Watershed Hydrology Protection
and
Flood Mitigation Project
Phase II - Technical Analysis

Stream Geomorphic Assessment

Final Report
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VERMONT WATERSHED HYDROLOGY PROTECTION & FLOOD HAZARD MITIGATION PROJECT

Vermont Watershed Hydrology Protection
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Flood Hazard Mitigation Project
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Executive Summary

This report is the second in a multi-phase project being undertaken by the State of Vermont, Agency of Natural Resources (ANR). Phase I of the project involved conducting a literature search and providing discussion and assessment of the impacts of land use change on stream ecology and how levels of change to a stream's hydrology and morphology affect aquatic ecosystems.

To help quantify the relationships between stream geomorphology and land use activities for Vermont conditions and to provide a technical foundation for possible future guidance governing stormwater management runoff control for growing watersheds, ANR commissioned this study under Phase II, *Technical Analysis* of the project. It is anticipated that Phase III of the project will involve the development of a stormwater management guidance manual for the State of Vermont and Phase IV will involve training and education on the implementation of the guidance.

ANR's goal for this phase of the project was to determine, in Vermont, the type and size of watershed hydrologic and geomorphic impact that could result from various watershed land use activities including, watershed development in the natural floodplain, various levels of urbanization, and logging activities.

This report documents multiple lines of evidence used to assess the above goal. The study methodology incorporated several complimentary components to derive relationships between and among the watershed land use activities and stream system health. The study methodology incorporated the following analyses in descending order of significance:

1. Validation of an empirical approach quantifying the relationship between total basin imperviousness and the enlargement of stream channel cross-sectional area.
2. Computation of current stream channel stability using a rapid geomorphic assessment technique.
3. Comparing previously collected stream channel biological monitoring results with total basin imperviousness and the results of the previous two assessments.
4. Comparing stream channel riparian cover as a percent of total channel length.

A total of 8 subwatersheds were investigated as part of the study. Data were collected in the field at 24 separate stream sampling locations (approximately 3 sampling locations per subwatershed). Land use data were provided by the Vermont Center for Geographic Information (VCGI) at the University of Vermont in combination with aerial photography obtained from the Vermont Mapping Program. Biological monitoring data were provided to the project team by the Vermont Agency of Natural Resources, Biomonitoring and Aquatic Studies Section.

Background on the Scope of the Study:

The first component of the study was to validate the empirical relationship of channel enlargement (as measured by cross-sectional area) as a function of total watershed impervious cover. Past investigations have found that channel enlargement is a function of basin imperviousness as well as the corresponding age of that impervious cover. This relationship can be defined by the function:

$$(\mathrm{Re})_{POST} = \left(\frac{(A_{BFL})_{POST}}{(A_{BFL})_{PRE}} \right)$$

where, Re is defined as the channel enlargement ratio, 'A' represents the cross-sectional area of the stream channel and the subscripts BFL, POST, and PRE refer to the bankfull stage, the post-disturbance condition, and pre-disturbance condition, respectively.

The age of the development is also a critical variable in the amount of channel enlargement. In general, the longer a channel is exposed to the forces causing accelerated channel erosion, the larger the channel cross-sectional area. The effect of the age of development is represented by the concept of a "relaxation period." This is defined as the period of time required for a channel to reach an "equilibrium" state in concert with the level of watershed alteration, where the channel erosion processes are in a relative balance with the watershed forces causing erosion.

The results of past investigations for channel enlargement and channel relaxation show strong correlations with basin imperviousness. The equation derived from past investigations for alluvial type (AL-Type) streams for the ultimate channel enlargement ratio is defined as:

$$(\mathrm{Re})_{ULT} = 0.00135(TIMP)^2 + 0.0167(TIMP) + 1.0$$

$$R^2 = 0.78, (n = 38)$$

where, $(\mathrm{Re})_{\mathrm{ULT}}$ is defined as the channel enlargement ratio once a stream is in equilibrium with its watershed hydrologic parameters, and TIMP is the total basin impervious cover, in percent. Note that the square of the correlation coefficient shows a very strong relationship between basin imperviousness and channel enlargement for the 38 sites investigated.

The hypothesis being tested in this part of the study was to evaluate the cross-sectional area to impervious cover relationship for eight Vermont watersheds and statistically compare the findings with those of previous investigations. If it could be shown that channel enlargement ratios for Vermont streams were drawn from the same population as channel enlargement ratios for non-Vermont streams then the existing relationships could be used to help predict and assess stream morphological impacts associated with different land use modifications.

The second component of the investigation utilized a rapid geomorphic assessment (RGA) technique to define the current stability of stream channels. The technique used a number of visually observed factors to provide a semi-quantitative assessment of a stream's current stability, referred to as the stability index (SI). The primary purpose of the RGA was to corroborate the findings of the more quantitative channel enlargement assessment and to help define past or current modes of channel adjustment (i.e., aggradation, degradation, widening and/or plan form adjustment). The RGA notes whether change in channel form has occurred or is still occurring, however, it does not provide a measure of the rate of change.

The third level of investigation involved the comparison of previously collected biological monitoring data with the corresponding level of impervious cover. The Vermont Agency of Natural Resources, Biomonitoring and Aquatic Studies Section and the Vermont Department of Fish and Wildlife provided the project team with macroinvertebrate and fish biological monitoring data covering a twelve year period (1986-1998). This analysis was intended to support the more quantitative geomorphological investigation of channel enlargement and channel stability and was not intended as a statistical evaluation of Vermont biological monitoring data.

The final element of the study involved comparing stream channel riparian cover length for each of the selected streams to assess whether or not riparian cover length was a factor in overall physical or biological condition. The methodology utilized aerial photography to estimate the extent of forest buffers in each subwatershed. The extent of the buffer was defined as the length of the forest buffer divided by the total stream length.

Methodology

The project team employed a ten step methodology to collect and analyze the data. As stated above, data were collected in eight Vermont subwatersheds. Table E.1 presents the basic project methodology.

Table E.1	**Basic Project Methodology for the State of Vermont - Watershed Hydrology Protection and Flood Hazard Mitigation Project - Phase II, Technical Analysis**
Step 1:	Select a list of potential candidate subwatersheds representing a range of land use activities
Step 2:	Compile historic data on candidate streams (cross-sectional data, biomonitoring, etc)
Step 3:	Select a "short list" of streams with historical cross-sectional data, past biomonitoring data, and desired range of land use activities; conduct field screening of potential sites
Step 4:	Select the final list of eight subwatersheds for field assessment
Step 5:	Produce base mapping of selected stream reaches (land use/land cover mapping to compute total basin impervious cover (TIMP) and identification of stream location)
Step 6:	Conduct field assessment of selected stream reaches (cross-sectional data and rapid geomorphic assessment at 24 cross-section locations -- 3 in each of the eight selected subwatersheds)
Step 7:	Compile and analyze biomonitoring data for selected streams
Step 8:	Conduct riparian buffer assessment of streams within the urbanized subwatersheds
Step 9:	Conduct data analysis to define channel enlargement relationships, channel stability class, and stream bedload analysis
Step 10:	Evaluate correlations between geomorphic parameters, biomonitoring and land use change as measured by TIMP

The first step was to select an initial candidate list of subwatersheds that met a range of land uses, had past biological monitoring data, and likely had historic stream cross-sectional surveys data (for estimating the pre-disturbance bankfull area, $(A_{BFI})_{PRE}$). Next, a data collection effort was conducted to obtain past biomonitoring information, historic cross-sectional information, and current and past land use information. Candidate sites were then field reviewed to eliminate those where possible conflicts existed. The final selection of subwatersheds and streams involved input from the Project Steering Committee and included reference subwatersheds, subwatersheds with a range of urban/suburban development densities, a subwatershed where recent logging activity had occurred, and two subwatersheds where upland development was present. Table E.2 lists the final subwatersheds selected for data collection and assessment.

Table E.2 Final Subwatersheds Selected for Data Collection and Assessment

Stream Name	Town	Dominant land use	Impervious Cover[1]	Approx. Drainage Area (Sq. Mi.)
Cold River	Clarendon	Reference	<1%	20.7
Dowsville Brook	Duxbury	Logging	6%[2]	6.4
Moon/Tenney Brooks	Rutland	Urban	13 and 6% resp.	5.3 and 4.4
Potash Brook	S. Burlington	Urban	22%	7.4
Roaring Brook	Sherburne	Upland dev.	6%[2]	5.4
Smith	Goshen	Reference	<1%	3.2
Stevens Brook	St. Albans	Urban	13%	6.9
W. Branch Little River	Stowe	Upland dev.	2%[2]	24

1 subwatershed impervious cover and drainage area at downstream most sampling location

2 impervious cover estimate includes an "equivalent" impervious value

Subwatershed impervious cover was computed at each of the 24 stream sampling points. Impervious cover was derived using the VCGI's geographic information system and review of aerial photography. An "equivalent" impervious cover value was estimated for those land uses where the hydrologic alteration was not attributed to impervious cover (e.g, logging activities). In these cases, a runoff coefficient approach, based on Natural Resource Conservation Service Methods (NRCS), was used to derive the equivalent impervious value.

Stream geomorphic data were collected in the field at 24 cross-section locations. The types of data collected at each station included, longitudinal channel slope, cross-sectional area, various measurements for channel depth and width, semi-quantitative assessments of channel stability using the RGA approach, stream substrate pebble data, and stream bank soil data. Stream data were analyzed using a series of spreadsheet models to calculate bankfull flowrate (Q_{BFL}), current cross-sectional area at bankfull stage, and Manning's roughness coefficient. Next, historical information of channel geometry (from older bridge construction plans, for example) and historical impervious cover estimates (from past aerial photography) were used to estimate the bankfull cross-sectional area for the historic channel [$(A_{BFL})_{PRE}$]. The resulting ratio of current cross-sectional area to historic cross-sectional area (Re_i) was used to calculate an ultimate channel enlargement ratio (Re_{ULT}). These data were then compared to channel enlargement data from non-Vermont streams using statistical tests. The RGA data were used to compute the stability index for each stream.

Biological monitoring data for macroinvertebrate and fish were assembled and evaluated as a function of subwatershed imperviousness. Biomonitoring data were presented for each stream and each sampling period. Only the overall biological "Community Assessments" for macroinvertebrates and fish are presented.

Summary of Results:

Channel Enlargement Assessment

Table E.3 lists a summary of the resulting data from the channel enlargement assessment for nine Vermont streams (note, Moon Brook and Tenney Brook are within the same subwatershed). The "observed" values were compared to "predicted" values derived from the non-Vermont Enlargement Curve to determine if they were drawn from the same population. Statistical tests for variance and mean were performed for these data and found to be statistically significant at the 95% confidence level.

Table E.3 Summary of Channel Enlargement Assessment

Basin	Site	Historic Channel Survey Data				Current Channel Survey Data				$[(Re)_{ULT}]_{OBS}$	$(A_{BFL})_{PRE}$
		A_{BFL} (ft^2)	t_i (yrs)	TIMP (%)	$(Re)_i$	A_{BFL} (ft^2)	t_i (yrs)	TIMP (%)	$(Re)_i$		(ft^2)
Cold	CLD4	Reference Stream				201.2	46.7	2.0		Reference Stream	
	CLD5	Reference Stream				52.2	80.5	1.0		Reference Stream	
Cold (Gould)	GLD6	Reference Stream				110.3	80.5	1.0		Reference Stream	
Dowsville	DOW1	Reference Stream				13.5	46.7	5.8		Reference Stream	
	DOW2	60.5	19.5	1.0	1.00	105.5	23.4	5.8	1.04	1.91	60.5
	DOW3	55.2	19.5	1.0	1.00	51.1	23.4	5.8	1.04	1.01	55.2
Moon	MOO1	33.8	19.1	9.3	1.07	41.3	53.7	13.0	1.35	1.39	31.7
	MOO2	51.3	19.8	7.7	1.05	37.4	49.7	13.0	1.32	0.84	48.7
Tenney	TEN1	39.9	4.3	1.0	1.00	57.7	49.6	6.0	1.11	1.50	39.9
Potash	POT1	47.1	14.1	14.4	1.08	75.6	41.5	22.0	1.61	2.18	43.5
	POT2	48.5	14.1	14.4	1.08	63.6	41.5	22.0	1.61	1.78	44.8
	POT3	40.2	13.1	10.6	1.10	59.9	42.7	20.0	1.81	1.76	36.4
Roaring	ROA1	106.9	25.0	1.5	1.01	124.2	30.6	6.0	1.17	1.29	105.9
	ROA2	103.4	25.0	1.5	1.01	165.2	28.0	7.0	1.07	1.78	102.4
	RBT1	Reference Stream				28.6	46.7	2.0		Reference Stream	
Smith	SMI1	Reference Stream				53.6	80.5	1.0		Reference Stream	
	SMI2	Reference Stream				53.6	80.5	1.0		Reference Stream	
	SMI3	Reference Stream				51.9	80.5	1.0		Reference Stream	
Stevens	STB7	26.8	41.7	8.8	1.15	35.6	48.9	11.0	1.24	1.65	23.3
	STB8	28.6	40.2	8.3	1.13	30.4	48.9	11.0	1.24	1.30	25.3
	STB9	72.7	33.1	12.0	1.18	60.3	52.8	13.0	1.34	1.05	61.5
West Branch	WBL1	303.8	32.0	2.0	1.02	379.0	55.0	2.0	1.03	1.28	299.2
	WBL2	336.5	32.0	2.0	1.02	433.0	55.0	2.0	1.03	1.32	331.4
	WBL3	227.3	43.3	3.0	1.00	216.4	55.0	3.0	1.02	0.99	226.9

A_{BFL}= Bankfull channel cross-sectional area; t_I= area weighted average age of disturbance;
TIMP = Total Basin Imperviousness; $(Re)_i$ = Enlargement Ratio at time t_I(i.e., current cross-section);
$[(Re)_{ULT}]_{OBS}$ = Ultimate channel Enlargement Ratio, based on observed survey data;
$(A_{BFL})_{PRE}$ = Pre-disturbance channel bankfull channel cross-sectional area

The original channel enlargement curve for alluvial type streams was revised by integrating the Vermont data into the original database and undertaking a curve fitting process. The following second order polynomial provided the best fit for the data:

Revised Equation for Channel Enlargement Incorporating Vermont Data

$$(\mathrm{Re})_{ULT} = 0.0013(TIMP)^2 + 0.0168(TIMP) + 1.0$$
$$(R^2 = 0.83, n = 52)$$

Channel Stability Assessment

Results of the channel stability assessment are presented in Table E.4. The RGA process was originally developed for application in older urban watersheds that had been under riparian vegetation management programs and, consequently, largely denuded of wooded species. As such, metrics indicative of early geomorphic alteration were not incorporated into the original RGA Protocol. In consideration of the above, a modified RGA protocol was developed for Vermont to include the additional parameters: the number of Large Organic Debris pieces (NLOD) observed within the channel and riparian zone, the number of debris jams (NJAMS) and the number of complete riffle lines (NRIFF). The results are contained within the modified RGA data presented in Table E.4.

Table E.4 Summary of Channel Stability Assessment Using the Modified Rapid Geomorphic Assessment Form

Basin	Site	RGA FACTOR				Stability Index(1)	Stability Class	Channel Type
		AI	DI	WI	PI	(SI)		
Cold	CLD4	0.14	0.20	0.14	0.13	0.15	Stable	AL(Ar)
	CLD5	0.14	0.00	0.00	0.38	0.13	Stable	AL(Ar)
Cold (Gould)	GLD6	0.14	0.20	0.29	0.13	0.19	Stable	AL(Ar)
Dowsville	DOW1	0.67	0.00	0.43	0.13	0.31	Transitional	AL(Ar)
	DOW2	0.14	0.00	0.71	0.38	0.31	Transitional	AL(Ar)
	DOW3	n/a	n/a	n/a	n/a	n/a	n/a	AL(Ar)
Moon	MOO1	0.67	0.40	0.88	0.63	0.64	In Adjustment	AL
	MOO2	0.71	0.00	0.86	0.63	0.55	In Adjustment	AL
Tenney	TEN1	0.33	0.17	0.63	0.63	0.44	In Adjustment	AL
Potash	POT1	0.57	0.20	0.86	0.50	0.53	In Adjustment	AL(Ar)
	POT2	0.33	0.60	0.83	0.43	0.55	In Adjustment	AL(Ar)
	POT3	0.60	0.00	1.00	0.60	0.55	In Adjustment	RB
Roaring	ROA1	0.20	0.00	0.83	0.17	0.30	Transitional	RB(Ar)
	ROA2	0.33	0.17	0.57	0.20	0.31	Transitional	AL(Ar)
	RBT1	0.14	0.00	0.71	0.33	0.30	Transitional	AL(Ar)
Smith	SMI1	0.17	0.20	0.29	0.00	0.16	Stable	AL(Ar)
	SMI2	0.00	0.00	0.38	0.00	0.09	Stable	AL(Ar)
	SMI3	0.00	0.20	0.33	0.00	0.13	Stable	AL(Ar)
Stevens	STB7	0.57	0.90	0.70	0.43	0.65	In Adjustment	AL(Ar)
	STB8	0.57	0.17	0.25	0.29	0.32	Transitional	AL
	STB9	0.14	0.17	0.50	0.29	0.27	Transitional	AL(Ar)
West Branch	WBL1	0.71	0.80	0.56	0.75	0.70	In Adjustment	AL
	WBL2	0.43	0.88	0.56	0.75	0.65	In Adjustment	AL
	WBL3	0.43	0.80	0.83	0.88	0.53	In Adjustment	AL(Ar)

(1) SI = Modified Stability Index for Vermont Conditions
AI = Aggradation Factor; DI = Degradation Factor;
WI = Widening Factor; PI = Planimetric Adjustment Factor;
n/a = not available; AL = Alluvial; Ar = Armored; RB = Rock Bed with alluvial banks;

The RGA protocol was applied to 23 sites surveyed in this study, with the exception of Site DOW3, A simple linear correlation analysis was undertaken relating the Stability Index to Total Basin Imperviousness (TIMP) for 20 of the 23 sites (W. Branch of Little River was excluded from the analysis because of past gravel mining operations) as follows:

$$\boldsymbol{SI} = 0.158(\boldsymbol{TIMP})^{0.413}, \boldsymbol{R} = 0.75, \boldsymbol{n} = 20$$

The above relation was found to be statistically significant at the 95% confidence level for variance and mean.

Biological Monitoring Analysis

Table E.5 lists a generalized assessment of the biological monitoring data for the nine Vermont streams evaluated in this. The results suggest that these Vermont streams can be related to their contributing impervious cover and fall into one of two categories. The generally "good" streams, from a biological community assessment perspective, fall into an impervious cover range of 6% and less. The "poor" streams have impervious cover of 12% or greater.

Table E.5 Comparison of Biological Monitoring to Subwatershed Imperviousness

Stream Name	Subwatershed Current Impervious Cover (%)	Macro-invertebrate Bio-monitoring - Overall Community Assessment*	Fish Bio-monitoring - Overall Community Assessment*
Roaring Brook	6	Fair	Excellent
Stevens Brook	13	Poor	Poor - Fair
Dowsville Brook	6	Good - Excellent	Good
Potash Brook	22	Poor - Fair	Fair - Good
Tenney Brook	6	Fair - Good	Good - Excellent
Moon Brook	13	Poor	Fair
Smith Brook	<1	Excellent	-
Cold River	<1	Good	-
West Branch Little River	2	Good - Fair	Good

* represents an average of all biomonitoring presented in Table 4.1

Riparian Cover Analysis

The results of the riparian cover analysis are presented in Table E.6. Forest buffers were identified based on aerial photography for each watershed A simple methodology was used to estimate the extent of forest buffers in each subwatershed. The extent of the buffer was defined as the length of the forest buffer divided by the total stream length. The criteria used to determine the length of stream and buffer were:

- The stream length represents the total length of *perennial* streams based on USGS quad sheets.
- A forest buffer is defined as at least a 50' width of forest cover along the stream, with at least 20' of forest cover on each side of the stream.

Based on methodology performed, the results presented in Table E.6 yield no conclusive results to suggest that the extent of riparian cover has an undue influence on biological or physical stream quality. It should be noted that the assessment was conducted for only those streams with measurable development within a fairly modest range of impervious cover (~6 to 22%).

Table E.6 Forest Buffer Length as a Fraction of Total Stream Length

Stream	Section	Buffer Fraction
Moon Brook	Lower	30%
	Upper	35%
Tenney Brook	--	55%
Stevens Brook	Lower	35%
	Upper	20%
Potash Brook	Lower	20%
	Middle	20%
	Upper	25%

A forest buffer is defined as at least a 50' width of forest cover along the stream, with at least 20' of forest cover on each side of the stream.

Conclusions:

The methodology and data analyses support a suite of conclusions on the findings of this study. The project team identified the following six major conclusions as a result of our work on the geomorphological, and biological assessments:

1. The key hypothesis of this study was to test whether stream geomorphological assessment techniques, that had been developed and tested in regions outside of Vermont, were valid for Vermont conditions. Specifically, two assessment techniques were evaluated: the Rapid Geomorphic Assessment technique that defines stream stability via a stability index value (SI) and the relationship of channel enlargement ratio [$(Re)_{ULT}$] to total basin imperviousness. The study results confirmed that both of these techniques could be applied with statistical significance to Vermont conditions.

An Enlargement Ratio equation and curve developed using stream geomorphological data from outside of Vermont was tested for inclusion with data from the Vermont streams investigated in this study and found to be statistically valid for the total population of data-points. This conclusion supports that there is now a statistically valid tool for Vermont conditions to help predict channel enlargement as a function of watershed imperviousness.

2. The channel enlargement ratio [$(Re)_{ULT}$] for the nine Vermont streams was found to be somewhat related to total basin imperviousness ($R^2 = 0.34$). The overall channel enlargement equation and curve present a strong correlation between enlargement ratio and total basin imperviousness ($R^2= 0.83$).

3. The channel stability index (SI) conducted using the Rapid Geomorphic Assessment technique for the nine Vermont streams was also found to be strongly related to total basin imperviousness ($R^2 = 0.78$). The slightly lower correlation coefficient is not surprising given the qualitative nature of the data collection protocol for SI versus the more quantitative nature for $(Re)_{ULT}$ data collection and analysis.

4. The concept of "equivalent impervious cover," where land uses that alter the hydrologic characteristics of watershed cover without creating impervious cover (e.g., logging and upland development land uses) are equated to an equivalent amount of imperviousness, was found to be a meaningful measure. The resulting channel enlargement and stability index in subwatersheds where this method was employed did not deviate significantly from those subwatersheds where conventional imperviousness was the indicator of hydrologic change.

5. The assessment of biological community health, relying on Vermont biomonitoring data, showed a general relationship of decreasing biological community health with increasing watershed impervious cover. However, since no statistical tests were conducted, the strength of this conclusion should be weighed against the more rigorous statistical tests that were performed for channel enlargement and channel stability class.

6. The methodology used to perform the analysis of the possible benefits of riparian cover on stream biological or physical quality yielded inconclusive results. The possible benefits associated with adjacent wetlands, the level of detail associated with this portion of the study, and/or the comparison between streams with only a modest difference in impervious could have impacted the study findings.

SECTION 1

BACKGROUND

SECTION 1: BACKGROUND

1.1: STUDY PURPOSE AND BACKGROUND

This is the second in a multi-phase project that is being undertaken by the State of Vermont, Agency of Natural Resources (ANR). The Agency is seeking to assess relationships between flood occurrence and stream resource degradation associated with various land use alteration activities. Phase I of the project involved conducting a literature search and providing discussion and assessment of the impacts of land use change on stream ecology and how levels of change to a stream's hydrology and morphology affect aquatic ecosystems (see Stone Environmental, 1998).

Several other investigators have documented adverse impacts to stream health as a function of increasing land cover alteration (such as urbanization). While the findings of many of these investigations are conclusive, including those presented by Stone Environmental (1998), nearly all work has been conducted outside Vermont, and nearly all outside of New England (see Schueler, 1994).

To help quantify these relationships for Vermont conditions and to provide a technical foundation for possible future guidance governing stormwater management runoff control for growing watersheds, ANR commissioned this study under Phase II, *Technical Analysis* of the project. It is anticipated that Phase III of the project will involve the development of a stormwater management guidance manual for the State of Vermont and Phase IV will involve training and education on the implementation of the guidance.

The ANR developed a list of watershed activities that it believed should be evaluated by this *Technical Analysis*. ANR's stated goal for this phase of the project was to "determine, in Vermont, the type and magnitude of watershed hydrologic and geomorphic reaction, and alterations in sediment distribution, water quality, and the integrity of aquatic ecosystem - that could result from the following activities:"

- Watershed development in the natural flood and migration paths of streams
- Urbanization
    - < Development patterns and cumulative growth in all areas of 1st, 2nd, and 3rd order watersheds as it relates to flood peaks and stream morphology.
    - < Riparian stream corridor changes.
    - < Land clearing and urbanization taking place in upland areas.
    - < Urbanized areas in the lowlands and middle elevations that have multiple storm water discharges, increased impervious areas, and changes in pervious surface from compaction and grading.
    - < Road building and maintenance.
    - < Channelization including alterations in stream gradient
- Forestry Practices - clear and selective cutting

The following project report documents the multiple lines of evidence used to assess the above stated goals. While not every physical, chemical, or biological impact associated with every activity listed above is quantified, the study methodology incorporates several complimentary components to derive relationships between and among many of the listed watershed activities and stream system health. The study methodology incorporates the following analyses in descending order of significance to help quantify the above relationships:

1. Validation of an empirical approach quantifying the relationship between total basin imperviousness and the enlargement of stream channel cross-sectional area.
2. Computation of current stream channel stability using a rapid geomorphic assessment technique.
3. Comparing previously collected stream channel biological monitoring results with total basin imperviousness and the results of the previous two assessments.
4. Comparing stream channel riparian cover as a percent of total channel length for those streams within urbanized subwatersheds.

1.1.1 Study Objectives

The overall objective of this study is to help quantify the relationships between watershed land use change and the alteration of channel morphology and aquatic ecology in Vermont streams. The principle component of the study design (item 1, above) is based on validation of an empirical approach relating land use change as measured by Total Basin Imperviousness (TIMP) with the enlargement of the cross-sectional area of the "active channel"[1]. The empirical approach expresses channel enlargement as a function of boundary material resistance, the degree of alteration of the sediment-flow regime, and the elapsed time from the occurrence of a disturbance within the watershed and the time required to achieve a new stable channel form. In cases where watershed impervious cover is low and not the principle component of altered land cover, a surrogate value equivalent to TIMP is used.

A secondary objective is to utilize a rapid geomorphic assessment (RGA) technique to quantify current stream channel stability as a function of TIMP. This assessment is intended to support the investigations of channel enlargement relationships to TIMP, as discussed above. Next, data from prior biological monitoring (collected from ANR's Biomonitoring Unit) is used to assess if relationships between total basin impervious cover and biological community health can be correlated with either channel enlargement or channel stability. Finally, the influence of riparian buffer length as a percentage of total channel length is estimated to assess if this watershed factor influences the results of the channel enlargement, channel stability, or biological assessments.

The channel enlargement relationships were developed using case studies on streams representing a variety of physiographic and climatic regions across the United States and Canada. Validation of these empirical relationships to Vermont conditions have the ability to provide decision makers with a useful tool for the assessment and mitigation of morphological impacts associated with land use change.

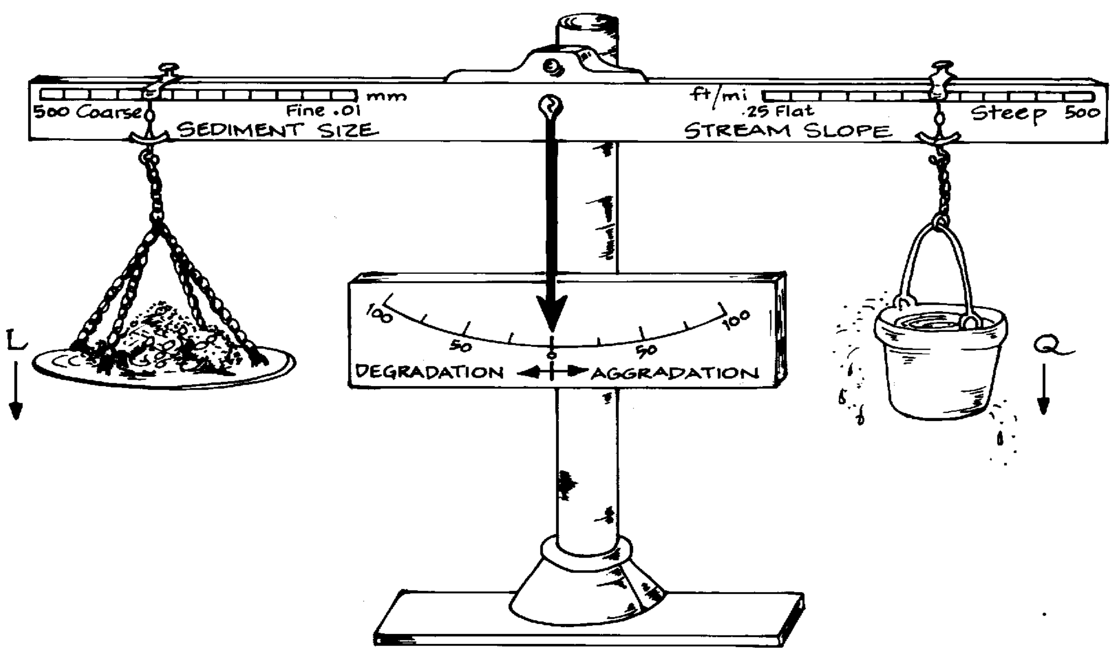
1.1.2 Background on the Channel Enlargement Assessment Methodology

1 The “active” channel is defined as that conduit conveying flows during dry weather periods and frequent flood flow events.

One possible stable state of a stream channel in erodible materials is one in which the dimensions of the channel forms a balance between the forces tending to erode the channel boundary materials and the resistance of these materials such that the channel is just able to move its sediment load (Leopold et al., 1964). Lane (1955) illustrated this balance using the following proportionality,

$$QS \propto Q_s \phi_i$$

in which Q represents the flow rate, S is the longitudinal channel slope, Q_S is the sediment influx and φ_i is the particle size for which i^{th} percent of the material is finer by mass. This proportionality is illustrated using a balance as shown in Figure 1.1.



Sediment Load x Sediment Size % Stream Slope x Stream Discharge

Figure 1.1: Sediment Load & Size Balanced against Stream Flowrate and Slope
(Source: adapted from Lane, 1955)

A stream is in "equilibrium" or a "stable"[2] state when the proportionality between stream flow rate (Q) and slope (S) are in balance with instream sediment load (Q_S) and particle size (φ_i). For example, when flow rate is increased disproportionately to other variables, the bucket representing flow rate and volume becomes heavier and tips the right-hand arm of the scale down causing the indicator to swing to "degradation" (downcutting of the channel bed). The right-hand-side of the proportionality represents stream power (the product of QS). As stream power increases the streams ability to do work increases. If the bed of the channel is worn into erodible materials then this increase in stream power may result in erosion of the bed materials and enhance channel downcutting.

On the left-hand-side of Lane's (1955) relation, an increase in sediment load (Q_S) or the size of the sediment particles (as represented by φ_i) that is disproportionate to the QS may result in "aggradation" (buildup of sediments on the bed). The impact of an increase in φ_i is related to stream competence. This is defined as the size of the largest particle the stream can move at a specified flow rate (e.g. the bankfull flow). That portion of the sediment delivered to the channel that exceeds stream competence will build-up within the channel. The impact of Q_S is related to the capacity of the stream. This is defined as the total mass of sediment the stream can move over a defined time period. Even where a stream may have the competence to move the sediment supply, if the mass of sediment entering the channel exceeds a stream's capacity to move it, the sediments will accumulate within the channel. This aggradation process typically leads to the over development of bar forms, infilling of pools, a loss of channel flow conveyance capacity, increased nuisance flooding, bank erosion, and adjustment of the planimetric form of the channel.

The balance shown in Figure 1.1 is dynamic. The "indicator" in Figure 1.1 swings back and forth between aggradation and degradation in response to variations in the sediment and flow inputs to the channel associated with normal climatic variation. Channel systems, such as those found in Vermont, typically possess a natural ability to absorb these variations within certain limits before a fundamental alteration in channel form may occur. These limits are referred to as thresholds. The terms "dynamic equilibrium" and "metastable equilibrium" have been coined to address adjustments in channel form associated with variations in the "natural"[3] system. A system that is in "metastable equilibrium" is defined as one in which:

a) the influx of sediment into the subject reach is equal to the mass of sediment leaving the reach (the system is in mass balance); and,
b) the average dimensions of the channel as represented by hydraulic geometry and plan form parameters are stationary through time.

The last condition does not mean that the channel form is fixed in space. The channel is free to

2 The term "stable" in Lane's (1955) balance refers to a one-dimensional mass balance wherein the influx of sediment to a specified reach is equal to the sediment output. This definition of stability may be best visualized by considering a mobile bed channel with ridge banks. If neither degradation (channel downcutting of the bed) or aggradation (the accumulation of sediment on the bed) is occurring in the reach than the channel is "stable".
3 "Natural" in this discussion refers to a channel system whose morphology is primarily determined by non-anthropogenic factors.

move through space (e.g. meander propagation) as long as the average dimension of its hydraulic geometry and plan form parameters fluctuate about a mean value that remains constant through time. An illustration of a system in "metastable equilibrium" compared with other channel cross sectional area variations is illustrated in Figure 1.2.

Vagaries in rainfall amounts and patterns can result in a disturbance to the factors controlling channel form. These disturbances may either result in temporary or long term morphological adjustment to channel form. The channel may respond to temporary disturbances that exceed thresholds for channel stability by departing from its "stable" form and either returning to its pre-disturbance state following cessation of the disturbance (as in the metastable equilibrium condition illustrated in Figure 1.2), or evolving toward a new equilibrium position. Long term variations in the driving mechanisms triggered by a progressive increase or decrease in climatic factors may result in long term adjustment to the fluvial system as in the trend with time condition illustrated in Figure 1.2. The modified system differs from the trend through time response in the degree and rate of change. However, both types of change can lead to dramatically different channel forms.

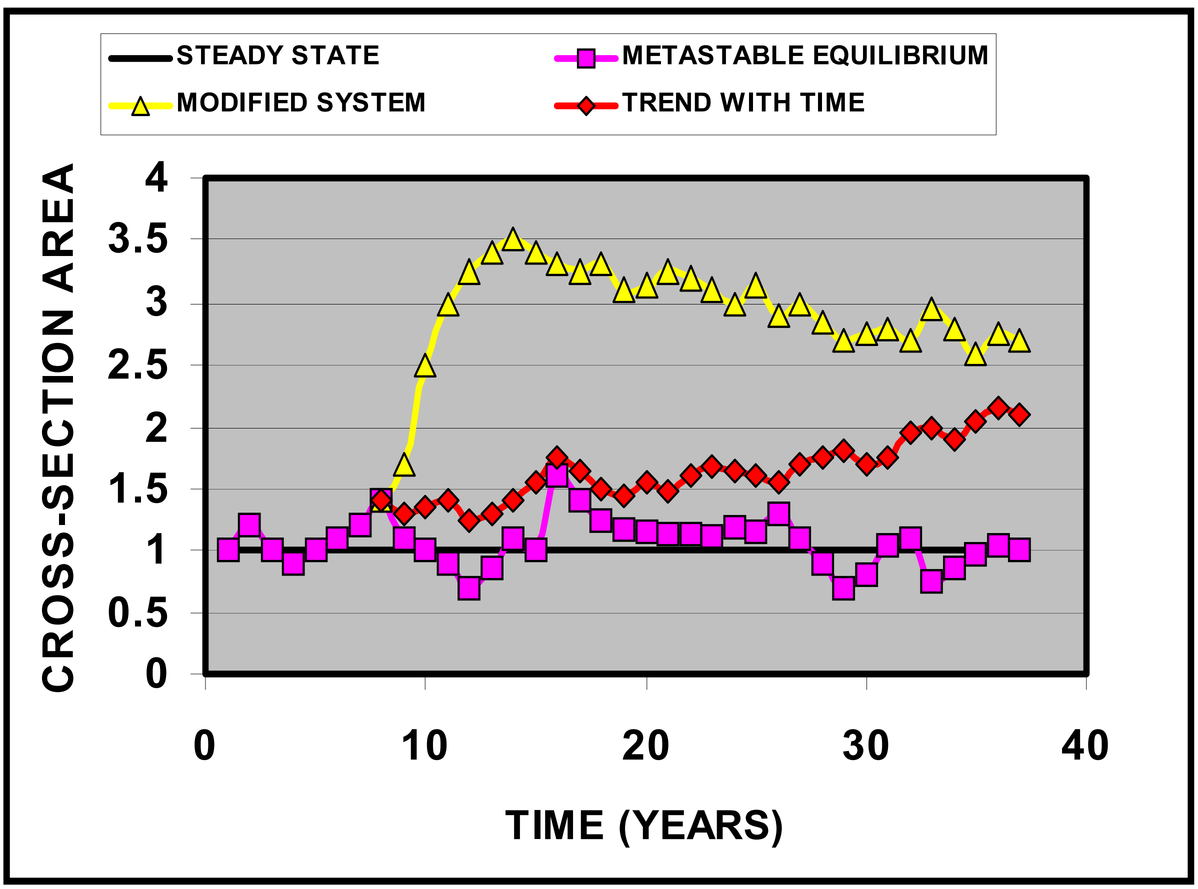


Figure 1.2: Conceptual Illustration of Various States of Equilibrium for Channel Cross Sectional Area Variation as a Function of Time

The modified response is typical of morphological impacts associated with a catastrophic event or a rapid alteration of the sediment-flow regime caused by forest fires, flow diversion-regulation or other land use alterations. Unlike catastrophic events, that represent short duration high energy episodes, land use impacts through development can lead to small incremental increases in flow energy but with a high frequency of occurrence over a long duration. The thresholds governing channel response to short term (catastrophic) versus long term (urbanization) disturbances may be entirely different. For example, many grasses can withstand flow velocities of 6 fps before their soil binding strength is exceeded. Consequently, they may provide a high level of protection against the erosive power of a rare flood flow event. However, a long term alteration in the flow regime may result in an increase in the frequency of occurrence of flow events that inundate the bank toe. This increase in bank toe inundation may in turn increase the "winnowing"[4] of fine soil materials within the bank despite the root binding provided by the grasses. The slow but progressive winnowing of these materials may eventually expose the roots resulting in plant mortality. The loss of root binding due to plant die off exposes the bank soils to the erosive action of the sediment-flow mixture carried by the stream. A gradual undermining of the bank may lead to bank collapse and ultimately cause adjustment of the channel form.

To summarize the discussion to this point, it has been noted that Lane's (1955) proportionality illustrates that there is a balance between a streams ability to perform work and the sediment load it carries. Secondly, this balance is not static but fluctuates between aggrading and degrading conditions in response to the normal randomness of the hydrologic system. This randomness may represent disturbances to the factors controlling channel form. Lane's (1955) balance does not explicitly include threshold parameters which implies that channel response is directly proportionate to the magnitude of the disturbance. While the concept of thresholds in geomorphology is well established, Lane's relation is consistent with the argument that different thresholds may apply to "short term" versus "long term" disturbances. Over the "long term" these thresholds may be relatively small implying that stream channels are more sensitive to a disturbance than previously thought.

Lane's (1955) proportionality provides a one dimensional qualitative prediction of the direction of change in channel form. The qualitative nature of the relation arises from our understanding of channel systems and their likely behavior under varying conditions. The one-dimensional approach is an attempt to illustrate in a simple manner a three-dimensional system that consists of complex, inter-related fluvial features covering a continuum of spatial scales. These complex features respond to the cumulative distribution of flow-sediment inputs that act on heterogeneous boundary materials and are modified by complex distributions of biotic forms (riparian vegetation and large organic debris), boulders and other elements contributing to perturbations within the flow field. The result is a system that defies characterization by current quantitative methods.

To better deal with the complex array of fluvial features Lewin (1979) divided them into three distinct categories based on temporal and spatial scales. These categories are:

4 "Winnowing" refers to the selective removal of fine particles by flowing water.

A. Macroforms – These forms include features at the scale of the flood plain width such as longitudinal channel slope, meander radius of curvature, pool-riffle spacing, sinuosity, and meander amplitude and wavelength.

B. Mesoforms – these forms include features at the scale of the width of the active channel. These features include bankfull parameters (channel width, depth and cross-sectional area) and bar forms such as point, medial, and diagonal bars.

C. Microforms – these forms include features measured at the scale of eddies in the flow field. These features include the spatial distribution of bar form sediments (transverse, longitudinal and vertical axis) and sediment structures such as imbricated sediment forms.

Imhof et al., (1997) in a compilation of other studies noted that the response time required for a feature to adjust to a new equilibrium position or return to its former position is proportional to the spatial scale of the feature. Macroforms require hundreds of years to adjust to a disturbance (10^2-10^3 years), while mesoforms require tens of years (10^1-10^2 years), and microforms may adjust on the time frame of a single flow event or series of events (10^{-3}-10^0 years).

Andrews (1979) observed that channel response to a disturbance can be described using three phases.

Phase 1: Thalweg realignment and modification of particle roughness due to destruction or reworking of microform features;

Phase 2: Adjustment of mesoform features (e.g. channel hydraulic geometry as represented by bankfull metrics: width, depth and cross-sectional area); and,

Phase 3: Macroform feature adjustment (longitudinal profile and plan form features (e.g. meander wavelength, amplitude, etc.).

In this model, microform features are characterized as the most sensitive and first to be altered followed by mesoforms and macroforms in that order. Consequently, the sensitivity of a channel to a disturbance is dependent upon the spatial scale of the feature of interest. It should be noted however, that all features regardless of scales and all phases of the adjustment process are inter-related. Completion of the adjustment process occurs when the balance between the micro and macroform features has been re-established. While macroform adjustment is preceded by mesoform and microform adjustment the reverse is not necessarily true. In other words, microform adjustment, while a prerequisite for mesoform adjustment, does not necessarily mean that mesoform adjustment will occur if microforms are altered.

The temporal and spatial scale of fluvial features presents geomorphologists with problems of observation, measurement and interpretation of the fluvial processes operating on the system. Microforms, because of their sensitivity can be destroyed and reconstructed during a single flow event. They may also undergo progressive alteration during a series of flow events only to be completely reworked during a subsequent event. Superimposed on these responses are site specific influences such as eddies created about a fallen tree, or debris from a failed bank or a large boulder. Microforms are also influenced by upstream and downstream changes in mesoforms and macroforms, such as the passage of a sediment wave or the upstream propagation of a knick point. Given the spatial diversity and temporal scale of change in form, it is difficult to collect data characterizing microform features. Further, microform alteration does not necessarily mean that mesoform and macroform adjustment will occur in all stream types. Consequently, it is difficult to predict channel form adjustment from microform alteration. Given these challenges, microform data have not traditionally been used as an indicator of channel adjustment.

Macroform features represent the other end of the spatial and temporal spectrum. Despite advances in methods of observation, such as large scale photogrammetry, the temporal scale of macroform adjustment presents a unique challenge. The time frame for measurement of change is in hundreds of years and detailed observations of channel form spanning these periods is not generally available. Further, the long adjustment period means that a disturbance that occurred in the past, such as deforestation for agricultural land use, may still be affecting channel planimetric form today. Consequently, the impact of more recent land use disturbances may be superimposed on geomorphic changes related to historic land use alteration. This overlap in the morphological response to a disturbance complicates the interpretation of macroform features. Finally, the response of macroforms to a specific land use alteration may not be observed until mesoforms have completed a significant portion of their adjustment. This means that macroforms may have lag times of tens to hundreds of years before morphological changes to macroform parameters are observed. Given these challenges, macroform parameters are also not typically employed as indicators of channel adjustment.

Mesoforms represent the middle of the spatial and temporal scale for fluvial features. These forms are well suited to standard survey techniques and the temporal scale of adjustment is also more manageable. Further, fluvial features at all spatial scales are inter-related, however, both microforms and macroform parameters are primarily determined by mesoform adjustment. Given the significance of mesoforms and the associated practicalities in observation and response time, it is reasonable that mesoform features should be used to measure and predict channel adjustment to a large scale, long term disturbance in the factors controlling channel form.

To summarize the above discussions it was noted that Lane's (1955) proportionality is a qualitative, one-dimensional method for the determination of channel response to a disturbance. However, stream channels are complex, three-dimensional systems represented by inter-related features covering a continuum of spatial and temporal scales. To aid our understanding of these complex systems Lewin, (1979) divided this continuum into three distinct groups based on their temporal and spatial scales: macroforms, mesoforms and microforms. Andrews (1979) proposed a three phase model to explain channel response to a disturbance that was consistent with these spatial and temporal scales. It was determined that channel sensitivity to a disturbance is scale dependent with microform features being the most sensitive and responding to a disturbance prior to mesoform and macroform features in that order. However, mesoforms parameters may be the primary determinant of microform and macroform characteristics. This consideration, and practicalities of observation and measurement, means that mesoforms are the best suited features for use in the determination and prediction of channel adjustment to a large-scale, "long term" disturbance in the factors controlling channel form. This means that Lane's (1955) proportionality applies to bankfull flow conditions.

