Supply, Inc., Prattsville, New York in the amount of $213,745.00. Total project cost including all construction modifications was $222,035.50.

6.7.2. Existing Stream Conditions

Note: Photographs cited below are at the end of this section, arranged to emphasize before and after views of locations. Their identifying numbers do not follow in consecutive order.

Problems exhibited by the selected stream, as it existed before the project began, included:

- Incision: The stream was incised; banks were vertical, and the stream could not properly access its floodplain (photos 6.17, 6.23 & 6.24).
- Over width: The stream was too wide for its proper stream type (photo 6.29).
- There were very few pools, and they tended to be quite shallow.
- Four headcuts were observed in the project reach, also indicating stream incision (photo 6.29).
- Severe bank erosion: This was due to incision and the absence of a sound riparian buffer on the overbanks.

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[12] Pending comments from involved individuals and agencies, the prioritization matrix is considered to be in draft form.

- A large gravel deposit had formed in 1999, when the stream burst its banks during a record flood. (This flood was the result of a localized storm in which over 6 inches of rain fell in approximately a 4-hour period on July 4, 1999. The resulting flow from this storm was significantly higher than the January 1996 event) (photos 6.27, 6.29).
- The existing stream on the Post farm was trending heavily toward a Type F (photo 6.31).

The effect of these problems was that this stream reach was not the proper type for its setting, and was not functioning properly. Specific failures to function properly included:

- Inadequate trout habitat.
- A major source of sediment due to the eroding banks. This was probably affecting the downstream portions of Town Brook, and causing increased deposition downstream.
- Large gravel deposits in the project reach. As previously mentioned, some of this was due to the flood of 1999.

6.7.3. Design

Note: **Map 6.3**, the proposed construction plus the existing stream's alignment, is included in at the end of this section.

The techniques used to design a stream channel that is in balance with its surrounding landscape (its watershed) involve a unique synthesis of hydrology, engineering and fluvial geomorphology.

There are two main methods of designing streams using the above principles:

- The Rosgen reference reach method: This is an analog design method. A *reference reach* (stable reach of the same stream type in a similar geomorphic setting) is used as the template to design the particular stream in question.
- Regime equations based on stable streams. Care must be taken to insure that the regime equations used are based on similar stream types in similar geomorphic settings. In this case, the Hey-Thorne equations were known to be acceptable for use in this setting.

A third method is to duplicate a previous stream alignment. This is usually done by using old aerial photos to design the plan form. However, these photos would not show the stream's cross-sectional area or shape. Care must also be taken to insure that the plan form being duplicated is, in fact, stable.

For this project, a combination of all three methods was used. It should be noted that this reach is in a transitional area in the valley. Valley and stream slope begin to flatten and stream type transitions from a B Type to a C Type.

The proposed alignment was based on the location and shape of the stream as it appeared on the aerial photos taken in 1943. The bend radii were generally in agreement with the

1943 photos. However, the Hey-Thorne equations were also used to determine arc length and radii. The two sets of radii were compared and the larger of the two were used for each bend. This was done because of concerns that, for a period of time immediately after construction, the new channel may have banks that are not “stiff” enough to resist floods. Also, while it was easy to determine the plan form of the stream from on the 1943 photos, scaling off the radii of the bends was more problematic due the graininess or fuzziness of the photo images. Therefore, it was preferable to use the conservative solution and use the slightly larger radius. Furthermore, it seemed wiser to use a computed value from accepted equations, than to scale off the radius from the old photos, which were somewhat difficult to interpret.

The shape and depth of the riffles and pools were computed from two reference reaches and the Hey-Thorne equations. The two reference reaches used were: 1) a reach from Pettis Brook and 2) a reach from Town Brook, downstream of the project site. The Town Brook reference reach gave values that were clearly too large. Results from the Pettis Brook reference reach and the Hey-Thorne equations were quite comparable. The design of the riffle was based on these two similar values. The riffle was also designed to both provide the required shear stress at bankfull flow and to convey the bankfull flow.

In natural streams, pools tend to occur at bends or meanders. However, natural stream design principles required more pools on this reach than the number of bends would allow. To maintain the proper pool-to-pool spacing, we designed pools to be built at drop structures (cross vanes) on straight stretches of the stream. Thus, two “pool types” were designed; one occurs at bends and the other occurs at the drop structures on the straight reaches. For this project, these pools were referred to as C and B type pools respectively. This pool type nomenclature refers to the stream type that they are usually found on.

The bankfull slope of the stream was selected based on: 1) providing the necessary shear stress, 2) conveying the bankfull flow, and 3) being in agreement with the stream length and sinuosity.

The width of the floodplain was set by being at least 2.2 times the bankfull width. This is in agreement with the entrenchment ratio for a Rosgen type C stream (*entrenchment ratio* 2.2 or greater).

Finally, the stream profile and plan form were adjusted to achieve an economical balance between cut and fill earthwork quantity. After adjustment for this, all the above-listed stream performance criteria still had to be met, which required further design adjustment.