Given that the mesoform features are best suited for the measurement and prediction of channel response to a disturbance, the next step is the definition of the factors affecting mesoform characteristics and dimensions. Schumm (1977) noted that the majority of the sediment (Q_S) and flow (Q) carried by the channel system originates within the "Production Zone" (see Figure 1.3). This Zone represents those areas that are outside of the flood plain valley as defined by the meander belt width of the active stream channel. The mass of sediment-water generated within the "Production Zone" is temporarily stored in or transported through the "Transfer Zone". The "Transfer Zone" represents the flood plain and active channel system within the meander belt width of an active channel. The sediments transported through the "Transfer Zone" are deposited in the ultimate receiver referred to as the "Deposition Zone." Note, Figure 1.3 is applicable to a wide variety of scales wherein the Production Zone could be a single catchment or as large as a watershed draining a third order tributary.

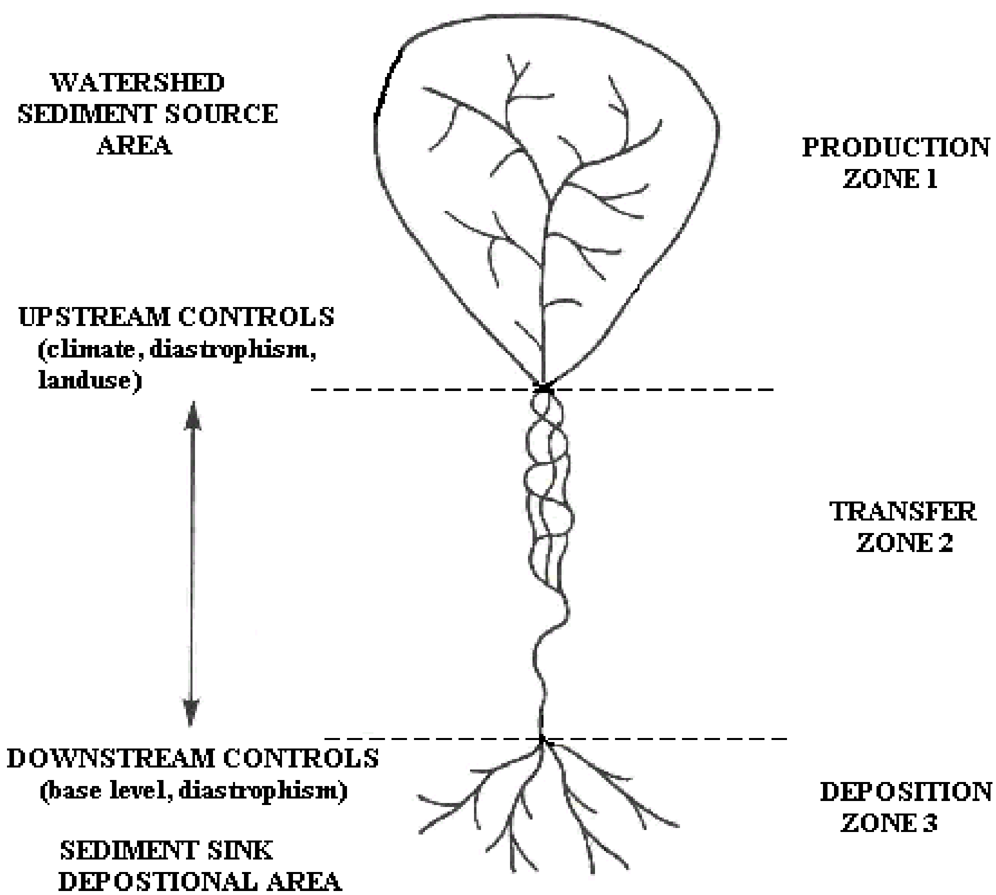


Figure 1.3: Illustration of Three Watershed Zones Showing Sediment -- Source, Transportation, and Deposition Areas

The delicate balance described by Lane (1955) is influenced by a number of watershed and instream factors as illustrated in Figure 1.4 (MacRae, 1991). Basin climate and geology, the only truly independent variables, define the hydrologic and sediment regime characteristics within the "Production Zone" and the valley slope within the "Transfer Zone". The sediment-flow regime within the "Production Zone" represent the factors that control and modify the cross-sectional area (Area) of the active channel. The controlling and modifying factors may be reversed during periods when a sediment influx exceeds stream competence or capacity. This may occur during the active construction phase of urbanization or logging. The shape of the channel, as measured by its width to depth ratio and general cross-section configuration is controlled by the boundary material characteristics as modified by riparian vegetation. The exception to this generality is for channel systems having bank heights of less than 2.5 feet wherein riparian vegetation may become the controlling factor.

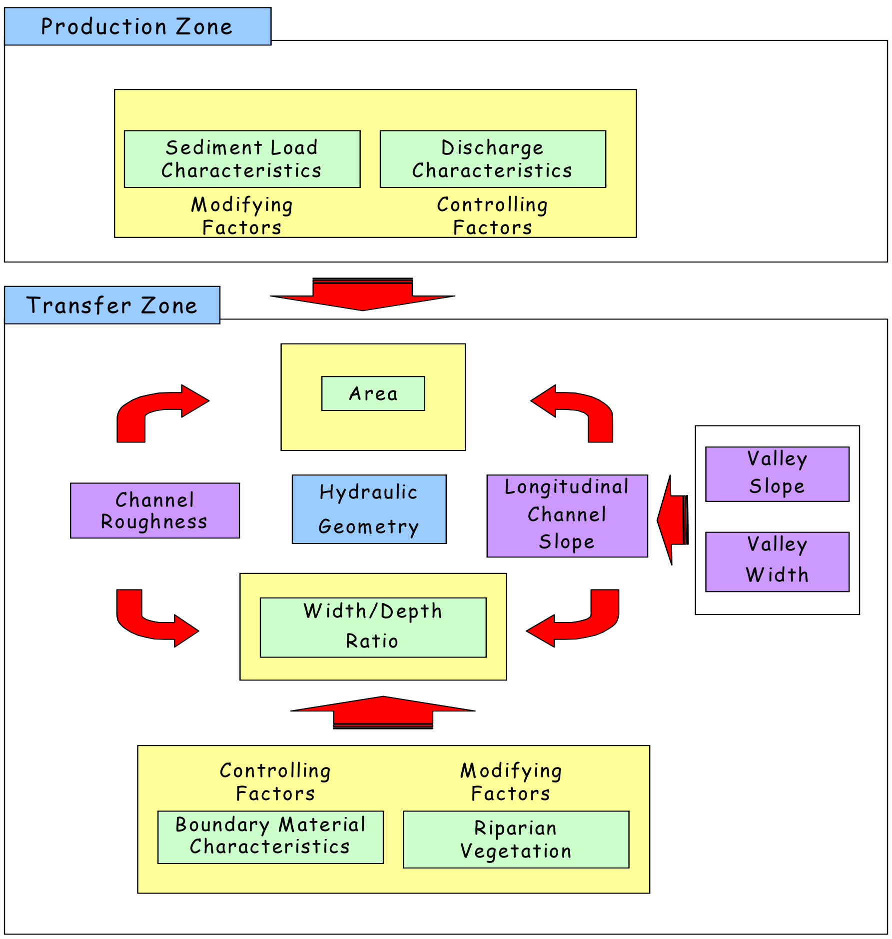


Figure 1.4 Conceptual Model of Stream Channel Morphological Response

The central portion of Figure 1.4 denotes the balance within the active channel between flow resistance (Channel Roughness), channel cross-sectional area (Area), channel width to depth ratio (Width/Depth), and slope (Longitudinal Channel Slope). This balance may be disrupted by either land use alteration within the "Production Zone" or through direct modification of the channel, e.g., riparian vegetation management programs, diversions, channelization, gravel mining, and so on within the "Transfer Zone".

Modifications in land use or land use practices typically alter the watershed storage capacity and timing characteristics of runoff from the "Production Zone." Hollis (1975) showed that flow rates for events having recurrence intervals of 6 months and 2 years may increase by 17.5 and 3.5 times the pre-disturbance flow rate, respectively, after a 30% paving of the basin. Marsalek (1993) observed that runoff volume also increases with increasing basin imperviousness such that at 30% imperviousness the direct runoff component of the hydrologic budget increases from about 15% for undeveloped conditions to nearly 35%. MacRae (1996) found that the conversion of an agricultural basin to medium density residential land use increased instream erosion potential by 4.7 times under built out conditions primarily due to the increase in occurrence of mid-bankfull flows.

While flow energy increases with increasing basin imperviousness, Wolman (1960) noted that sediment yield actually decreases. Depending on the predominate soil type, clearing of forests for agricultural use typically results in an increase in sediment yield in the order of 25 times resulting in aggradation within the channel-flood plain system and widening of the active channel (NVPDC,1980). Sediment yields begin to decline as cultivated fields are reforested or transformed into scrublands or pasture. During the active construction phase of urbanization sediment yields increases in the order of 150 times those rates observed under forested conditions (MWCOG, 1990). However, as the urban surface is stabilized and paved over, sediment yield declines abruptly to approximately twice the yield observed under forested conditions. The reduction in sediment yield results in a significant decrease in suspended solids producing a "hungry water"[5] phenomena. Referring to Lane’s (1955) relation (Figure 1.1), a decline of sediment influx to the channel along with an increase in flow would result in degradation of the channel.

Based on the above assessment of land use alteration, a paving of the land surface results in both an increase in flow energy and decrease in sediment yield. Consequently, basin imperviousness may be considered a surrogate for the direct measurement of parameters characterizing sediment yield (particle size, mass, and timing) and flow regime characteristics (flow rate, volume and timing) from the "Production Zone" (Figures 1.3 and 1.4). Morisawa and Laflure (1979) correlated morphological impacts with basin imperviousness in a study of ten alluvial streams in Pennsylvania and New York States. Morphological impact was expressed in terms of channel enlargement (Re) as defined by the ratio,

5 Sediment particles in suspension within the water column are carried both downstream by the primary flow velocity and vertically through eddies. The mass of the suspended particles and the collision between particles results in a loss of flow energy through momentum exchange. The result is a dampening effect on flow turbulence. Flow competence requires both drag (the downstream component of flow) and lift (the vertical component of flow) to entrain and transport particles. The dampening effect diminishes as sediment concentration declines within the water column resulting in an increase in stream competence, all other factors being equal.

$$(\text{Re})_{POST} = \left(\frac{(A_{BFL})_{POST}}{(A_{BFL})_{PRE}} \right)$$

in which ‘A’ represents the cross-sectional area of the active channel and the subscripts BFL, POST and PRE refer to bankfull stage, the post-disturbance channel and the pre-disturbance channel respectively.

Allen and Narramore (1985) also demonstrated that channel enlargement is a function of basin imperviousness in a study of interbedded shale-limestone and chalk streams in north central Texas. However, both the Morisawa and Laflure (1979) and Allen and Narramore (1985) studies included streams that were still undergoing land use modification. Given that some of the streams studied by the above authors may still have been in the process of adjustment, it is possible that they may have underestimated the ultimate channel enlargement.

To address this issue of continued channel enlargement, also defined as channel relaxation, MacRae et al., (1999) collected data from 60 sites in eleven mature urban watersheds in Austin, Texas. These watersheds had been fully developed for between 35 and 65 years. Total Basin Imperviousness (TIMP) was also relatively high ranging from between 35 and 75 percent. The 60 sites were selected based on the availability of historic engineering surveys from which the historic channel cross-sectional area at bankfull stage was determined [$(A_{BFL})_{HIS}$]. Each site was then re-surveyed to obtain a current estimate of cross-section area [$(A_{BFL})_{CUR}$]. These data indicated that channel enlargement varied with the resistance of the boundary materials. Channels worn into alluvium (AL-Type) reported the highest enlargement ratios followed by channels with rock beds and one or more alluvial banks (RB-Type). The lowest enlargement ratios were recorded for channels with massive rock bed and rock banks. These channel systems were referred to as Rock Controlled (RC-Type). The survey sites were divided into these three categories based on boundary material resistance.

Historic land use data were used to reconstruct the development sequence within the watershed area tributary to each site from a period representing the pre-disturbance condition to the time of the current survey. The pre-disturbance condition was defined as the pre-urbanization period. For approximately 15 of the AL-Type sites, the historic survey closely approximated the pre-disturbance land use condition. In these instances, the historic data were assumed to represent the pre-disturbance channel form [$(A_{BFL})_{PRE}$]. A first approximation of the ultimate enlargement ratio was then obtained using the relation,

$$(\text{Re})_{ULT} = a\left(\frac{(A_{BFL})_{CUR}}{(A_{BFL})_{HIS}} \right)^{b}$$

in which $(\text{Re})_{ULT}$ represents the ultimate channel enlargement ratio where the mesoform parameters reach an equilibrium state with the altered hydrology of the "Production Zone" and ‘a’ and ‘b’ are coefficients.

The above relation was then used to determine the $[(A_{BFL})_{PRE}]$ for the remaining AL-Type sites using the historic ($[(A_{BFL})_{PRE}]_{HIS}$) and current ($[(A_{BFL})_{PRE}]_{CUR}$) survey data. The two estimates of $[(A_{BFL})_{PRE}]$ were then correlated and a second approximation of the "Relaxation Curve" for AL-Type streams was derived wherein the correlation coefficient was maximized. The resulting relation was of the following form:

Relationship of Channel Relaxation as a Function of Age of Development - for AL-Type Streams

$$\left(\frac{(\mathrm{Re})_i - 1}{(\mathrm{Re})_{ULT} - 1}\right) = 1.032\left(\frac{(t_i - t_l)}{(t_r - t_l)}\right) - 0.028, R^2 = 0.82, n = 54$$

in which $(\mathrm{Re})_i$ represents the enlargement ratio at the time of the survey, t_i is the area weighted average age of development, t_l represents the lag time required before a significant morphological response is observed in the cross sectional area (t_l=2.5), and t_r is total time of the relaxation period (t_r=67.0 years).

The value of t_l and t_r in the above relation were determined through curve fitting techniques. The value of t_i was determined by dividing the time from pre-disturbance to the date of the historic or current survey into time periods corresponding to available land use information (topographic mapping, aerial photography and land use mapping). The beginning and ending date of the time period was noted and the developed drainage area of the basin (DDA) in each time period was measured. These data were entered into the following relation to determine the value of t_i,

$$t_i = \frac{\sum_{i=1}^{n} 0.5DDA_i\left[(t_n - t_j) + (t_n - t_k)\right]_i}{\sum_{i=1}^{n} DDA_i}$$

in which DDA is the developed drainage area of the basin tributary to the survey site that has been urbanized or undergone land use alteration during the i^{th} time period, t_n represents the year of the survey and t_j and t_k are the starting and ending years of the i^{th} time period respectively.

The Austin Relaxation Curve was then validated using data collected from 42 historic and 35 current cross-sections along a 2,625 ft (800 m) reach of Humber Creek, Toronto, Ontario representing 5 sites (each site consisting of 7 cross-sections on average. The Humber Creek data closely approximated the Austin Relaxation Curve (MacRae and DeAndrea, 1999). The final form of the curve for AL-Type streams is illustrated in Figure 1.5.

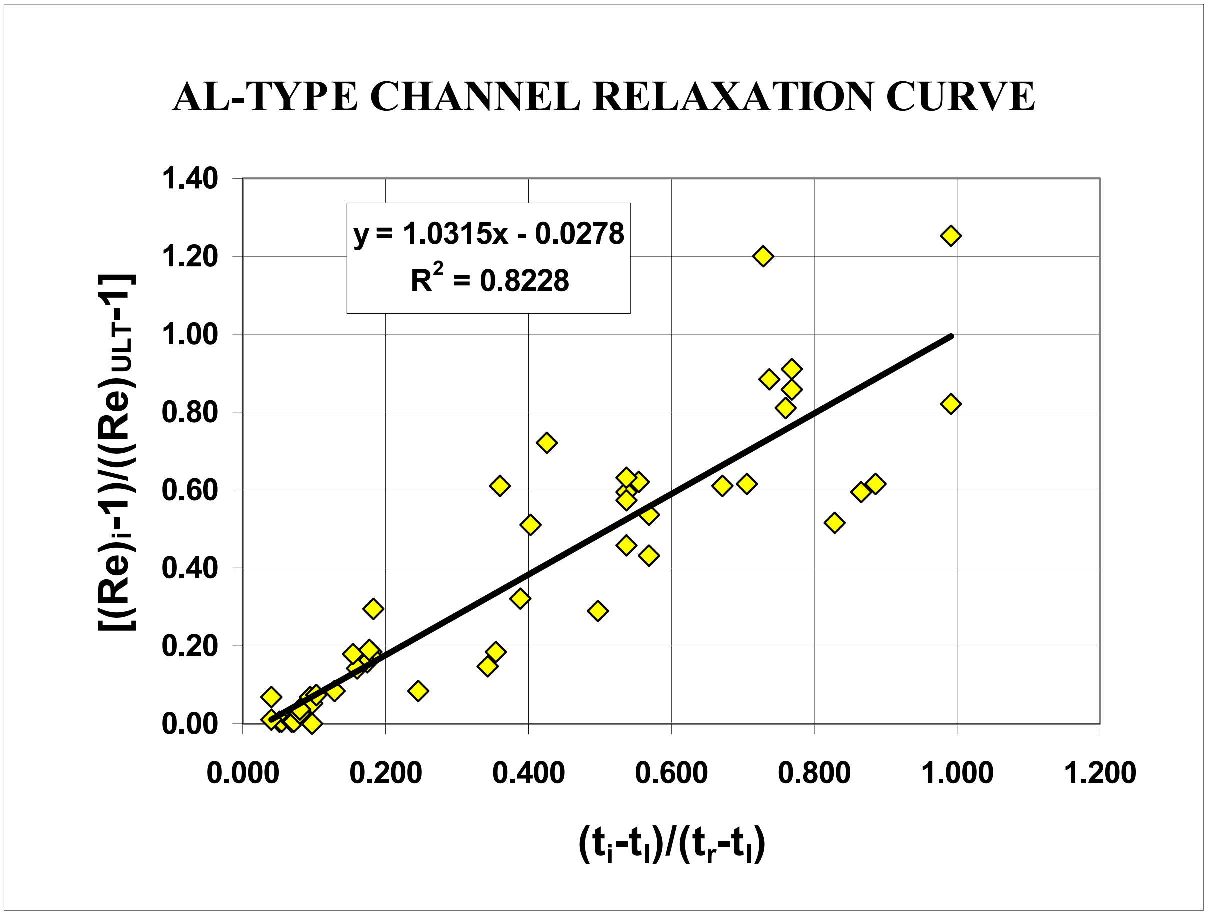


Figure 1.5: Relaxation Curve for Estimating Channel Enlargement at any Given Time Period (Source: MacRae, et.al, 1999)

The resulting estimates of $(Re)_{ULT}$ were then used to develop the channel "Enlargement Curve." The adopted form of the channel "Enlargement Curve" was a second order polynomial forced through $(Re)_{ULT}$ =1.0 at TIMP=1.0 percent. This form of the relation was adopted because conceptually it can be argued that the channel will not continue to enlarge indefinitely in an exponential manner. The final form of the "Enlargement Curve" for AL-Type streams is,

Original Relationship of Ultimate Channel Enlargement as a Function of Total Impervious Cover

$$(\mathrm{Re})_{ULT} = 0.00135(TIMP)^2 + 0.0167(TIMP) + 1.0$$
$$R^2 = 0.78, (n = 38)$$

in which TIMP is the total basin imperviousness and $(Re)_{ULT}$ is the ultimate enlargement ratio at $t_i = t_r$.

Figure 1.6 illustrates the resulting channel "Enlargement Curves" for AL-Type streams incorporating data from Austin, TX. The primary focus of this study is to test these baseline data and the corresponding channel Enlargement Curve by comparing estimates of channel enlargement obtained from the curve to values of channel enlargement obtained for Vermont streams. If it can be shown that the two data sets are drawn from the same population then the existing Enlargement Curve can be used to help predict and assess stream morphological impacts associated with proposed land use modifications. Further, the Enlargement Curve can help in the design of stormwater mitigation strategies in streams already impacted by land use change.

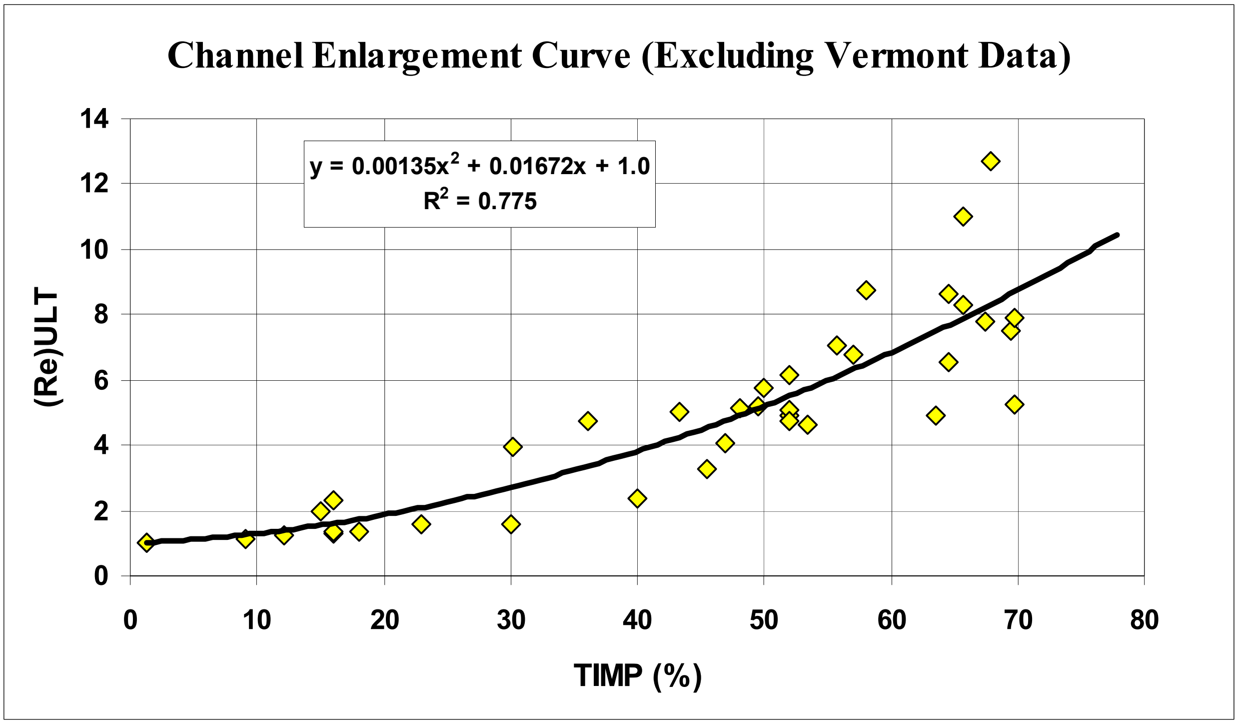


Figure 1.6: Channel Enlargement Curve for AL-Type and RB-Type Streams (Enlargement Ratio as a Function of Total Basin Imperviousness (TIMP) for all Channels Excluding Vermont Streams) (Source: MacRae, et al, 1999)

SECTION 2

PROJECT METHODOLOGY

SECTION 2: PROJECT METHODOLOGY

As presented in Section 1, the project methodology consisted of a complimentary approach of four components to help quantify the relationships between watershed land use change and alteration of stream morphology and aquatic ecology for Vermont streams. The primary component of the study was the development of channel enlargement relationships related to land use change as measured by total basin imperviousness (TIMP) that was statistically valid for Vermont conditions. Supporting elements consisted of assessing current channel stability in the field using a rapid geomorphic assessment (RGA) technique, evaluating prior collected biomonitoring data for correlations with channel enlargement and stream stability, and conducting a comparison of stream channel riparian buffer length as a percent of total stream length using aerial photography.

Due to project budget constraints, only a limited number of Vermont streams could be evaluated for the project assessment. The Project Team, with the agreement of a Project Steering Committee, settled on a set of eight subwatersheds of varying land use activity and development intensity. It was felt that eight subwatersheds was the minimum number necessary to provide a representative range of land use activities desired by ANR while providing the necessary additional data points to validate the empirical approach discussed in Section 1.

The following project methodology (Table 2.1) was developed as a guide to accomplish the goals of the project. The original project methodology that was approved by the Project Steering Committee is presented in Appendix A.

Table 2.1	**Basic Project Methodology for the State of Vermont - Watershed Hydrology Protection and Flood Hazard Mitigation Project - Phase II, Technical Analysis**
Step 1:	Select a list of potential candidate subwatersheds representing a range of land use activities
Step 2:	Compile historic data on candidate streams (cross sectional data, biomonitoring, etc)
Step 3:	Select a "short list" of streams with historical cross sectional data, past biomonitoring data, and desired range of land use activities; conduct field screening of potential sites
Step 4:	Select the final list of eight subwatersheds for field assessment
Step 5:	Produce base mapping of selected stream reaches (land use/land cover mapping to compute total basin impervious cover (TIMP) and identification of stream location)
Step 6:	Conduct field assessment of selected stream reaches (cross sectional data and rapid geomorphic assessment at 24 cross section locations -- 3 in each of the eight selected subwatersheds)
Step 7:	Compile and analyze biomonitoring data for selected streams
Step 8:	Conduct riparian buffer assessment of streams within urbanized subwatersheds
Step 9:	Conduct data analysis to define channel enlargement relationships, channel stability class, and particle size distribution
Step 10:	Evaluate correlations between geomorphic parameters, biomonitoring and land use change as measured by TIMP

2.1: Stream Selection Process

A major component of the project was to select streams representative of land use/land cover activities common to Vermont. As a guide, the original selection criteria was to ultimately select eight subwatersheds from the range of land uses as listed in Table 2.2.

Table 2.2 Target land use/land cover for subwatershed selection
• 4 urban/suburban/rural subwatersheds exposed to past development activity. 1 in the 0 - 10% impervious cover range 1 in the 11 - 15% impervious cover range 1 in the 16 - 25% impervious cover range 1 with impervious cover exceeding 25%
• 1 subwatershed exposed to past logging activity.
• 1 undeveloped or "least impacted" subwatershed to serve as a reference in a paired analysis with the logging activity stream.
• 1 upland or steep terrain subwatershed exposed to past development activity in the vicinity of an upland development.
• 1 undeveloped or "least impacted" stream to serve as a reference in a paired analysis with the upland development stream.

The project team employed the following basic sequence to arrive at the final list of subwatersheds:

1. Locate subwatersheds where past biological monitoring was performed.
2. Locate subwatersheds over a broad geographic region of the state with the varying degree of land use/land cover activity presented in Table 2.2.
3. Initially screen a candidate list of approximately 24 subwatersheds that have the following characteristics:
    - have undergone past biological monitoring;
    - fall in the range of impervious cover presented above;
    - at least two that are 3rd order tributaries;
    - subwatersheds with older development (to allow time for the stream to react to altered hydrology);
    - subwatersheds where significant flooding has not occurred in the recent past;
    - at least two that have been exposed to significant logging activity; and,
    - at least two that have been exposed to upland development.
4. Investigate various sources to obtain pre-disturbance channel form data (e.g., cross-section topographic surveys for older bridge construction, sanitary sewer piping plans, flood plain studies, and land development projects).
5. Select the best 10 to 11 subwatersheds that have:
    - good historical cross sectional data;
    - fall within the desired range of impervious cover;

- 1 exposed to logging activity;
- 1 exposed to upland development; and,
- 2 to 3 undeveloped reference streams.

The stream selection process targets primarily 1st and 2nd order stream systems to document the longer term hydrological impacts from altered land cover. The basis for this decision is two fold:

- Higher order tributaries tend to be disproportionally impacted by major flooding events. These rivers are subjected to greater *stream-power* (the product of flow rate and longitudinal channel slope) and higher *shear stresses* (force or pull of water per unit area) than their smaller headwater counterparts because of the volume of flow they convey. They also tend to be formed in finer grained materials. Many low order mountainous Vermont streams tend to be heavily armored relative to their higher order lowland counterparts. The combination of greater erosive power and less resistant boundary materials translates into a higher degree of sensitivity in higher order streams to erosion by catastrophic floods.

- Perhaps more importantly from a management perspective, it is difficult, if not impossible to assess the cumulative impacts of thousands of individual watershed land cover alterations at the 3rd to 4th order scale. On the smaller subwatershed scale of 1st to 2nd streams, land use/land cover alterations are more immediately related to adjacent stream channel modifications. It is, therefore, realistic to connect the application of land management strategies with how adjacent streams respond.

2.2: HISTORICAL DATA COLLECTION

To accomplish the above sequence, the project team started with a long list of potential sites that were likely to meet the candidate stream selection criteria. The project team interviewed Vermont Agency of Natural Resources (ANR) staff to obtain a list of streams which had biological monitoring data available. Streams that had been monitored for either benthic macro-invertebrates or fish and met the other site-selection criteria (first or second order watersheds, same physiographic region, etc.) were chosen as candidate streams. Table 2.3 contains the short list of streams that met the initial screening criteria.

The project team conducted an investigation of state and local records to locate and obtain historical data related to the candidate subwatersheds. Sources consulted included private industry (Vermont Gas Co., telephone company, private consultants and resort owners), municipal governments, sewer and water authorities, State agencies(ANR, the Agency of Transportation (AOT), and the District Environmental Commission offices) and federal agencies (the Federal Emergency Management Administration (FEMA), and the Natural Resources Conservation Service (NRCS). A complete list of contacts is in Appendix E. The best sources for historical cross-sectional data were the State AOT and the survey data (available from Karl Jurentkoff) on microfilm for the HUD flood studies that were conducted for numerous towns in Vermont during the 1970s.

Table 2.3 Candidate Subwatersheds Meeting Selection Criteria for Geomorphic Assessment

Stream Name	Town	Dominant land use	Approx. impervious cover (%)[2]	Approx. Drainage Area (mi^2)	# of historical cross sections
Allen	Williston	Ref	3	4.6	?
Bartlett	S. Burlington	Urban	17	1.5	>10
Potash	S. Burlington	Urban	18	7.5	>3
Moon	Rutland	Urban	higher	8.7	>10
Tenney	Rutland	Urban	lower	5.1	>3
Cold River	Clarendon	Ref	-[1]	<6	-
Falls Brook	Sherburne	Ref	-	<6	-
Smith Brook	Goshen	Ref	-	<6	-
Roaring Brook	Sherburne	Upland dev	lower	<6	1
Roaring Brook trib.	Sherburne	Upland dev	lower	<6	1
West Branch Little River	Stowe	Upland dev	lower	25±	5
Stevens	St. Albans	Urban	higher	12.7	3
Preston	Huntington	logged	-	6±	-

Notes: [1] - indicates that information is not needed for ref. streams
[2] preliminary estimate based on review of street map road density

2.3: Candidate Site Reconnaissance

The project team conducted a two day reconnaissance of candidate stream reaches to verify that the historic cross section locations were accessible, reasonably unaltered (e.g., little bank armoring, or channelization), and/or that a nearby unaltered cross-section was available.

2.4: Final List of Subwatersheds Selected for Assessment

On October 8, 1998 the Project Steering Committee and the project team met to review the historical data collection efforts and select the final list of 8 subwatersheds for conducting the rapid geomorphic assessment. Discussion among the project team and Steering Committee revolved around site location, stream order and size, whether or not biological monitoring data were available, the degree and age of logging activity and the quality of historical cross-sectional data. Table 2.4 lists these subwatersheds along with accompanying data.

Table 2.4 Final Subwatersheds and Stream Cross Sectional Characteristics

Stream Name	Historical Cross Sections		Current Cross Sections	
	Date	Location	Location	Approx. Drainage Area (mi^2)
Cold River	N/A	N/A	. 1.5 miles upstream of confluence with North Branch	20.7
			Gould Brook upstream of confluence with Cold River	10.8
			Cold River upstream of confluence with Gould Brook	4.1
Dowsville Brook	N/A	N/A	0.5 miles upstream of Route 100	6.4
			1.5 miles upstream of Route 100	5.4
			Trib. 1.5 miles upstream of Route 100, north of Dowsville Road	0.5
Moon/ Tenney Brooks	1922	Tenney at Lincoln Ave	Main Street	4.4
	1954	Moon at Main Street	Granger Street	5.3
			Near Brightview Avenue	3.0
Potash Brook	1967	Shelburne Road	Queen City Park	7.4
			Near Farrell St. and Swift St.	6.0
			Near Interchange 13 of I-89	5.0
Roaring Brook	1950	Roaring at Routes 100/4	Roaring at Routes 100/4	5.4
	1976	Roaring Tributary near Sherburne Firehouse	Roaring Tributary near Sherburne Firehouse	0.7
			Roaring upstream of Tributary	4.5

Table 2.4 Final Subwatersheds and Stream Cross Sectional Characteristics

<table>
<tr><th rowspan="2">Stream Name</th><th colspan="2">Historical Cross Sections</th><th colspan="2">Current Cross Sections</th></tr>
<tr><th>Date</th><th>Location</th><th>Location</th><th>Approx. Drainage Area (mi^2)</th></tr>
<tr><td>Smith Brook</td><td>N/A</td><td>N/A</td><td>3 sections near confluence with Brandon Brook</td><td>3.2</td></tr>
<tr><td rowspan="3">Stevens Brook</td><td>1975</td><td>Kellogg Road</td><td>Kellogg Road</td><td>6.9</td></tr>
<tr><td>1986</td><td>Lincoln Avenue</td><td>Lincoln Avenue</td><td rowspan="2">1.4</td></tr>
<tr><td>1980</td><td>Route 36</td><td>Route 7</td></tr>
<tr><td rowspan="3">West Branch Little River</td><td rowspan="2">1972</td><td rowspan="2">Route 108 Luce Hill Road</td><td>Route 108</td><td>24</td></tr>
<tr><td>Luce Hill Road</td><td>23</td></tr>
<tr><td>1964</td><td>Bridge near Topnotch</td><td>Bridge near Topnotch</td><td>17</td></tr>
</table>

2.5: STREAM BASE MAPPING

This section presents the location of each selected subwatershed within Vermont (Figure 2.1) as well as specific locations of monitoring and assessment sites for each stream (Figures 2.2 through 2.9).

Figure 2.1 was derived from the State's GIS database and shows the eight subwatersheds (note; Moon Brook and Tenney Brook represent one subwatershed) with the county boundary lines. The second set of maps (Figures 2.2 to 2.9) depict each stream reach being evaluated and shows the locations of historic and current cross sections, and fish and macroinvertebrate monitoring site locations. The cross sections were used to complete the geomorphic assessment described in Section 1 and Section 2.6 and summarized in Section 3. The biological monitoring assessment is discussed in Section 4. Figures 2.2 to 2.9 were produced using the State's GIS database with the help of Jim Pease of the Agency of Natural Resources.

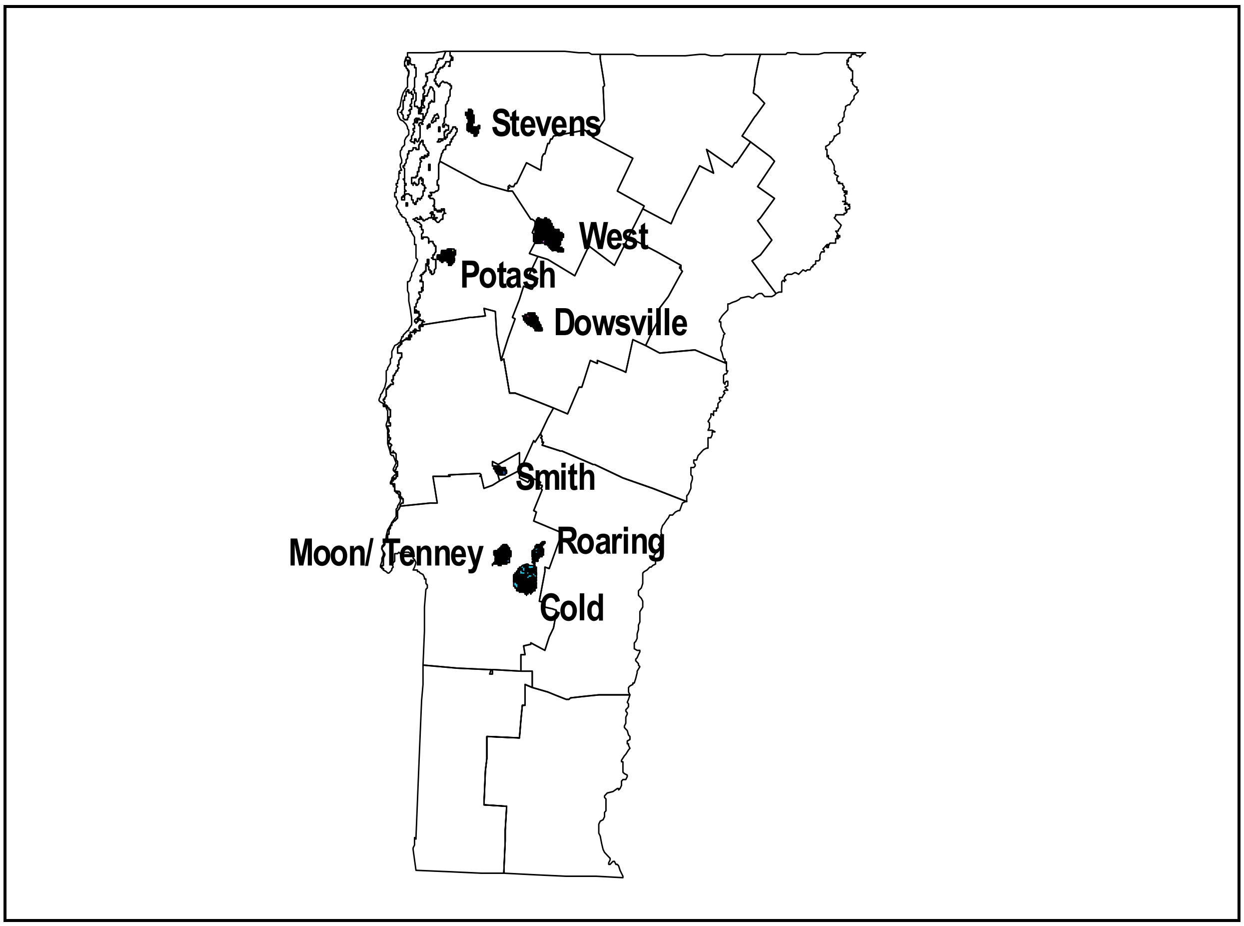


Figure 2.1: Selected Subwatershed Locations in Vermont

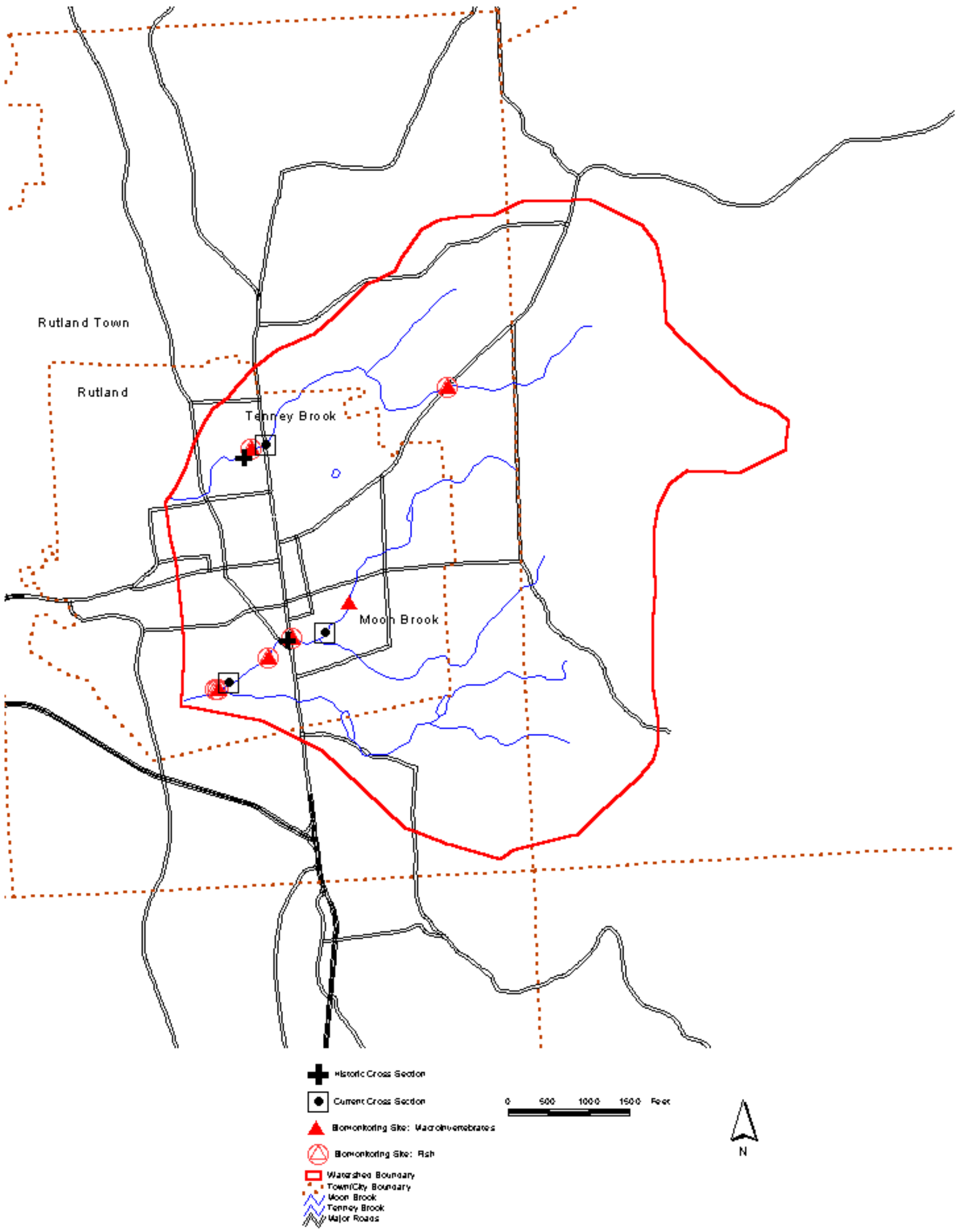


Figure 2.2: Moon Brook and Tenney Brook Stream Reach Location Map

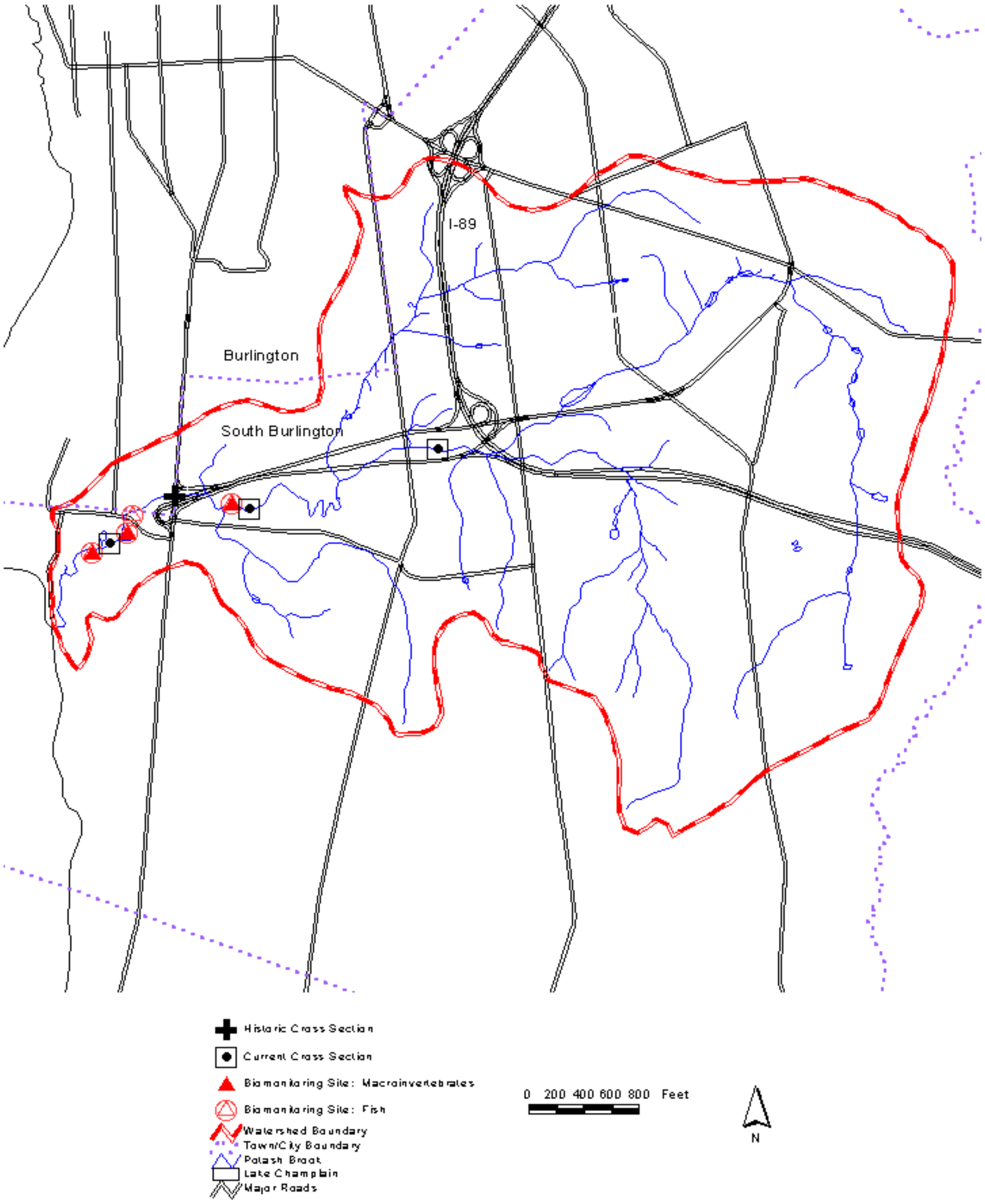


Figure 2.3: Potash Brook Stream Reach Location Map

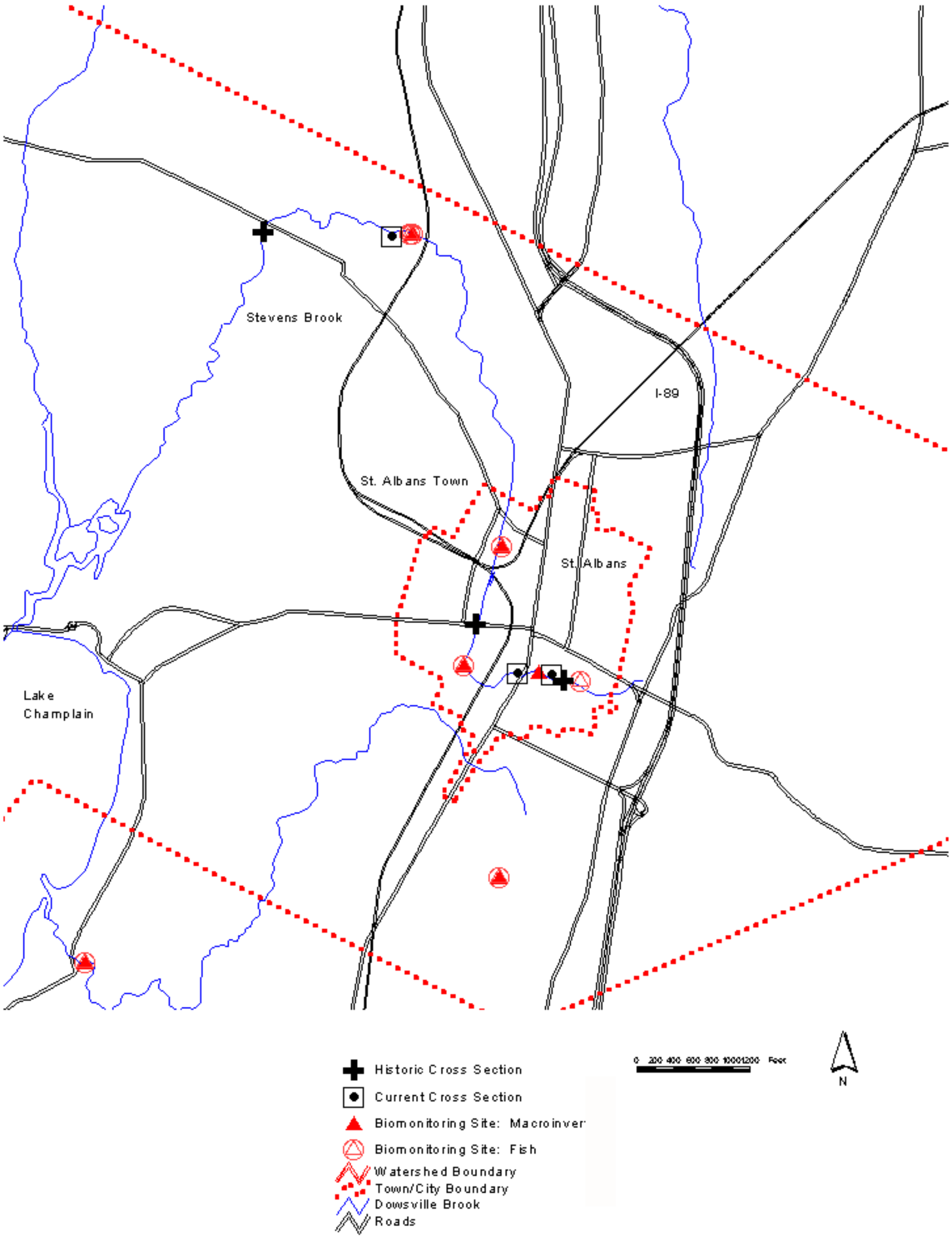


Figure 2.4: Stevens Brook Stream Reach Location Map

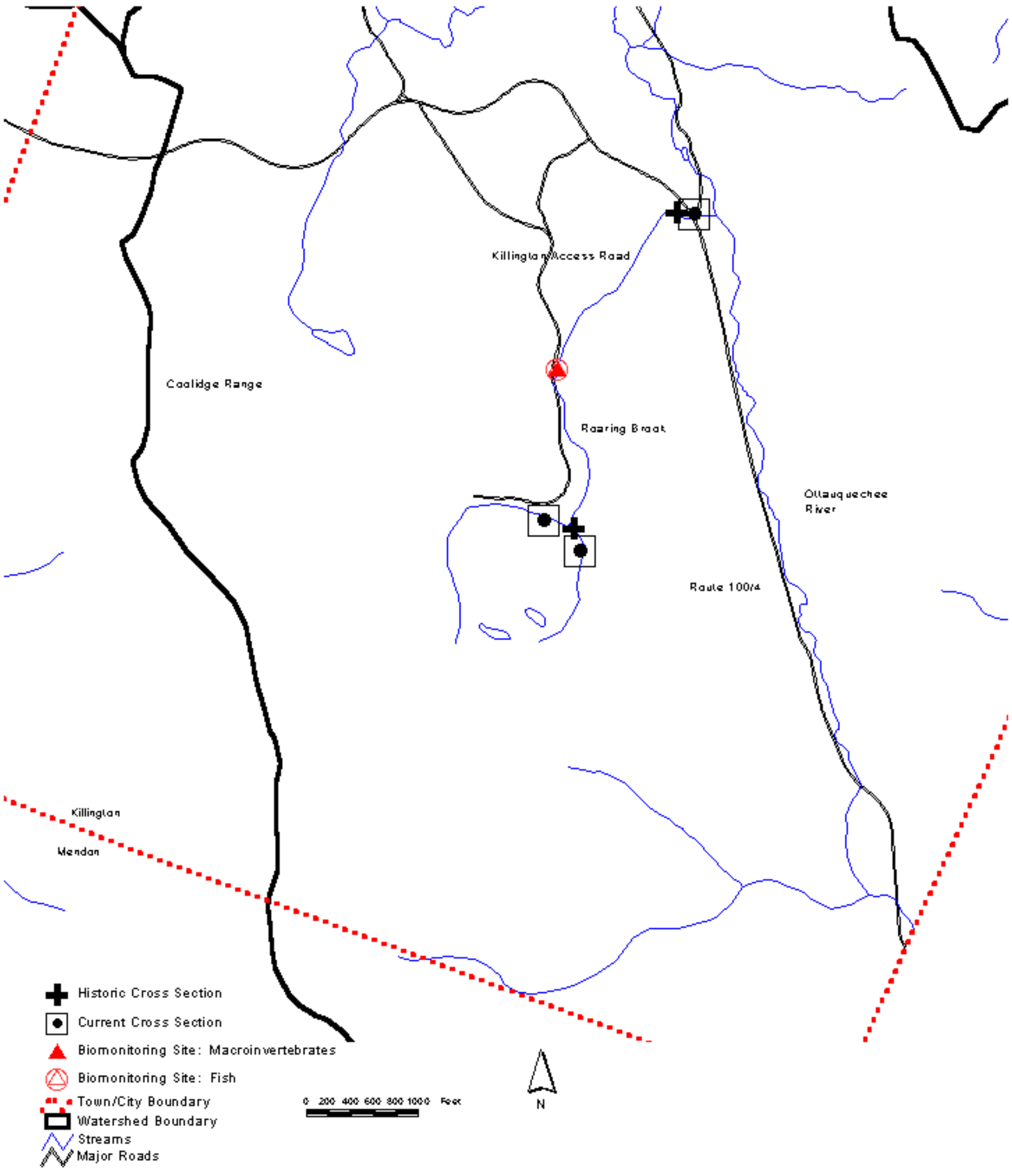


Figure 2.5: Roaring Brook Stream Reach Location Map

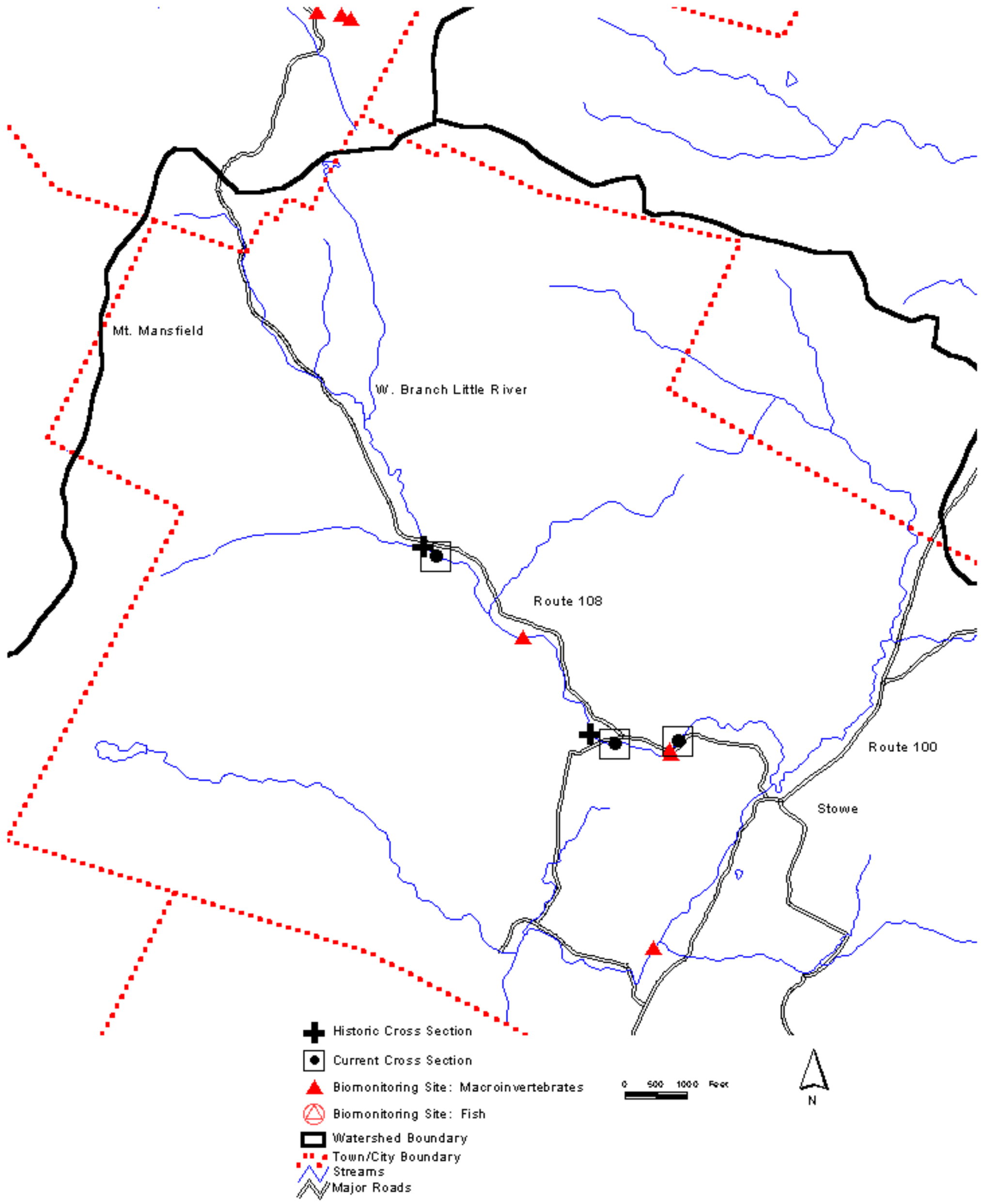


Figure 2.6: West Branch Stream Reach Location Map

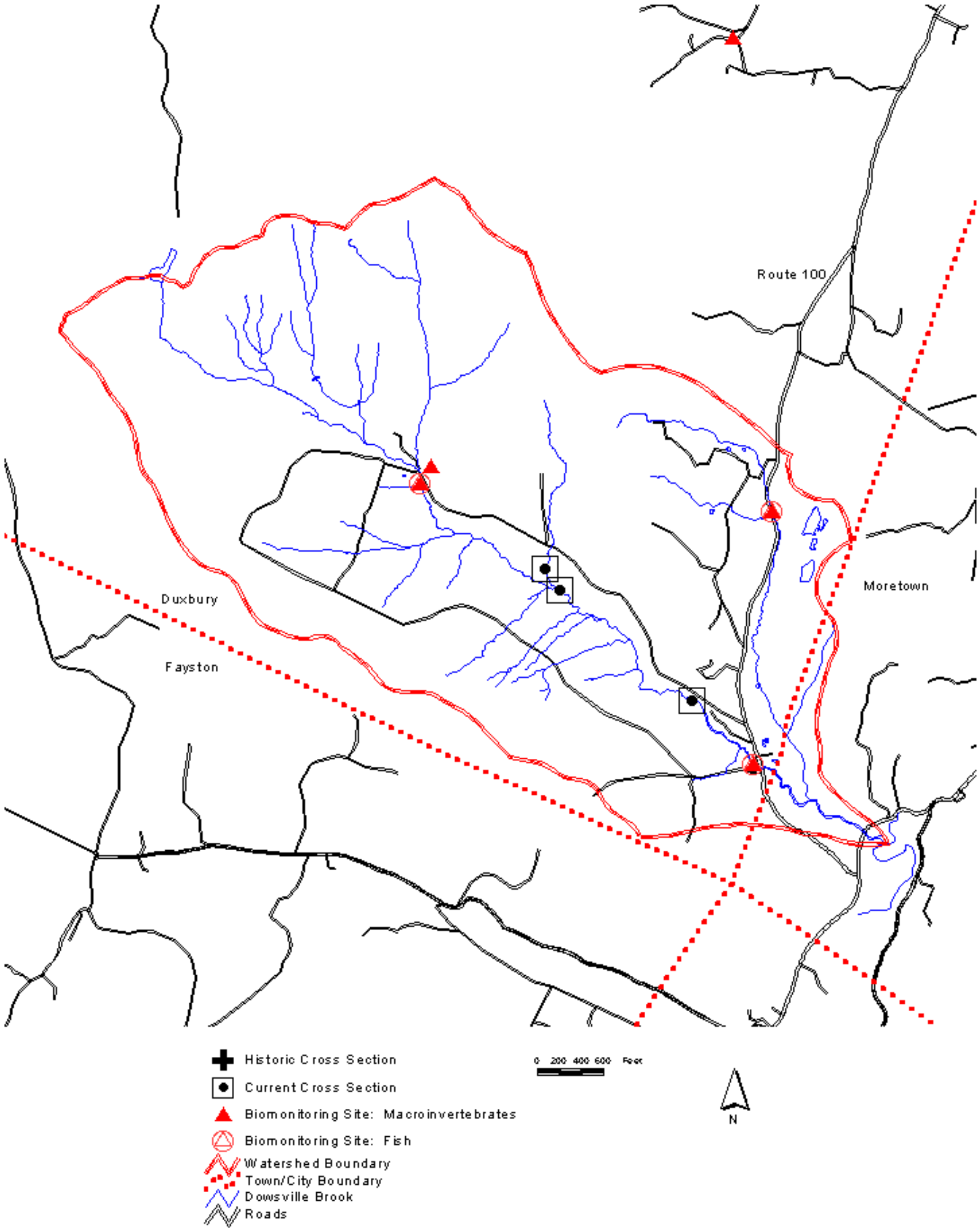


Figure 2.7: Dowsville Brook Stream Reach Location Map

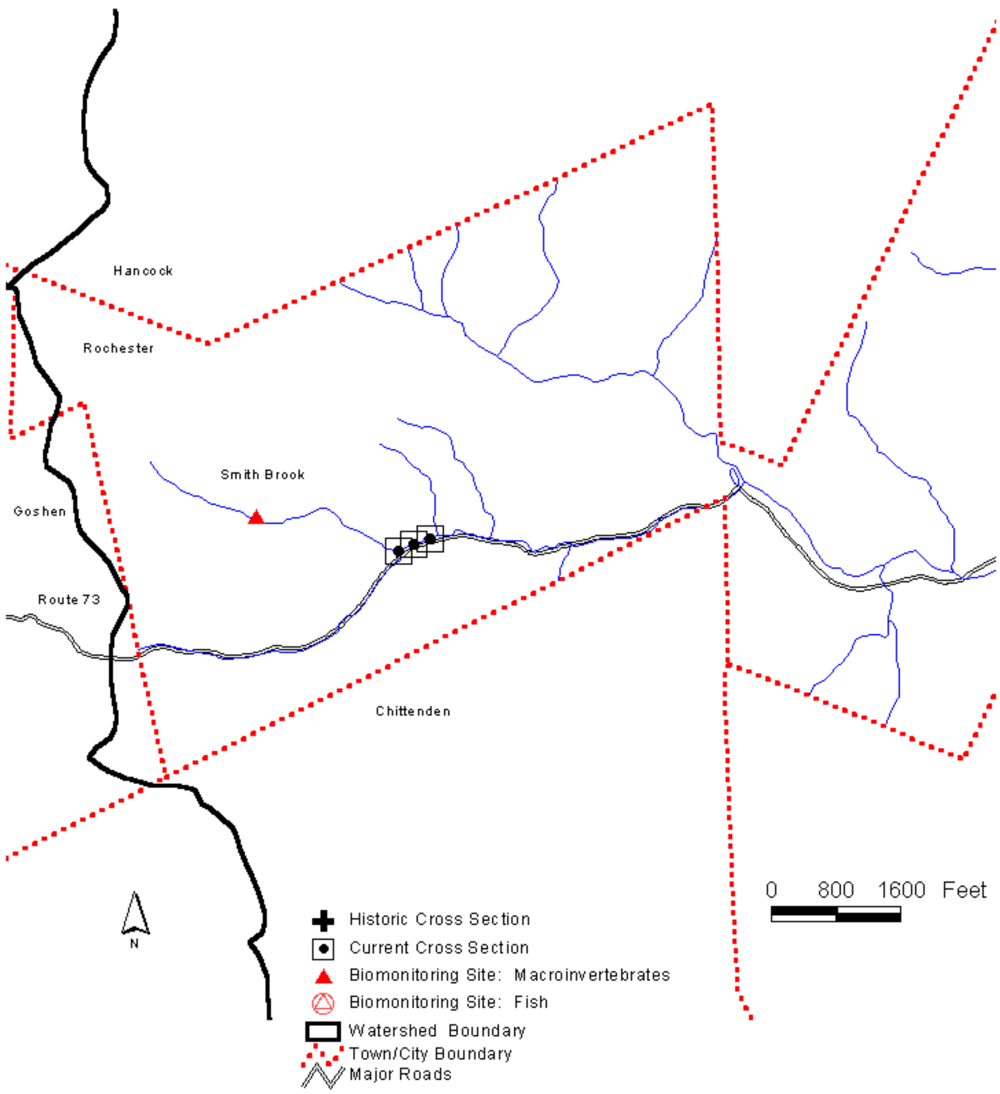


Figure 2.8: Smith Brook Stream Reach Location Map

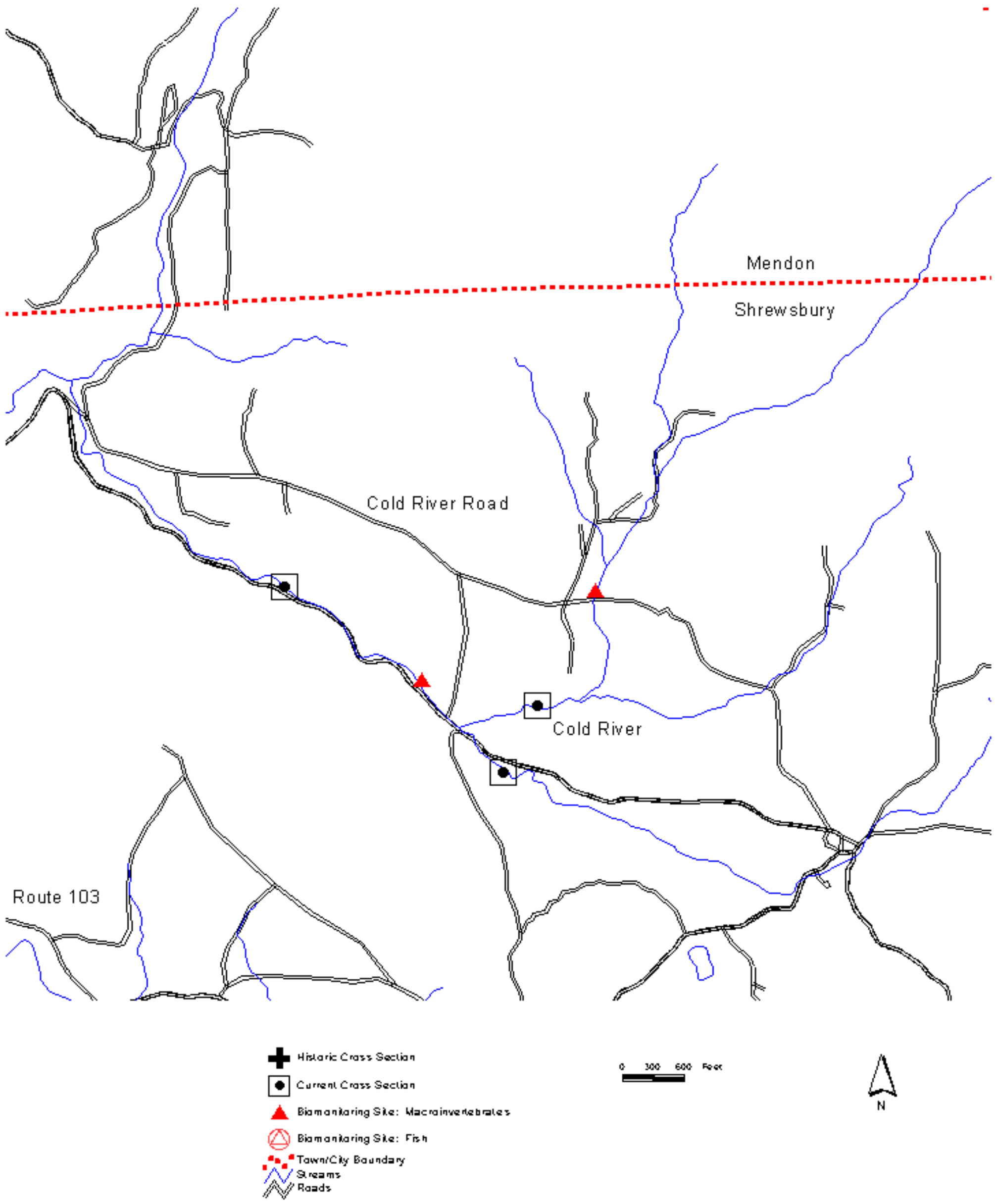


Figure 2.9: Cold River Stream Reach Location Map

2.6: FIELD GEOMORPHIC DATA COLLECTION AND DATA PROCESSING TECHNIQUES

The field component of the project consisted of collecting data to evaluate the two major channel geomorphic assessment elements discussed in Section 1.1.1. The first of these two elements consists of the validation of the empirical approach of documenting channel enlargement as a function of total basin impervious (TIMP) and the second element being the use of a rapid geomorphic assessment technique (RGA) to assess current channel stability. Data for both elements were collected in the field using a standardized diagnostic procedure. An example of a completed Diagnostic Geomorphic Field Survey Form for Potash Brook (POT1) is provided in the Appendix C.

Data were collected at three cross-sections for each of the subwatersheds, with the exception of Moon Brook and Tenney Brook watersheds, where a total of three cross-sections were evaluated for these two tributaries to Otter Creek. A total of 24 cross-section locations were evaluated (see Figures 2.2 through 2.9 for locations).

2.6.1: Channel Enlargement Survey Data

The reaches chosen in each of the streams were surveyed to determine their longitudinal and cross-sectional profiles. The survey was carried out primarily using a Sokkia engineers level and standard leveling techniques including methods of stadia. Some site data were also obtained using a "Total Station," a completely automated surveyor's transit.

The longitudinal profiles were taken by a survey along the thalweg for distances of 175 ft to 760 feet. (average 324 ft). These distances correspond to approximately 8 times the average width of the "active channel" at bankfull stage. The resulting data were used to determine longitudinal channel slope (S).

The cross-section for each site was surveyed at a riffle crossover point that was determined to be representative of that reach. Cross-sectional ordinates were surveyed to determine the hydraulic geometry of the channel at selected stages, including the adjacent floodplain, to a depth of approximately twice the bankfull stage. The primary ordinates sought were:

1. major break of slope points (e.g., the top of bank, terraces, bank toe, bar faces, and the thalweg);
2. bio-indicators such as root zone depths, root lines, thatch lines, moss and lichens;
3. geomorphic indicators; e.g. bank inflection points and the tops of bars; and,
4. soil profiles indicating distinct stratigraphic units.

The resolution of the cross-sections were sufficient to map geomorphic features such as bar forms, terraces, major slope breaks, and bio-indicators. Bankful stage was also recorded as estimated from geomorphic and bio-indicators at the primary cross-section and at ancillary cross-sections located at 82 ft and 164 ft (25.0 and 50.0 m respectively) both upstream and downstream of the primary cross-section.

2.6.2: Rapid Geomorphic Assessment

The Rapid Geomorphic Assessment (RGA) process uses a number of visually observed factors to provide a semi-quantitative assessment of a stream's current stability. The primary purpose of the RGA is to corroborate the findings of the more quantitative channel enlargement assessment and to help define past or current modes of channel adjustment (i.e., aggradation, degradation, widening and/or plan form adjustment). The RGA notes whether change in channel form has occurred or is still occurring, however, it does not provide a measure of the rate of change.

The Rapid Geomorphic Assessment (RGA) was performed at each field survey site. Typically three sites were chosen on each study watercourse to summarize the overall stability of the watershed. Sections were chosen based on the representativeness of each reach. A length of approximately 12 times bankfull channel width was investigated for each site to determine geomorphic and channel metrics.

The RGA consisted of identifying the presence of in-stream channel features resulting from a variety of geomorphic processes. The processes were represented by four factors: aggradation (AI); widening (WI); downcutting (DI); and planimetric form adjustment (PI)). Each factor is composed of 7 to 10 indices for which a “present” or “absent” response is required. The total number of “present” or “yes” responses is summed and divided by the total number of responses to derive a value for each factor. An example of an RGA Form is included in the Diagnostic Geomorphic Field Survey Form in Appendix C. A stability index (SI) value is then determined from the following equation:

$$SI = \frac{AI + DI + WI + PI}{m}$$

in which ‘m’ is the number of factors (typically 4 for alluvial streams).

The stability index (SI) provides an indication of the stability of the creek channel at a given time. It should be noted that the SI value is not a measure of the rate of change in geomorphic activity (e.g, the rate of channel widening or meander bend propagation) and, as stated above, the geomorphic features observed may be current or historic. Consequently, other corroborative levels of investigation are required to determine whether evidence of instability is associated with current processes and what the magnitude of the activity rates may be. In interpreting the SI value the following general guidelines are employed:

1. Stable: 0.0#SI#0.2 denotes a reach wherein the metrics describing channel form are within the expected range of variance (typically accepted as within one standard deviation from the mean) for channels of similar type;
2. Transitional: 0.2#SI#0.4 represents a reach that is within the expect range of variance as defined in (1) above but with evidence of stress; and,
3. In Adjustment: 0.4<SI#1.0 represents a channel that is outside of the expected range of variance for channels of similar type.

In addition to completing the RGA, the Diagnostic Geomorphic Field Survey Form also included the collection of several corroborative factors such as bed material characteristics to help assess roughness coefficients, channel bank soil consistency to help assess historic degradation or aggradation patterns, and data on large organic debris, debris jams, and riffle line characteristics to help provide indicators of early microform adjustment (see discussion in Section 1). The following discussion describes each of these elements.

Bed Material Assessment

Pebble counts were used to characterize the bed material. Samples were collected near the location of the primary cross-section along two transects perpendicular to the banks running from left bank toe to right bank toe. The pebble counts consisted of measuring the lengths of the three major axes; length (l), width (w), and height (h), of individual pebbles obtained through random grab samples along the transect. These data were then used to calculate a grain size distribution or mass curve from which the following quantiles were estimated:

1. the geometric mean φ_g; and,
2. the particle size for which 16%, 50%, 75% and 84% of the material are finer by mass (φ_{16}, $\varphi_{50,}$ $\varphi_{75,\text{ and}}$ φ_{84} respectively).

A minimum of 50 pebbles, wherever feasible, were collected at each station to obtain the above metrics. Data collection included all particles regardless of size including large anomalous boulders. In determination of the mass curves, however, the largest particle, if more then 15% larger then the second largest particle, was removed from the analysis.

These data were used to help classify the channel in the RGA analysis. For example, a high DI value implies that degradation has occurred or is still occurring. If a "Potentially Degrading Environment" is determined using the shear stress analysis then it may be inferred that the process of degradation is still active. These observations help support the channel enlargement ratio calculations.

Bank Soil survey

Bank materials were analyzed during the field study using standard soil consistency tests: stickiness (X1); plasticity (X2); and, firmness (X3) (see Diagnostic Geomorphic Field Survey Form, Appendix C). These metrics were determined for each definable soil horizon or stratigraphic unit on both left and right banks. The three metrics were then summed to determine a value that was subsequently correlated with shear stress to derive the critical shear stress value for each stratigraphic unit.

Large Organic Debris

Due to the nature of the Vermont survey sites, the presence of Large Organic Debris (LOD) was investigated during the field study as a possible indicator of channel stability. An increase in LOD may be anticipated in adjusting channels due to channel widening and the undercutting of riparian vegetation. Conversely, for channels whose mode of response is primarily through degradation, a significant increase in LOD may not be noted. Consequently, the mode of adjustment may have a bearing on the applicability of LOD as a measure of channel stability. Other researchers have found a trend of decreasing LOD with increasing disturbance (May *et al*., 1997). The complicating factors appear to be that as disturbance increases, so too may the influx of riparian vegetation, yet high stream velocities may also increase the tendency to "flush" LOD from the system. At the same time, landowners may "clean-up" streams of LOD to prevent flooding or other undesirable impacts, thereby decreasing the amount of LOD measured in-stream. So, the use of LOD as an early indicator of disturbance may or may not be a useful tool. At any rate, an index based on the number of pieces of LOD was investigated as a measure of channel stability

An increase in the number of pieces of LOD along the channel may also increase the number of debris jams observed. Debris jams can affect channel form through localized scour and the diversion of flows resulting in the formation of chutes. Consequently, the number of debris jams also represents a potential index of channel stability.

The RGA was originally developed for mature urban systems for which the enlargement process was in the final stages. Furthermore, many of these streams had been subject to riparian management programs that involved the removal of LOD that might fall into the channel and obstruct flow. Consequently, the presence of LOD was not a major concern. To adapt the RGA to Vermont conditions, a measure of the number of pieces of LOD and the number of debris jams was integrated into the RGA to produce a *modified RGA*. The inclusion of these indices of channel stability are discussed in Section 3 of this report.

The number of pieces of LOD, their location (instream, on the bank, or within the floodplain riparian zone), and their orientation (parallel, perpendicular, or obtuse to the primary flow path) was noted during the survey. These data were recorded upstream and downstream of the primary cross-section over a distance of approximately 328 feet (longer survey lengths were used in larger channels). The occurrence of debris jams was noted over the same survey length.

Field Sketches

Sketches of the left bank and right bank profiles were made as part of the field notes for each site. Features included in these sketches consisted of soil horizons, bank vegetation, major terraces and approximate elevations of such features.

2.6.3: Data Processing

The process of reducing data from the field was accomplished using the following multi-step procedure:

1. Reduction of the data into a suite of spreadsheet models to determine key parameters such as stage-area, stage-discharge and stage-velocity relationships, longitudinal slope, Manning's roughness, and critical shear stresses.
2. Determination of current bankfull stage, depth and flow rate to compute current cross-sectional area at bankfull stage $(A_{BFL})_{CUR}$.
3. Selection of suitable historical cross-section locations from the available engineering

drawings.

4. Determination of historical bankfull flow rates and depths from selected historical cross-sections to determine historic cross-sectional area at bankfull stage $(A_{BFL})_{HIS}$:
5. Determination of enlargement ratios by:
   a. Estimating TIMP from land use mapping.
   b. Determining the area weighted average age of development (t_i).
   c. Estimating the pre-disturbance channel cross-sectional area $(A_{BFL})_{PRE}$, from both the historic and current survey estimates using the *Relaxation Curve*.
   d. Calculating the current and historic enlargement ratios ($(Re)_i$).
   e. Calculating the "observed" ultimate enlargement ratios from the current survey data using the *Relaxation Curve*.
   f. Comparing the observed and estimated values of the ultimate enlargement ratio $(Re)_{ULT}$.
   g. Revising the Enlargement Curve to incorporate the Vermont data.

1. Spreadsheet Models

Data collected in the field were processed using spreadsheet models developed for the City Wide Erosion Assessment Study for the City of Austin, Texas (MacRae, 1997). These spreadsheets were used to analyze the data and derive standard hydrologic and geomorphic parameters. The specific spreadsheets used were named *longitudinal.xls, x-section.xls*, and *pebble.xls*. The functions of the models are described below. Example calculations and output are provided in the Appendix D.

longitudinal.xls

The longitudinal survey data, consisting of water surface and bed elevations relative to an arbitrary datum were entered into the model. Distance and elevation changes were calculated for both the water surface profile and the bed profile. The data were also plotted to provide a visual reference. The average slope for each surveyed reach was then determined by averaging the slope obtained using three separate approaches:

1. A linear regression of successive riffle crest elevations;
2. A linear regression of the measured water surface profile; and,
3. A linear regression of the thalweg profile.

pebble.xls

The pebble count data were entered into the pebble.xls spreadsheet in order to determine a Manning's (n) value and a critical shear stress for the streambed. This is achieved by converting the l, w, and h measures for each particle to an equivalent diameter and then producing a grain size distribution curve. From this curve, the percentiles were calculated, including most importantly, the median size of the bed material (φ_{50}) and the 84th percentile (φ_{84}). The φ_{50} is used to determine the roughness of the channel bed in terms of Manning's roughness coefficient (n). For cases where the bankfull flow depth is greater than three times the φ_{50}, Manning’s coefficient was calculated using a relationship derived by Strickler

(1923),

$$n = 0.04\phi_{50}^{1/6}$$

where: the φ_{50} exceeded ⅓D_{BFL}, then the 'n' value was approximated from stream data compiled by Rosgen (1996) and other literature references.

The φ_{84} was used to determine the critical shear stress of the bed material and also to provide an additional estimate of bankfull depth.

x-section.xls

The cross-section data spreadsheet model was used to calculate hydraulic flow data at water depths in 0.5 ft increments up to and exceeding bankfull depth as well as bankfull depth. The surveyed cross-sectional ordinates, the estimated longitudinal channel slope, and Manning's roughness coefficient (n) were entered into the spreadsheet. The model generates a number of stage relationships including stage-discharge, stage-area and stage-velocity curves using Manning's equation:

$$Q = \frac{1}{n} AR^{2/3} S^{1/2}$$

where: *n* is Manning's roughness coefficient, A is the cross-sectional area, R is the hydraulic radius and S is the channel slope.

2. Determination of Current Bankfull Cross-sectional Area

Determination of current bankfull area requires the determination of bankfull flow. This is a challenging procedure in impacted channel systems. Fortunately, the degree of impact on many of the study streams was such that bankfull stage could still be defined using geomorphic and bio-indicators. To minimize error in the estimate of bankfull flow, a corraborative parallel approach was adopted using the following methods:

1. Geomorphic indicators;
2. Hydrologic approach - peak flow rate for the 1.5 year flow;
3. Bio-indicators;
4. Hydrologic geometry approach (see discussion on determining historic bankfull flow); and
5. Stream power relations based on the φ_{84}.

As a first approximation, current bankfull stage estimates were obtained by bio-indicators and geomorphic indicators in the field. These data were used to determine the bankfull flow rate (Q_{BFL}). Plots of drainage area versus bankfull flow rate were created and examined for consistency between successive sites on the same channel system. They were also compared to peak flow estimates for selected watersheds using NRCS, TR-55. In some instances, these estimates of bankfull flow were inconsistent with the drainage area-flow plots. As an example, site STB9 on Steven's Brook (DA = 6.9 mi^2), had a lower Q_{BFL} than STB7 or STB8 with drainage areas of 1.3 and 1.6 mi^2 respectively. In these cases the field estimate of bankfull stage was revisited using site photographs, bank sketches and ancillary data such as hydraulic geometry plots and stream power relationships. Where agreement between bankfull estimates using the various approaches could not be obtained, the flow estimates based on drainage area-flow curves were used.

3. Selection of Suitable Historic Cross-sections

An extensive search of municipal, State and federal archives was undertaken to locate engineering surveys containing historical cross-section data for the selected streams (see discussion in Section 2.2). The survey information was screened to obtain suitable quality cross-section data representative of historic channel conditions. Suitability was defined using the guidelines outlined in Table 2.5.

Table 2.5: Guidelines for Acceptance and Assessment of Historic Survey Data

Factor		**Ranking Criteria**			
		Most Desirable Rank=1; c=1	**Desirable Rank=2; c=1**	**Marginal Rank=3;c=1**	**Unacceptable c=0**
Degree of offset (α) of cross-sectional orientation to a line perpendicular to the channel centerline		0 to 10º	11 to 30º with geometric correction	31 to 45º with geometric correction	> 45º
Number of ordinates (ξ) defining the cross-section		$12	9 to 12	5 to 8	< 5
Channel geometry (β)		Well defined flood plain & channel	Distinguishable active channel	Poorly defined active channel	Active channel not readily identifiable
Channel planform location (φ)	Meandering pool-riffle stream	Riffle cross-over point	Riffle segment	Any location subject to conditions described under "unacceptable"	Alteration caused by 1) backwater; 2) sediment wedge; 3) knick point migration; 4) channelization & riparian maintenance programs
	Step-pool	Step crest	Step segment		
	Cascade-pool	Cascade crest	Cascade segment		
Area weighted average age of disturbance (g)		Historic cross-section survey pre-dates the initiation of disturbance or TIMP < 7%	Historic cross-section survey was recorded within 5 years of initiation of disturbance and 7%<TIMP<10%	Historic cross-section survey was recorded 5 to 10 years after initiation of disturbance and 10%<TIMP<15%	*Historic cross-section survey was recorded more than 10 years after initiation of disturbance and TIMP >15%

* not unacceptable, but Rank = 4; c =1.

The above guidelines provide a systematic methodology for the elimination of poor quality information and the assessment of the overall quality of the selected historic cross-sections. The method for assessment of the quality of the historic data (ζ_i) for any site used the following equation:

$$\varsigma_i = c\left(\frac{\alpha + \beta + \phi + \xi}{4}\right)\varepsilon$$

Based on the above guidelines, the original 27 historic cross-sections were reduced to a total of 13. These selected historic cross-sections were used to represent 16 current survey sites. Some of the historic surveys date back to 1922 (Tenney Brook) and others are as recent as 1981 (Steven's Brook). A site-by-site summary of the historic cross-section information is provided in Appendix F.

Using the above relation, the quality of the historic data for an individual site can be assessed as ζ=1 (most desirable) to ζ=13 (least desirable). An average value of the historic cross-sectional information (ψ) was determined as,

$$\psi = \frac{\sum_{i=1}^{n} \varsigma_i}{n}$$

in which "n" is the total number of sites and ψ is the average value of ζ for all sites. The value obtained using this relation can be interpreted as ψ=1 (most desirable) and ψ=13 (least desirable). In this instance, a value of ψ=4.79 (see Appendix F) was obtained indicating that the historic data may be considered to be of moderately high quality.

4. Determination of Historic Bankfull Cross-sectional Area

Bankfull flow is used to establish bankfull depth and subsequently, bankfull channel cross-sectional area for both current and historic conditions for the calculation of channel enlargement. Cross-sectional area is sensitive to small variations in bankfull depth, consequently, the accuracy of bankfull flow estimates is important to the success of the proposed procedure. Unfortunately, historical cross-section data are usually limited to cross-section ordinates without ancillary descriptions of boundary materials, riparian vegetation characteristics or fluvial features that may assist in the direct determination of bankfull stage. Consequently, indirect approaches must be employed to estimate the historical bankfull flow rate. A variety of methods have been used by other investigators, including:

1. Regional hydraulic geometry relations;
2. Regional flow relations
3. Historical flow time series;
4. Previous studies;
5. Empirical relations; and,
6. The interpretation of channel hydraulic geometry.

In this particular case, the first four possible approaches were not available. Consequently, bankfull stage must be determined indirectly from estimates of bankfull flow derived from empirical or channel hydraulic geometry approaches (#5 and #6 above). A procedure for the estimation of bankfull stage relying on channel hydraulic geometry uses the minimum point obtained from a plot of channel width (W) over depth (D) against channel cross-sectional area (A) (Leopold et al., 1964). This method provides a direct estimation of bankfull depth for streams having well defined active and flood plain channels and simple cross-sectional structure. This method is not appropriate for incised channel systems and requires interpretation for streams with complex cross-sectional forms. After a detailed analysis, this approach was not found to be applicable to the surveyed streams.

Therefore, two empirical techniques (#5 above) were analyzed to derive the historical bankfull cross-sectional area. The methods are described below:

Empirical Methods

The two empirical methods employed to determine historic bankfull flow were:

a) The ratio of post to pre-disturbance flow based on curves developed by Hollis (1975) relating the increase in flow rate to basin impervious cover; and,

b) The Runoff Coefficient Method where a runoff coefficient is assigned to both pervious and impervious surfaces and a subsequent flow ratio is calculated.

Both of the above Methods require completion of similar steps as listed below:

i) Estimate current bankfull flow $(Q_{BFL})_{CUR}$ and Total Basin Imperviousness $(TIMP)_{CUR}$;

ii) Estimate Total Basin Imperviousness under land use conditions at the time of the historic survey ($TIMP_{HIS}$);

iii) Using various empirical relations, determine historic bankfull flow ($(Q_{BFL})_{HIS}$) as a function of the change in basin imperviousness; and,

iv) Estimate bankfull cross-sectional area from hydraulic relations (curves expressing flow rate and channel cross-sectional area as a function of flow depth) developed from the historic survey data.

Steps i), ii) and iv) are the same for both of the above methods with the approach adopted for Step iii) being unique for each method. Each Step is briefly described in the following discussion.

STEP i): Bankfull flow under current land use conditions was determined for each site using five independent, corroborative approaches. In general, bankfull channel area and flow rate were then determined from flow-depth and depth-area curves developed from hydraulic analysis of the current cross-section and longitudinal survey data. The flow rates determined for sites within any watershed were checked for consistency using plots of flow rate versus drainage area (Figure 2.10).

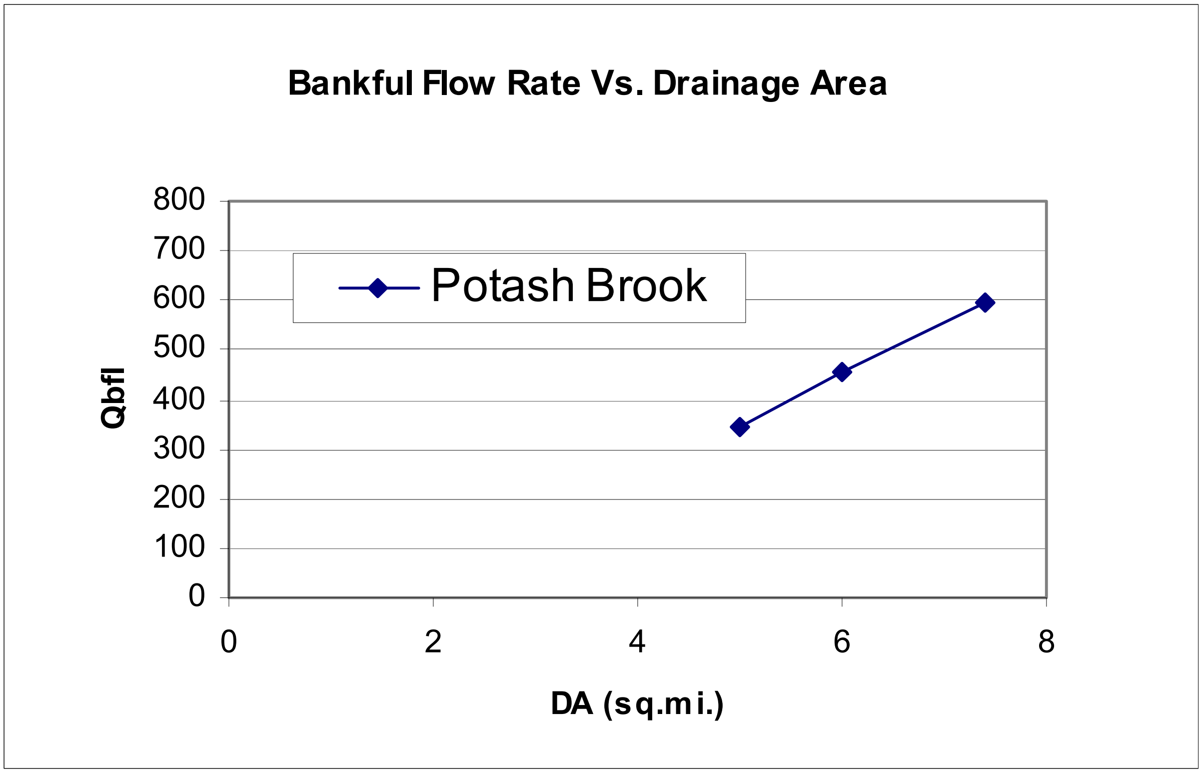


Figure 2.10: Example Plot of Flow Rate versus Drainage Area for Potash Brook

It should be noted that where the location of the historical and current cross-sections did not coincide, the bankfull flow rate for the current cross-section $(Q_{BFL})_{CUR}$, was prorated by Drainage Area (DA) to obtain the flow rate for the point tributary to the historic site.