The most obvious feature of the new stream is the rock vane structures (photos 6.21, 6.22, 6.25, 6.26, 6.28, 6.30, 6.33). These serve 4 purposes:

- Act as grade control structures.
- Create pools.
- Redirect the flow of water.
- Take stress off the channel banks.

There are three types of rock vanes on this project:

- Cross vanes that form a kind of u-shaped structure across the full width of the channel.
- Single vanes that direct the flow water.
- A double vane structure. It can be thought of as two cross vanes stacked up on top of each other. It is based on bedrock vanes found in natural streams. Its primary function is to serve as grade control. The vertical drop through the structure is about 4 feet, and this allows the design slope of 0.013 feet/foot to be maintained.

It should be noted here that almost 9 feet of vertical drop had to be made up in only 1200 lineal feet of project. The rock vanes were instrumental in allowing this to be done. Rocks for the vanes were sized using the bank shear/rock size curve from Rosgen.

There is a single log cross vane structure on the project (photos 6.20, 6.34). It is located at the outlet of a small brook (tributary), just a few feet from the bank of Town Brook. This log cross vane was intended to concentrate flow from the small brook and prevent a delta from being formed where it enters Town Brook.

Other significant design features were:

- A "rock lined riffle" at the culvert outlet, which was lined with medium stone fill to prevent erosion from the high *velocity* water leaving the culvert outlet during large storms (photo 6.18).
- Excelsior matting on the floodplain banks near the culvert outlet.
- Excelsior matting on the top of the channel bank as a temporary erosion control measure until vegetation became established (upper left corner of photo 6.22).
- Live willow stakes at the top of the vane arms. When grown the willows will reinforce the bank at the top of vane arms and help prevent the bank being eroded during major floods.

The following dimensions were used for the reconstruction of this stream (all dimensions refer to the bankfull condition). Keep in mind that all dimensions are based on fluvial geomorphological principles, and reflect the shape and size of natural stable streams in similar settings.

- Riffle Width 17.34'
- Riffle Depth 1.97'
- Riffle Cross-sectional Area 21.44 sf
- Pool Width 16.26' (B Pool) 14.81' (C Pool)
- Pool Depth 3.24' (B Pool) 2.62' (C Pool)
- Pool Cross-sectional Area 28.52sf (B Pool) 24.83sf (C Pool)
- Bankfull Slope 1.3%

A cattle crossing consisting of pre-cast concrete slats was constructed across the new stream in coordination with the Watershed Agricultural Program CREP project (photo 6.30). The cattle crossing was designed in coordination with the stream reconstruction to insure that the crossing did not interfere with the hydraulic properties of the new stream.

This effort was a “first” for both programs, and all participants were pleased with the outcome.

6.7.4. Construction

Generally speaking, construction proceeded smoothly. We did experience three major storms, and one that was smaller but still significant. If not for the inclement weather, the project could have been completed much sooner that it was. The stream was dewatered, then construction began upstream and proceeded downstream. We had to describe to the contractor’s workforce not just *what* to do but *how* and *why* it was to be done. Unless the contractor has experience on stream restoration projects, this is necessary to obtain a good product. After viewing how well the partially-completed project weathered the first flood, the construction crew took a real interest in the project. They asked more questions and checked their own work more diligently.

During construction, we experienced the following problems:

- The rocks delivered by the quarries tended to be too large. The required minimum diameter was 3'. This should be interpreted as a cube 3' on each side, or 27 cubic feet. Rocks often exceeded this volume by 50% or more. One rock even displaced 98 cubic feet. Repeated trips to the quarry helped, but the situation was never completely resolved.

- This portion of Town Brook is a very small stream, with a design riffle width of only 17.34 feet. Working in a stream this small is always difficult. The equipment can be “too large” for the stream, and proper rock placement is more difficult in a small stream. Since so many of the rocks were overly large, the difficulties only increased. In future projects, consideration should be given to using log vanes instead of rock vanes on streams this small.

- Flooding: We experienced four major storms while building this project. The first was estimated to be about a “five-year” storm event. Work had just begun, there was no vegetation started, and the floodplain was raw earth. Fortunately, there was virtually no damage and the floodplain withstood the flood with essentially no damage. This gave us confidence that our design judgments were correct. Two smaller but still significant events followed. Work had to be suspended briefly, and when it resumed the ground was saturated, making earth-work difficult. When the channel and floodplain were about 80% completed, we had a 25- year event (estimated). There was no damage to the floodplain to speak of, as only some seed was washed off. The structures handled it well (photos 6.33-6.36), reaffirming that our design was adequate.

- We installed excelsior matting on the terrace slope near the culvert outlet. We did this to ensure that we had adequate mulching on an area that we judged to be sensitive to flood flows exiting the culvert pipe with high velocity. The matting performed well — it stayed in place on the slopes, and vegetative growth was rapid.

- For similar reasons, we installed excelsior matting at the top of the channel bank on the very edge of the floodplain. During the 25-year event, this material came loose and piled together, usually at the top of vane arms. These resulting balls of excelsior matting prevented flowing water from plunging back down over the vane arm and into the channel, or at higher flow from flowing properly out onto the floodplain. This caused erosion at the very top of the channel bank. This was the only erosion we experienced during the 25-year event.