STEP ii): Land use data generated from aerial photography, topographic maps and other sources were used to determine the nature and extent of the disturbance at the time of measurement of the historic survey as described in Section 2.7. These data provide estimates of the incremental area developed or disturbed and the equivalent Total Basin Imperviousness, $(TIMP)_{HIS}$ as a percent, associated with that disruption.

STEP iii)
Method A: Ratio of Post- to Pre-Disturbance Flow Based on Hollis (1975):

Hollis (1975) provides a graphical approach for estimating a ratio of post-development flow rate to pre-development flow rate as a function of watershed imperviousness and flow recurrence interval (Figure 2.11).

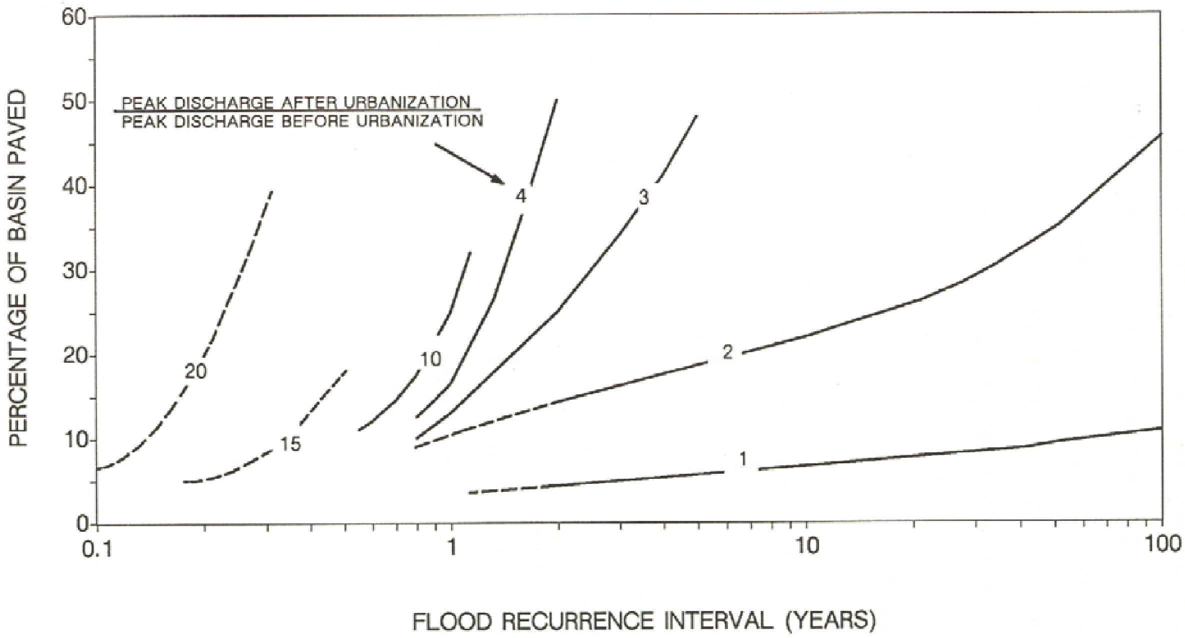


Figure 2.11: Illustration of the Effect of Urbanization on Flood Peaks for Various Recurrence Intervals (Hollis, 1975)

Application of this approach is illustrated using the Moon Brook (MOO1) site. Under current land use conditions basin imperviousness was determined to be $(TIMP)_{1998}$=13% and the bankfull flow rate was estimated at $(Q_{BFL})_{1998}$=100 cfs. The corresponding channel cross-sectional area was estimated to be $(A_{BFL})_{1998}$=41.3 ft^2. Correcting for differences in Catchment Drainage Area between the current and historic survey sites produced an adjusted flow rate of $[(Q_{BFL})_{1998}]_{ADJ}$=96 cfs. Based upon an assumed recurrence interval for bankfull flow of RI=1.5 years and $(TIMP)_{1998}$=13%, the ratio of post to pre-disturbance peak flow for the current survey period was estimated to be,

$$\left(\frac{(Qp)_{POST}}{(Qp)_{PRE}}\right)_{1998} = 2.04$$

Similarly, assuming RI=1.5 years with an historical $TIMP_{1954}$=9%, a ratio of post to pre-disturbance peak flow for the historical survey period was estimated to be,

$$\left(\frac{(Qp)_{POST}}{(Qp)_{PRE}}\right)_{1954} = 1.57$$

It should be noted that some development had occurred prior to the historic cross-section date of 1954. Consequently, some degree of impact is expected as indicated in the above ratio. The historic bankfull flow rate $(Q_{BFL})_{HIS}$ was then calculated as;

$$(Q_{BFL})_{1954} = \left[96cfs\left(\frac{1.57}{2.04}\right) \right] = 74cfs$$

By examining the flow-area relations determined from the hydraulic analysis of the historic cross-sections, the bankfull depth and associated cross-sectional area were estimated. For MOO1, a historic bankfull flow rate $(Q_{BFL})_{1954}$=74 cfs was found to corresponds to a cross-sectional area of $(A_{BFL})_{1954}$=33.8 ft^2 and a bankfull flow depth of $(D_{BFL})_{1954}$=2.7 feet.

Method B: Runoff Coefficient Method

In this approach a runoff coefficient is assigned to both pervious and impervious surfaces and a ratio of pervious to impervious drainage area for 1998 and the historic condition was calculated for each survey site. The coefficients used were C_{IMP}=0.95 for the impervious surfaces and C_{PER}=0.2 for the pervious surface area. The impervious and pervious areas were calculated from the TIMP values. The peak flow rate was then estimated using the Rational Formula,

$$Q_P = C \cdot I \cdot DA$$

in which, Q_P is the peak flow rate resulting from a rainfall of intensity (I), over the Drainage Area (DA) and C is the weighted runoff coefficient. The value of C can be expressed in terms of the pervious and impervious surface areas within a catchment as,

$$Q_P = C_{IMP} \cdot I \cdot A_{IMP} + C_{PER} \cdot I \cdot A_{PER}$$

in which, the area covered by impervious and pervious surface materials are represented by A_{IMP} = A_{TOT}·TIMP and A_{PER}=A_{TOT}·(1-TIMP) respectively, and, C_{IMP} and C_{PER} are runoff coefficients for the impervious and pervious areas respectively. Assuming total drainage area and rainfall intensity are constant over time they may be disregarded resulting in the following ratio of the peak flow rate under historic $(Q_{BFL})_{HIS}$) and current $(Q_{BFL})_{1998}$) land use conditions equated to the ratio of runoff coefficients under historic and current land use conditions,

$$\frac{(Q_{BFL})_{HIS}}{(Q_{BFL})_{CUR}} = \frac{C_{IMP}(TIMP)_{HIS} + C_{PER}(1 - TIMP_{HIS})}{C_{IMP}(TIMP)_{CUR} + C_{PER}(1 - TIMP_{CUR})}$$

Application of the above relation is illustrated below for Moon Brook, site MOO1.

$$\frac{(Q_{BFL})_{1954}}{[(Q_{BFL})_{1998}]_{ADJ}} = \frac{[(0.95 \cdot 0.09) + (0.2 \cdot (1 - 0.09))]}{[(0.95 \cdot 0.13) + (0.2 \cdot (1 - 0.13))]} = 0.899$$

Since $[(Q_{BFL})_{1998}]_{ADJ}$ is equal to 96 cfs, the resultant historical bankfull flow rate is $(Q_{BFL})_{1954}$=0.899(96) = 87 cfs. Using the stage-flow-area relationships from the hydraulic analysis of the historic cross-section a bankfull area of $(A_{BFL})_{1954}$=38.6 ft^2 and a depth $(D_{BFL})_{1954}$=2.9 ft was derived.

Comparison of Methods

Table 2.6 summarizes the estimates of channel cross-sectional area at bankfull stage for the historic channel area using the above methods.

Table 2.6: Comparison of Selected Methods For the Estimation of Historic Channel Cross-sectional Area at Bankfull Stage

Basin	**Site**	**Historical Cross-Sectional Area Estimate**			**1998 Survey Observed Cross-sectional Area $(A_{BFL})_{CUR}$ (ft^2)**
		Hollis Approach $[(A_{BFL})_{HIS}]_{HOL}$ (ft^2)	Runoff Coefficient $[(A_{BFL})_{HIS}]_{RC}$ (ft^2)	Average Value $(A_{BFL})_{His}$ (ft^2)	
Cold River	CLD4	reference			
	CLD5	reference			
	GLD6	reference			
Dowsville Brook	DOW1	n/a	n/a	n/a	n/a
	DOW2	60.5	65.3	62.9	105.5
	DOW3	55.2	59.7	57.5	51.1
Moon Brook	MOO1	33.8	38.6	36.2	41.3
	MOO2	51.3	58.5	54.9	37.4
Tenney Brook	TEN1	39.9	43.1	41.5	57.7
Potash Brook	POT1	47.1	55.2	51.2	75.6
	POT2	48.5	53.6	51.1	63.6
	POT3	40.2	44.1	42.2	59.9
Roaring Brook	ROA1	106.9	114.4	110.7	124.2
	ROA2	103.4	113.7	108.6	165.2
	RBT1	n/a	n/a	n/a	n/a
Smith Brook	SMI1	reference			
	SMI2	reference			
	SMI3	reference			
Stevens Brook	STB7	26.8	27.2	27.0	35.6
	STB8	28.6	30.2	29.4	30.4
	STB9	72.7	86.9	79.8	60.3
W. Branch Litter River	WBL1	[1]	305.7	305.7	379.0
	WBL2	[1]	313.8	313.8	433.0
	WBL3	[1]	227.3	227.3	216.4

Notes: n/a: not available; [1]: due to low impervious cover, parameter not computed

From Table 2.6, it can be seen that the two empirical methods provide similar estimates of historic channel cross-sectional area at bankfull stage for all sites. The Runoff Coefficient Method, however, produces consistently higher estimates in the order of approximately 9 percent on average. Since the values are, on average, within 9 percent of each other, the Hollis Method was deemed satisfactory and was the sole method used in the data analysis (see Section 3).

5. Determination of Enlargement Ratios

The determination of the enlargement ratio for Vermont involved the seven steps presented above (see Section 2.6.3: Step 5(a) to (g), pg. 2-20). As discussed in Section 1, the development of channel enlargement relationships for Vermont required measuring or estimating channel cross-sectional area at four distinct time periods: pre-disturbance, historic, current and ultimate. The methodology for computing the current bankfull cross-sectional area was described above in this Sub-Section (see 2.6.3 (2)). Likewise, in Sub-Section 2.6.3 (4) the method for calculating the historic cross-sectional area was explained. This discussion pertains to the determination of the channel enlargement ratio for Vermont streams in accordance with Step 5(a) through (g) as follows:

a. This step involved computing total basin impervious cover (TIMP). The methodology for calculating current and historic imperviousness is discussed in detail in Section 2.7.
b. This step involved the computation of the area weighted age of the development. This involved dividing the time from pre-disturbance to the date of the current survey into time periods corresponding to the dates of available land use mapping. The beginning and ending time period of each development epoch (dates of succeeding mapping) was noted and the area of the basin developed over that time period was computed. Each of these time periods, multiplied by their corresponding change in developed area were then added together and divided by the total developed drainage area (DDA). Section 1 presents a detailed discussion of this step.
c. In this step, the pre-disturbance cross-sectional area at bankfull stage is computed from the historic data. As discussed above, in most cases the historic channel cross-sectional data for the selected streams post-dated disturbance within the watershed. Therefore, in order to obtain a value for the pre-disturbance channel cross-sectional area, the *Relaxation Curve* (see Section 1) was used to project back through time to the pre-disturbance condition. This was accomplished by using the area weighted average age of development at the time of the historic channel survey (see Step b, above and Section 1), the known type of stream (i.e., AL, AL-RB, or RB), and the historic cross-sectional area at bankfull stage to arrive at the pre-disturbance cross-sectional area. In addition, as a check of the accuracy of the historic data, the current cross-sectional dataset was also projected back to the pre-disturbance condition (see discussion in Section 3).
d. In this step the historic and current enlargement ratios $(Re)_{HIS}$ and $(Re)_{CUR}$ are computed simply by dividing the historic bankfull cross-sectional area and current bankfull cross-sectional area by the pre-disturbance cross-sectional area, respectively.
e. This step required a computation to arrive at the ultimate channel enlargement ratio $(Re)_{ULT}$ or the expected maximum bankfull cross-sectional area assuming no additional watershed alteration. With the exception of the reference streams, the area weighted age of development for all the study streams was less than the "relaxation period" (the total time for mesoform channel features to reach equilibrium with altered watershed hydrologic conditions). Consequently, the "Relaxation Curve" was used to project into the future to the

ultimate condition. This was accomplished by using the area weighted average age of development at the time of the current channel survey (again, see Step b, above and Section 1), the known type of stream, and the current cross-sectional area at bankfull stage to arrive at the ultimate bankfull cross-sectional area.

f. In this step, the computed or "observed" ultimate channel enlargement ratios were compared with the values obtained by solving the original enlargement curve:

$$(\mathrm{Re})_{ULT} = 0.00158(TIMP)^2 + 0.00522(TIMP) + 1.0$$

The two sets of enlargement data were compared using statistical tests for variance and mean based on a hypothesis that the samples were drawn from the same population. If the two sets of data demonstrated agreement that was statistically significant, then the hypothesis was accepted with the conclusion that the original enlargement curve would be representative of Vermont conditions (at least for the streams selected for this study). If however the hypothesis was rejected, then the modification of the enlargement curve could be considered or a unique enlargement curve could be required for Vermont streams.

g. This step was undertaken where the hypothesis presented above was rejected. In this step, the dataset from the Vermont streams were integrated into the dataset from the previous studies to derive a new enlargement curve. A new hypothesis was presented using statistical tests for variance and mean to see if the Vermont samples were drawn from the same population of all previous data including the Vermont samples. The results of this analysis are presented in Section 3.

2.6.4: Quality Control

All data collected in the field were entered into spreadsheets for data analysis. In order to ensure accuracy and completeness of data, the raw data were printed to hard copy, where they were cross-referenced against field notes. Errors or anomalies were flagged and subsequently corrected in the spreadsheets.

In order to substantiate derived values a parallel corroborative approach was employed wherein a number of independent approaches were used to estimate a parameter value. If the different approaches converged on a unique solution then the estimate was considered reasonable. If agreement between the various approaches could not be obtained then the approaches were prioritized according to the perceived degree of reliability, and the estimate of the parameter value based on the most reliable approach was adopted. For an example of this approach, see the above discussion on the estimation of bankfull flow.

2.7: SUBWATERSHED LAND COVER ANALYSIS

The primary goal of this study was to help quantify the relationships between land cover alteration and stream health, specifically for Vermont streams. Impervious cover was used as the primary variable to describe land cover in each subwatershed. The impervious cover analysis included a factor accounting for "equivalent impervious cover" for logging and ski trails. In addition, an analysis of riparian forest buffers was completed in urban watersheds.

2.7.1: Impervious Cover Analysis

As a basis for analyzing each stream reach's quality, the impervious cover draining to each cross-section was calculated (See Table 2.7). The impervious cover was estimated in each drainage area using digital land use data provided by the Vermont Center for Geographic Information (VCGI) at the University of Vermont, in combination with aerial photography obtained from the Vermont Mapping Program. In watersheds with ski trails or logging, these disturbed pervious surfaces were accounted for using an "equivalent impervious cover." Finally, the average age of development was estimated using historical aerial photographs. The process was completed in five steps:

Step 1: Develop a land use dataset for the drainage area of each reach.
Step 2: Associate an impervious fraction with each land use category.
Step 3: Use the resulting data set to calculate impervious cover in the drainage area of each reach.
Step 4: In logged or ski development watersheds, add equivalent impervious cover for these disturbed pervious surfaces.
Step 5: Estimate the historical impervious cover based on aerial photographs.

Step 1: Develop a land use dataset for the drainage area of each reach

The end product of this step is a table that includes the area of each of the VCGI's "Land Use/Land Cover Codes" in each drainage area. VCGI provided the Center for Watershed Protection with land use/ land cover data layers for major watershed boundaries that included the watersheds of interest. This layer was developed from 1992-1993 satellite imagery. These data layers were then clipped using ArcView 3.1 (ESRI, Inc.) to create a land use layer for each drainage area. Figure 2.12 is an example GIS layer Moon Brook. Summary data for each drainage area were compiled to produce a table of land use areas. Table 2.8 includes the land use data extracted from this GIS layer.

Step 2: Associate an impervious fraction with each land use category

In this step, each land use code was assigned a corresponding impervious cover fraction. Agricultural land was assigned a value of 2%, and other non-urbanized land use or land cover categories were assigned a value of 0%. For urban and suburban land uses, including transportation, residential, commercial, industrial, and other urban land, aerial photos were consulted to develop impervious cover relationships specific to the watershed. This last analysis was not completed in Smith Brook or Cold River; the drainage areas to these reference streams had very little development, so standard impervious cover numbers were used to characterize the urban land uses in these subwatersheds. Table 2.9 includes the dates of the aerial photography used to estimate the current impervious cover in each subwatershed.

Table 2.7 Impervious Cover in Selected Streams

Stream	Section	Current Impervious Cover	Historic Impervious Cover
Moon/ Tenney	Lower Moon	13%	1974: 12% 1962: 11% 1942: 7%
	Upper Moon	13%	1974: 12% 1962: 9% 1942: 6%
	Tenney	6%	1974: 5% 1962: 4% 1942: 3%
Stevens	Lower Stevens	13%	1974: 12% 1962: 9% 1942: 8%
	Upper Stevens	11%	1974: 8% 1962: 8% 1942: 6%
Potash	Lower Potash	22%	1974: 19% 1962: 15% 1942: 3%
	Middle Potash	22%	1974: 19% 1962: 15% 1942: 3%
	Upper Potash	20%	1974: 17% 1962: 15% 1942: 3%
Roaring*	Lower Roaring	6%	Ski development started about 30 years ago, with very little other impervious cover. 1993: 7%
	Upper Roaring	7%	
	Trib	1%	--
West*	Lower West	2%	1974: 2% 1962: 1% 1942: 1%
	Middle West	2%	1974: 2% 1962: 2% 1942: 1%
	Upper West	3%	1974: 2% 1962: 2% 1942: 1%
Dowsville*	Lower Dowsville	6%	Logging occurred about three years ago. Very little other impervious cover.
	Trib	6%	
	Upper Dowsville	6%	

* Streams with an asterix have "equivalent impervious cover" added for ski trails or logging

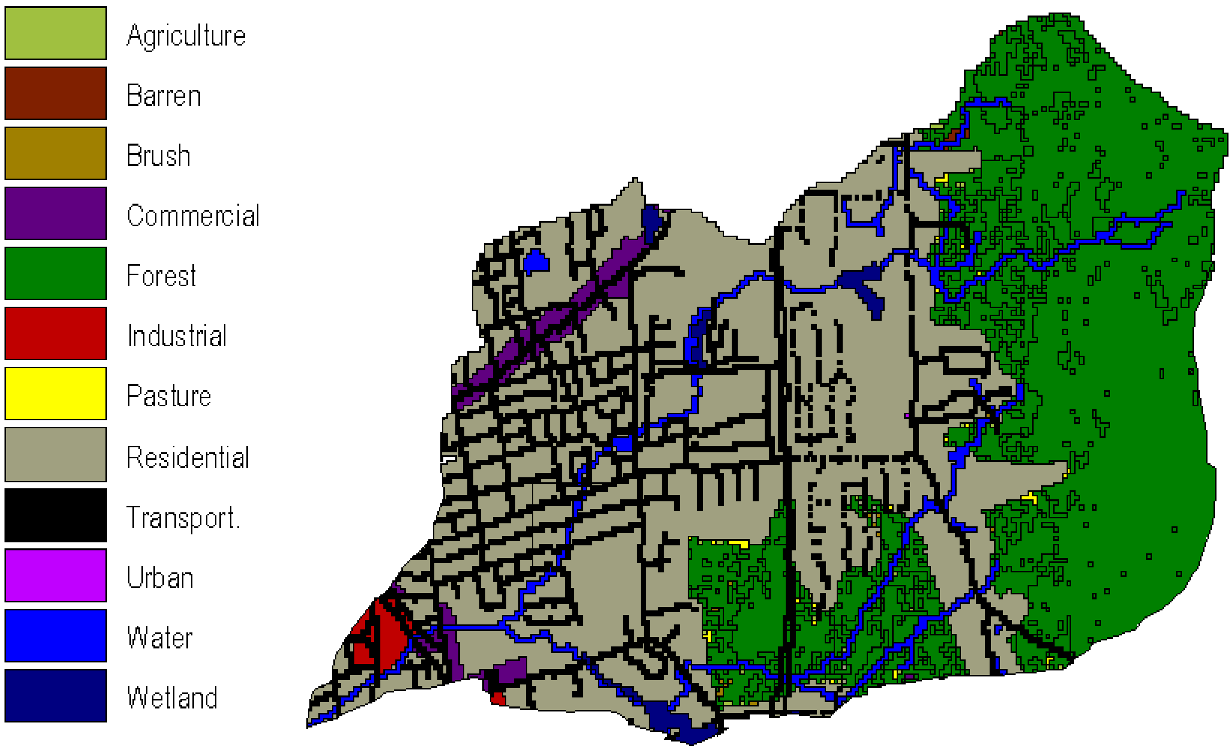


Figure 2.12: Land Use GIS Layer for Moon Brook

TABLE 2.8 LAND USE DATA IN MOON BROOK		
Land Use Code	**Land Use**	**Area (Acres)**
3	Brush/ Transitional	2.63
5	Water	137
7	Barren Land	1.70
11	Residential	1412
12	Commercial	53.6
13	Industrial	20.4
14	Transportation	426
17	Other Urban	0.15
24	Agriculture/ Mixed Open	0.31
41	Deciduous Forest	884
42	Coniferous Forest	200
43	Mixed Forest	208
62	Non- Forested Wetland	33.96
211	Row Crops	4.32
212	Hay/ Pasture	6.33
	Total	3,390

Table 2.9 Dates of Current Aerial Photography	
Stream	**Date**
Potash[1]	1988
Moon/ Tenney	1994
Stevens	1995
Roaring[2]	1994
West Branch[2]	1979-1988
Dowsville	1997

1: Supplemented with a current impervious cover digital layer, supplied by Jim Pease with ANR.
2: Supplemented with ski trail data

Transportation

For transportation land uses, impervious cover was computed based on a weighted average impervious cover for each of three types of roadways. An impervious fraction was assigned to each type of roadway, the length of each roadway type was determined, and a weighted average impervious cover for the transportation land use was established.

The transportation land use in the VCGI land cover/ land use layer includes roads of all classes, and utility lines. The average width of the transportation layer corridors as they appear in the GIS data layer is about 30 meters (98 feet). It was assumed that transportation represents the road right of way, so the impervious cover that would appear within the 98 foot corridor of a given roadway was estimated. The three types of roadways defined for these land use data were:

Major Highway (Interstate):

In general, interstate highways appear on the GIS system as two separate lines. Each side of an interstate highway was described as including two driving lanes, and two shoulders. Thus, total impervious cover included:

- Two 12' driving lanes
- Two 8' shoulders

Therefore:

IA = (2*12'+2*8')/98' = 41%

Minor Highways:

Minor highways were defined as undivided highways with two driving lanes in each direction, but which were represented on the GIS system as one line. The impervious cover for minor highways includes:

- Four 11' driving lanes
- Two 6' sidewalks, shoulders
- Additional 2' of impervious surface for each travel direction to account for turn and merge lanes

Therefore:

IA = (4*11'+2*6'+ 2*2')/98' = 61%

Residential Streets:

Residential streets were defined as relatively small roads with a single driving lane in each direction and sidewalks. The total impervious cover on residential streets includes:

- 30' roadway
- Two 4' sidewalks
- 2' to account and other impervious cover such as cul de sacs and shoulders

Therefore:

IA = (30'+2*4'+2')/98' = 41%

The total length of transportation (L_T) was calculated as:

$$L_T = A_T/98 \qquad (1)$$

Where:
A_T = Area of Transportation (Square Feet)

Major highways (e.g., interstates) and minor highways (e.g., state roads or main streets) were measured from aerial photos and street maps. The length of residential roads was determined using the following equation:

$$L_R = L_T - L_M - L_m - L_U \qquad (2)$$

Where:
L_R = Length of Residential Roads (Feet)
L_M = Length of Major Highways (Feet)
L_m = Length of Minor Highways (Feet)
L_U = Length of Utility Lines (Feet)

Finally, the average impervious fraction for the transportation land use was calculated using the weighted average equation:

$$I_T = 0.41C(L_R/L_T) + 0.41C(L_M/L_T) + 0.61C(L_m/L_T) + 0C(L_U/L_T) \qquad (3)$$

Where:
I_T = Impervious fraction for transportation

In the downstream section of Moon Brook, for example, the impervious cover for transportation was calculated using the following data:

A_T = 18,566,249 square feet
L_M = 0 feet
L_m = 39,928 feet
L_U = 17,913 feet

Applying equation 1:

L_T = 18,566,249/98 = 189,450 feet

Applying Equation 2:

L_R = (189,450 - 39,928 - 17,913) = 131,609 feet

Applying Equation 3:

$$I_T = 0.41\left(\frac{131{,}609}{189{,}450}\right) + 0.41\left(\frac{0}{189{,}450}\right) + 0.61\left(\frac{39{,}928}{189{,}450}\right) + 0\left(\frac{17{,}913}{189{,}450}\right) = 41\%$$

Residential Land Uses

The VCGI land uses codes include only one category for residential land, which may include anything from low density to multi-family residential. Thus, it was necessary to characterize the nature of urban land within each drainage area by sampling various types of residential land. In Moon Brook, for example, four types of residential land use were identified, and an impervious cover value calculated for each type by sampling an example block of this land use. In each of these blocks, impervious cover was calculated, excluding roads and sidewalks, by measuring the area of houses and other impervious cover. The area of impervious cover was then divided by the area of residential land in the sampling block.

One adjustment was needed to accurately depict the impervious cover for the area represented in the GIS land use layer. The area of the block that was sampled includes both residential land and transportation. Therefore, if the impervious cover were calculated using the area of the entire block, it would underestimate the impervious cover of the residential land depicted in the GIS system. In order to adjust for this bias, the area of the sampling block was multiplied by a factor that accounts for the area of the sampling block that is transportation. This factor is defined as:

$$f = 1 - \left(\frac{98 \bullet L_R}{A_R}\right) \qquad (4)$$

Where:

A_R = area of residential land (square feet)

Figure 2.13 illustrates the medium density residential sampling block used for the Moon Brook downstream section. The data used in this section included:

- 129 houses (2,200 square feet)
- 129 driveways (Use 475 square feet because some driveway area was counted as transportation)
- The sampling block area is 2,691,000 square feet.
- The area of residential land is 61,499,800 square feet
- The length of residential streets is 131,609 feet

Therefore, the impervious cover for medium density residential land (I_{MDR}) is determined by:

$$I_{MDR} = \frac{\#res.units\left(res.unit\ imp.area + driveway\, imp.area\right)}{sampling\, block\ area\left(1 - \frac{width\ res.ROW \bullet length\ res.street}{area\, of\ res.land}\right)} \quad (5)$$

or:

$$I_{MDR} = \frac{129 \bullet (2{,}200 + 475)}{2{,}691{,}000 \bullet \left(1 - \frac{98 \bullet 131{,}609}{61{,}499{,}800}\right)} = 16\%$$

Once the impervious cover was calculated for each type of residential land use, the average impervious cover for residential land was calculated using a weighted average. In the Moon Brook example, residential land uses were divided into four classes:

- High Density Residential(HDR), at 17% impervious and 10% of the total residential area
- Medium Density Residential (MDR)at 16% impervious and 25% of the total residential area
- Low Density Residential (LDR) at 10% impervious and 50% of the total residential area; and
- Other Residential (OR) at 25% impervious and 15% of the total residential area (Churches,

Figure 2.13: "Sampling Block" for Moon Brook

Cemeteries, Schools, etc.)

Therefore, the weighted average impervious cover for residential land within this subwatershed (I_R) is defined as:

$$I_R = \% \text{ area}_{HDR} (\% \text{ imp.}) + \% \text{ area}_{MDR} (\% \text{ imp.}) + \% \text{ area}_{LDR} (\% \text{ imp.}) + \% \text{ area}_{OR} (\% \text{ imp.}) \quad (6)$$

Where: I_R = percent impervious cover for residential land

Therefore:

$$I_R = 0.10(0.17) + 0.25(0.16) + 0.50(0.10) + 0.15(0.25)$$

Or,

$$I_R = 14\%$$

Commercial, Industrial, and Other Urban Land Uses

In general, these land uses constituted a very small fraction of the overall drainage area. Thus, although it was necessary to use aerial photographs to estimate the actual impervious cover associated with these land uses, a fairly simple methodology was used. For each land use, a sample area was measured to determine the impervious fraction, and this value was used to characterize the land use. For the area draining to the downstream section of Moon Brook, 80% impervious cover was estimated for commercial land and 60% impervious cover for industrial land.

Step 3: Use the data from the first two steps to calculate impervious cover in the drainage area of each section

In this step, the imperviousness was calculated in each drainage area based on a weighted average of the area of each land use/ land cover category and the imperviousness associated with that category. The land use data in Table 2.8 were combined with the impervious cover analyses described above to calculate the imperviousness in Moon Brook. A summary of the data used in this analysis is presented in Table 2.10. Appendix B has similar data for all watersheds in this analysis. Using these data, the impervious cover of Moon Brook was estimated as:

$$I = 13\%$$

Table 2.10 Summary Data for Moon Brook			
Land Use Code	**Land Use**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	2.63	0%
5	Water	137	0%
7	Barren Land	1.70	0%
11	Residential	1412	14%
12	Commercial	53.6	80%
13	Industrial	20.4	60%
14	Transportation	426	41%
17	Other Urban	0.15	60%
24	Agriculture/ Mixed Open	0.31	2%
41	Deciduous Forest	884	0%
42	Coniferous Forest	200	0%
43	Mixed Forest	208	0%
62	Non- Forested Wetland	33.96	0%
211	Row Crops	4.32	2%
212	Hay/ Pasture	6.33	2%
	Total	3,390	13%

Step 4: *In logged or ski development watersheds, add equivalent impervious cover for these disturbed pervious surfaces.*

Ski development or logging was significant in three of the watersheds in this study. Although these land uses do not add much impervious cover in the form of pavement or rooftops, the alteration of the land does impact stream quality and morphology. It is important to note that other pervious land uses, such as agriculture and urban lawns, also behave differently than forest in terms of hydrology.

However, ski trails and logging are unique in that they represent relatively recent disturbances. The purpose of this study is to evaluate the changes in the stream channel in response to upland development, largely by comparing a current cross-section to a historical cross-section. While converting forest to agriculture does alter hydrology, agriculture has generally existed long before the historical sections in this study. Similarly, while urban lawns may be a new form of impervious cover, they have often been developed to replace row crops or pasture, with little alteration to hydrology.

In this study, a simplified approach that relates pervious land disturbance with an "equivalent impervious cover" was used. The NRCS Curve Number approach (USDA, 1986) was used as the basis for this analysis. In this approach, a number known as a "curve number" is assigned to an area, based on landuse and soil type. Soils are divided into four "Hydrologic Soils Groups," labeled A through D, based on the infiltrative capacity of the soil. "A" soils are typically sandy, and allow the greatest fraction of precipitation to infiltrate into the ground's surface; "D" soils, on the other hand, usually contain large amounts of clay, and allow the least amount of infiltration of all the soil groups. Therefore, "D" soils produce the most runoff, while "A" soils produce the least runoff. Table 2.11 shows example curve numbers for various land uses and soils. Once the curve number is calculated, it can be used to determine the volume of runoff for various storm events.

Table 2.11 Example Curve Numbers (Source: USDA, 1986)

Land Use/ Land Cover	Condition	Curve Numbers for Hyrologic Soil Group			
		A	B	C	D
Straight Row Crops	Poor	71	80	87	90
	Good	67	78	85	89
Contoured Row Crops	Poor	70	79	84	88
	Good	65	75	82	86
Continuous Meadow	-	30	58	71	78
Forest	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Urban Lawns	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Paved Surfaces	-	98	98	98	98

When evaluating the equivalent impervious cover for a given curve number, the following assumptions were incorporated:

- The soils are a mixture of B and C soils.
- The "base" (i.e., zero impervious cover) land use is woods in good condition.

The curve number is determined as a weighted average of area and curve number for each land cover type. The curve number for a site with woods in good condition on B and C soils with impervious cover added could be determined by:

$$CN = 62.5(1- I) + 98(I) \qquad (7)$$

Where:

62.5 = the curve number for woods in good condition (B/C soils)
98 = the curve number for impervious surfaces
I = the impervious cover fraction
CN = curve number

Equation 7 was then rearranged to produce the equation used to determine the equivalent impervious cover associated with disturbed pervious surfaces, which is:

$$I_P = \frac{CN - 62.5}{35.5} \qquad (8)$$

Where: I_P = Equivalent impervious cover associated with a pervious surface

Both logging and ski slopes were assumed to have a curve number equivalent to lawn in fair condition. Thus, for B/C soils, the equivalent curve number would be 74. Therefore, the impervious cover associated with that land use was assumed to be 32%. Similarly, the curve number for gravel roads, or "work roads" was assumed to be 87, with an associated impervious cover of 69%. Assuming that work roads account for about 10% of the area in ski slopes, the impervious cover associated with ski slopes is approximately 35%. This same percentage (35%) was used to characterize the logged areas in Dowsville Brook. Therefore, the impervious cover for watersheds with logging or ski slopes is:

$$I = I_0 + \frac{0.35 \bullet A_P}{A} \qquad (9)$$

Where:

I_0=Impervious cover from paved surfaces
A_P = Area of disturbed pervious surfaces
A = Total area

An example of this technique is illustrated below for the upstream section of Dowsville Brook. Based on impervious surfaces, the impervious cover draining to this section was estimated as less than 1%. However, a significant portion of this watershed was logged. Using 1997 aerial photography, assisted with the identification of logged parcels from the Agency of Natural Resources' water quality monitoring report on Dowsville Brook (ANR, 1998), the logged areas in the Dowsville Brook watershed were identified (See Figure 2.14), and their areas measured. It was determined that:

I_0 = 0.01
A_P= 495 acres
A = 3,460 acres

Applying equation 9:

$$I = 0.01 + \frac{0.35 \bullet 495}{3{,}460} = 6\%$$

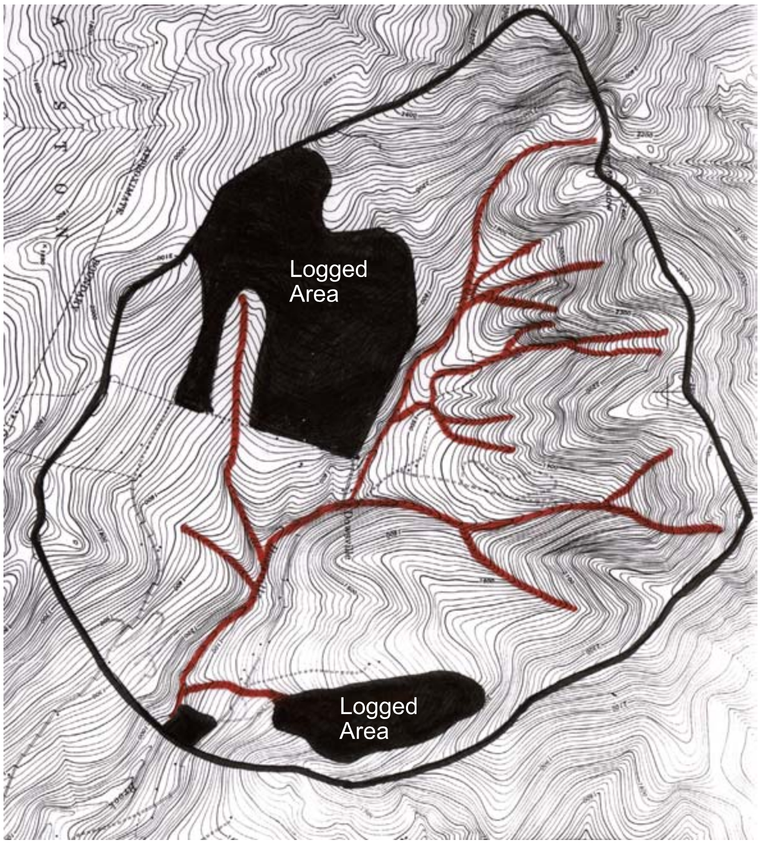


Figure 2.14: Dowsville Brook Watershed

<u>Test of the Curve Number Method</u>
The "equivalent impervious cover" technique was evaluated using a test subwatershed, the upstream section of the Roaring Brook subwatershed. Since the technique uses the SCS Curve Number technique (TR-55; USDA, 1986), the method used by the project team was validated by comparing flows computed using TR-55 with flows computed based on channel geometry.

The method was tested using the upstream section of the Roaring Brook subwatershed. (See Table 2.12 for a summary). Pioneer Environmental Associates of Middlebury, VT provided the Center with data for an area covering more than two thirds of this watershed. These data indicated that the subwatershed was almost entirely (98%) C soils. Thus, the analysis used curve numbers for C soils. Using land use data from the VCGI land use cover, combined with information about ski trails and work roads in the subwatershed, a curve number of 74 was calculated. A time of concentration of 0.52 hours, based on slopes from USGS quad sheets was used for the analysis. The bankfull storm event was assumed to be 2.4". This value is approximately equal to the 1 ½ year storm event for Killington, Vermont. The analysis revealed a peak discharge of 1,052 cubic feet per second. This is compared to a value of 1,332 cfs based on stream channel morphology characteristics. Since the value calculated using TR-55 is within 25% of the value calculated using channel morphology, it was assumed that using curve numbers to characterize pervious surfaces is acceptable.

Step 5: Estimate the historical impervious cover based on aerial photographs
When development has occurred in a watershed since the historical cross-section, it is especially important to quantify the average age of development. Historical aerial photographs were used to determine what the impervious cover was at various points in time. Rather than complete the entire impervious cover analysis for each year, each historical photograph was compared with the current aerial photograph and a determination was made as to how much impervious cover was added from the date of the historical photograph to the present. Historical imperviousness was calculated using the equation:

$$I_H = I_C - \frac{A_N}{A} \tag{10}$$

Where:

I_H = Historical Impervious Cover
I_C = Current Impervious Cover
A_N = Area of New Impervious Cover (Acres)
A = Drainage Area (Acres)

Table 2.12 TR-55 Analysis for Roaring Brook

PEAK DISCHARGE SUMMARY				
JOB:	vermont			
DRAINAGE AREA NAME:	roaring brook			20-Jan-99
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D?	CN *from* TABLE 2-2	AREA (In acres)
Brush		C	65	2.00 Ac.
Water			98	164.00 Ac.
Residential		C	77	22.00 Ac.
Commercial		C	93	18.00 Ac.
Transportation		C	85	91.00 Ac.
Ag/ Mixed Open		C	75	202.00 Ac.
Forest		C	70	1847.00 Ac.
Wetlands		C	75	17.00 Ac.
Row Crops		C	82	76.00 Ac.
Pasture		C	74	80.00 Ac.
Ski Trails/ Work Roads		C	80	368.00 Ac.
		AREA SUBTOTALS:		2887.00 Ac.
Time of Concentration 2-Yr 24 Hr Rainfall = 0.0 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	woods, light brush	'n'=0.40	100 Ft.	35.00% 0.13 Hrs
Shallow Flow	UNPAVED		2900 Ft. 10.20 F.P.S.	40.00% 0.08 Hrs.
Channel Flow (a) Hydraulic Radius =2.30	165.0 SqFt	'n'=0.039 71.7 Ft.	6000 Ft. 24.00 F.P.S.	13.00% 0.07 Hrs.
(b) Hydraulic Radius =2.50	1.8 SqFt	'n'=0.039 4.7 Ft.	6000 Ft. 15.74 F.P.S.	5.00% 0.11 Hrs.
(c) Hydraulic Radius =2.50	165.0 SqFt	'n'=0.039 4.7 Ft.	7000 Ft. 14.07 F.P.S.	4.00% 0.14 Hrs.
Total Area in Acres =	2887.00 Ac.	Total Sheet	Total Shallow	Total Channel
Weighted CN =	74.34083824	Flow=	Flow=	Flow =
Time Of Concentration =	0.52 Hrs.	0.13 Hrs.	0.08 Hrs.	0.31 Hrs.
Pond Factor =	0.95	RAINFALL TYPE II		
STORM	*Precipitation* (P) inches	*Runoff* (Q)	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1.5 Year	2.4 In.	0.6 In.	1052.6 CFS	5,935,167 Cu. Ft.

Figures 2.15 and 2.16 represent the current (1994) and 1974 aerial photographs for a portion of the Moon Brook drainage area. The circled sections on Figure 2.16 represent the areas that were present in 1994, but not in 1974. Using the measurements from aerial photographs, and the current impervious cover calculated in Step 3, it was determined that:

I_C = 0.13
A_N= 50 acres
A = 3,390 acres

Applying equation 10:

$$I_{1974} = 0.13 - \frac{50}{3,390} = 12\%$$

This analysis was repeated for the other historical photographs available, 1962 and 1942, with the following results:

I_{1962} = 11%
I_{1942} = 7%

These data were used to determine the average age of development in the drainage area. The average age of development was calculated based on the historical impervious cover. In Roaring Brook and Dowsville Brook, the historic impervious cover was not calculated for each year because most anecdotal information regarding logging or ski trail development provided a more accurate history of when disturbed pervious cover was added to these watersheds. In Dowsville Brook, logging did not occur until recently, and therefore no logging appeared on any historical photographs. In Roaring Brook, the primary source of information regarding ski trail development was a ski trail map supplied by John Cole of Killington Ski Resort, and a land use table supplied by Mary Nealon of Pioneer Environmental. Mr. Cole provided a narrative description of when ski trail development had occurred at Killington.

See Table 2.7 for the summary of historical impervious cover estimates for all of the study subwatersheds.

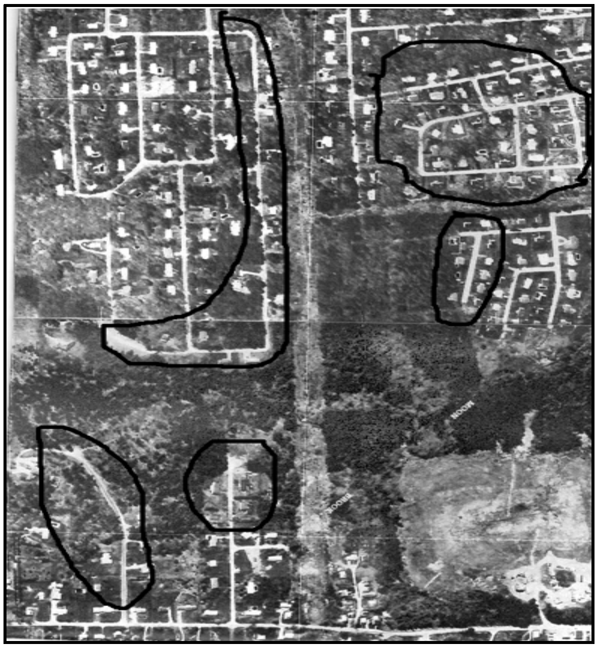


Figure 2.15: Current Aerial Photography in Moon Brook

Figure 2.16: 1974 Aerial Photography in Moon Brook

2.7.2: Riparian Buffer Analysis

As discussed in Section 1, the fourth element of the study involved an assessment of riparian cover along each stream within the urbanized subwatersheds. A few researchers have found that in addition to impervious cover, another factor that can impact stream health is the presence or absence of a riparian buffer. In one study of urban streams in the Puget Sound region of Washington State, a mature forest buffer was one of the two main factors influencing the biological integrity of streams; the other being impervious cover (May et al., 1996). Macroinvertebrate and fish data indicate that Potash Brook has a slightly better habitat value than Stevens Brook and Moon Brook, despite Potash's higher impervious cover (See Section 4). The project team considered the possibility that this disparity could be partially explained by a greater stream buffer in Potash Brook. However, the forest cover analysis revealed that the riparian cover in Potash Brook was in fact less extensive than in any of the other urban streams (see Table 2.13). This result indicated that another factor or series of factors may have slowed or alleviated habitat degradation in Potash Brook.

A simple methodology was used to estimate the extent of forest buffers in each subwatershed. The extent of the buffer was simply defined as the length of the forest buffer divided by the total stream length. The criteria used to determine the length of stream and buffer were:

- The stream length represents the total length of *perennial* streams based on USGS quad sheets. On the quad sheet for Potash Brook, all streams appeared as perennial streams. Thus, only streams greater than first order were included in the analysis. This assumption did not influence the final data significantly, but was made to ensure that the same criteria were used to evaluate each stream.
- A forest buffer is defined as at least a 50' width of forest cover along the stream, with at least 20' of forest cover on each side of the stream.

Forest buffers were identified based on aerial photography for each watershed, and the length of the buffer was recorded. This length was divided by the total stream length, as estimated from USGS quad sheets. In the case of Potash Brook, the most recent aerial photography was from 1988. These aerial photographs were used to make a "first cut" identification of impervious cover. Then, areas where new development occurred were identified based on VCGI land cover data. If no forest cover appeared around the stream on the land cover map, then it was assumed that there was no forest buffer in that stream section.

Table 2.13 Forest Buffer Length as a Fraction of Total Stream Length

Stream	Section	Buffer Fraction
Moon Brook	Lower	30%
	Upper	35%
Tenney Brook	--	55%
Stevens Brook	Lower	35%
	Upper	20%
Potash Brook	Lower	20%
	Middle	20%
	Upper	25%

A forest buffer is defined as at least a 50' width of forest cover along the stream, with at least 20' of forest cover on each side of the stream.

2.7.3: Wetland Analysis

Another factor that may influence a stream's response associated with watershed land use alteration is the amount of riparian wetlands along a stream segment. Wetlands can help to attenuate the flow of water through the system, trap sediment and associated pollutants and provide storage for stormwater runoff. Thus, a second analysis was completed, which determined the length of each stream that intersects with wetlands as determined by the National Wetlands Inventory (NWI). The analysis was completed by James Pease at the ANR, and involved overlaying streams (as they appeared in the VCGI database) with wetlands, and calculating the fraction of the length of stream that intersected these wetlands. The results of this analysis are included in Table 2.14. As the data indicate, Potash Brook has a greater amount of riparian wetlands than any stream with the exception of Tenney Brook. This may help to partially explain why Potash has better habitat value than Stevens Brook and Moon Brook.

Table 2.14 Riparian Wetland Length as a Fraction of Total Stream Length

Stream	Wetland Fraction
Moon Brook	12%
Tenney Brook	31%
Stevens Brook	7%
Potash Brook	26%
Roaring Brook	7%
West Branch	3%
Dowsville Brook	0%
Smith Brook	9%
Cold River	5%

SECTION 2.8: REPRESENTATIVE PHOTOGRAPHS OF SELECTED STREAMS

In this section several figures (Figures 2.17 through 2.29) are presented illustrating typical field conditions of the nine selected streams selected for assessment. The photographs were taken during the collection of field data from October 13 through October 18, 1998. Additional photographs of Potash Brook are included in Appendix C in the example of the Diagnostic Geomorphic Field Survey Form. Representative photographs of the remaining eight streams are on file with the Vermont Agency of Natural Resources.

Figure 2.17: Cold River - Looking Downstream

Figure 2.18: Dowsville Brook - Looking Downstream

Figure 2.19: Dowsville Brook - Watershed View Showing Logging Activity

Figure 2.20: Moon Brook - Looking Downstream at Small Debris Jam

Figure 2.21: Moon Brook - View of Right Bank Soil Profile

Figure 2.22: Tenney Brook - Looking Downstream

Figure 2.23: Roaring Brook - Looking Upstream

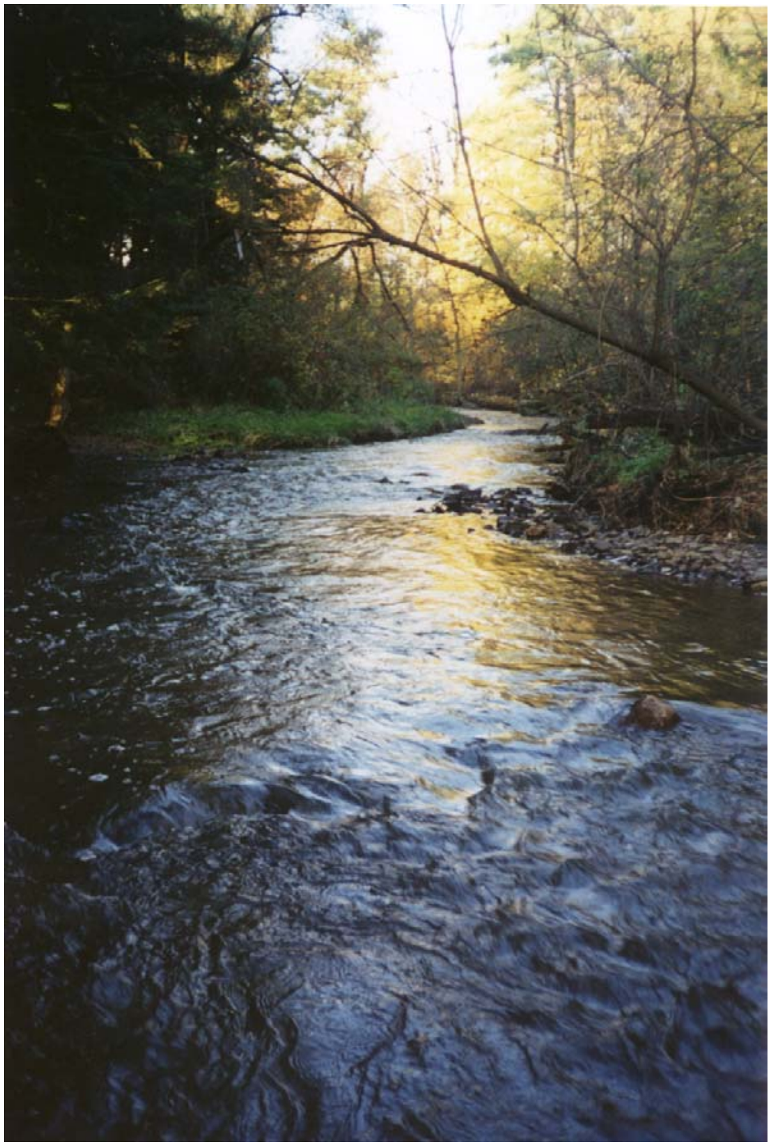


Figure 2.24: Potash Brook - Looking Upstream

Figure 2.25: Smith Brook - Looking Upstream

Figure 2.26: Stevens Brook - Looking Upstream

Figure 2.27: Stevens Brook - Field Survey Equipment

Figure 2.28: West Branch Little River - Looking Downstream

Figure 2.29: West Branch Little River - Looking Upstream

SECTION 3

SUMMARY OF FIELD GEOMORPHIC ASSESSMENT DATA

3.0: SUMMARY OF GEOMORPHIC ASSESSMENT

The results of the stream geomorphic assessment are presented and discussed herein under four major sub-sections as outlined below.

Section 3.1 presents the results of the channel hydraulic data collection and analysis. The physical parameters that characterize the current stream channel conditions are presented in Table 3.1. These parameters include bankfull depth, width, and cross-sectional area, as well as the bankfull flow rate, Manning's 'n', channel slope (S), total basin imperviousness (TIMP) and catchment drainage area (CDA). These data were used to compute the channel Enlargement Curves.

Section 3.2 summarizes the development of the Enlargement Curves for Vermont conditions. The original Enlargement Curve was developed from data from streams outside of New England. Specifically, data from the eight Vermont subwatersheds are used to test whether this Enlargement Curve can be applied to Vermont with statistical significance, or whether additional data are needed to generate Vermont specific Enlargement Curves.

As discussed in Section 2.6, one of the key tasks of the project was to conduct the Rapid Geomorphic Assessment (RGA) procedure in Vermont to establish whether physical, climatological, or geological conditions specific to Vermont would alter or modify channel stability relationships developed in other regions of North America. The results of the RGA and its applicability to Vermont conditions are presented in Section 3.3

Section 3.4 summarizes the use of the pebble count data and bank material characterization components of the study.

3.1: Summary of Active Channel Hydraulic Parameters

The results of the active channel hydraulic data analysis are presented in Table 3.1. This table lists the physical characteristics of each cross-section as measured in the field or subsequently computed using the procedures described in Section 2.6.

One component of the study was to assess the land cover/stream condition relationship pertaining to forestry activities and upland (ski slope) development. In general, these activities do not add significant amounts of impervious area to a watershed but can alter watershed hydrology and thus, erosive energy. In order to incorporate this type of disturbance into the geomorphic assessment, an "equivalent impervious cover" was assigned to these land uses in the W. Branch of Little River, Roaring Brook, and Dowsville Brook watersheds. Section 2.7.1 details the technique by which impervious cover percentages were assigned to these areas. A test was conducted on the Roaring Brook watershed to help assess the validity of this technique. Table 3.1 lists the computed bankfull flow rate using the measured geometry of the channel, the derived bankfull roughness coefficient (n), and the computed slope (S). The bankfull flow rate generated from the measured channel parameters of Q_{BFL}=1332 cfs compares favorably with the rate of 1053 cfs computed using the NRCS, TR-55 technique presented in Section 2.7.1.

Table 3.1 also lists the current bankfull cross-sectional area. This is the key "observed" value that is used to compute the enlargement ratios as discussed in Section 3.2.

Table 3.1.   Summary of Active Channel Bankfull Morphometrics

Basin	Site	TIMP (%)	D_{BFL} (ft)	w_{BFL} (ft)	A_{BFL} (ft^2)	Q_{BFL} (cfs)	n_{BFL}	S (ft/ft)	CDA (mi^2)
Cold	CLD4	1	4.5	79.9	201.2	1504	0.043	0.0139	20.7
	CLD5	1	2.3	65.5	52.2	264	0.039	0.0246	4.1
Gould	GLD6	1	3.4	46.0	110.3	1139	0.038	0.0228	10.6
Dowsville	DOW1	2	1.5	18.5	13.5	112	0.046	0.1031	0.5
	DOW2	6	2.4	75.9	105.5	668	0.048	0.0272	6.4
	DOW3	6	2.7	27.6	51.1	500	0.039	0.0300	5.4
Moon	MOO1	13	3.3	21.0	41.3	100	0.032	0.0012	5.3
	MOO2	13	3.4	25.7	37.3	84	0.038	0.0022	3.0
Tenney	TEN1	6	2.4	39.6	57.7	405	0.034	0.0156	4.4
Potash	POT1	22	3.4	33.1	75.6	596	0.037	0.0121	7.4
	POT2	22	2.6	30.9	63.6	456	0.035	0.0116	6.0
	POT3	20	2.4	52.3	59.9	345	0.038	0.0182	5.0
Roaring	ROA1	6	5.6	36.8	124.2	1577	0.055	0.0466	5.4
	ROA2	7	5.0	70.9	165.2	1332	0.039	0.0154	4.5
	RBT1	1	2.1	33.2	28.6	181	0.035	0.0283	0.7
Smith	SMI1	1	2.5	28.9	53.6	570	0.040	0.0385	3.2
	SMI2	1	2.2	33.1	53.6	525	0.040	0.0385	3.2
	SMI3	1	3.2	30.2	51.9	523	0.041	0.0385	3.2
Stevens	STB7	11	2	20.6	35.6	250	0.044	0.0243	1.4
	STB8	11	1.9	25.1	30.4	116	0.027	0.0040	1.4
	STB9	13	2.6	31.7	60.3	584	0.043	0.0341	6.9
West Branch	WBL1	2	6.4	157.9	379.0	2931	0.034	0.0100	24.0
	WBL2	2	7	144.2	433.0	2769	0.036	0.0556	23.4
	WBL3	2	4	71.5	216.4	2049	0.038	0.0139	17.0

TIMP = Total Basin Imperviousness, D_{BFL} = Bankfull channel depth, W_{BFL} = Bankfull channel width
A_{BFL} = Bankfull channel cross-sectional area, Q_{BFL} = Channel bankfull flow rate
n_{BFL} = Manning roughness coefficient at bankfull depth, S = Channel longitudinal slope
CDA = Cumulative basin drainage area

Section 3.2: Summary of Channel Enlargement Analysis

Table 3.2 presents the results of the channel enlargement assessment for the selected subwatersheds. As stated in Section 1, the assessment of the modifications to channel form as a function of altered land cover is being tested through an empirical analysis of data collected from other streams located in Texas, Pennsylvania, New York, British Columbia and Ontario. These prior collected data have been compiled into an Enlargement Curve that represents the ratio of the ultimate channel cross sectional area at bankfull stage divided by the pre-disturbance channel cross-sectional area at bankfull stage.

The hypothesis being tested is that if this curve can be applied to the unique morphologic and hydrometric conditions in Vermont, then the curve can provide a predictive tool for the assessment of land use change on the morphology of Vermont streams. To test the validity of the "Curve" on

Vermont streams, channel enlargement was calculated for selected sites where historic data could be obtained to characterize the pre-disturbance channel form. A total of 16 sites within six of the eight subwatersheds were selected for evaluation as impacted reaches (note, Moon Brook and Tenney Brook are considered to be within the same watershed as they both drain to Otter Creek). The remaining eight sites represent "reference" streams. The "observed" values were then compared to the values predicted using the existing Enlargement Curve using tests of variance and mean to determine if they are drawn from the same population.

Table 3.2. Summary of Channel Enlargement Assessment

Basin	Site	Historic Channel Survey Data				Current Channel Survey Data				$[(Re)_{ULT}]_{OBS}$	$(A_{BFL})_{PRE}$
		A_{BFL} (ft^2)	t_i (yrs)	TIMP (%)	$(Re)_i$	A_{BFL} (ft^2)	t_i (yrs)	TIMP (%)	$(Re)_i$		(ft^2)
Cold	CLD4	Reference Stream				201.2	46.7	2.0		Reference Stream	
	CLD5	Reference Stream				52.2	80.5	1.0		Reference Stream	
Cold (Gould)	GLD6	Reference Stream				110.3	80.5	1.0		Reference Stream	
Dowsville	DOW1	Reference Stream				13.5	46.7	5.8		Reference Stream	
	DOW2	60.5	19.5	1.0	1.00	105.5	23.4	5.8	1.04	1.91	60.5
	DOW3	55.2	19.5	1.0	1.00	51.1	23.4	5.8	1.04	1.01	55.2
Moon	MOO1	33.8	19.1	9.3	1.07	41.3	53.7	13.0	1.35	1.39	31.7
	MOO2	51.3	19.8	7.7	1.05	37.4	49.7	13.0	1.32	0.84	48.7
Tenney	TEN1	39.9	4.3	1.0	1.00	57.7	49.6	6.0	1.11	1.50	39.9
Potash	POT1	47.1	14.1	14.4	1.08	75.6	41.5	22.0	1.61	2.18	43.5
	POT2	48.5	14.1	14.4	1.08	63.6	41.5	22.0	1.61	1.78	44.8
	POT3	40.2	13.1	10.6	1.10	59.9	42.7	20.0	1.81	1.76	36.4
Roaring	ROA1	106.9	25.0	1.5	1.01	124.2	30.6	6.0	1.17	1.29	105.9
	ROA2	103.4	25.0	1.5	1.01	165.2	28.0	7.0	1.07	1.78	102.4
	RBT1	Reference Stream				28.6	46.7	2.0		Reference Stream	
Smith	SMI1	Reference Stream				53.6	80.5	1.0		Reference Stream	
	SMI2	Reference Stream				53.6	80.5	1.0		Reference Stream	
	SMI3	Reference Stream				51.9	80.5	1.0		Reference Stream	
Stevens	STB7	26.8	41.7	8.8	1.15	35.6	48.9	11.0	1.24	1.65	23.3
	STB8	28.6	40.2	8.3	1.13	30.4	48.9	11.0	1.24	1.30	25.3
	STB9	72.7	33.1	12.0	1.18	60.3	52.8	13.0	1.34	1.05	61.5
West Branch	WBL1	303.8	32.0	2.0	1.02	379.0	55.0	2.0	1.03	1.28	299.2
	WBL2	336.5	32.0	2.0	1.02	433.0	55.0	2.0	1.03	1.32	331.4
	WBL3	227.3	43.3	3.0	1.00	216.4	55.0	3.0	1.02	0.99	226.9

A_{BFL}= Bankfull channel cross-sectional area; t_I= area weighted average age of disturbance;
TIMP = Total Basin Imperviousness; $(Re)_i$ = Enlargement Ratio at time t_I(i.e., current cross-section);
$[(Re)_{ULT}]_{OBS}$ = Ultimate channel Enlargement Ratio, based on observed survey data;
$(A_{BFL})_{PRE}$ = Pre-disturbance channel bankfull channel cross-sectional area

The pre-disturbance cross-sectional area at bankfull stage was estimated from the historic survey data. In some instances, the historic sites were surveyed subsequent to significant disturbance within the watershed. In such circumstances, the historic survey cross-sectional area may not be representative of the pre-disturbance condition. To obtain an estimate of the pre-disturbance channel, the Relaxation Curve was used. The Relaxation Curve predicts how channel cross-sectional area adjusts through time(see discussion in Section 1). Using previously collected data, different Relaxation Curves have been developed for boundary materials of differing resistance. Consequently, by knowing the area weighted average age of disturbance from the time of the survey and the resistance of the boundary materials, it was possible to project back through time to the pre-disturbance channel form. Once the pre-disturbance channel area was obtained, the post-disturbance ultimate channel enlargement ratio was determined as the ratio of post-development cross-sectional area to the pre-development cross-sectional area (measured at bankfull stage).

The current channel cross-sectional area was calculated from the cross-sectional survey data collected as part of this study in the vicinity of the historic survey locations. Bankfull flow was determined using the Hollis method as described in Section 1 and Section 2 of this report. Bankfull stage was then established from a plot of flow rate as a function of flow depth for each channel section and the corresponding cross-sectional area was obtained from a plot of area versus flow depth. Total Basin Imperviousness (TIMP) and the area weighted average age of development was determined for the pre-disturbance, historic (if not the pre-disturbance condition) and current conditions. The amount of channel enlargement was determined for the current channel and the historic channel, if the later was not the same as the pre-disturbance condition.

The Relaxation Curve was employed to estimate the ultimate channel enlargement ratio using both the historic and current cross-sectional data. Ideally the historic survey data would satisfy the following conditions:

A. Represent the pre-disturbance condition; and,
B. The current survey would be taken immediately adjacent to or at the historic survey site.

It can be seen from the estimates of Total Basin Imperviousness (TIMP) and the Enlargement Ratio ($(\mathrm{Re})_i$) from the historic survey data reported in Table 3.2 that the historic survey data may be considered representative of the pre-disturbance channel state for 8 of the 16 historic survey sites. In other words $(\mathrm{Re})_i$ is approximately unity for eight of the sites. The degree of enlargement experienced by the remaining sites at the time of the historic survey ranged from 1.05 to 1.18 with a mean value of $[(\mathrm{Re})_i]_{HIS}$=1.11. In contrast, the enlargement ratio for the current survey data ranged from 1.04 to 1.81 with a mean value of $[(\mathrm{Re})_i]_{CUR}$ =1.25, indicating a greater degree of impact had occurred since the time of the historic surveys.

For the non-reference stream sites, the pre-disturbance channel area was approximated by projecting backward through time. Two of the channels were classified as RB-Type streams while the remaining channels were considered to be AL-Type systems (Table 3.3). Consequently, Relaxation Curves for both AL- and RB-Type channels were required for the estimation of the pre-disturbance channel cross-section area. The procedure for "hind casting" and "forecasting" to obtain values for $(\mathrm{Re})_{ULT}$ was as follows (see Appendix D for a sample calculation using Potash Brook, station POT1, as an example):

Using the Relaxation Curve presented in Section 1:

$$\left(\frac{(\mathrm{Re})_i - 1}{(\mathrm{Re})_{ULT} - 1}\right) = 1.032\left(\frac{(t_i - t_l)}{(t_r - t_l)}\right) - 0.028, R^2 = 0.91, n = 54$$

1. Enlargement and Relaxation Curves for AL- and RB-Type channels derived from data collected for non-Vermont streams were assumed to be representative of Vermont conditions;
2. The value of the area weighted average age of development (t_i) was determined from land use, and lag time (t_l) and total relaxation time (t_r), were determined based on stream type;
3. The value of $(Re)_{ULT}$ was estimated using the original Enlargement Curves for the appropriate stream type;
4. The Relaxation Curves were solved to obtain an estimate of the historic enlargement ratio $[(Re)_i]_{HIS}$ - i.e., that amount of enlargement that had occurred at the time of the historical cross sectional survey;
5. This estimate of the amount of channel enlargement was then used to obtain an estimate of the pre-disturbance channel cross-sectional area from the historic survey data set $[(A_{BFL})_{PRE}]_{HIS}$;
6. The value for $(Re)_{ULT}$ from the original Enlargement Curve and the Relaxation Curve was then used to compute the ultimate cross sectional area from the current data set $[(A_{BFL})_{ULT}]_{CUR}$. The "observed" value of the ultimate channel enlargement $[(Re)_{ULT}]_{OBS}$ was computed by dividing $[(A_{BFL})_{ULT}]_{CUR}$ by $[(A_{BFL})_{PRE}]_{HIS}$.

With respect to the location of the current survey in relation to the historic survey, the current survey sites were located as close to the historic survey sites as possible. This was desirable to limit differences in channel morphology that may be attributed to variations of hydraulic and boundary material characteristics. In some instances, however, the historic sections were modified following completion of the historic survey precluding the location of the current survey immediately adjacent to or at the historic site. Consequently, site-by-site comparisons of the data for a particular site are not possible. However, site-specific discrepancies may be overcome when the data are analyzed collectively.

The application of a statistical approach assumes that errors in the data will result in an equal over and underestimation of the actual cross-sectional area. This condition is not completely satisfied. In selection of the historic cross-sections an effort was made to select sites within straight reaches or at riffle crossover points. This could not be achieved in all cases because mapping illustrating planimetric channel form was not available for most historic sites. Consequently, some historic sections may have been located within meander bends. Given that channel cross-sectional area may vary between a meander bend and a riffle section, with slightly larger areas being observed along meander bends, a slight overestimation of the pre-disturbance channel area may result when using the historic data. It is anticipated, however, that this error is within the limits of measurement error of the methodology employed. Consequently, it is not expected to alter the conclusions presented in this study.

The ultimate channel enlargement ratio was predicted using the original channel Enlargement Curve based on TIMP values reported for the Vermont streams. A second order polynomial form for AL-Type and an exponential function for RB-Type streams was adopted, as noted below, because they provided the highest degree of correlation with the data, *Original Channel Enlargement Curve for AL- Type Streams Based on Non-Vermont Data*

$$\boldsymbol{AL-Type:}(\mathrm{Re})_{ULT} = 0.00135(TIMP^2) + 0.0167(TIMP) + 1.0,$$
$$\{R^2 = 0.78, n = 38\}$$

Original Channel Enlargement Curve for RB- Type Streams Based on Non-Vermont Data

$$\boldsymbol{RB-Type}:(\mathrm{Re})_{\boldsymbol{ULT}} = \boldsymbol{e}^{(0.0229(\boldsymbol{TIMP}))}$$
$$(\boldsymbol{R}^2 = 0.15, \boldsymbol{n} = 20)$$

The R^2 value for the RB-Type streams is low because the data span a small range in TIMP values and therefore create a cluster of points through which the curve was fitted (the curve is forced through TIMP=1.0 and $(\mathrm{Re})_{ULT}$=1.0). This cluster of points also limited the fitting of a 2nd order polynomial, which is considered to be the preferred model. Comparison of the enlargement ratios calculated from the Vermont data (observed ratios) and those predicted using the above relations are presented in Table 3.3.

The mean value of the Vermont data set ($\mathbf{x_1}$=1.44) is higher than the mean derived from the values predicted using the above relations ($\mathbf{x_2}$=1.35) possibly because of the sampling protocol for historic sites as noted previously. The variance for the Vermont data is also higher than that obtained from the predicted values although this is not unexpected. Despite these differences, a comparison of the variance and mean for these samples (n=16) concluded that these data are drawn from the same population at the 95% confidence limit. Consequently, it was concluded that the original Enlargement Curves may be representative of Vermont conditions as represented by the sample sites.

The Enlargement Curves for AL- and RB-Type streams were revised by integrating the Vermont data into the original data base and undertaking a curve fitting process. For AL-Type streams a second order polynomial provided the best fit to the data resulting in the following relation:

Revised Channel Enlargement Curve for AL-Type Streams Incorporating Vermont Data

$$\mathrm{AL-Type:}(\mathrm{Re})_{ULT} = 0.0013(TIMP^2) + 0.0168(TIMP) + 1.0$$
$$(R^2 = 0.83, n = 52)$$

This relation was found to be statistically significant at the 0.05 level. Estimates of channel enlargement from the revised equation are presented in Table 3.1.

Table 3.3 Comparison of Observed and Predicted Channel Enlargement Ratios

Basin	Site	Stream Type	TIMP (%)	$(Re)_{ULT}$ Observed[1]	Predicted: Original Equation	Predicted: Revised Equation
Dowsville	DOW2	AL	6	1.91	1.14	1.15
	DOW3	AL	6	1.01	1.14	1.15
West Branch	WBL1	AL	2	1.28	1.04	1.04
	WBL2	AL	2	1.32	1.04	1.04
	WBL3	AL	3	0.99	1.06	1.06
Moon	MOO1	AL	13	1.39	1.44	1.44
	MOO2	AL	13	0.84	1.44	1.44
Tenney	TEN1	AL	6	1.50	1.14	1.15
Potash	POT1	AL	22	2.18	2.02	2.00
	POT2	AL	22	1.78	2.02	2.00
	POT3	RB	20	1.76	1.59	1.60
Roaring	ROA1	RB	6	1.29	1.15	1.15
	ROA2	AL	7	1.78	1.18	1.18
Stevens	STB7	AL	11	1.65	1.34	1.34
	STB8	AL	11	1.30	1.34	1.34
	STB9	AL	13	1.05	1.44	1.44
Mean				1.439	1.345	1.344
Variance				0.14	0.10	0.09

[1] Observed values for $(Re)_{ULT}$ based on current cross sectional survey data "forecasted" to ultimate conditions

Tests for variance and mean between the predicted values using the revised curve and the observed enlargement values concluded that these data were drawn from the same population at the 95% confidence limit. Figure 3.1 provides an illustration of the revised Enlargement Curve for AL-Type streams with the Vermont data and non-Vermont data superimposed on the curve. As anticipated, the revised curve closely approximates the original curve. It was concluded from this assessment that the revised Enlargement Curve is representative of Vermont conditions as represented by the sample sites. Consequently, the revised curve can provide a reasonable basis for the prediction of the impact of land use alteration on channel form for streams in the State of Vermont whose morphology is similar to the study streams.

A similar analysis was conducted for the RB-Type streams. Unfortunately, the number and distribution of data points is not conducive to the fitting of a second order polynomial. In this case an exponential function forced through the point (1,1) provided the best fit to the data. The resulting equation is of the form:

Revised Channel Enlargement Curve for RB-Type Streams Incorporating Vermont Data

$$\text{RB - Type:} (\text{Re})_{\text{ULT}} = e^{(0.0234(\text{TIMP}))}$$
$$(R^2 = 0.59, n = 22)$$

This relation was found to be significant at the 5.0% confidence limit. The square of the correlation coefficient increased significantly with the addition of the two Vermont data points because of their plotting position outside of the cluster of data points represented by the original data set. It was concluded from this assessment that revised regression was also applicable to Vermont conditions as characterized by the limited number of RB-Type streams tested.

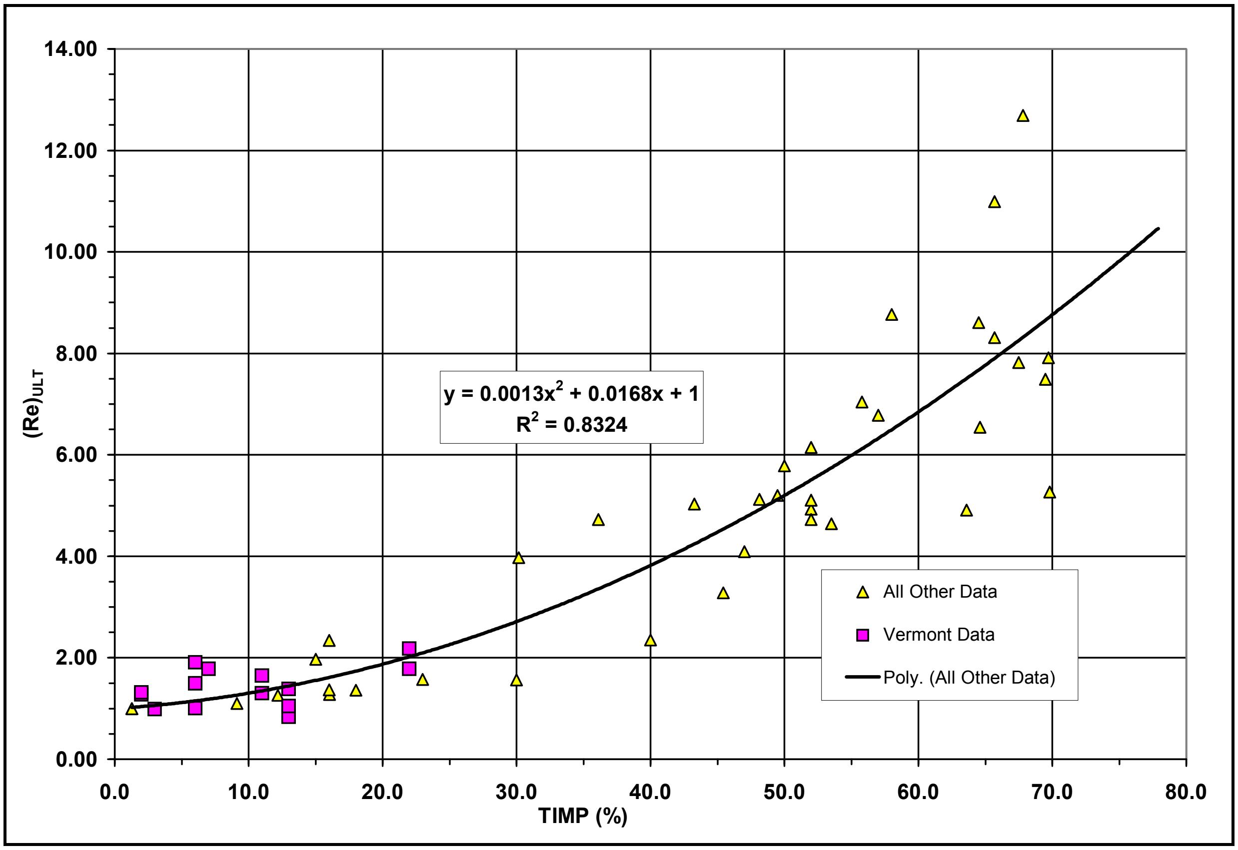


Figure 3.1: Channel Enlargement Curves as a Function of Total Impervious Cover Illustrating Revised Enlargement Curve, Observed Enlargement Ratios for Vermont Streams (Squares) and All Other Stream Data (Triangles).

Section 3.3: Summary of Channel Stability Assessment

In order to customize the RGA procedure for Vermont conditions, three additional stream assessment parameters were investigated to help determine, in a quantitative sense, whether a stream is *stable, transitional,* or *in adjustment* (refer to discussion in Section 2.6). These three parameters included the number, orientation, and location of Large Organic Debris (LOD) pieces, LOD Jam characteristics, and measures of stream riffle continuity. These parameters were selected as potential indicators of early signs of stream channel alteration. Since many of the subwatersheds included in the study were in the lower range of impervious cover (all less than 25%, and most less than 12%), this was viewed as a significant element towards customizing the RGA procedure for

Vermont conditions. However, in order for these new assessment parameters to be valid as channel alteration indicators, it was necessary to test whether each parameter related to the channel Stability Index in a statistically significant manner. The results of these investigations are summarized in Sections 3.3.1 through 3.3.4.

Section 3.3.1: Results of Channel Stability Assessment

The Stability Index (SI) is a measure of the departure of metrics describing channel morphology from the expected channel form. A channel is considered to be stable if its metrics are within one standard deviation of the mean obtained for "stable" channels within similar hydrographic and physiographic regions. These statistics are normally derived from a regional database. In the absence of such a data base, as is the case for this study, the SI values defining Stable, Transitional and In Adjustment are taken from previous studies.

Table 3.4 Summary of Channel Stability Assessment Using the Modified Rapid Geomorphic Assessment Form

Basin	Site	RGA FACTOR				Stability Index(1)	Stability Class	Channel Type
		AI	DI	WI	PI	(SI)		
Cold	CLD4	0.14	0.20	0.14	0.13	0.15	Stable	AL(Ar)
	CLD5	0.14	0.00	0.00	0.38	0.13	Stable	AL(Ar)
Cold (Gould)	GLD6	0.14	0.20	0.29	0.13	0.19	Stable	AL(Ar)
Dowsville	DOW1	0.67	0.00	0.43	0.13	0.31	Transitional	AL(Ar)
	DOW2	0.14	0.00	0.71	0.38	0.31	Transitional	AL(Ar)
	DOW3	n/a	n/a	n/a	n/a	n/a	n/a	AL(Ar)
Moon	MOO1	0.67	0.40	0.88	0.63	0.64	In Adjustment	AL
	MOO2	0.71	0.00	0.86	0.63	0.55	In Adjustment	AL
Tenney	TEN1	0.33	0.17	0.63	0.63	0.44	In Adjustment	AL
Potash	POT1	0.57	0.20	0.86	0.50	0.53	In Adjustment	AL(Ar)
	POT2	0.33	0.60	0.83	0.43	0.55	In Adjustment	AL(Ar)
	POT3	0.60	0.00	1.00	0.60	0.55	In Adjustment	RB
Roaring	ROA1	0.20	0.00	0.83	0.17	0.30	Transitional	RB(Ar)
	ROA2	0.33	0.17	0.57	0.20	0.31	Transitional	AL(Ar)
	RBT1	0.14	0.00	0.71	0.33	0.30	Transitional	AL(Ar)
Smith	SMI1	0.17	0.20	0.29	0.00	0.16	Stable	AL(Ar)
	SMI2	0.00	0.00	0.38	0.00	0.09	Stable	AL(Ar)
	SMI3	0.00	0.20	0.33	0.00	0.13	Stable	AL(Ar)
Stevens	STB7	0.57	0.90	0.70	0.43	0.65	In Adjustment	AL(Ar)
	STB8	0.57	0.17	0.25	0.29	0.32	Transitional	AL
	STB9	0.14	0.17	0.50	0.29	0.27	Transitional	AL(Ar)
West Branch	WBL1	0.71	0.80	0.56	0.75	0.70	In Adjustment	AL
	WBL2	0.43	0.88	0.56	0.75	0.65	In Adjustment	AL
	WBL3	0.43	0.80	0.83	0.88	0.53	In Adjustment	AL(Ar)

(1) SI = Modified Stability Index for Vermont Conditions
AI = Aggradation Factor; DI = Degradation Factor;
WI = Widening Factor; PI = Planimetric Adjustment Factor;
N/a = not available; AL = Alluvial; Ar = Armored; RB = Rock Bed with alluvial banks;

Instability within the active channel may be caused by a number of factors as described previously. In this analysis sites were selected to reduce the possible influence of other factors such that the "Causative Factor" may primarily be due to the alteration in the sediment-flow regime within the Production Zone associated with land use alteration. Flow regime alteration was determined for each basin tributary to the channel survey site and expressed as an equivalent Total Basin Imperviousness (TIMP).

A Rapid Geomorphic Assessment (RGA) protocol was developed for the determination of channel stability and the mode of alteration. The protocol is comprised of four factors: Aggradation (AI), Degradation (DI), Channel Widening (WI), and Planimetric Form Adjustment (PI). Each Factor consists of 7 to 11 indices, which are measures of the morphological state of the channel. For example, presence of leaning trees, fence posts, etc., to which the observer is required to provide a "yes" response if present or "no" response if absent. The total number of "yes" responses is totaled for each Factor and divided by the total number of "yes" and "no" responses to derive a Score for each Factor. These Scores are then summed and divided by 4 to arrive at the Stability Index (SI). Previous experience with the RGA protocol indicates that the Score values may be interpreted as follows:

Interpretation of RGA Form Stability Index (SI) Values

Stable (SI#0.2):	Channel metrics are within the expected range of variance (one standard deviation from the mean)
Transitional (0.2<SI #0.4):	Channel metrics are within the expected range of variance for a stable condition but channel shows signs of stress; and,
In Adjustment (SI >0.4):	Channel is outside of the expected range of variance and evolving toward a new equilibrium position.

The RGA protocol was applied to 24 sites surveyed in this study, with the exception of Site DOW3, A simple correlation analysis was undertaken relating the Stability Index to Total Basin Imperviousness (TIMP) as follows:

$$SI = 0.158(TIMP)^{0.413}, R^2 = 0.75, n = 20$$

The above relation was found to be statistically significant at the 0.05 level for variance and mean. The three sites on the West Branch of the Little River were excluded from the analysis due to the possible impact of gravel mining on channel form.

The RGA form was originally developed for application in older urban watersheds that had been under riparian vegetation management programs and, consequently, largely denuded of wooded species. As such, metrics for the characterization of Large Organic Debris were not incorporated into the original RGA Protocol. Further, the RGA form was developed for channel systems that were well advanced in the adjustment process. Consequently, metrics for the early detection of morphologic adjustment were excluded from the original Protocol. In consideration of the above, a modified RGA protocol was developed for Vermont to include the additional parameters: the number of Large Organic Debris pieces (NLOD) observed within the channel and riparian zone, the number of debris jams (NJAMS) and the number of complete riffle lines (NRIFF). These metrics are discussed separately in Sections 3.3.2 through 3.3.4.

A simple regression analysis was undertaken relating the Stability Index (SI) to TIMP using this modified RGA Protocol (Figure 3.2). A logarithmic relationship was found to be of the form,

$$SI = 0.16(TIMP)^{0.426}, (R^2 = 0.78, n = 20)$$

The three sites on the West Branch of the Little River were excluded from the analysis as noted above. The original and modified relations provide similar predictions with slightly better agreement obtained for the modified RGA protocol. Both relations indicate that instability within the active channel can occur at TIMP . 3% with In-Adjustment beginning at TIMP . 7 to 9 %.

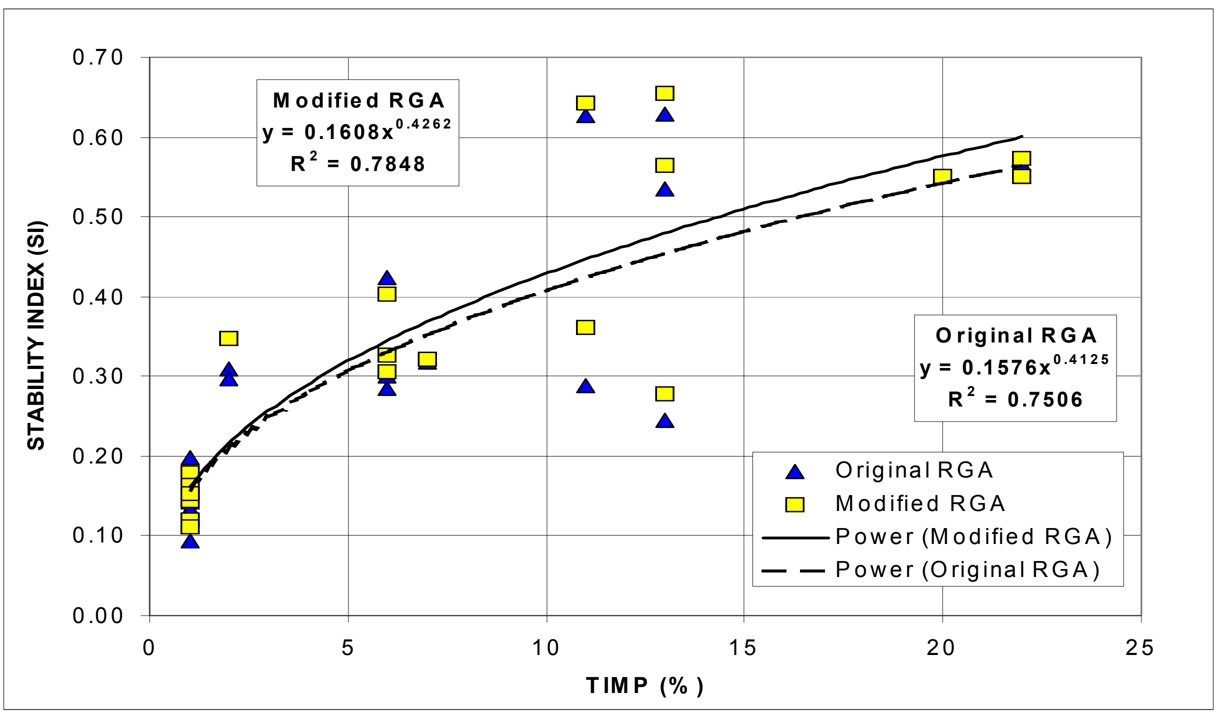


Figure 3.2: Stability Index (SI) as a Function of Total Basin Imperviousness (TIMP) for the Modified and Original RGA Assessment Protocol

3.3.2: Summary of Large Organic Debris Survey

The results of the Large Organic Debris (LOD) survey are presented in Table 3.4(a), below. As stated earlier, these data were used to refine the RGA procedure to reflect conditions prevalent in Vermont.

Table 3.4(a): Summary of Large Organic Debris Survey

Basin	Site	No. of Pieces per 10 x $(w_{BFL})_{AVE}$ (1)	Orientation			Location			TIMP
			Perpend	Obtuse	Parall.	Instream	On Bank	Over Bank	(%)
Cold	CLD4	2.72	0	1	1	0	1	1	1
	CLD5	1.38	0	0	2	0	0	2	1
Cold (Gould)	GLD6	0.00	0	0	0	0	0	0	1
Dowsville	DOW1	4.94	7	7	4	2	12	4	2
	DOW2	14.74	2	3	6	7	4	0	6
	DOW3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6
Moon	MOO1	7.63	12	1	7	n/a	n/a	n/a	13
	MOO2	7.04	7	8	6	17	0	4	13
Tenney	TEN1	2.93	0	1	3	2	0	2	6
Potash	POT1	1.86	0	4	7	4	1	6	22
	POT2	3.64	8	4	8	12	4	4	22
	POT3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	20
Roaring	ROA1	11.49	7	4	6	2	4	11	6
	ROA2	1.01	0	0	1	0	0	1	7
	RBT1	2.08	1	4	0	1	2	1	2
Smith	SMI1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1
	SMI2	0.00	0	0	0	0	0	0	1
	SMI3	0.00	0	0	0	0	0	0	1
Stevens	STB7	2.71	0	2	3	0	2	3	11
	STB8	2.93	1	1	4	1	1	4	11
	STB9	2.12	0	1	2	3	0	0	13
West Branch	WBL1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2
	WBL2	2.06	0	0	2	2	0	0	2
	WBL3	1.59	0	1	1	2	0	0	2

(1) Measurements are made over a distance of 10 x $(w_{BFL})_{AVE}$;
$(w_{BFL})_{AVE}$ = average bankfull width through the survey reach;
Perpend = perpendicular to the active channel;
Obtuse = At an angle of 30 to 60 degrees to the active channel;
Parall = Parallel to the active channel;
Instream = Within the low flow area of the active channel:
On Bank = On the bank of the active channel out of the low flow channel; and,
Over Bank = On the flood plain valley bottom.

Several metrics characterizing the number of Large Organic Debris (NLOD) pieces were correlated with the Stability Index (SI). These included:

1. The Total Number of LOD Pieces ($NLOD_{TOT}$) observed (instream, on bank, and over bank) over the entire Survey Reach Length (L) reported for each Site (varies from Site-to-Site);
2. The Total Number of LOD Pieces observed over a fixed Survey Reach Length of 328 ft (100 m; $NLOD_{100m}$);
3. The Total Number of LOD Pieces observed over a Survey Reach Length defined as ten bankfull channel widths (varies from Site-to-Site, ($10(w_{BFL})$); and,
4. The Total Number of Instream LOD Pieces observed in the stream and on the bank over the Survey Reach Length.

Intuitively, the amount of LOD material entering the stream would increase with destabilization of the active channel through erosion of its banks and the influx of riparian vegetation. All of the above measures of NLOD demonstrated a positive trend between NLOD and SI as anticipated. That is, as SI increases the channel tends toward an unstable condition and the number of LOD pieces increased proportionately. However, the only measure of NLOD found to be statistically significant for variance and mean at the 0.05 level was for the total number of LOD pieces for the entire Survey Reach Length (number (1) in the preceding list). The resulting relation may be expressed as,

$$NLOD_{TOT} = 29.74(SI) - 1.84$$

This relation reported a correlation coefficient of R^2=0.43 (n=14 observations).

Assuming that a value of SI=0.2 represents the division between a stable and transitional channel system, then the total number of LOD pieces must be $NLOD_{TOT}$ # 4.3 over L=328 ft (100 m) for a stable channel. If the number of LOD pieces exceeds 4.3 pieces over this length then the channel may be Transitional or In Adjustment. *Consequently, this measure may be used as an indicator of channel instability.*

The above relation is based on two conditions:

a) The data for the Sites exceeding w_{BFL} = 50 feet were excluded from the data set in the development of the above relation; and,
b) An average Survey Reach Length of L = 328 feet was adopted as described below.

With respect to condition a) above, as channel bankfull width increases the ability of the stream to transport LOD pieces also increases. Consequently, in larger channels the amount of LOD material may diminish. The sensitivity of NLOD to channel width was inspected by incrementally eliminating the channels with the greatest bankfull channel widths. The best results were obtained for channels having bankfull widths of w_{BFL} # 50 feet. A larger data set would be required to test the validity of this observation.