- Mechanical breakdowns: The contractor used mechanical thumbs on his excavators (to lift and place the rocks). Several times, they broke loose from the boom arm, and had to be welded back on. Naturally, work on the vane arms had to stop while the thumbs were being repaired.

6.7.5. Design Changes

During the construction process, it is important to remain flexible to any design adjustments that appear necessary. We experienced four major storm events, which resulted in three design changes. During these events, water ran down the channel and onto the newly constructed floodplain (remember that the channel had been dewatered for construction purposes). At these times the stream was "operating". When carrying water, the stream provides clues as to how it will operate, and what design features, if any, should be changed or modified.

- Fish passage became a concern at some of the cross-vane structures. NYSDEC recommended pool dimensions of a maximum one-foot jump height, with a two-foot minimum pool depth. At the time this information became available, it was no longer feasible to reconstruct the rock vanes. With DEC cooperation and after further discussion, it was decided to cut notches in the "throat rocks" of the cross vanes where necessary, to lower the jump height to an acceptable limit. At the same time, in an attempt to deepen the pools, we removed some large stones from the bottom of certain pools. If this notching technique works, it will provide a low-cost way to open up stream reaches otherwise closed to spawning or migrating trout. For example, tall bedrock steps on natural streams could be notched, and this would allow the trout to move up the stream.

- During one large storm event the water scoured out a deep pool at cross vane number 7. Construction of this vane had already been completed, but the channel downstream of it was not. The pool formed by this event was deeper than the designed pool. It also permitted fish passage without the need to notch the throat rocks. We surveyed this and all constructed pools (i.e. for cross vanes 8-13), readjusting our design to mimic this "natural" pool.

- The alignment was changed between station 9+50 to 12+00. Bends at 9+75 and 10+50 were eliminated. This was done because:

  - Our experience with the reconstructed stream during the storms showed that the normal pool spacing (5-7 channel widths apart) worked fine.
  - The three bends at the end of the project taken from the 1943 aerial photographs were very tight and were closer than the normal 5-7 channel widths.
  - The stream in the 1943 photos also displayed bends greater than 5-7 channel widths apart, i.e. there was a long straight section between bends.
  - Field observation has shown that on natural stable streams of the type being constructed there is commonly a long straight reach between bends. Usually there is a drop pool on this long straight section. This takes the place of the pools at the bends.
  - The design stream is a “hybrid” Type C/Type B. Therefore, bends further apart than the usual 5-7 channel widths were acceptable. However, the pool-to-pool spacing of 5-7 channel widths should be maintained.
  - The straightened channel reach, while having no bends, would maintain the proper pool spacing by the use of cross vanes.
  - The riffle length between the bends would have been shorter than the designed riffle length. Experience from the three storms indicated that the design riffle length was correct.
  - A grove of apple trees would have been destroyed by constructing the stream in the original design location. This would destroy existing riparian habitat.
  - Overall, it seemed wiser to adjust the stream and eliminate two of the tight bends (bends at 9+75 and 10+50).
  - Subsequent operation of the stream has shown that these adjustments were appropriate.

6.7.6. Project Summation

- The constructed stream is a hybrid TypeB/TypeC.
- The stream is functioning as designed.
- All design modifications are functioning.
- The high, eroded banks that were contributing to sediment load have been eliminated.
- Access to the floodplain has been restored.
- The restored reach withstood a 25-year flood with essentially no damage or instability.
- In regard to fish passage*:*
  - At the flows at which fish passage ordinarily occurs, jump height appears adequate.
  - Fish have already been observed moving upstream
  - Bio-mass and fish monitoring will continue to ensure that steps already taken to insure fish passage are functioning properly.

Figure 6.16 Photo taken during construction showing newly excavated channel and layout for a vane structure.

6.7.7. Lessons Learned

This section is intended to summarize the lessons learned on this project: what went right, what went wrong, and where we can improve.

- Using the 1943 aerial photos to design the alignment worked well. For future projects use should be made of old aerial photos if they are available. Care must be taken to insure that the old alignment was stable.

- Non-technical people have trouble interpreting engineering plans. Therefore at the time that the design is 80-90% complete the design team should walk over the project with the property owner.

- The delivered rock was some times larger than called for by the specification. A new specification and close coordination before construction begins between the design team, the contractor, and the quarry is recommended.

- Coordinating the stream reconstruction, with CREP and the cattle crossing was a success. The two programs are mutually beneficial.

- Rocks of the size required are difficult to work with on a small stream like this. We should seriously consider using log vanes on small streams.

- Full geomorphic project construction contracts should be of 2 year duration. The project would be built in the summer, and then there are 6-9 months of water running in the channel. The stream then has a chance to shape it self and Apolish off the rough spots@. The next summer the contractor comes back and makes any necessary changes or modifications. This second season work would typically not be extensive. It would be reasonable to assume that a vane or two may be repaired or adjusted, and there could be minor repairs to the flood plain (it there has been a major flood before the vegetation establishes).