An arbitrary Survey Reach Length of L=328 ft was employed as the standard length for 19 of the 24 channel sites. This length is representative of "L" for the 14 sites used in the development of the above relation. A longer Survey Reach Length was used in the remaining five Sites resulting in an average length of L=361 feet. In general, the Survey Reach Length selected is approximately 12 times the bankfull channel width for the 14 Sites used in the analysis. Table 3.4(b) provides summary statistics describing channel bankfull width and Survey Reach Length for the entire 24 sites.

Table 3.4(b) Descriptive Statistics for Metrics Used in the Assessment of the Number of LODs

Metric	Survey Reach Length (L)		Bankfull Channel Width (W_{BFL})		Ratio of L : W_{BFL}	
	All Sites (ft)	Sites with W_{BFL}#50 ft	All Sites (ft)	Sites with W_{BFL}#50 ft	All Sites (ft)	Sites with W_{BFL}#50 ft
Mean	361	334	50	30.4	9.5	11.7
Range	272	82	139.4	27.5	13.9	10.6
Maximum	600	410	157.9	46	17.7	17.7
Minimum	328	381	18.5	18.5	3.8	7.1

As noted in Table 3.4(b), bankfull channel width varies significantly from site to site. As a result, the fixed Survey Reach Length ranges from as little as 7.1 times the bankfull channel width to a maximum of 17.7 times. To account for these variations in the ratio of Survey Reach Length to bankfull channel width, the number of LOD pieces observed over "L" was normalized by dividing NLOD by bankfull channel width ($NLOD_{wBFL}$). The resulting relationship, however, was not found to be statistically significant.

The relatively poor correlation and high degree of variance obtained in these relationships may be due to a number of factors including errors in observation, differences between observers, the size of the data set or the Survey Reach Length selected. Despite the need for further testing of the use of NLOD as a metric for the assessment of channel stability, *it was incorporated into the Rapid Geomorphic Assessment (RGA) Protocol* as an index of channel widening for streams satisfying the condition w_{BFL}#50ft. The index was established as a "yes" or "no" response to the question, "Does the number of LOD pieces exceed 4 over a survey length of L=328 ft." If this condition is true, a "yes" response is recorded indicating a Transitional or In Adjustment condition exists. If the condition is false then a "no" response is reported indicating that a stable channel condition exists.

3.3.3: Summary of Large Organic Debris Jam Characteristics

The results of the LOD debris jam survey are presented in Table 3.5. As stated earlier, these data were used to potentially refine the RGA procedure to reflect conditions prevalent in Vermont.

Table 3.5 Summary of Large Organic Debris Jam Survey Data

Basin	Site	No. of Debris Jams per 10 x $(w_{BFL})_{AVE}$	$(w_{BFL})_{AVE}$ (ft)	Survey Reach Length (ft)	Age of Debris Jam			Span Morphology	
					Young	Recent	Old	Complete	Partial
Cold	CLD4	1.36	44.7	328	0	0	1	0	1
	CLD5	0.00	22.7	328	0	0	0	0	0
Cold (Gould)	GLD6	0.00	32.4	328	0	0	0	0	0
Dowsville	DOW1	0.55	9.0	328	1	1	0	0	2
	DOW2	1.34	44.0	328	0	1	0	0	1
	DOW3	N/a	18.9	328	N/a	N/a	N/a	N/a	N/a
Moon	MOO1	2.67	12.5	328	2	0	5	4	3
	MOO2	2.01	11.0	328	3	1	2	1	5
Tenney	TEN1	0.73	24.0	328	0	0	0	1	0
Potash	POT1	0.34	22.2	400	0	0	2	2	0
	POT2	1.27	24.5	410	6	1	0	6	1
	POT3	N/a	25.0	328	N/a	N/a	N/a	N/a	N/a
Roaring	ROA1	0.68	22.2	328	0	1	0	0	1
	ROA2	0.00	33.0	328	0	0	0	0	0
	RBT1	2.08	13.6	328	0	0	5	1	4
Smith	SMI1	N/a	21.4	328	N/a	N/a	N/a	N/a	N/a
	SMI2	0.00	24.4	328	0	0	0	0	0
	SMI3	0.00	16.2	328	0	0	0	0	0
Stevens	STB7	0.54	17.8	328	1	0	0	0	1
	STB8	0.98	16.0	328	0	0	2	0	2
	STB9	0.71	23.2	328	1	0	0	0	1
West Branch	WBL1	N/a	59.2	600	N/a	N/a	N/a	N/a	N/a
	WBL2	2.06	61.9	600	2	0	0	0	2
	WBL3	1.59	54.1	410	1	1	0	0	2

(1) Measurements were made over 10 $(w_{BFL})_{AVE;}$
$(w_{BFL})_{AVE}$ = bankfull channel width averaged over the survey reach;
Complete = Complete span of the active channel from bank to bank;
Partial = Partial span of the width of the active channel;
Young = Small branches and twigs, may have abundant leaves still on tree, bark intact;
Recent = Most small branches removed, few or no leaves, bark may be damaged through abrasion;
Moderate to Old = Only major branches remaining, bark mostly or completely removed, various degree of decay, may be moss covered, may have sap trees growing vertically out of trunk of downed tree; and,
N/a = Not available.

A correlation analysis between the Stability Index (SI) and the number of debris jams (NJAMS) was performed using various measures of NJAMS. These measures include:

1) The number of jams observed over a Survey Reach Length of $10(w_{BFL})_{BFL}$;
2) The number of jams observed over a fixed Survey Reach Length of 328 ft (100 m);
3) The number of jams observed over the entire Survey Reach Length (varies from site-to-site as described for NLOD).

The only relation found to be statistically significant for both variance and mean was a correlation between NJAMS as measured over the entire Survey Reach Length and SI as presented below,

$$NJAMS = 9.34SI - 1.13$$

This relation produced a correlation coefficient of R^2=0.45 (n=15).

The correlation implies that the frequency of debris jams increases with the de-stabilization and adjustment of the active channel. Assuming a value of SI=0.2 represents the threshold between a stable and transitional morphological state, a value of NJAMS # 0.74 over a Survey Reach Length of approximately 328 ft (100 m) indicates that the reach is stable. Conversely, a value of NJAMS > 0.74 implies a Transitional or In Adjustment condition.

While the correlation was considered statistically significant, additional data collection and testing are recommended before this measure is incorporated into the RGA procedure.

3.3.4: Summary of Riffle Line Survey

The results of the Riffle Line survey are presented in Table 3.6. As stated earlier, these data were used to potentially refine the RGA procedure to reflect conditions prevalent in Vermont.

The Total Number of Riffle Lines which completely span the active channel $(NRIFF)_{COM}$, as measured over 10 average bankfull channel widths $((w_{BFL})_{AVE})$, was regressed against Stability Index (SI) to arrive at the following relation,

$$NRIFF_{COM} = -7.66SI + 5.46$$

This relation was found to be statistically significant at the 95% level for both variance and mean (R^2 = 0.51, number of observations n=16).

Table 3.6 Summary of Riffle Line Survey Data

Basin	Site	No. of Riffle Lines per 10 x $(w_{BFL})_{AVE}$ (1)	Riffle Line Morphology			
			Complete	Partial		
				1/4	1/4 -1/2	½ -3/4
Cold	CLD4	6.81	4	1	0	0
	CLD5	8.30	6	2	2	2
Cold (Gould)	GLD6	12.85	7	2	2	2
Dowsville	DOW1	3.29	5	4	1	2
	DOW2	9.38	3	0	1	3
	DOW3	n/a	n/a	n/a	n/a	n/a
Moon	MOO1	0	0	0	0	0
	MOO2	0	0	0	0	0
Tenney	TEN1	2.93	2	0	0	2
Potash	POT1	2.54	4	0	2	19
	POT2	1.27	6	0	0	1
	POT3	n/a	n/a	n/a	n/a	n/a
Roaring	ROA1	n/a	n/a	n/a	n/a	n/a
	ROA2	n/a	n/a	n/a	n/a	n/a
	RBT1	n/a	n/a	n/a	n/a	n/a
Smith	SMI1	n/a	n/a	n/a	n/a	n/a
	SMI2	n/a	n/a	n/a	n/a	n/a
	SMI3	n/a	n/a	n/a	n/a	n/a
Stevens	STB7	1.09	0	0	1	1
	STB8	1.46	3	0	0	0
	STB9	7.07	3	4	3	0
West Branch	WBL1	1.35	3	0	0	0
	WBL2	6.19	3	0	1	2
	WBL3	8.76	2	1	3	5

(1) Measurements were made over 10 $(w_{BFL})_{AVE}$
$(w_{BFL})_{AVE}$ = bankfull channel width averaged over the survey reach
Complete = Complete span of the active channel from bank to bank
Partial = Partial span of the width of the active channel
n/a = Not available
Complete = Span of active channel from bank to bank
Partial = Proportion of active channel spanned ranges from 0-1/4, ¼ to ½ and ½ to ¾.

Assuming a value of SI=0.2 represents the threshold between a stable and transitional condition, the number of complete riffle lines would be $(NRIFF)_{COM}$, \$ 4 for a stable channel. The inverse nature of the relationship indicates that riffle structures are destroyed or reworked as the channel de-stabilizes and enters into an adjustment phase resulting in a reduction in the number of complete riffle lines. Based on the strength of the above relation, *the number of complete riffle lines was incorporated into the RGA Stability Assessment protocol* as an index of Planimetric Form Adjustment (PI). This index was formulated as the following question: "Are there less than 4 complete riffle lines per 10 average bankfull channel lengths?" If "true" a "yes" response is entered onto the form as an indication of channel instability. Conversely, if the answer to the question is "false" a "no" response is entered onto the form as an indication of channel stability.

Section 3.4: Summary of Channel Sediment Analysis

Bank material and pebble count data were used in the determination of channel type and stability, mode of adjustment, critical shear stress, and Manning's roughness coefficient.

This information not only provided the means for deriving the above mentioned values, but also provided a means for checking the validity of other assessment parameters. For example, the bed material critical shear stress calculated from the pebble count data was compared to the instantaneous critical shear stress calculated for bankfull flow conditions. If bed material critical shear stress was found to be much less than the instantaneous critical shear stress at bankfull flow, then degrading channel conditions should be expected. This was then compared to Stability Index, as an independent means of confirmation.

While no stand alone analysis was performed on the channel sediment, this information was critical to the completion of the channel stability and enlargement assessments.

Table 3.7 Summary of Channel Pebble Analysis

Basin	Site	Equivalent Diameter (inches)					
		Geo. Mean	16^{th} (d_{16})	50^{th} (d_{50})	75^{th} (d_{75})	84^{th} (d_{84})	Std. Dev
Moon	MOO1	No Pebble Count Data (silty-sand bed material)					
	MOO2	No Pebble Count Data (silty-sand bed material)					
Tenney	TEN1	2.61	4.27	7.26	10.05	10.84	2.09
Potash	POT1	1.27	4.18	6.70	7.92	8.83	2.21
	POT2	2.46	3.17	4.45	5.67	5.94	1.42
	POT3	2.56	4.41	7.36	9.17	9.21	2.29
Roaring	ROA1	No Pebble Count Performed					
	ROA2	2.50	5.77	9.11	10.91	11.30	2.99
	RBT1	2.31	4.75	6.33	8.71	9.27	2.43
Dowsville	DOW1	2.42	4.33	7.19	9.01	9.06	2.13
	DOW2	2.50	3.71	4.85	5.74	6.11	1.58
	DOW3	1.93	2.56	4.37	4.68	4.88	1.29
Little	WBL1	7.47	7.67	9.71	11.88	12.51	2.53
	WBL2	2.36	2.56	3.80	4.59	4.79	1.08
	WBL3	3.35	4.64	6.02	7.94	8.48	1.96
Steven's	STB7	2.10	4.38	6.63	6.74	7.21	2.04
	STB8	1.36	1.39	2.06	3.01	3.37	0.59
	STB9	1.84	3.77	5.37	6.45	6.52	1.73
Smith	SMI1	3.55	3.91	5.58	8.83	9.04	1.79
	SMI2	2.67	3.29	4.95	6.30	6.61	1.56
	SMI3	3.21	5.33	8.73	9.83	10.06	2.59
Cold	COLD4	6.00	6.46	10.75	13.51	13.78	3.00
	COLD5	3.29	3.87	5.56	7.01	7.16	1.68
	GLD6	5.48	11.60	16.12	19.65	19.92	5.45

Geo. Mean = geometric mean

$d_{ith\ percentile}$ = ^{ith} percentage of particles are equivalent to, or less than the indicated value, in inches

SECTION 4

BIOLOGICAL MONITORING ANALYSIS

SECTION 4: BIOLOGICAL MONITORING ANALYSIS

One sub-component of the project was to collect and review past biological monitoring data for the selected subwatersheds and to evaluate this data for possible correlations between a stream's physical characteristics, the subwatershed's impervious cover, and the biological health of the resident fish and benthic macroinvertebrate communities.

The Vermont Agency of Natural Resources (ANR), Biomonitoring Unit and the Vermont Department of Fish and Wildlife (DFW) supplied the project team with past biological monitoring data for each of the streams. ANR data included benthic macroinvertebrate and fish sampling results from a few to several locations in each stream over a number of years. DFW fisheries data included individual fish species counts at one to a few locations in each stream over a period of a few years. It should be noted that the fish sampling data was not recent (only two streams were sampled in 1997, with the remaining streams sampled between 1988 through 1995).

Table 4.1 lists a summary of biological monitoring at the selected streams. The community assessment, a broad assessment of the overall health of the biological community, has been provided by ANR for both the benthic macroinvertebrate and fish communities for most of the sampling events. While not presented in Table 4.1, the ANR Biomonitoring Unit data also included a table of the assessment metrics as well as the number and identity of the taxa collected at each station. These data provided some additional insights into the relative health of the selected streams.

Table 4.1 Summary of Biological Monitoring at Selected Streams
(Source: ANR Biomonitoring Unit and Vermont Dept of Fish and Wildlife)

	Macroinvertebrate Biomonitoring			Fish Community Biomonitoring		
Stream Name	Sampling Date	Location (River Mile)	Community Assessment	Sampling Date	Location (River Mile)	Community Assessment
Roaring Brook	10/13/87	Pickle Brl. (1.4)	Poor			
	9/26/88	"	Fair			
	10/15/92	"	Fair			
	10/02/97	"	Fair	10/29/97	Pickle Brl. (1.4)	Excellent
Stevens Brook	10/07/86	Jewett Rd (4.2)	Poor	10/07/86	Jewett Rd (4.2)	Poor
	8/18/87	"	Poor	8/18/87	"	Poor
	8/12/88	"	Poor	8/12/88	"	Fair
	10/17/89	"	Fair	10/17/89	"	Fair
	7/31/90	"	Poor	11/03/90	"	Fair
	9/05/91	"	Poor	9/05/91	"	Fair
				9/29/92	"	Fair
	10/18/93	Jewett Rd (4.2)	Poor			
	10/20/98	"	Poor			
	10/17/89	Pearl St (6.8)	Poor	10/17/89	Weldon St (7.5)	Poor
	10/04/91	"	Poor			
	10/17/89	Weldon St (7.5)	Poor			
	10/20/98	Lincoln St (9.0)	Poor			
Dowsville Brook	9/27/95	DB #5 (1.0)	Excellent	10/27/95	DB #5 (1.0)	Good
	9/27/95	DB #2 (3.3)	Good	9/27/95	DB #2 (3.3)	**
	9/09/96	DB #1 (3.4)	Excellent			
	10/09/97	"	Good			
Potash Brook	9/30/93	W. Dist. Pond (0.4)	Poor	9/24/93	W. Dist. Pond (0.4)	Fair
	10/26/87	Queen City Park (0.6)	Poor			
	10/19/88	"	Poor	8/09/88	Queen City Park (0.6)	Good
	10/18/89	"	Fair			
	7/31/90	"	Poor			
	9/30/91	"	Poor	9/30/91	Queen City Park (0.6)	Good
	10/15/92	"	Poor	8/25/92	"	Fair
	9/30/93	"	Poor	9/24/93	"	Good
				8/10/88	Farrel Street (1.1)	Good
	10/18/89	Farrel Street (1.1)	Good	8/02/89	"	Good
	10/13/94	"	Good			
	9/22/97	"	Fair			
Tenney Brook	10/04/88	Route 7 (1.0)	Fair	10/04/88	Route 7 (1.0)	Excellent
	10/04/88	Route 4 (3.0)	Good	10/04/88	Route 4 (3.0)	G - E

Table 4.1 Summary of Biological Monitoring at Selected Streams
(Source: ANR Biomonitoring Unit and Vermont Dept of Fish and Wildlife)

	Macroinvertebrate Biomonitoring			Fish Community Biomonitoring		
Stream Name	Sampling Date	Location (River Mile)	Community Assessment	Sampling Date	Location (River Mile)	Community Assessment
Moon Brook	9/30/86 10/05/88 9/12/91 10/06/93 9/20/94 9/25/96 9/12/91 10/05/88 9/30/86 10/05/88	Forester Street (0.3) " " " " " Howe Cntr (0.7) Route 7 (1.0) Jackson Street (1.6) "	Poor Poor Poor Poor Poor Poor Poor Poor Poor Poor	9/30/86 10/06/93 9/12/91 10/04/88	Forester Street (0.3) Forester Street (0.3) Howe Cntr (0.7) Route 7 (1.0)	Poor Poor Fair Good
Smith Brook	9/25/97 9/24/98	FS Road 61A (1.3) "	Excellent Excellent			Trout Stream *
Cold River	10/01/93 10/06/93	N. Shrewsbury (0.6) Cold River Rd (6.8)	Good Good			
West Branch Little R.	9/09/98 9/26/97 9/27/97	Route 108 (1.9) Top Notch LF (3.7) "	Fair Excellent Good	8/22/91	Stowe-Moscow Rd (2.5)	Good

* Trout stream designation from Vermont Fish and Wildlife data based on fish community.

** The Vermont Fish Index of Biotic Integrity (IBI) requires at least 4 non-salmonid species for a community assessment to be made. Only brook trout occurred at this station.

Roaring Brook received community assessments for benthic macroinvertebrates in the poor to fair range, yet appears to have many of the attributes typical of a small, high gradient, coldwater stream. These higher elevation headwater streams are often less productive than their lower elevation counterparts, which may be partially responsible for the lower macroinvertebrate community scores. ANR habitat data indicates that the substrate in Roaring Brook tends to be high in sand and often greater than 50% embedded. This would also contribute to the lack of expected diversity in the benthic population. The fish community assessment rating of excellent is due to the abundance of Brook Trout (Salvelinus fontinalis) and Slimy Sculpin (Cottus cognatus), both sensitive coldwater fish species. Both species are tolerant of sandy substrates if there remain areas of adequate spawning substrate in the vicinity. This may help explain the differences between the fish and macroinvertebrate community ratings.

Potash Brook, with the greatest amount of impervious cover of all the selected streams, exhibits a generally poor to fair biological assessment. This stream displays the confounding effects of both chronic and episodic water quality and stream habitat impacts. The macroinvertebrate community at the most downstream sampling station, below the Water District treatment pond, appears to show organic enrichment typical of the influence from pond effluents. Upstream, the earliest macroinvertebrate sampling conducted in 1987 and 1988 at river mile 0.4 appears to indicate impact from the construction of I-89 connector with some slight recovery in the year immediately following, but recovery appears limited likely due to the long term/permanent impacts of I-89 and existing upstream non-point source pollution. Upstream of this sampling station, at river mile 1.1, macroinvertebrate sampling indicates increasing long-term (1989-1997) non-point source impacts as indicated by a significant increase in the collector-filterer trophic group, predominately Hydropsychidae and a significant decrease in the proportion of Plecoptera and Ephemeroptera in the samples over the time period.

The fish community of Potash Brook also indicates water quality and habitat impacts. The fish community at all stations sampled in Potash Brook (river mile 0.4, 0.6 and 1.1) was dominated by Blacknose Dace or Blacknose Dace and creek chub. Both of these species are considered tolerant of water quality and habitat impacts. Potash Brook, at river mile 0.6, has the most extensive sampling record spanning the years 1988 through 1993. Over this time period, Blacknose Dace increased in numbers while longnose dace, decreased in numbers. Longnose dace inhabit higher velocity riffle portions of a stream, are benthic insectivores and are moderately tolerant of non-point source water quality impacts. The decrease in the Longnose Dace population indicates a lowering of the quality of the riffle habitat at this station. The reduction of their numbers would indicate physcical habitat impacts such as increasing sedimentation and embeddeddness. This appears to agree with the macroinvertebrate sampling results at this station.

Stevens Brook in St Albans appears to exhibit typical impacts associated with urbanization, yet has a relatively modest level of imperviousness (about 13%). Limitations in macroinvertebrate community health of Stevens Brook are indicated in general by a high percentage of collector-filterers (Hydropsychidae) and low percentages of Plecoptera and Ephemeroptera and the dominance of the community by pollution tolerant Oligochaete worms. The fish communities exhibited low species diversity and were dominated by tolerant species such as Blacknose Dace (Rhinichthys atratulus) or Creek Chub (Semotilus atromaculatus) at all samples stations. These results may be associated with poor habitat conditions (habitat assessment monitoring data were not available to the project team), toxicity effects associated with the nearby railroad yard, or possibly the location of impervious cover within the watershed's upper reaches. Other researchers have speculated that the location, as much as the magnitude of impervious cover, can significantly affect stream biological health (Bannerman, 1998).

Dowsville Brook is a small, high quality, headwater stream. All Macroinvertebrate samples were rated as good to excellent. Fish sampling, conducted along the lower reaches of the stream, yielded a rating of good. The Fish community was sampled, but not assessed in the upper reaches (river mile 3.3), due to the fact that Brook Trout was the only species collected. The Vermont IBI requires at least four non-salmonid species to be present in order to calculate a community assessment score.

Tenney Brook and Moon Brook are both tributaries to Otter Creek and flow through the center of Rutland, Vermont. Tenney has much less impervious cover than Moon, 6% versus 13%, respectively, and exhibits the characteristics of a classic small, coldwater stream fish assemblage. The fish community consists of Brook Trout, Slimy Sculpin and Blacknose Dace. The first two are indicators of cold water habitat conditions (Galli, 1990). Moon Brook has a much more warmwater-oriented fish assemblage, a consistently poor macro-invertebrate community assessment, and evidence of warm water discharges (such as below a pond). Riparian cover along Moon Brook is also limited and may be a contributor to fair to poor biological community health.

The West Branch of the Little River generally received good to excellent community assessment scores for macroinvertebrates and fish (note however, only one fish sampling event). Although, the most recent macroinvertebrate sampling at Route 108 (river mile 1.9) yielded a fair community assessment score, many of the individual metrics, including species richness, rated as good. The dominance of Dipterans may suggest specific impacts to habitat quality in the vicinity of the sampling site. This sample was collected as part of an assessment of the Trapp indirect discharge and thus may not reflect conditions elsewhere in the watershed. Note also, that the State has listed the West Branch as "impaired" waters for secondary water contact recreational use based on data from the Vermont Department of Fish and Wildlife (see Table 4.2).

Both Smith Brook and Cold River were intended to represent reference conditions and received good to excellent macroinvertebrate community assessments. The Vermont Fish and Wildlife Service conducted fish species counts on Smith Brook and documented a sensitive coldwater Trout Stream. Fish data were not reviewed for the Cold River.

Table 4.3 lists a generalized biological community assessment for each stream as a function of watershed imperviousness. The results suggest that these Vermont streams can be related to their contributing impervious cover and fall into one of two categories. The generally "good" streams, from a biological community assessment perspective, fall into an impervious cover range of 6% and less. The "poor" streams have impervious cover of 12% or greater. These results tend to confirm findings by other researchers across North America that indicate biological impairment beginning at about 10% impervious cover. (Klein, 1979, Schueler, 1994).

A couple of caveats to this general classification are worth discussing. First, our analysis did not include a review of streams within the 6 - 12% impervious cover range. Thus, biological impacts may certainly accompany streams with impervious cover less than 12%. Also, several of the streams with less than 6% impervious cover (Roaring Brook, Tenney Brook, and the West Branch of Little River) had individual benthic community assessments scoring in the "fair" range. These headwater streams tend to support the most sensitive macroinvertebrate and fish communities and can be adversely affected at even low levels of imperviousness. The State of Vermont has listed both Roaring and West Branch in their most recent listing of "impaired" waters as part of their 303D reporting (see Table 4.2). These findings may support those of other researchers who have indicated that even at very low levels of impervious cover (5 -7% range), the most sensitive aquatic species show signs of impairment (Horner, et al, 1997).

Table 4.2: State of Vermont Listing of Impaired Surface Waters 1998
(Source: VT, DEC, as part of 1998 303D reporting to EPA)

Stream	Pollutant	Surface Water Quality Problems	Current Status/Situation
Roaring Brook	sediment, iron	Land development, erosion, road runoff	Fair biological condition,; moderate organic enrichment
Moon Brook	sediment, nutrients, pathogens, toxics, metals	Land development; erosion; urban runoff; no monitoring data on pollutants	Poor overall biological condition (91-96); Habitat degradation
Stevens Brook	Sediment, oil, grease, Hydrocarbons, organic enrichment, toxics	Land development, erosion/sedimentation urban runoff	Poor biological condition, habitat degradation; toxicity enrichment
Potash Brook	Sediment, pathogens, undefined typical (metals, nutrients, toxics)	Urban runoff, land development, erosion; frequent beach closures	Poor biological condition (90-93,98), habitat degradation, limited improvement since '88
West Branch Little River	Physical habitat changes	Increased peak stormwater flows and runoff from urbanizing area; loss riparian vegetation	DF&W fishery data indicates impairment; cumulative hydrologic effects
Dowsville Brook Tributaries 1 & 11	Sediment	Logging related erosion	On-going biological monitoring, biological functional shifts noted, fair biological condition (1997)

Table 4.3 Comparison of Biological Monitoring to Subwatershed Imperviousness

Stream Name	Subwatershed Current Impervious Cover (%)	Macro-invertebrate Bio-monitoring - Overall Community Assessment*	Fish Bio-monitoring - Overall Community Assessment*
Roaring Brook	6	Fair	Excellent
Stevens Brook	13	Poor	Poor - Fair
Dowsville Brook	6	Good - Excellent	Good
Potash Brook	22	Poor - Fair	Fair - Good
Tenney Brook	6	Fair - Good	Good - Excellent
Moon Brook	13	Poor	Fair
Smith Brook	<1	Excellent	-
Cold River	<1	Good	-
West Branch Little River	2	Good - Fair	Good

* represents an average of all biomonitoring presented in Table 4.1

SECTION 5

DISCUSSION

SECTION 5: DISCUSSION

As presented in Section 1, the project relies on several corroborative approaches to document alterations in stream morphology with altered watershed land cover. To evaluate the overall results of the study, Table 5.1 was developed to compare three of these elements (channel enlargement, channel stability, and biological community health) as a function of impervious cover. The nine streams presented in Table 5.1 are each draining different subwatersheds (Moon and Tenney are counted as one subwatershed) and are listed in increasing impervious cover.

The purpose of Table 5.1 is to illustrate the overall condition for each of the nine streams in the vicinity of biomonitoring stations and geomorphic assessment stations. The cross-section deemed most representative of those evaluated by the project team was selected for illustrative purposes, here, as the section that was either lowest in the watershed or most immediately adjacent to watershed land use activities, and closest to biomonitoring stations.

Table 5.1 Overall Summary of Morphological and Biological Data of Nine Vermont Streams										
Stream & location(1)	DA(2) (mi^2)	TIMP (%)	Age(4) (yrs)	$(Re)_i$	$[(Re)_{ULT}]_{OBS}$	$(A_{BFL})_{CUR}$ (ft^2)	Stab. Class	Bio. Macro.	Bio. Fish	Notes
Cold-d/s	21	1	80	1.01	1.01	201.2	Stable	Good	nd	Reference
Smith-m	3.2	1	80	1.01	1.01	53.6	Stable	Exc	Exc	Reference
West Br.-m	23	2(3)	55	1.03	1.32	433.0	Adjust.	Gd-Fr	Good	Upland dev./gravel extr.
Dowsville-d/s	6.4	6(3)	23	1.04	1.91	105.5	Trans.	Gd-Ex	Good	Logging (1995)
Roaring-u/s	4.5	6(3)	28	1.07	1.78	165.2	Trans.	Fair	Exc	Upland dev.
Tenney	4.4	6	50	1.11	1.50	57.7	Adjust.	Fr-Gd	Gd-Ex	Slight urbanization
Stevens-m	1.4	11	49	1.24	1.30	30.4	Trans.	Poor	Fair	Moderate urbanization
Moon-d/s	5.3	13	50	1.32	0.84	37.3	Adjust.	Poor	Pr-Fr	Moderate urbanization
Potash-d/s	7.4	22	42	1.61	2.18	75.6	Adjust.	Pr-Fr	Fr-Gd	Medium urbanization

Notes For Table 5.1:

(1)The location is at the sampled cross-section locations deemed most representative of the reach being evaluated,
d/s - downstream
m - middle
u/s - upstream
DA - Drainage area
(2)The drainage area is at the representative channel cross-sectional location.
TIMP - Total subwatershed imperviousness
(3)TIMP for these subwatersheds includes "equivalent impervious area" from resort development or clear-cut logging (see Section 2.7).
Age - Average area weighted age of land cover alteration
(4)The age does not necessarily reflect the exact age of a disturbance (such as 3 years from Logging activity on Dowsville), instead, it reflects a "weighted age" which incorporates the varied nature of altering land cover over time through the various activities.
$(Re)_i$ - Current channel Enlargement Ratio
$[(Re)_{ULT}]_{OBS}$ - Ultimate channel Enlargement Ratio, based on observed data
A_{BFL} - Channel cross-sectional area at the bankfull stage
Stab. Class - Stability classification, either stable, in transition, or in adjustment
Bio Macro. - Generalized Community Assessment of benthic macro-invertebrates (excellent, good, fair, poor)
Bio Fish - Generalized Community Assessment for fish (excellent, good, fair, poor)
nd - no data

5.1: Discussion

One observation from Table 5.1 is the general relationship of increasing Channel Enlargement Ratio with increasing impervious area. The two reference streams, Cold River and Smith Brook, as well as Dowsville Tributary 1 (DOW1) show enlargement ratios of approximately one. These results tend to confirm that the streams selected for assessment respond to increasing impervious cover (or altered watershed hydrology) with increasing cross sectional area in a similar manner as other streams outside of Vermont and the reference streams exhibit little or no enlargement. Table 5.1 also suggests that channel stability, as measured using the RGA technique, is related to watershed alteration, or as discussed below, instream channel activity. The reference streams exhibit stable channel conditions.

As stated in Section 3, the data from this study were used to derive "observed" enlargement values $[(Re)_{ULT}]_{OBS}$. These observed values were compared to predicted enlargement values using relations constructed from data collected for streams located outside of the New England region. It was noted that the mean value for $(Re)_{ULT}$ computed from the Vermont data (1.44) was higher than that determined using the Enlargement Curve for AL-Type streams (1.34). This may be due to differences in hydraulic geometry attributable to inconsistencies in the planimetric location of the current and historic cross-sections. The current survey sites were located in straight reaches close to or at riffle cross-over points, while the planimetric location of all of the historic cross-sections could not be confirmed. Consequently, some of the historic cross-sections may have been located on meander bends which tend to have a larger cross-sectional area than riffle sections. Other undocumented activities (such as gravel extraction, or altered riparian cover) may also have impacted the selected historic sites and contributed to the larger cross-sectional area. However, it is believed to be within the margin of error attributed to the techniques employed in this study and as confirmed by tests of variance and mean that demonstrated that the two data sets were found to be drawn from the same population at the 95% confidence level.

The Vermont data were integrated into the original data set and the Enlargement Curves for AL- and RB-Type streams were regenerated using curve fitting techniques. As anticipated, the resulting curves were of the same general form and of no statistical difference than the original relations. The "observed" and predicted values of $(Re)_{ULT}$ were found to be drawn from the same population according to tests of variance and mean. The plotting position for the Vermont data is unique to the original data set in that they occupy that region of the curve within the lower impervious values. Consequently, the Vermont data significantly enhances the overall representativeness of the data set and hence the confidence level in the resulting relations.

Figure 5.1 illustrates the relationship between total basin impervious cover (TIMP) and channel Enlargement Ratio $[(Re)_{ULT}]$. Superimposed on Figure 5.1 is the Stability Index value (SI) data derived from the Rapid Geomorphic Assessment (RGA) form. The enlargement data show a modest correlation with total basin impervious cover (R^2=0.34), while the Stability Index demonstrates a significant correlation (R^2=0.78) with basin impervious cover if the values for West Branch of the Little River (WBL) are excluded from the regression. These values were excluded from the assessment because of the probable morphological impact of past gravel extraction activities as noted in Section 3. The SI data for all West Branch of the Little River sites suggests that watershed land use activity (as measured by impervious, or "equivalent impervious" cover), while a significant factor in the determination of channel stability, is one of several other possible contributing factors. Instream works, gravel extraction operations, and riparian vegetation management programs may also contribute to the alteration of a water course.

A further observation from Figure 5.1 is the total basin imperviousness at which the SI value indicates that the channel enters into the Transitional or In Adjustment categories. Figure 5.1 suggests that the channel may begin to show signs of morphologic stress at the mesoscale level at TIMP . 2 % and enter into the In-Adjustment phase by TIMP . 9 percent. The channel may experience microscale adjustments within the 2#TIMP#9% range and thereby impact fisheries habitat value prior to entering into the In-Adjustment phase.

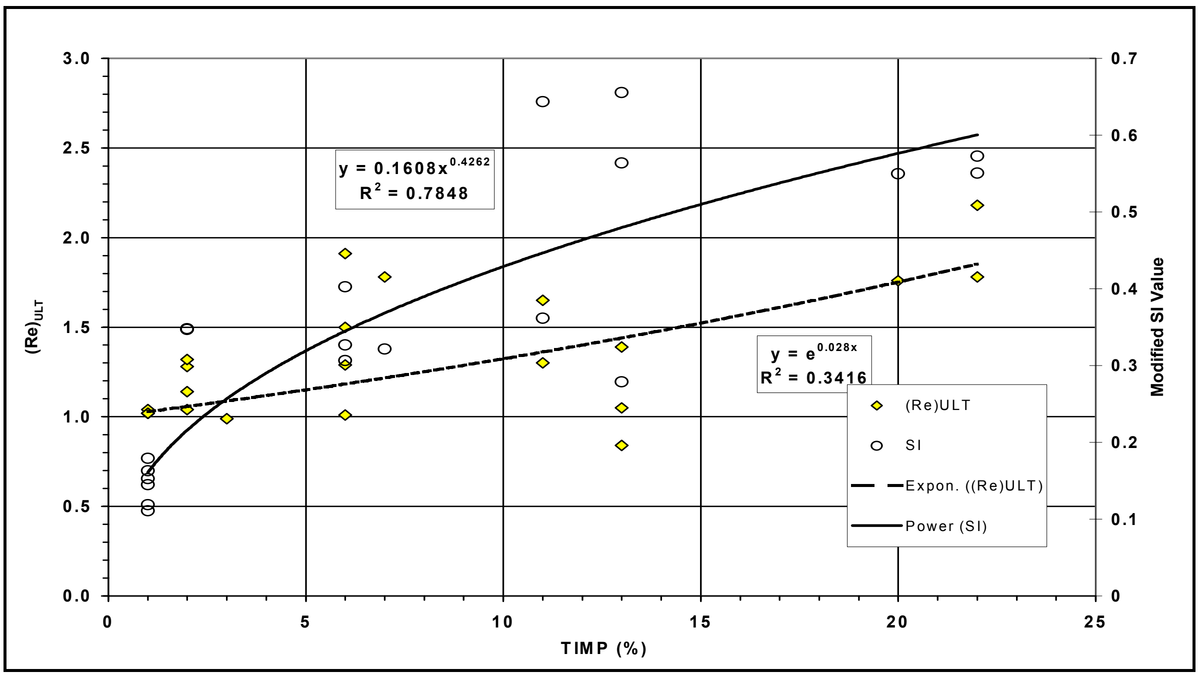


Figure 5.1 Ultimate Channel Enlargement Ratio $(Re)_{ULT}$ and Stability Index for Nine Vermont Streams as a Function of Total Impervious Cover

The assessment of the SI values shown in Figure 5.1 is consistent with relationships between the Enlargement Ratio and biological community health. In general, where the current Enlargement Ratio is less than $(Re)_{ULT}<1.25$, with a corresponding Stability Index of SI<0.3, biological community health is in the good to excellent range. Where $(Re)_{CUR}>2.0$, corresponding to SI>0.47, biological community health tends to be in the fair to poor range (although there are notable exceptions in Moon Brook, Roaring Brook and Dowsville Brook). See Figure 5.2 for the general relationship between total basin impervious cover and biological community health. Note that the fish community appears to be more resilient than the macro invertebrate community to the direct impacts from increased impervious cover; likely due to the fact that fish can move about to seek refuge during periods of stress.

It is not surprising that those streams that are In Adjustment (SI>0.5) also tend to exhibit poorer biological community assessments. Exceptions to this might include streams where the age of the disturbance is older (such as West Branch and Tenney Brook) or the rate of the adjustment is slower, allowing the biological communities a chance to stabilize between periods of stress.

The age of land cover alteration is also an important parameter to the overall stream channel characteristics, but a much more complicated element to define. Since urbanization and upland development, and to a lesser extent logging, occur over a period of time, there is generally not a single pulse of altered hydrology, but a "creep" towards an altered state (this may be due to a long term equilibrium shift, as reviewed in Section 1). The complicating factor for many of the streams evaluated in this study was that land disturbances had occurred prior to the date of the historic cross-sectional surveys (refer to the discussion in Section 2.6). This essentially means that these channels had already begun the enlargement process prior to the date of the historic cross sectional survey, meaning that the total age of the alteration was much harder to estimate.

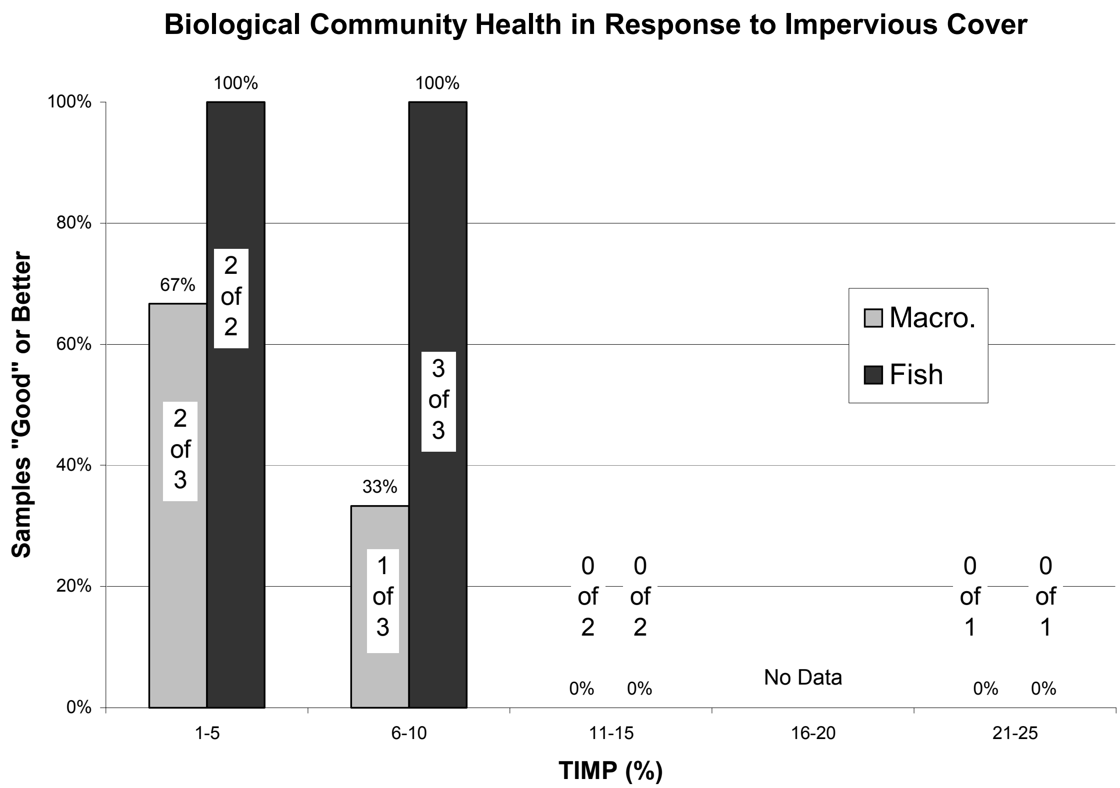


Figure 5.2 General Relationship of Biological Community Assessment as a Function of Channel Stability

5.2: Conclusions

The methodology and data presented in previous sections support a suite of conclusions on the findings of this study, many of which have been discussed in previous sections. The project team identified the following six major conclusions as a result of our work on the geomorphological, and biological assessments:

1. The key hypothesis of this study was to test whether stream geomorphological assessment techniques, that had been developed and tested in regions outside of Vermont, were valid for Vermont conditions. Specifically, two assessment techniques were evaluated: the Rapid Geomorphic Assessment technique that defines stream stability via a stability index value (SI) and the relationship of channel enlargement ratio [$(Re)_{ULT}$] to total basin imperviousness. The study results confirmed that both of these techniques could be applied with statistical significance to Vermont conditions.

   An Enlargement Ratio equation and curve (see equation on page 3-6 and Figure 3.1 on page 3-8) developed using stream geomorphological data from outside of Vermont was tested for inclusion with data from the Vermont streams investigated in this study and found to be statistically valid for the total population of data-points. This conclusion supports that there is now a statistically valid tool for Vermont conditions to help predict channel enlargement as a function of watershed imperviousness.

2. The channel enlargement ratio [$(Re)_{ULT}$] for the nine Vermont streams was found to be modestly related to total basin imperviousness ($R^2 = 0.34$). The overall channel enlargement equation and curve (see equation on page 3-6 and Figure 3.1 on page 3-8) present a strong correlation between enlargement ratio and total basin imperviousness ($R^2= 0.83$).

3. The channel stability index (SI) conducted using the Rapid Geomorphic Assessment technique for the nine Vermont streams was also found to be strongly related to total basin imperviousness ($R^2 = 0.78$). The slightly lower confidence level is not surprising given the qualitative nature of the data collection protocol for SI versus the more quantitative nature for $(Re)_{ULT}$ data collection and analysis.

4. The concept of "equivalent impervious cover" (see Section 2.7, page 2-40 through 2-43), where land uses that alter the hydrologic characteristics of watershed cover without creating impervious cover are equated to an equivalent amount imperviousness, was found to be a meaningful measure. The resulting channel enlargement and stability index in subwatersheds where this method was employed did not deviate significantly from those subwatersheds where conventional imperviousness was the indicator of hydrologic change.

5. The assessment of biological community health, relying on Vermont biomonitoring data, showed a general relationship of decreasing biological community health with increasing watershed impervious cover. However, since no statistical tests were conducted, the strength of this conclusion should be weighed against the more rigorous statistical tests that were performed for channel enlargement and channel stability class.

6. The methodology used to perform the analysis of the possible benefits of riparian cover on

stream biological or physical quality yielded inconclusive results. The possible benefits associated with adjacent wetlands, the level of detail associated with this portion of the study, and/or the comparison between streams with only a modest difference in impervious could have impacted the study findings.

5.3: Limitations and Uncertainties

First, and perhaps most importantly, the above discussion is based on a very small data-set of Vermont streams. While, the amended Enlargement Curve (see Section 3) can be used to predict channel enlargement characteristics for other Vermont streams with statistical significance, additional data collection would be desirable to further test the relationships established in this study.

The issue of the age of land cover alteration is significant in establishing where Vermont streams lie in the channel evolutionary process. The time period for a channel to reach this "equilibrium," known as the Relaxation period, may be different for Vermont streams than for those evaluated in Austin, TX, where the Relaxation Curve was derived. It is noted, however, that the Relaxation Curves for AL- and RB-Type streams was verified independently on Humber Creek, Toronto, Ontario (an alluvial stream worn into glacial sediments). The scope of this study, as well as the limitation of finding available historical data for streams where the enlargement process has reached a metastable equilibrium state (see Section 1), precluded testing the validity of the Relaxation Curve for Vermont streams. The establishment of Vermont-specific or, at least, New England specific Relaxation Curves should be considered for future studies.

The benefits or impacts associated with riparian cover were not conclusively demonstrated in this study (see Section 2.7). While, some attempt was made to quantify the relative amount of riparian cover for each of the nine streams, the analysis performed should only be considered a planning level assessment. A much more detailed, on the ground, methodology should be undertaken to quantitatively establish how the width, length, and quality of riparian cover and riparian buffer area contribute to the relationships derived in this study. Other researchers have documented the benefits of riparian cover on protecting overall stream quality (geometry, habitat and biota), but this research is, to date, limited (Horner, et. al. 1997).

Finally, one goal of the State of Vermont in undertaking this series of studies was to examine the effects of land use alteration on the recurrence of extreme flooding events and their subsequent property damage (see Stone Environmental, 1998). This study attempted to isolate these potential impacts by selecting subwatersheds where recent extreme storms were believed not to have occurred. Extreme events can have a significant impact to channel geomorphology, particularly in northern climates where "rain-on-snow" events can cause significant flooding in watersheds even with very low impervious cover (again, see Stone Environmental, 1998).

5.4: Potential Management Implications

The results of this study suggest that the amount of impervious cover (including "equivalent impervious" cover) is a strong indicator of stream health. The State, Regional Planning Commissions, and local communities should consider land use and land cover decisions that monitor and limit the amount of total impervious cover, if stream degradation is to be avoided.

This study was conducted on watersheds where stormwater management controls were limited. Some of the streams had quite a few documented facilities, while others had only a few. The criteria for most of these facilities, according to Jim Pease, of ANR, consisted of ten year storm control for older facilities, and two year control for newer facilities. Few of the facilities specifically provided water quality controls. Several researchers have documented a poor level of performance of these types of facilities in protecting channels from accelerated channel erosion or removal of stormwater pollutants. The impacts to stream geomorphology can be somewhat remediated by applying sophisticated controls for stormwater runoff both at the source and potentially at larger, more centrally located facilities. The State and local authorities should consider developing specific design criteria for the control of stormwater runoff for channel protection and pollutant load reduction.

While not conclusively documented in this study, other researchers have observed benefits to stream systems resulting, in part, from the protection of riparian areas and their adjacent buffer zones. The State and/or local authorities should consider conducting a separate, more detailed study on the benefits of riparian cover, as a potential strategy for protecting Vermont streams and rivers.

The above three recommendations would be best accomplished utilizing a watershed planning approach. It is never easy to address the issue of land use without raising issues of fairness, property rights, and economic considerations. Watershed-based planning focuses on the resource potential within specific watershed boundaries and encourages land management decisions consistent with resource protection goals. The implementation of stormwater management criteria specific to watershed protection goals is also a key element of a "watershed approach." Likewise, stream riparian buffer protection strategies will vary depending on the goals of a particular watershed protection plan.

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APPENDIX A

ORIGINAL PROJECT METHODOLOGY

APPENDIX A: APPROVED PROJECT METHODOLOGY

The study methodology tests whether or not the relationships between land use and stream geomorphology established in other physiographic regions of North America can be applied with statistical significance to Vermont streams. In short, the approach relies on using a limited number of Vermont specific streams to calibrate existing empirical relationships developed elsewhere.

The approach consists of selecting eight streams within eight separate subwatersheds representing different land use disturbance levels. For each stream, current geomorphic parameters and sediment characteristics are compared with pre-disturbance (historical channel form data) parameters to quantify the degree of channel alteration associated with different land uses.

An eleven step methodology was followed to accomplish the goals for the project as follows:

Step 1: The first step of the process consisted of identifying potential candidate subwatersheds that represent a range of land disturbance intensity (e.g., different impervious cover, forestry activity, upland development activity) where past biological monitoring has been performed.

The study protocol targets 1st and 2nd order stream systems to document the longer term hydrological impacts from altered land cover. The main reasons include:

- Higher order tributaries tend to be disproportionally impacted by major flooding events. These rivers are subjected to greater *stream-power* (the rate of doing work; equal to force times velocity) and higher *shear stresses* (force or pull of water per unit area) than their smaller headwater counterparts, yet generally have similar bank materials to resist erosive forces, which tends to lead to more catastrophic impacts by these storms. The channel forming process for lower order stream and rivers tends to be more strongly influenced by the more frequent 1 to 2 year storm events (Leopold, et. al., 1964).
- Perhaps more importantly from a management perspective, it is difficult, if not impossible to assess the cumulative impacts of thousands of individual land cover alterations at the 3rd to 4th order scale. On the smaller subwatershed scale of 1st to 2nd streams, land use alterations are more immediately related to adjacent stream channel modifications. Therefore, it is realistic to connect the application of land management strategies with how adjacent streams respond.

Step 2: This step involved collecting existing data relevant to the project. Pertinent data consisted of historical channel form, biological monitoring results, flow characteristics, water quality, and land use/land cover information. As stated above, the protocol calls for using historical channel data, compared with current cross sectional data to calibrate channel enlargement relationships. Therefore, the foundation of the initial data collection effort relied on obtaining this historical channel form data for subwatersheds exposed to various intensities of land alteration. The primary goal is to establish these relationships on streams where past biological monitoring has occurred. In addition, flow characteristic data was important for the subwatershed selection process and land use mapping data was necessary to verify that streams fall within the desired range of land development intensity.

Step 3: In this step, the list of candidate streams was narrowed to a short list of subwatersheds based on a field reconnaissance to establish locations where current cross sectional data could be collected. The criteria for selection of cross section locations included: being able to map stream segments into like geomorphic reaches (having similar morphology or boundary material composition), and having current sections located relative to their historical counterparts (with the ability to move away from obstructions or local hydrologic influences, but remain within a reach with like geomorphic features).

Step 4: The final eight subwatersheds were selected based on the Subwatershed Selection Criteria -- August 31, 1998, and as approved by the Project Steering Committee.

Step 5: In this step, base mapping was produced for the stream segments to be field surveyed. The purpose of the mapping was to have a common reference for stream cross section locations for field data collection, as well as a reference for the final report.

Step 6: Step six involved a review of the past biological monitoring data and discussions with the Steering Committee to set targets for biological indicators for protection.

Step 7: In this step, the field geomorphic assessment methodology was modified for Vermont condition to collect data that could be used to correlate stream channel stability with biological integrity.

Step 8: In this step the field geomorphic assessment and current field cross-sectional data were collected at each of the eight streams. Measurements were taken at three locations in each stream where historical data is available. The Rapid Geomorphic Assessment classification technique (developed by Aquafor Beech, Ltd.) was used to characterize each stream's level and mode of channel adjustment (i.e., aggradation, degradation, widening, and/or planimetric form adjustment). This characteristic was then used to classify the streams as *stable, in transition, or unstable.* The classification allows the investigator to establish where the channel lies in the overall stream channel adjustment process.

The next element of the field assessment was to measure the channel cross sectional geometry at each location. The data was used to establish the channel enlargement ratio and the relaxation characteristics. The enlargement ratio is the value of the ultimate post disturbance channel cross-section at the bankfull stage, divided by the pre-disturbance channel as it responds to a watershed land disturbance. The time it takes a stream to re-establish the balance between erosion forces and those tending to resist erosion is referred to as the relaxation time. During this phase of the project, a photographic record was compiled to document current conditions in the vicinity of the geomorphic assessment locations.

Step 9: Here, stream bankfull discharges were computed to establish relationships between land use/land cover and flow for each of the eight streams. Past geomorphic assessments for North American streams used impervious cover as the variable representing hydrologic alteration for the contributing subwatershed land area. In Vermont, the study design still relied on impervious cover, but also utilized the NRCS curve number (CN) to compute an equivalent impervious cover for the non-urban subwatersheds. The team tested this approach in one subwatershed by comparing the computed bankfull discharge to the equivalent discharge computed using NRCS methods. In this step the land use/ land cover (% imperviousness) was also quantified and mapped for both historic and current conditions.

Step 10: In this step the project team analyzed the collected data to determine the validity of the *enlargement* and *relaxation* curves based on the collected data. The project team performed statistical tests for the data sets representing the predicted and observed amounts of enlargement to test whether the Vermont data is statistically valid when compared to the other data from North American Streams.

Step 11: Based on the results of step 10, the project team reviewed the relationships between land use/land cover alterations and the physical stream geomorphic parameters as compared to the biological monitoring data to make recommendations regarding management implications.

APPENDIX B

LAND USE TABLES FOR IMPERVIOUS COVER

TABLE B-1: SUMMARY DATA FOR MOON BROOK					
Land Use Code	**Land Use**	**Downstream**		**Upstream**	
		Area (Acres)	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	2.63	0%	0.46	0%
5	Water	137	0%	72.1	0%
7	Barren Land	1.70	0%	1.69	0%
11	Residential	1,412	14%	912	13%
12	Commercial	53.6	80%	30.7	80%
13	Industrial	20.4	60%	0	--
14	Transportation	426	41%	263	39%
17	Other Urban	0.15	60%	0.15	60%
24	Agriculture/ Mixed Open	0.31	2%	0.15	0%
41	Deciduous Forest	884	0%	399	0%
42	Coniferous Forest	200	0%	85.7	0%
43	Mixed Forest	208	0%	107	0%
62	Non- Forested Wetland	33.96	0%	17.9	0%
211	Row Crops	4.32	2%	1.70	2%
212	Hay/ Pasture	6.33	2%	2.68	2%
	Total	**3,390**	**13%**	**1,893**	**13%**

TABLE B-2: SUMMARY DATA FOR TENNEY BROOK			
Land Use Code	**Land Use**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	3.86	0%
5	Water	90.5	0%
7	Barren Land	8.49	0%
11	Residential	579	11%
12	Commercial	34.9	80%
13	Industrial	0.46	60%
14	Transportation	195	39%
17	Other Urban	0.31	60%
24	Agriculture/ Mixed Open	0.92	2%
41	Deciduous Forest	811	0%
42	Coniferous Forest	475	0%
43	Mixed Forest	275	0%
61	Forested Wetland	112	0%
62	Non- Forested Wetland	17.6	0%
211	Row Crops	124	2%
212	Hay/ Pasture	111	2%
	Total	**2,839**	**6%**

TABLE B-3: SUMMARY DATA FOR POTASH BROOK							
Land Use Code	**Land Use**	**Downstream**		**Middle**		**Upstream**	
		Area (Acres)	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	10.7	0%	10.4	0%	5.86	0%
5	Water	243	0%	201	0%	161	0%
11	Residential	1,025	11%	629	13%	634	11%
12	Commercial	454	60%	315	60%	151	60%
13	Industrial	54.1	50%	54.1	50%	54.1	50%
14	Transportation	698	46%	566	46%	415	46%
17	Other Urban	167	5%	142	5%	53.6	5%
24	Agriculture/ Mixed Open	32.4	0%	29.7	2%	23.2	0%
41	Deciduous Forest	143	0%	115	0%	85.6	0%
42	Coniferous Forest	120	0%	73.6	0%	61.6	0%
43	Mixed Forest	170	0%	148	0%	111	0%
61	Forested Wetland	40.8	0%	39.7	0%	37.7	0%
62	Non- Forested Wetland	55.3	0%	52.8	0%	50.7	0%
211	Row Crops	781	2%	764	2%	694	2%
212	Hay/ Pasture	511	2%	464	2%	431	2%
XX	Airport	257	100%	257	100%	257	100%
	Total	**4,760**	**22%**	**3,862**	**22%**	**3,225**	**20%**

TABLE B-4: SUMMARY DATA FOR STEVENS BROOK

Land Use Code	Land Use	Downstream		Upstream	
		Area (Acres)	Impervious Cover	Area (Acres)	Impervious Cover
3	Brush/ Transitional	11.3	0%	1.08	0%
5	Water	246	0%	48.5	0%
11	Residential	755	26%	144	23%
12	Commercial	141	70%	14.5	85%
13	Industrial	1.70	90%	0.77	90%
14	Transportation	551	47%	109	46%
17	Other Urban	0.93	50%	0.31	50%
24	Agriculture/ Mixed Open	132	2%	18.1	2%
41	Deciduous Forest	808	0%	315	0%
42	Coniferous Forest	41.3	0%	1.54	0%
43	Mixed Forest	242	0%	43.7	0%
61	Forested Wetland	40.3	0%	92.2	2%
62	Non- Forested Wetland	24.3	0%	107	2%
211	Row Crops	717	2%	92.2	2%
212	Hay/ Pasture	691	2%	107	2%
	Total	**4,403**	**13%**	**895**	**11%**

TABLE B-5: SUMMARY DATA FOR ROARING BROOK							
Land Use Code	**Land Use**	**Downstream**		**Tributary**		**Upstream**	
		Area (Acres)	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	2.16	0%	0	--	2.01	0%
5	Water	193	0%	10.5	0%	164	0%
11	Residential	86.8	11%	9.21	11%	22.5	11%
12	Commercial	21.2	80%	0.62	80%	18.4	80%
14	Transportation	139	45%	10.4	45%	91.4	48%
17	Other Urban	0.62	50%	0.16	80%	0.15	80%
24	Agriculture/ Mixed Open	202	2%	14.1	2%	202	2%
41	Deciduous Forest	2,036	0%	221	0%	1,612	0%
42	Coniferous Forest	535	0%	137	0%	447	0%
43	Mixed Forest	272	0%	56.2	0%	156	0%
61	Forested Wetland	6.26	0%	1.62	0%	4.63	0%
62	Non- Forested Wetland	12.2	0%	0	--	12.2	0%
211	Row Crops	85.4	2%	1.39	2%	75.8	2%
212	Hay/ Pasture	81.6	2%	2.78	2%	79.9	2%
	Preliminary Total	**3,478**	**3%**	**464**	**1%**	**2,889**	**2%**
	Ski Trails/ Work Roads	368	35%	0	--	368	35%
	Total	**3,478**	**6%**	**464**	**1%**	**2,889**	**7%**

TABLE B-6: SUMMARY DATA FOR WEST BRANCH							
Land Use Code	**Land Use**	**Downstream**		**Middle**		**Upstream**	
		Area (Acres)	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	2.63	0%	2.47	0%	1.39	0%
5	Water	928	0%	892	0%	654	0%
11	Residential	44.0	10%	0.77	10%	0.31	10%
12	Commercial	4.79	80%	3.09	80%	0.93	80%
14	Transportation	541	45%	491	45%	272	46%
24	Agriculture/ Mixed Open	469	2%	468	2%	4,684	2%
41	Deciduous Forest	6,037	0%	5,995	0%	4,807	0%
42	Coniferous Forest	2,720	0%	2,646	0%	1,743	0%
43	Mixed Forest	3,670	0%	3,599	0%	2,303	0%
61	Forested Wetland	30.0	0%	19.8	0%	7.88	0%
62	Non- Forested Wetland	9.11	0%	6.49	0%	5.71	0%
211	Row Crops	504	2%	451	2%	182	2%
212	Hay/ Pasture	506	2%	381	2%	141	2%
	Preliminary Total	**15,465**	**1%**	14,960	1%	**10,589**	**1.0%**
	Ski Trails/ Work Roads	480	35%	480	35%	480	35%
	Total	**15,465**	**2%**	**14,960**	**2%**	**10,589**	**3%**

TABLE B-7: SUMMARY DATA FOR COLD RIVER							
Land Use Code	**Land Use**	**Downstream**		**Gould Brook**		**Upstream**	
		Area (Acres)	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**	**Area (Acres)**	**Impervious Cover**
3	Brush/ Transitional	3.09	0%	0.15	0%	0.46	0%
5	Water	450	0%	239	0%	95.97	0%
7	Barren Land	30.4	0%	0	--	0	--
11	Residential	96.8	15%	3.86	15%	82.57	15%
12	Commercial	0.62	80%	0	--	0.46	80%
14	Transportation	274	41%	95.3	41%	117.13	41%
17	Other Urban	0.62	50%	0	--	0.62	50%
24	Agriculture/ Mixed Open	0.15	2%	0	--	23.2	0%
41	Deciduous Forest	7,293	0%	3,747	0%	1,149	0%
42	Coniferous Forest	3,608	0%	2,130	0%	813	0%
43	Mixed Forest	1,270	0%	676	0%	283	0%
61	Forested Wetland	58.7	0%	10.7	0%	44.2	0%
62	Non- Forested Wetland	25.8	0%	0.15	0%	25.6	0%
211	Row Crops	52.5	2%	10.4	2%	15.3	2%
212	Hay/ Pasture	69.3	2%	12.1	2%	13.3	2%
	Total	**13,234**	**1%**	**6,924**	**1%**	**2,641**	**2%**

TABLE B-8: SUMMARY DATA FOR SMITH BROOK			
Land Use Code	**Land Use**	**Area (Acres)**	**Impervious Cover**
5	Water	84.9	0%
14	Transportation	0.07	41%
41	Deciduous Forest	1571	0%
42	Coniferous Forest	138	0%
43	Mixed Forest	244	0%
211	Row Crops	1.39	2%
212	Hay/ Pasture	0.46	2%
	Total	**2,039**	**0%**

TABLE B-9: SUMMARY DATA FOR DOWSVILLE BROOK*			
	Downstream	**Upstream**	**Tributary**
Watershed Area (Acres)	4,100	3,450	300
Impervious Cover (excluding logging)	1%	1%	1%
Area Logged (Acres)	600	500	45
Impervious Cover (Logged Areas)	35%	35%	35%
Total Impervious Cover	**6%**	**6%**	**6%**

* Digital data were not used to determine impervious cover in Dowsville Brook, because the data did not reflect logging that occurred in the drainage area. The data were measured from aerial photographs.

APPENDIX C

DIAGNOSTIC GEOMORPHIC SURVEY FORM

Representative Example for Potash Brook

DIAGNOSTIC GEOMORPHIC FIELD SURVEY FORM

TITLE PAGE

PROJECT TITLE: VERMONT

PROJECT No: 68005

DATE OF SURVEY: **YR:** 98 **MO:** 10 **DY:** 16

WATERCOURSE NAME: POTASH BROOK

STATION NUMBER: POT 1

STATION LOCATION: QUEENCITY PARK ROAD 0.5 to 0.6 miles from Confluence

FIELD CREW MEMBERS:

Craig MacRAE	Bob Kort
Lori Barg	Jim Pease
Mike Fischer	

STREAM TYPE:

	HISTORIC CHANNEL	EXISTING CHANNEL
ALLUVIAL (AL)		AL(Ar)
ROCK BED (RB)		
ROCK CONTROLLED (RC)		

exposed bedrock outcrop u/s of SECNO 1.

RAPID GEOMORPHIC ASSESSMENT

Table 1. Rapid Geomorphic Assessment Form

FORM/ PROCESS	GEOMORPHIC INDICATOR No.	Description	PRESENT No	PRESENT Yes	FACTOR VALUE
Evidence of Aggradation (AI)	1	Lobate bar	✓		4/7
	2	Coarse material in riffles embedded	✓		
	3	Siltation in pools		✓	
	4	Medial bars		✓	
	5	Accretion on point bars	✓		
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	—	—	1/5
	2	Exposed sanitary/storm sewer/pipeline/etc.	—	—	
	3	Elevated stormsewer outfall(s)	—	—	
	4	Undermined gabion baskets/concrete aprons/etc.	—	—	
	5	Scour pools d/s of culverts/stormsewer outlets	—	—	
	6	Cut face on bar forms	✓		
	7	Head cutting due to knick point migration	✓		
	8	Terrace cut through older bar material		✓	
	9	Suspended armor layer visible in bank	✓		
	10	Channel worn into undisturbed overburden/bedrock	✓		
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.		✓	6/7
	2	Occurrence of Large Organic Debris		✓	
	3	Exposed tree roots		✓	
	4	Basal scour on inside meander bends		✓	
	5	Basal scour on both sides of channel through riffle		✓	
	6	Gabion baskets/concrete walls/armor stone/etc. out flanked	—	—	
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe/cable/etc.	—	—	
	9	Fracture lines along top of bank	✓		
	10	Exposed building foundation	—		
Evidence of Planimetric Form Adjustment (PI)	1	Formation of cute(s)		✓	4/7
	2	Evolution of single thread channel to multiple channel	✓		
	3	Evolution of pool-riffle form to low bed relief form		✓	
	4	Cutoff channel(s)	✓		
	5	Formation of island(s)	✓		
	6	Thalweg alignment out of phase with meander geometry		✓	
	7	Bar forms poorly formed/reworked/removed		✓	
STABILITY INDEX (SI) = (AI+DI+WI+PI)/m				SI= 0.58	

GEOMORPHIC INDICATORS OF BANK EROSION PROCESSES

Table 2. Field Indicators of Bank Erosion Processes

INDICATOR		Present
Shear Dominated Fluvial Forms		
1. Smoothed banks remaining after the passage of a flood flow		
2. Frequent bank overhangs along the length of the channel (may have straight tension cracks parallel to but set back from the top of bank)		
3. Cantilever failure of the banks resulting in largely intact blocks of bank material lying at the bank toe (often grasses continue to grow on the block)		
Falling Stage Dominated Fluvial Forms		
4. Deep seated failures, typically occur as rotation slumps, arc shaped bank cross-section profile		
5. Arc shaped plan form (may have arc shaped tension cracks in the tableland near the top of bank but set back further from the edge of bank than noted for surficial failures		
6. Failure material in the form of a slurry (bank materials having lost their original structure)		
Non-Fluvial Processes		
Physical Weathering	7. Expansion-Contraction, e.g. freeze-thaw/wet-dry: cracks and sloughing of a thin veneer of surficial material	
	8. Ice gouging/plucking: e.g. striations-groves in bank material / fractured	
	9. Cavitation pressure: e.g. concave form of riser portion of knickpoint	
	10. Soil piping: e.g. multiple small diameter tunnels (pockets) extending into the bank – often form a row along the interface between two stratigraphic units	
Bio-Weathering	11. Livestock trampling of banks/cropped grasses amounts taller weeds	
	12. Borrowing animals	
Chemical Weathering	13. Presence of solutional forms	
Aeolean Weathering	14. Dunes, ripples, drift features	
Pluvial Weathering	15. Pot marks and rivulets down bank face	

HYDRAULIC GEOMETRY

Table 3. Bankfull Depth

Indicator	Left Bank			Right Bank		
	Sub-Inset	Inset	Active	Sub-Inset	Inset	Active
Top-of-Bank						
Inflection Point						
Terrace						
Change in Bar Material						
Top of Point Bar						
Presence of Lichens						
Water Stains						
Wormholes						
Bird Nests						
Animal Burrows						
Other						

DISCHARGE MEASUREMENTS

Table 4 Manning's Roughness Coefficient

X (m)	t (sec)	v (m/s)	A (m^2)	Q (m^3/s)	n	
					Measured	Predicted

Figure 1. Low Flow Channel Cross-Section Profile

CHANNEL PLAN FORM GEOMETRY

Figure 2. Planimetric Form Sketch

LONGITUDINAL PROFILE

Table 5. Longitudinal Survey Data

Obs No.:	Horizontal Distance (Z) ~~(m)~~ (ft)	Vertical Distance (Y) ~~(m)~~ (ft)	Water Depth ~~Level~~ (WL) ~~(m)~~ (ft)	Comment
1	-127	96.96	1.2	Pool
2	-109	97.19	1.0	Bottom of Riffle
3	-94	98.31	2.8	Top of Riffle
4	-77	98.30	1.2	Pool
5	-50	97.94	1.6	mid - Pool
6	-19	98.64	1.0	Bottom of Riffle
7	± 16	98.72	1.2	middle of Riffle
8	+30	99.26	1.3	Top of Riffle
9	+42	99.00	1.5	Pool
10	+59	99.70	0.9	Bottom of Riffle
11	+72	99.91	1.0	Top of Riffle
12	+100	99.50	1.5	Pool
13	+115	100.03	1.0	Bottom of Riffle
14	+125	100.69	0.9	top of Riffle
15	+154	101.13	0.7	riffle run
16	+178	101.44	0.8	run
17	+194	101.22	1.5	top of riffle

CROSS-SECTION ORDINATES

Table 6. Cross-Section Survey Data

Obs No.:	Horizontal Distance (Z) ~~(m)~~ (ft)	Vertical Distance (Y) ~~(m)~~ (ft)	Water Level (WL) (m)	Comment
-1	-32	108.075		On LEFT BANK TERRACE LB
0	0	108.31		
1	+7	107.875		Grade Break
2	+10	107.17		TOP OF LEFT BANK
3	+19.5	103.235		BOTTOM OF SLOPE ≈ BANKFULL
4	+29	102.07		EDGE OF VEGETATION & GRADE BREAK
5	+30	100.39		BOTTOM OF BANK
6	+32	99.98		2nd VEGETATED PLATEAU.
7	+32	98.79		EDGE OF WATER
8	+38	99.22		MID CHANNEL
9	+44	99.93		THALWEG
10	+52	100.17		EDGE OF WATER (COBBLE BAR)
11	+57	100.125		EDGE OF CHUTE
12	+59	100.00		BOTTOM OF STEEP BANK
13	+59	101.515		EDGE OF BANK.
14	+60	102.16		EDGE OF GRASSES
15	+86	102.94		BOTTOM OF BANK ≈ BANKFULL
16	+91	105.53		EDGE OF BIG TREES.
17	+99	108.27		
18	+108	112.40		
BM	+52	100.00		BM2 - IN CHANNEL - LARGE ROCK

CHANNEL HYDRAULIC PARAMETERS

SOIL CONSISTENCE: DEFINITION OF TERMS

X1 (STICKNESS):	VERY MOIST CONDITION
0 = NON-STICKY	Almost no adhesion of soil materials to fingers (Sa)
1 = SLIGHTLY STICKY	Soil material adheres to one finger but the other finger remains clean
2 = STICKY	Soil material adheres to both fingers and thumb, stretches somewhat
3 = VERY STICKY	Soil material strongly adheres to both thumb and finger but bulk of material remains intact, stretches
4 = EXTREMELY STICKY	Soil material preferentially adheres to hand, thumb and finger, soil material structure becomes incoherent

X2 (PLASRICITY):	MOIST CONDITION
0 = NON-PLASTIC	No "wire" (thread or bead) can be formed by rolling the material between the palms of the hands
1 = SLIGHTLY PLASTIC	Only short wires ($L<1$ cm) of $\phi > 2$ mm can be formed
2 = PLASTIC	Longer wires ($2 \leq L \leq 3$ cm) of $\phi > 2$ mm can be formed
3 = VERY PLASTIC	Long wires ($L>3$ cm) and $\phi \leq 2$ mm can be formed and moderate pressure is required to deform a block of molded materials
4 = EXTREMELY PLASTIC	Long wires ($L>3$ cm) and $\phi \leq 2$ mm can be formed and much pressure is required to deform a block of molded materials

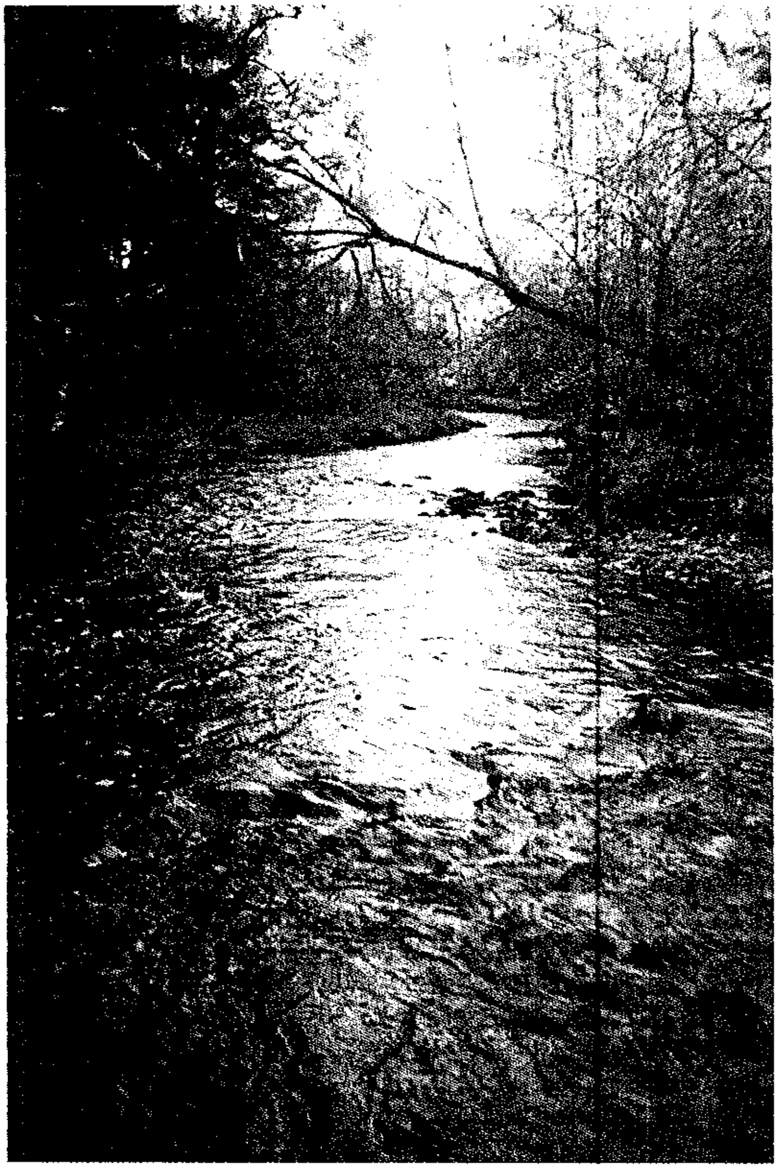
X3 (FIRMNESS):	DRY CONDITION
0 = LOOSE	Soil material is non-coherent (comprised primarily of individual grains) and finger can penetrate bank easily.
1 = VERY SOFT	Soil material is comprised of loose aggregates which crush with gentle pressure between the thumb and finger (friable), finger penetrates intact material with moderate pressure.
2 = SOFT	Moderate thumb and finger pressure required to crush aggregates, finger penetrates intact material with difficulty (between 1st and 2nd joint).
3 = FIRM	Strong thumb and finger pressure is required to crush aggregates and finger can only dent intact materials.
4 = STIFF	Aggregates cannot be broken by thumb and finger pressure and intact material can only be dented with finger nail.

The above consistence tests are for soil material moisture content at or slightly above the "field moisture capacity" (gravitational water) with the exception of the FIRMNESS test which is a dry soil condition. The tests are not to particles of diameter equal to or exceeding fine gravel.

GLOSSARY OF TERMS

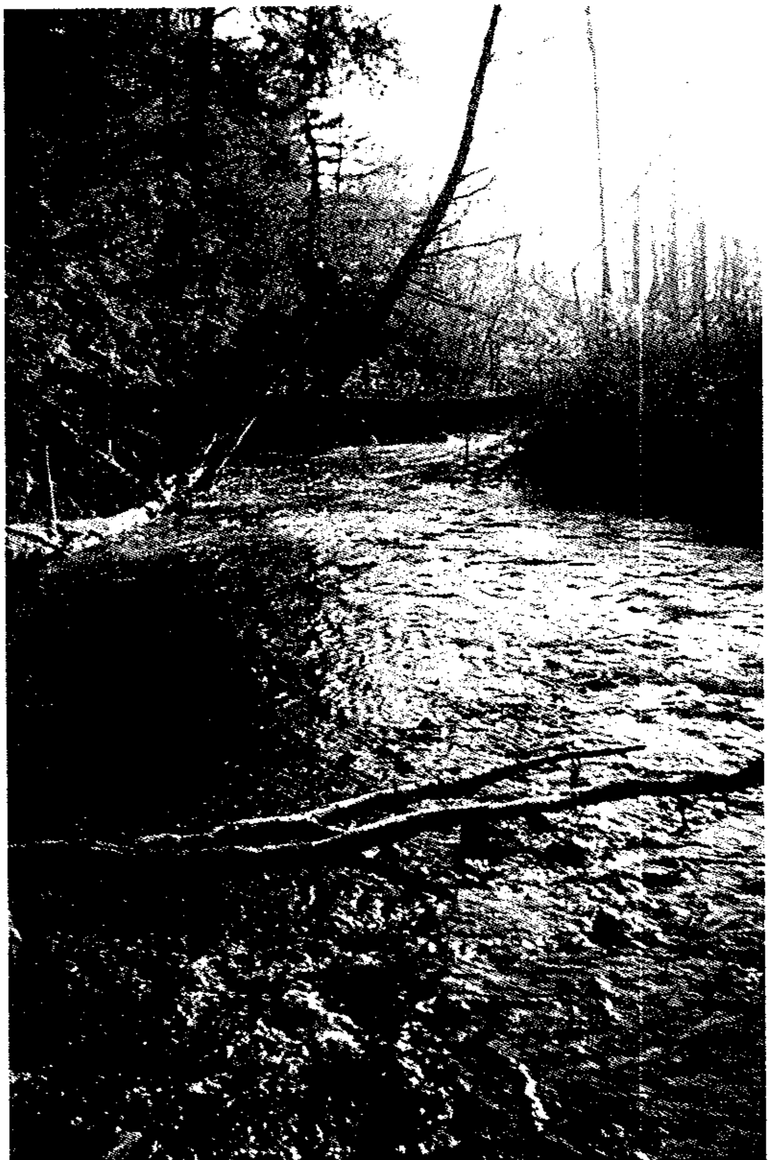
Cl = Clay	Si = Silt	Sa = Sand	Gr = Gravel	Co = Cobble	Bo = Boulder
Lm = Loam	Al = Alluvium	Rk = Rock	Bl = Black	Br = Brown	Gr = Grey
Bl = Blue	Mt = Mottled	Ca = Coarse	Fn = Fine	Md = Medium	Lft = Left
Rht = Right	u/s = Upstream	Mu = Muck	Ml = Marl	Dt = Detritus	d/s = Downstream
τ = boundary shear stress		CRT = Critical	PI = Plasticity Index		

View of Channel Looking u/s **Roll No.:** 10 **Photo No.:** 4



Notes:

View of Channel Looking d/s | Roll No.: 10 | Photo No.: 5

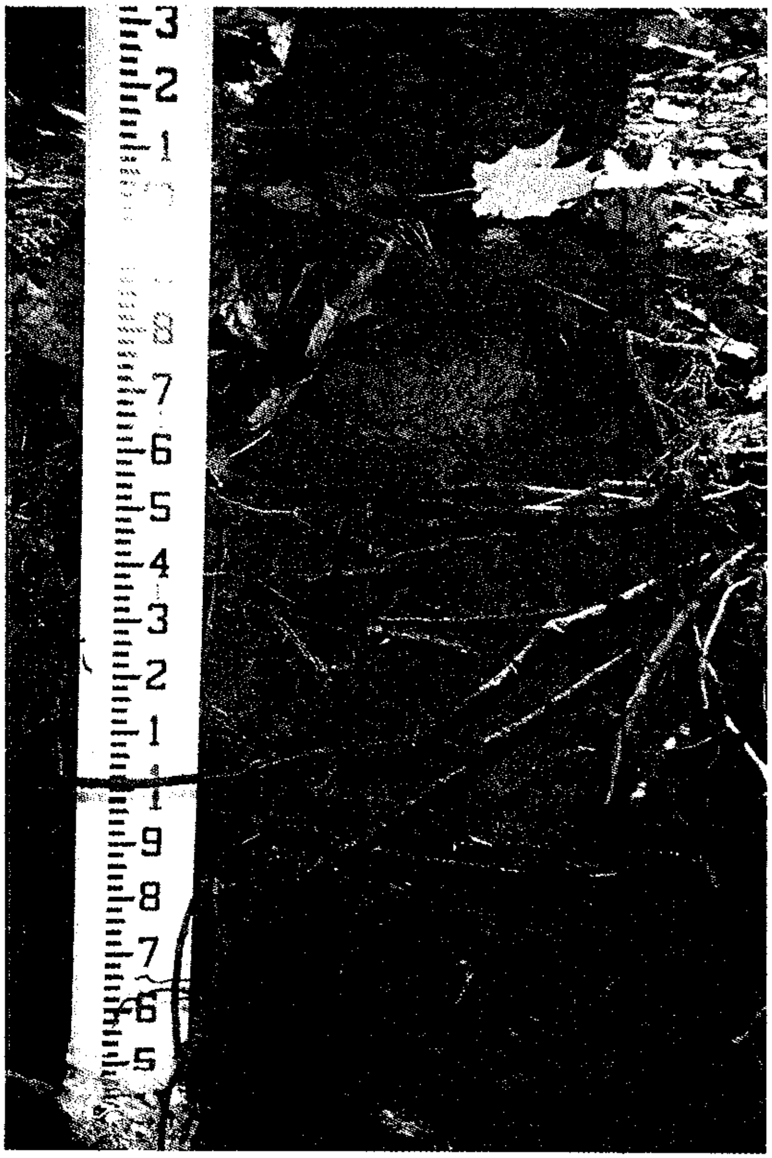


Notes:

View of LEFT Bank

Roll No.: 10

Photo No.: 0



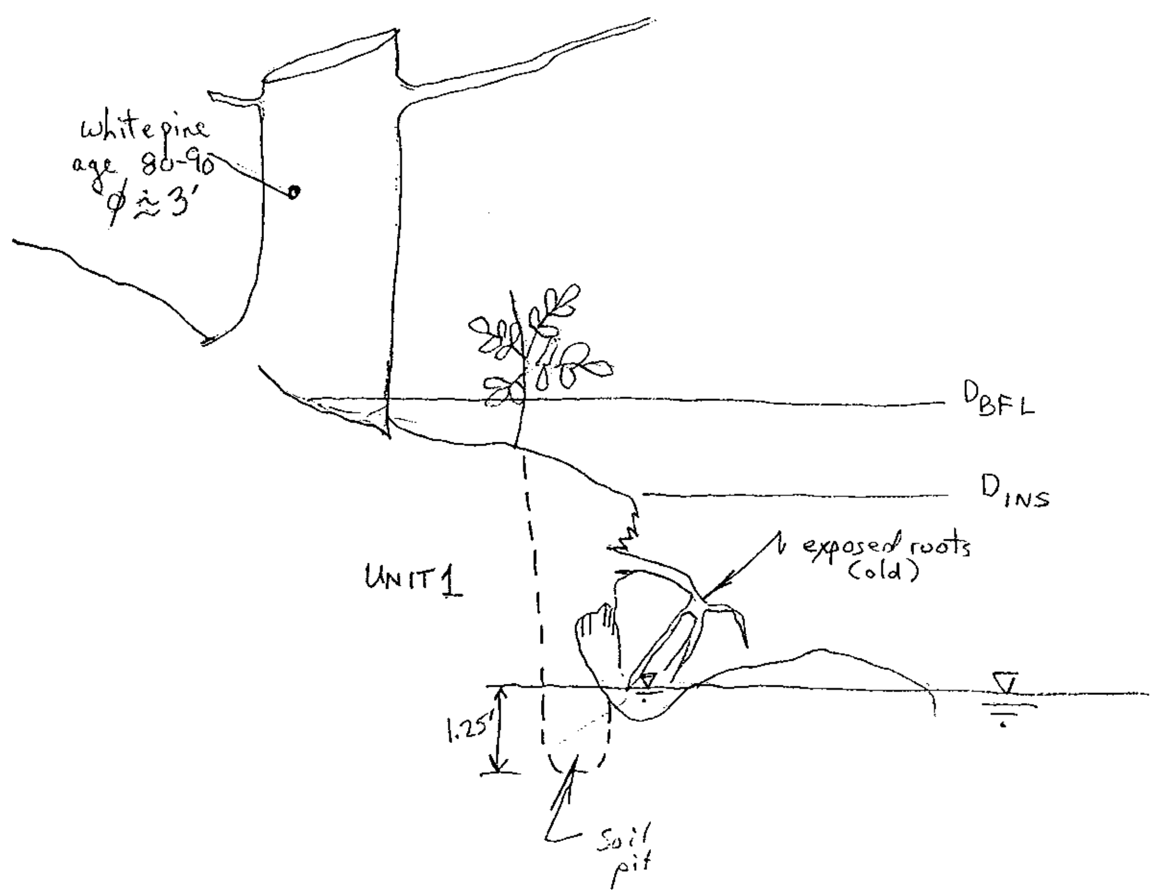
Notes:

BANK MATERIAL COMPOSITION

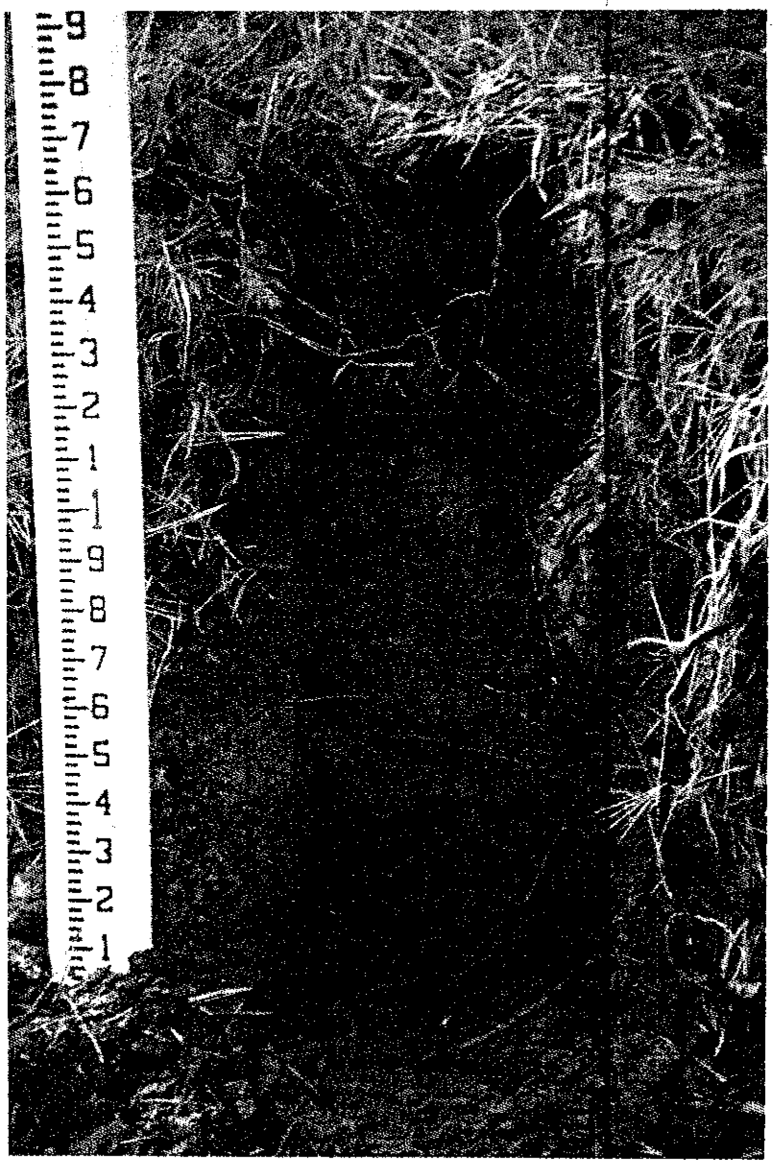
Table 7. LEFT Side (View looking u/s)

Unit No.:	SCORE				PARTICLE SIZE (%)				Soil Class	PI	τ_{CRT}
	X1	X2	X3	Σ	Gr	Sa	Si	Cl			
1	1	2	1	4					SiLm with Sa Inclusions		

Figure 3. Bank Profile: LEFT Bank



View of RIGHT Bank | Roll No.: 10 | Photo No.: 2



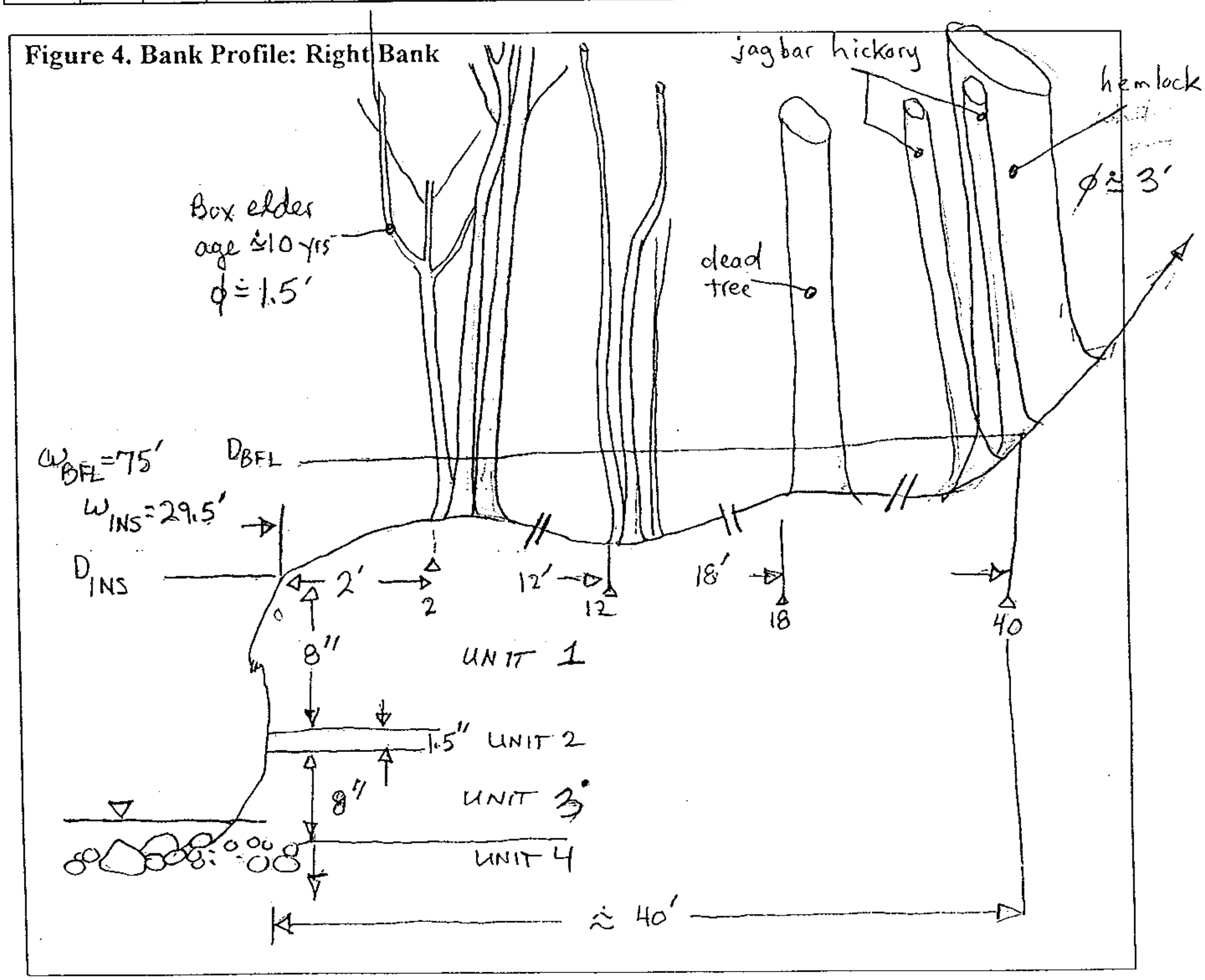
Notes:

BANK MATERIAL COMPOSITION CONT'D

Table 8. RIGHT Side (View looking u/s)

Unit No.:	SCORE				PARTICLE SIZE (%)				Soil Class	PI	τ_{CRT}
	X1	X2	X3	Σ	Gr	Sa	Si	Cl			
1		3	1	4					Si Lm with SA Inclusions		
2									Co Sa lens		
3									Si Sa		
4									Gr Co in Si Sa matrix		

Figure 4. Bank Profile: Right Bank



BED MATERIAL COMPOSITION

* measured in tenths of feet

Table 9. Substrate Composition: Transect 1

OBS No.	Material Type	Location	Particle Size l	w	h	OBS No.:	Material Type	Location	Particle Size l	w	h
1	Ed	LB	.8'	.9'	.7'	36		RB	1.9'	1.4'	.7'
2		LB	.7	.6	.26	37	upstream tow →	LB	4.4'	2.0'	1.5'
3		LB	1'	1'	—	38		LB	.64'	.40'	.30'
4		LB	.74'	.32'	.3'	39		LB	2.45'	1.90'	1.1'
5		1/3 CR	1.6'	1.2'	.6'	40		LB	.52'	.28'	.20'
6		1/3 CR	.45'	.26'	.17'	41		1/3 CR	1.20'	1.6'	.65'
7		1/2 CR	.48'	.32'	.20'	42		1/3 CR	1.10'	.90'	.58'
8		1/2 CR	.34'	.25'	.20'	43		1/2 CR	.42'	.32'	.26'
9		1/2 CR	.22'	.18'	.10'	44		1/2 CR	.70'	.30'	.60'
10		1/2 CR	.6'	.11'	.50'	45		1/2 CR	.60'	.55'	.31'
11		1/2 CR	.51'	.60'	.17'	46		2/3 CR	.68'	.43'	.23'
12		1/2 CR	.38'	.36'	.20'	47		2/3 CR	.38'	.17'	.11'
13		1/2 CR	.15'	.16'	.15'	48		2/3 CR	.88'	.35'	.20'
14		1/2 CR	.45'	.34'	.22'	49		2/3 CR	.55'	.40'	.36'
15		2/3 CR	.42'	.24'	.11'	50	Medial bar →	2/3 CR	.32'	.30'	.21'
16	Medial bar →	2/3 CR	.54'	.50'	.34'	51	↓	2/3 CR	.75'	.51'	.32'
17	Medial bar	2/3 CR	.24'	.22'	.15'	52		2/3 CR	.55'	.37'	.20'
18	↓	RB	.36'	.25'	.14'	53		RB	.48'	.22'	.5'
19		RB	.40'	.30'	.21'	54		LB	.50'	.22'	.17'
20		RB	.40'	.20'	.19'	55	↓	LB	.29'	.25'	.23'
21		RB	.32'	.33'	.09'	56					
22		RB	.44'	.23'	.22'	57					
23		RB	.41'	.20'	.21'	58					
24		RB	.36'	.24'	.15'	59					
25		RB	.40'	.32'	.70'	60					
26		RB	1.0'	.76'	.31'	61					
27		RB	.24'	.10'	.27'	62					
28		RB	.42'	.34'	.10'	63					
29		RB	.18'	.25'	.10'	64					
30		RB	.15'	.20'	.10'	65					
31		RB	.17'	.15'	.08'	66					
32		RB	.34'	.30'	.19'	67					
33		RB	.20'	.13'	.38'	68					
34	⊥	RB	.14'	.18'	.08'	69					
35		RB	.42'	.25'	.24'	70					

BED MATERIAL COMPOSITION CONT'D

Table 10. Substrate Composition: Transect 2 MEASURED IN 1/10th ft.

OBS No.	Material Type	Location	Particle Size			OBS No.:	Material Type	Location	Particle Size		
			l	w	h				l	w	h
1		RB	2.7	2.1	0.6	36			4.5	2.7	2.0
2			4.0	2.1	0.9	37			3.0	2.3	1.8
3			5.0	2.4	1.8	38			4.5	4.0	2.0
4			5.5	3.3	3.0	39			15.0	13.0	6.0
5			3.6	3.2	1.7	40			19.0	6.0	4.5
6			4.0	3.0	2.9	41			4.0	2.0	1.3
7		1/8	3.5	3.1	1.8	42		5/8	7.0	7.0	3.5
8			9.0	6.0	1.6	43			5.5	3.5	1.5
9			7.0	4.6	2.2	44			3.6	2.5	1.2
10			5.5	4.0	3.8	45			7.0	4.5	3.5
11			3.1	2.7	1.5	46			4.8	3.2	1.6
12			1.2	0.8	0.3	47			2.8	1.3	0.7
13			0.6	0.5	0.4	48			2.7	2.4	1.7
14			1.6	1.2	1.1	49			5.5	4.8	3.0
15			0.8	0.7	0.5	50			5.0	3.0	2.5
16		1/4 across	0.4	0.3	0.11	51		3/4	5.5	3.1	1.2
17			0.4	0.3	0.3	52		ON BAR	4.7	4.5	2.8
18			4.4	2.8	3.2	53			3.0	1.7	1.5
19			1.0 ↔	1.1	0.3	54			5.0	2.0	1.5
20			1.3	0.7	0.5	55			1.5	1.8	1.2
21			1.0	0.9	0.5	56			2.0	1.7	1.4
22			4.8	4.0	1.7	57			4.0	2.0	1.7
23			4.0	3.5	2.7	58			2.2	1.5	1.1
24			4.5	3.5	1.5	59			1.9	1.6	1.2
25			4.1	3.1	2.3	60			2.5	2.1	1.5
26			5.0	5.0	1.8	61			1.0	0.8	0.4
27			9.0	5.0	3.0	62		7/8	3.7	2.5	1.6
28		3/8	10.0	7.0	5.0	63			3.7	1.8	1.6
29			6.0	2.5	2.2	64			2.7	1.6	1.5
30			18.0	9.0	4.0	65			3.3	3.3	1.6
31			11.0	7.0	4.0	66			1.7	1.4	1.0
32			8.0	7.2	3.5	67			0.9	0.9	0.3
33			8.5	4.0	3.7	68			3.2	2.7	0.5
34			4.7	3.6	1.2	69			1.2	0.9	0.3
35		1/2	9.0	7.0	2.5	70			0.8	0.6	0.1

GRAVEL MATRIX

D BANKFUL ESTIMATE = 4.6 ?

View of Channel BED

Roll No.: 10

Photo No.: 6

Notes:

PEBBLE COUNT MASS CURVE & PARTICLE DISTRIBUTION PARAMETRICS

Table 11. Composition of (Intact Bed Material)

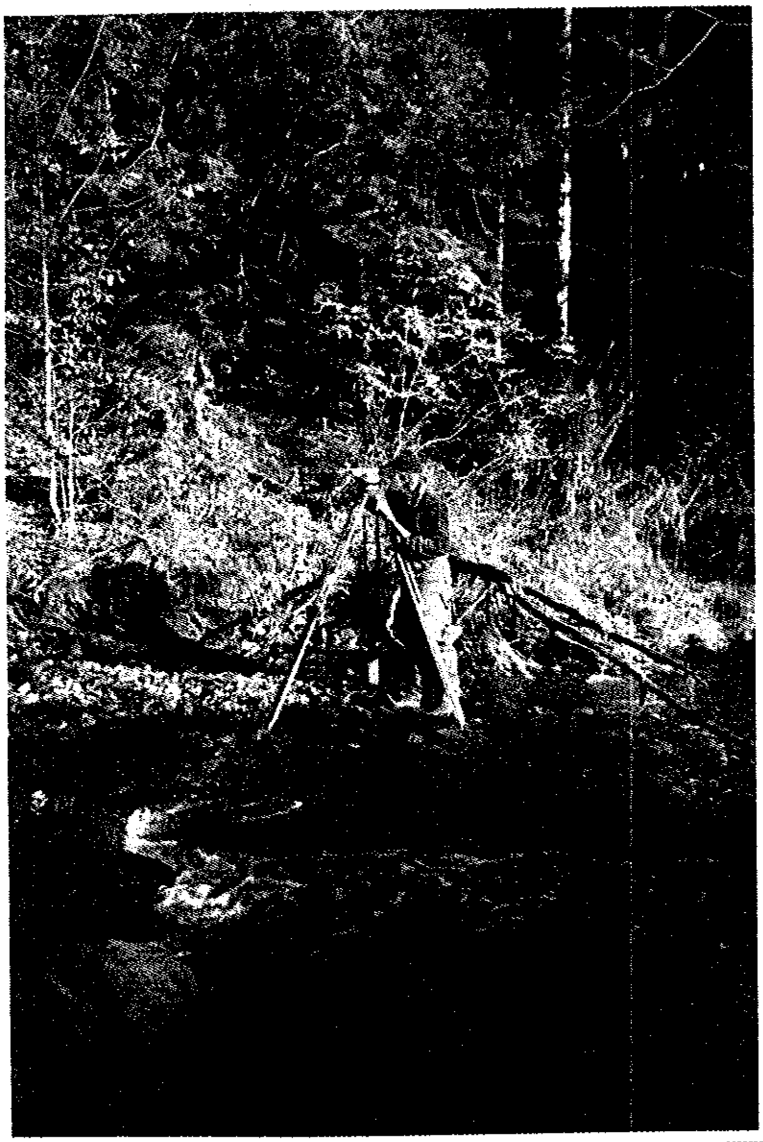
SUBSTRATUM CLASS		Degree of Compaction	AERIAL COVERAGE (%)
Silty-Clay		Loose/soft/firm/stiff/cemented	
Clayey-Silt		Loose/soft/firm/stiff/cemented	
Sandy-Silt		Loose/soft/firm/stiff/cemented	
Silty Sand		Loose/soft/firm/stiff/cemented	
Gravel in Silty-Sand Matrix		Loose/soft/firm/stiff/cemented	
Cobbles in Sandy-Gravel Matrix		Loose/imbricated/cemented Imbeddedness (<25;25-50;>50%)	
Boulders & Cobbles in Sandy-Gravel Matrix		Loose/imbricated/cemented Imbeddedness (<25;25-50;>50%)	
Boulders & Cobbles		Loose/imbricated/cemented Imbeddedness (<25;25-50;>50%)	
Rock	Sandstone	Soft/Hard Fractured/Friable	
	Shale (mudstone-siltstone)	Soft/Hard/ Fractured/Friable	
	Interbedded Shale-Limestone	Thinly Bedded	
		Thickly Bedded	
	Limestone	Massive/Soft/ Hard/Fractured	
	Metamorphic/Igneous	Massive Fractured	

Figure 5. Sketch Of Bed Transect

Special Features

Roll No.: /

Photo No.: /



Notes:

No special features – just an extra photo.

Large Organic Debris

Quantity			
$L \geq W_{INS}$ =	11	m	
No. of Pieces 0-50m u/s : $N_{U/S}$	5	0-50m d/s : $N_{D/S}$	6
Total, $N = N_{U/S}+N_{D/S}$	11		

Number, N_i	1 +	2 +	3 +	4 +	5 +	6 −	7 −	8 −	9 −	10 −	11 −	12	13	14	15	16	17	18	19	20	21	22	23	24
X (+:u/s, -:d/s)	66/91	134	187/160	177/155	210/170	52	66/45	121/-78	124/144	128/169	181													
Orientation																								
Perpendicular																								
Obtuse	✓	✓				✓	✓																	
Parallel			✓	✓	✓			✓	✓	✓	✓													
Location																								
Instream		✓				✓	✓				✓													
On Bank		✓				✓	✓			✓	✓													
Overbank	✓	✓	✓	✓	✓	✓		✓	✓															

Debris Jams

Quantity			
No. of Jams 0-50m u/s : $M_{U/S}$	2	0-50m d/s : $M_{D/S}$	1
Total, $M = M_{U/S}+M_{D/S}$	2		

Number, M_i	1 +	2 −	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
X (+:u/s, -:d/s)	134	52																						
Function																								
SedimentTrapping	✓	✓																						
$D_S \leq 1/4\ D_{INS}$																								
D_S = 1/4 to 1/2																								
D_S = 1/2 to 3/4																								
D_S = 3/4 to 1																								
Span																								
• Complete																								
Side Vent																								
Under Flow	✓	✓																						
Over Flow																								
• Incomplete																								
1/4 W_{INS}																								
1/4 to 1/2 W_{INS}																								
1/2 to 3/4 W_{INS}																								
Age																								
Very Young																								
Recent																								
Moderate	✓	✓																						
Old																								
Integrity																								
Very Solid																								
Solid																								
Moderate	✓	✓																						
Weak																								

Bankfull Measurements

Location	Bankfull		Inset		Water Level	
	W_{BFL} (ft)	D_{BFL} (ft)	W_{INS} (ft)	D_{INS} (ft)	$W_{W/L}$ (ft)	$D_{W/L}$ (ft)
U/S ~~+50m~~ 200ft	69'	4.6	20.7	2.22	14.9	1.6
U/S ~~+25m~~ 100 ft.	83'	4.6	22.7	2.8	10.5	1.7
0	75'	4.6	29.3	2.95	8.6	1.5
D/S ~~-25m~~ 100 ft	115 ft	9.2	25.3	4.85	23.3	1.4
D/S ~~-50m~~ 200ft	Spill		35.2	3.7	24.4	1.2

Riffle Lines

Number, K_i	1 +	2 +	3 +	4 +	5 +	6 +	7 +	8 +	9 –	10 –	11 –	12 –	13 –	14 –	15 –	16	17	18	19	20	21	22	23	24
X (+:u/s, -:d/s)	187	160	153	125	101	10	5	0	15	63	78	97	111	142	170									
Complete Riffle Line				✓	✓						✓	✓												
Orientation																								
Diagonal			✓	✓	✓					✓		✓	✓											
Perpendicular						✓		✓	✓					✓	✓									
V-Shape	✓>	✓>					✓>				✓													
Complex																								
Partial Riffle Line																								
1/4 W_{INS}																								
1/4 - 1/2 W_{INS}										✓				✓										
1/2 - 3/4 W_{INS}	✓	✓	✓			✓	✓	✓	✓				✓		✓									

APPENDIX D

EXAMPLE OUTPUT FOR SPREADSHEET MODELS

EXAMPLE CALCULATIONS OF ULTIMATE ENLARGEMENT RATIO $(RE)_{ULT}$ USING THE THREE SPREADSHEET MODELS *LONGITUDINAL.XLS, PEBBLE.XLS, AND X-SECTION.XLS* FOR POTASH BROOK AT STATION POT1

Step 1. Compute Current Cross-Sectional Area at Bankfull Stage

Use the measured bankfull flow depth (D_{BFL}) based on field observations

For POT1, D_{BFL} = 3.40 ft.

Use the pebble count spreadsheet (pebble.xls) to calculate the median particle size (φ_{50}) for the section. The pebble count spreadsheet converts the measured particle dimensions into an equivalent particle diameter and produces a grain size distribution curve.

For POT1, φ_{50} = 9.35 inches = 0.237 meters

Use the Strickler Equation ($n = 0.04\ (\varphi_{50})^{1/6}$) to compute Manning's roughness coefficient (n) for the channel bottom.

For POT1, $n = 0.04(0.237)^{1/6} = 0.031$

Estimate Manning's n for the side slopes, below D_{BFL}, based on literature values and then compute a weighted channel n value for the entire channel below D_{BFL} using the percentage of the value as a function of the total wetted perimeter.

Use longitudinal.xls to calculate the average slope of the reach section by averaging the slope obtained using linear regressions for the measured water surface profile and the surveyed thalweg profile. Depending on the type of stream (e.g., step pool or meandering) investigators may use one or the other of these data.

For POT 1: slope = computed slope for the water surface profile = 0.0121

Use x-section.xls and surveyed stream cross-sectional data to develop a rating curve of the hydraulic flow data at depths of 0.5 ft up to and exceeding the bankfull depth.

For POT 1: see Appendix C, Tables 5 and 6 for cross-sectional data
see plot of cross-section, and plots of flow depth versus flow area, and flow depth versus flowrate illustrated in Spreadsheet 1.

For POT 1: at flow depth = 3.4 feet (field measured bankfull depth) $A_{BFL} = 75.6\ ft^2$

Step 2. Compute Historic Cross-Sectional Area at Bankfull Stage

The Hollis method was employed to determine historic flow and consequently the historic bankfull cross-sectional area $(A_{BFL})_{HIS}$ (see discussion in Section 2.6.3: Data Processing, Step 4.).

Ratio of Post to Pre-disturbance Flow Based on Hollis:

For POT1: $TIMP_{1998} = 22\%$, $(Q_{BFL})_{1998} = 596$ cfs, and $(A_{BFL})_{1998} = 75.6\ ft^2$
$[(Q_p)_{POST} / (Q_P)_{PRE}]_{1998} = 3.5$ (see Figure 2.11, after Hollis, 1975)

for $TIMP_{1967} = 14\%$, $[(Q_p)_{POST} / (Q_P)_{PRE}]_{1967} = 2.15$.
$(Q_{BFL})_{1967} = [596cfs(2.15/3.5)] = 366$ cfs
for Q = 366 cfs, from hydraulic flow data (see Spreadsheet 2), interpolate $A_{BFL} = 47.1\ ft^2$

Step 3. Hindcast to Estimate Pre-disturbance Cross-sectional Area $(A_{BFL})_{PRE}$

In this step the "relaxation curve" is used to estimate the pre-disturbance cross sectional area of the channel section using the historic cross-section data (see discussion in Section 1). First, the ultimate channel enlargement ratio is computed using original channel enlargement curve (see page 1-14), this value is inserted into the relaxation curve (see page 1-13) using the average weighted age of development at the time of the historic cross section.

for POT1, TIMP = 14.4%, t_r = 67 years, t_i = 14.1 years, t_l = 2.5 years, and $(A_{BFL})_{HIS}$ = 47.1 ft^2
$(Re)_{ULT} = 0.00135(14.4)^2 + 0.01672(14.4) + 1.0 = 1.51$

from relaxation equation on page 1-13, using the historic data set:
$(Re)_i = [(1.032((14.1 - 2.5)/(67 - 2.5)) - 0.028)*(1.51 - 1.0)] + 1.0 = 1.08$

therefore:
$[(A_{BFL})_{PRE}]_{HIS} = (A_{BFL})_{HIS} / (Re)_i = 47.1\ ft^2 / 1.08 = 43.5\ ft^2$

Step 4. Estimate Current Enlargement Ratio $(Re_i)_{CUR}$

Using the original channel enlargement curve with the current TIMP, calculate $(Re)_{ULT}$

for POT1, TIMP = 22.0%, t_r = 67 years, t_i = 41.5 years, t_l = 2.5 years, and $(A_{BFL})_{CUR}$ = 75.6 ft^2
$(Re)_{ULT} = 0.00135(22)^2 + 0.01672(22) + 1.0 = 2.02$

from relaxation equation on page 1-13, using the historic data set:
$(Re)_i = [(1.032((41.5 - 2.5)/(67 - 2.5)) - 0.028)*(2.02 - 1.0)] + 1.0 = 1.61$

therefore, an alternative $(A_{BFL})_{PRE}$ can be computed by the following calculation:
$[(A_{BFL})_{PRE}]_{CUR} = (A_{BFL})_{CUR} / (Re)_i = 75.6\ ft^2 / 1.61 = 46.9\ ft^2$

This value is then compared to the $[(A_{BFL})_{PRE}]_{HIS}$ that was calculated in Step 3 above. For those stations where there is close agreement between the two calculated $(A_{BFL})_{PRE}$ values, it can be inferred that the historic data set is providing a reliable estimate of the $(A_{BFL})_{PRE}$. Where there is not close agreement between the two values, it is likely that the veracity of the historic data set is questionable.

Step 5. Compute $(A_{BFL})_{ULT}$

Use the pre-disturbance channel cross sectional area calculated in Step 4 above $[(A_{BFL})_{PRE}]_{CUR}$, multiplied by the $(Re)_{ULT}$ value from Step 4 (obtained from the original channel enlargement equation) to compute a $(A_{BFL})_{ULT}$.

for POT 1, $(Re)_{ULT}$ = 2.02, $[(A_{BFL})_{PRE}]_{CUR}$ = 46.9 ft^2

therefore:
$(A_{BFL})_{ULT} = 2.02 * 46.9 = 94.74\ ft^2$

Step 6. Compute $[(Re)_{ULT}]_{OBS}$

Divide $(A_{BFL})_{ULT}$ from Step 5 above by $[(A_{BFL})_{PRE}]_{HIS}$ to obtain $[(Re)_{ULT}]_{OBS}$.

for POT 1, $(A_{BFL})_{ULT}$ = 94.74 ft^2, $[(A_{BFL})_{PRE}]_{HIS}$ = 43.5 ft^2

therefore:
$[(Re)_{ULT}]_{OBS} = 94.74 / 43.5 = 2.18$

APPENDIX E

LIST OF CONTACTS FOR HISTORICAL STREAM CHANNEL DATA

APPENDIX E

PARTIAL LIST OF AGENCIES CONTACTED TO OBTAIN HISTORICAL CROSS-SECTIONAL INFORMATION

Municipal Offices:
Sherburne town offices, Judy Hanson 422-3242
Rutland: Alan Shelby, City engineer 773-1813
Rutland, Warren Connor
Colchester, Steve Woodsworth
Burlington DPW sewer/water crossings, no x-sections, built as they went
Burlington, Bill Rowley, Street dept.
Champlain Water District, Dick Pratt (864-7454).
S. Burlington, Don Whitten Airport WWTP
S. Burlington Sewage Treatment plant, Jerry McArdle
Essex Jct Regional Engineer, Ernie Christianson 879-5675

Vermont AOT
Charlie O Brien, Rutland,
Paul Hodges, Montpelier
Joe Ynsuela, Berlin
George Docell, St. Albans,
*Steve Fugere, Montpelier

State Records Office
Middlesex

Vermont Agency of Natural Resources
Barry Cahoon,
Jim Kellogg,
Cathy Kashanski,
Jim Pease,
Fred Nicholson
Pete Barranco- 241-3451, Dam inspection program,
Brian Kooiker
Randy Bean, stormwater permits
*Carl Jurentkoff,
Phil Tubbs, (retired)
Jim Burke
Bill Moulton, forest service, land use
Jeff Cueto, hydrologic data
Harry Rausch
Gary Sawyer for Honey Hollow Block of Camel's Hump State Park.

Appendix E - Partial list of agencies contacted to obtain historical cross-sectional information

Rich Langdon

District Environmental Commission
*DEC, Bill Burke, Rutland, Joyce Fagan, 786-5920

Universities
Fred Larsen, Norwich
Barry Doolan, UVM, CentennialBrook,
Harris Abbot, surveying 656-1449,
Greg Irish, surveying
Al Cassell (Eugene.Cassell@uvm.edu) 656-4280

Federal Agencies
NRCS, Bruce Chappel
NRCS, Ray Godfrey
NRCS Bill Forbes, Rutland
NRCS Rob Allen, Winooski
NRCS, Dan Young, White River, Sherburne

*HUD flood management studies, (precursor to FEMA)
FEMA's federal insurance administration. They did flood plain mapping of most of the towns in Vt. put in the cross sections , surveys and elevations. These maps were done in the late 1970s for most towns and cities.
FEMA, Dave Coburn

USGS stream gage x-xections
Green Mtn Forest Service , Steve Roy, 747-6700

Private industries
Vt. Gas Co..plan views only, no x-sections
Telephone Co, Bell Atlantic and predecessors
Krebs and Lansing engineers, Bob Krebs,
Wagner, Heindell & Noyes, Dori Barton
Killington, Carl Spangler, John Cole engineer, Dave Wilcox, 422-3333
Mark Haberly , VCGI

*BEST SOURCES

APPENDIX F

SITE BY SITE SUMMARY OF HISTORICAL CROSS-SECTION INFORMATION

APPENDIX F: SITE BY SITE SUMMARY OF HISTORIC CROSS-SECTION SURVEY DATA

Basin	Site	Historic Land Use		Historic Survey Data Summary								
		Type of Disturb-ance	TIMP (%)	Date of Survey (year)	No. of Sections Selected	No. of Possible Sections	(t_i) (yrs/Rank)	Degree of Offset (°/Rank)	Channel Geometry (Rank)	Planform Location (Rank)	No. of Ordinates (No/Rank)	Quality of Historic Data **
Cold	CLD4	Ref.	1									
	CLD5	Ref.	1									
Dowsville	DOW1	Logging		N/a								
	DOW2	Logging	2	1937	1	1	19.5(1)	0-10°(1)	3	3	8(3)	2.50
	DOW3	Logging	2	1937			19.5(1)					
Gould	GLD6	Ref.	<2									
Moon	MOO1	Urban	9	1954	1	>10	19.1(2)	0-10°(1)	2	3	10(2)	4.00
	MOO2	Urban	8	1954			19.8(2)					
Potash	POT1	Urban	15	1961	1	>3	14.1(4)	0-10°(1)	3	3	5(3)	10.00
	POT2	Urban	15	1961	1		14.1(4)	0-10°(1)	2	3	6(3)	9.00
	POT3	Urban	15	1955	1		12.1(4)	0-10°(1)	3	2	6(3)	9.00
Roaring	ROA1	Resort	2	1953	1	1	25.0(1)	0-10°(1)	2	2	9(2)	1.75
	ROA2	Resort	2	1953			25.0(1)					
	RBT1	Resort		N/a	0	1						
Smith	SMI1	Ref.	<2									
	SMI2	Ref.	<2									
	SMI3	Ref.	<2									
Stevens	STB7	Urban	10	1961	1	3	41.7(2)	0-10°(1)	2	3	10(2)	4.00
	STB8	Urban	9	1977	1		40.2(2)	0-10°(1)	3	2	7(3)	4.50
	STB9	Urban	12	1975	1		33.1(4)	0-10°(1)	3	2	8(3)	9.00
Tenney	TEN1	Urban	2	1922	1	>3	4.5(1)	0-10°(1)	2	3	9(2)	2.00
Little	WBL1	Resort	2	1972	1	5	32.0(1)	0-10°(1)	2	3	9(2)	2.00
	WBL2	Resort	2	1972	1		32.0(1)	0-10°(1)	3	3	12(2)	2.25
	WBL3	Resort	2	1963	1		40.9(1)	0-10°(1)	3	2	8(3)	2.25
									AVERAGE (Quality of Data Indicator ψ)			4.79

Most Desirable: Rank =1, c=1; Desirable: Rank = 2, c=1; Marginal: Rank=3, c=1; Unacceptable: c = 0

Degree of Offset=α; Channel Geometry =β; Planform Location=φ; Number of Ordinates =ξ; Area Weighted Average Age of Disturbance =ε

**Quality of Historic Data = $c[(\alpha+\beta+\varphi+\xi)/4]\varepsilon$

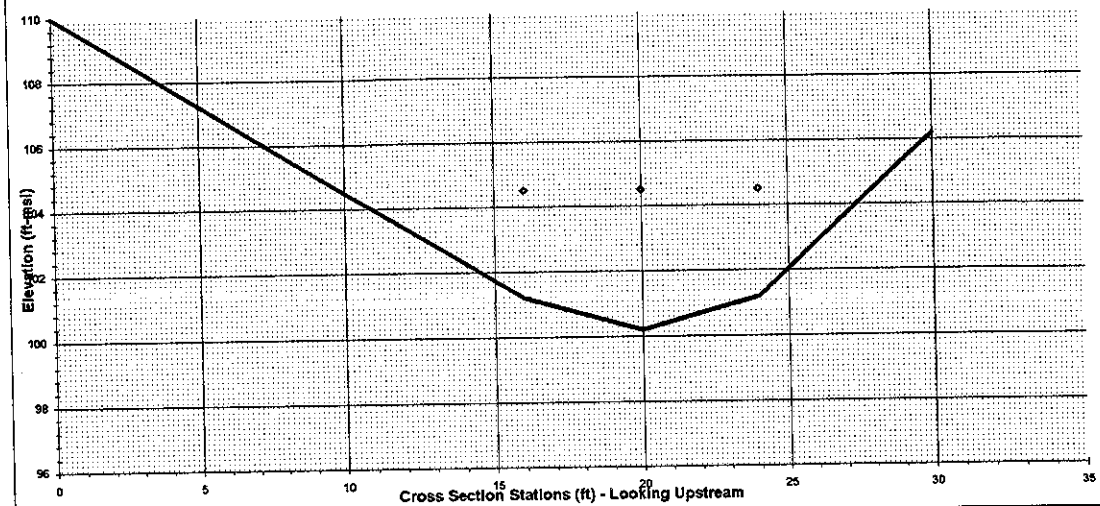
Cross Section No. 3

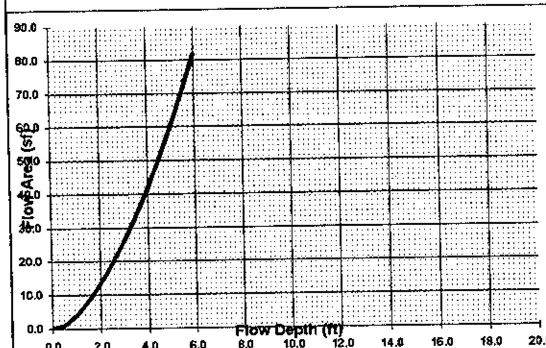
Pot1 - Spreadsheet 2: Historical - @ Hwy #7

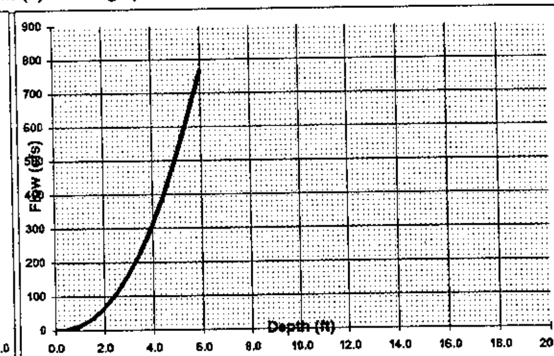
Channel Type : / Reference No.:

Hydraulic Flow Data [1]

Water Surface Elevation (ft-msl)	Depth (ft)	Flow Area (ft^2)	Flow Rate (cfs)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Top Width (ft)	Average Velocity (fps)	Weighted Mannings n [2]	Critical Depth [3] (ft)
100.2	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
100.7	0.5	1.0	2	4.1	0.243	4.0	1.7	0.037	0.2
101.2	1.0	4.0	11	8.2	0.485	8.0	2.7	0.037	0.4
101.7	1.5	8.4	33	10.1	0.832	9.5	3.9	0.037	0.7
102.2	2.0	13.5	65	11.9	1.137	11.0	4.8	0.037	1.0
102.7	2.5	19.4	108	13.7	1.416	12.5	5.6	0.037	1.3
103.2	3.0	26.0	163	15.5	1.678	14.0	6.3	0.037	1.6
103.7	3.5	33.4	229	17.3	1.928	15.5	6.9	0.037	1.9
104.2	4.0	41.6	309	19.2	2.171	17.1	7.4	0.037	2.2
104.7	4.5	50.5	402	21.0	2.407	18.6	8.0	0.037	2.4
105.2	5.0	60.1	509	22.8	2.639	20.1	8.5	0.037	2.7
105.7	5.5	70.6	631	24.6	2.867	21.6	8.9	0.037	3.0
106.2	6.0	81.7	768	26.4	3.092	23.1	9.4	0.037	3.3







* Average channel velocity and critical depth calculations do not apply above overbank elevation. [4]

Bankfull Depth Hydraulic Conditions and Cross Section Data

Bankfull Flow Elevation (ft-msl)	104.51 *
Channel Slope (ft/ft)	0.0121
Max. Critical Depth Elevation (ft-msl) [4]	106.2
Maximum Evaluated Elevation (ft-msl)	106.2
Depth of Flow (ft)	4.31
Weighted Mannings n [2]	0.037
Total Flow Area (ft^2)	47.0
Wetted Perimeter (ft)	20.3
Hydraulic Radius (ft)	2.318
Mannings Flow (cfs)	364.7
Average Channel Velocity (fps)	7.8
Topwidth (ft)	18.0
Critical Depth "y_c" (ft) [3]	2.3
y_c Elevation (ft-msl)	102.5

Cross Section Skew Angle (deg) = 0

Station No. Range (Left to Right)	0 to 16	16 to 20	20 to 24	24 to 30											*
Mannings n	0.037	0.037	0.037	0.037	0.037	0	0	0	0	0	0	0	0	0	
Relative Elevation (ft-msl)	110	101.2	100.2	101.2	106.2	0	0	0	0	0	0	0	0	0	
Station (ft)	0	16.0	20.0	24.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Flow Area (sf)	10.0	15.2	15.2	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Wetted Perimeter (ft)	6.9	4.1	4.1	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Topwidth (ft)	6.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

Station No. Range (Left to Right)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mannings n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Relative Elevation (ft-msl)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Station (ft)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flow Area (sf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetted Perimeter (ft)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Topwidth (ft)																

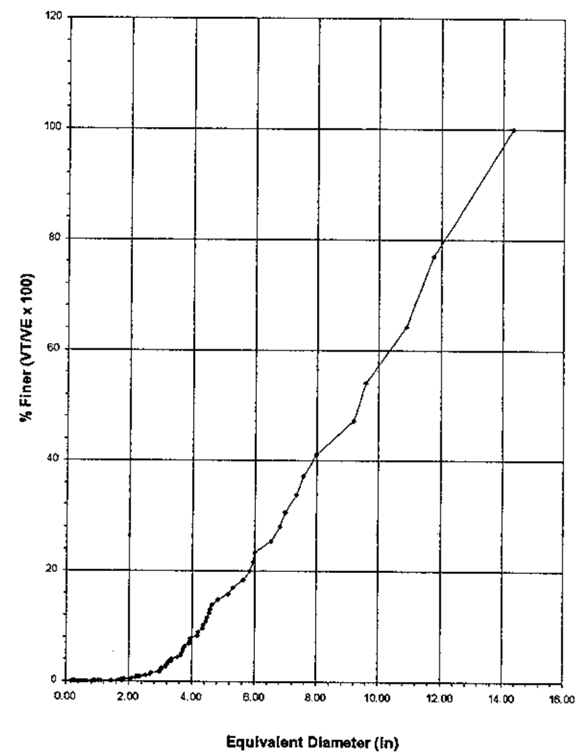
* Note: All input data are displayed in boxed areas.

1 Flow rates and velocities are based on Mannings equation.
2 Weighted Mannings n is the product of the Mannings n and wetted perimeter for each cross section segment divided by the total wetted perimeter for a specific flow depth.
3 Critical depth is based on [Q2/g = A3/Topwidth], where A = topwidth x critical depth.
4 Maximum elevation evaluated for critical depth. Critical depth is not considered applicable, using equation (see note 3), when flow depth exceeds overbank elevation.

Enter Cross Section Number 3

Pebble Count Results - Cross-Section Number 3
Pot1
Wastewater Line Sheet No.

	Unsorted Raw Data (Starting at Rt Side of Channel)			Data Sorted by Equivalent Diameter in Ascending Order													
	Dimension 1 Length (in)	Dimension 2 Length (in)	Dimension 3 Length (in)	Dimension 1 Length (in)	Dimension 2 Length (in)	Dimension 3 Length (in)	Major Axis Length "L" (in)	Major Axis Length "W" (in)	Breadth "H" (in)	Roundness	Flatness	Equivalent Radius (in)	Equivalent Diameter (in)	Equivalent Volume (VE) (in^3)	Cummulative Equivalent Volume (in^3)	V_E/V_T x 100
0.001	3.60	2.40	0.84	0.17	0.22	0.10	0.22	0.17	0.10	1.26	2.00	0.09	0.17	0.00	0.00	0.00
0.002	0.84	0.72	0.31	0.20	0.18	0.10	0.20	0.18	0.10	1.18	2.00	0.09	0.17	0.00	0.00	0.00
0.003	1.20	1.20	0.12	0.18	0.24	0.12	0.24	0.18	0.12	1.22	1.75	0.10	0.20	0.00	0.01	0.00
0.004	0.89	0.38	0.36	0.18	0.19	0.18	0.19	0.18	0.18	0.92	1.03	0.10	0.21	0.00	0.01	0.00
0.005	1.92	1.44	0.72	0.26	0.22	0.12	0.26	0.22	0.12	1.23	2.00	0.11	0.22	0.00	0.01	0.00
0.006	0.54	0.31	0.20	0.22	0.30	0.12	0.30	0.22	0.12	1.34	2.15	0.11	0.22	0.00	0.02	0.00
0.007	0.58	0.38	0.24	0.29	0.12	0.32	0.32	0.29	0.12	1.28	2.55	0.13	0.25	0.01	0.02	0.00
0.008	0.41	0.30	0.24	0.46	0.20	0.13	0.46	0.20	0.13	1.74	2.50	0.13	0.26	0.01	0.03	0.00
0.009	0.26	0.22	0.12	0.29	0.26	0.18	0.29	0.26	0.18	1.06	1.53	0.14	0.27	0.01	0.04	0.00
0.01	0.19	0.13	0.60	0.19	0.13	0.60	0.60	0.19	0.13	2.14	3.00	0.14	0.28	0.01	0.04	0.00
0.011	0.61	0.72	0.20	0.38	0.40	0.11	0.40	0.38	0.11	1.37	3.61	0.14	0.29	0.01	0.05	0.00
0.012	0.46	0.43	0.24	0.24	0.16	0.46	0.46	0.24	0.16	1.56	2.23	0.15	0.29	0.01	0.06	0.00
0.013	0.18	0.19	0.18	0.50	0.29	0.13	0.50	0.29	0.13	1.66	3.00	0.15	0.30	0.01	0.07	0.00
0.014	0.54	0.41	0.26	0.48	0.36	0.12	0.48	0.36	0.12	1.54	3.50	0.16	0.31	0.01	0.08	0.00
0.015	0.50	0.29	0.13	0.43	0.30	0.17	0.43	0.30	0.17	1.36	2.18	0.16	0.32	0.01	0.09	0.00
0.016	0.65	0.60	0.41	0.43	0.29	0.18	0.43	0.29	0.18	1.35	2.00	0.16	0.32	0.01	0.11	0.00
0.017	0.28	0.26	0.18	0.50	0.41	0.12	0.50	0.41	0.12	1.53	3.80	0.17	0.33	0.01	0.12	0.00
0.018	0.43	0.30	0.17	0.48	0.24	0.23	0.48	0.24	0.23	1.42	1.58	0.17	0.34	0.01	0.13	0.00
0.019	0.48	0.36	0.25	0.35	0.30	0.28	0.35	0.30	0.28	1.00	1.17	0.17	0.35	0.02	0.15	0.00
0.02	0.48	0.24	0.23	0.41	0.30	0.24	0.41	0.30	0.24	1.17	1.48	0.17	0.35	0.02	0.16	0.00
0.021	0.38	0.40	0.11	0.49	0.24	0.25	0.49	0.25	0.24	1.40	1.55	0.18	0.35	0.02	0.18	0.00
0.022	0.53	0.28	0.26	0.60	0.26	0.20	0.60	0.26	0.20	1.66	2.12	0.18	0.36	0.02	0.20	0.00
0.023	0.49	0.24	0.25	0.41	0.36	0.23	0.41	0.36	0.23	1.12	1.68	0.18	0.37	0.02	0.21	0.00
0.024	0.43	0.29	0.18	0.54	0.31	0.20	0.54	0.31	0.20	1.47	2.09	0.18	0.37	0.02	0.23	0.01
0.025	0.48	0.38	0.84	0.38	0.36	0.25	0.38	0.36	0.25	1.04	1.48	0.19	0.37	0.02	0.25	0.01
0.026	1.20	0.91	0.37	0.53	0.28	0.26	0.53	0.28	0.26	1.38	1.52	0.19	0.38	0.02	0.27	0.01
0.027	0.29	0.12	0.32	0.58	0.32	0.22	0.58	0.32	0.22	1.48	2.08	0.19	0.39	0.02	0.29	0.01
0.028	0.50	0.41	0.12	0.48	0.36	0.25	0.48	0.36	0.25	1.20	1.67	0.20	0.40	0.02	0.31	0.01
0.029	0.22	0.30	0.12	0.50	0.30	0.29	0.50	0.30	0.29	1.26	1.40	0.20	0.40	0.02	0.34	0.01
0.03	0.18	0.24	0.12	0.46	0.43	0.24	0.46	0.43	0.24	1.11	1.85	0.20	0.41	0.02	0.36	0.01
0.031	0.20	0.18	0.10	0.62	0.34	0.24	0.62	0.34	0.24	1.49	2.00	0.21	0.42	0.03	0.39	0.01
0.032	0.41	0.36	0.23	0.58	0.38	0.24	0.58	0.38	0.24	1.35	2.00	0.21	0.43	0.03	0.42	0.01
0.033	0.24	0.16	0.46	0.54	0.41	0.26	0.54	0.41	0.26	1.23	1.80	0.22	0.44	0.03	0.45	0.01
0.034	0.17	0.22	0.10	0.50	0.38	0.31	0.50	0.38	0.31	1.13	1.42	0.22	0.44	0.03	0.48	0.01
0.035	0.50	0.30	0.29	0.48	0.36	0.36	0.48	0.36	0.36	1.07	1.17	0.22	0.45	0.03	0.51	0.01
0.036	2.28	1.68	0.84	0.66	0.44	0.24	0.66	0.44	0.24	1.41	2.30	0.23	0.47	0.04	0.55	0.01
0.037	5.28	2.40	1.80	0.96	0.72	0.12	0.96	0.72	0.12	1.94	7.00	0.25	0.49	0.04	0.59	0.01
0.038	0.77	0.48	0.36	0.61	0.72	0.20	0.72	0.61	0.20	1.42	3.26	0.25	0.51	0.05	0.64	0.01
0.039	2.94	2.28	1.32	1.06	0.42	0.24	1.06	0.42	0.24	1.97	3.08	0.27	0.54	0.06	0.69	0.02
0.04	0.62	0.34	0.24	0.82	0.52	0.28	0.82	0.52	0.28	1.48	2.41	0.28	0.55	0.06	0.75	0.02
0.041	1.44	1.92	0.78	0.89	0.38	0.36	0.89	0.38	0.36	1.58	1.77	0.28	0.56	0.06	0.82	0.02
0.042	1.32	1.08	0.70	0.77	0.48	0.36	0.77	0.48	0.36	1.33	1.73	0.29	0.58	0.07	0.89	0.02
0.043	0.50	0.38	0.31	0.66	0.48	0.43	0.66	0.48	0.43	1.13	1.32	0.29	0.58	0.07	0.96	0.02
0.044	0.84	0.36	0.72	0.48	0.38	0.84	0.84	0.48	0.38	1.38	1.72	0.30	0.61	0.08	1.04	0.02
0.045	0.72	0.66	0.37	0.65	0.60	0.41	0.65	0.60	0.41	1.06	1.53	0.31	0.61	0.08	1.12	0.02
0.046	0.82	0.52	0.28	1.20	1.20	0.12	1.20	1.20	0.12	1.90	10.00	0.32	0.63	0.09	1.21	0.03
0.047	0.46	0.20	0.13	0.72	0.66	0.37	0.72	0.66	0.37	1.13	1.85	0.32	0.64	0.09	1.31	0.03
0.048	1.06	0.42	0.24	0.84	0.72	0.31	0.84	0.72	0.31	1.29	2.50	0.33	0.65	0.10	1.41	0.03
0.049	0.66	0.48	0.43	0.72	0.60	0.48	0.72	0.60	0.48	1.07	1.38	0.34	0.67	0.11	1.51	0.03
0.05	0.38	0.36	0.25	0.84	0.36	0.72	0.84	0.72	0.36	1.23	2.17	0.34	0.68	0.11	1.63	0.04
0.051	0.90	0.61	0.41	0.90	0.61	0.41	0.90	0.61	0.41	1.31	1.85	0.34	0.69	0.12	1.75	0.04
0.052	0.66	0.44	0.24	1.20	0.91	0.37	1.20	0.91	0.37	1.43	2.84	0.42	0.84	0.21	1.96	0.04
0.053	0.58	0.32	0.22	1.08	1.08	0.36	1.08	1.08	0.36	1.27	3.00	0.42	0.85	0.22	2.18	0.05
0.054	0.60	0.26	0.20	1.32	0.96	0.36	1.32	0.96	0.36	1.51	3.17	0.44	0.87	0.24	2.42	0.05
0.055	0.35	0.30	0.28	0.96	0.84	0.60	0.96	0.84	0.60	1.08	1.50	0.44	0.89	0.25	2.67	0.06
0.056	3.24	2.52	0.72	1.44	1.08	0.36	1.44	1.08	0.36	1.54	3.50	0.47	0.93	0.29	2.96	0.06
0.057	4.80	2.52	1.08	1.32	1.20	0.36	1.32	1.20	0.36	1.40	3.50	0.47	0.94	0.30	3.26	0.07



Data Summary — Pot1

	Equivalent Diam. (in)	Equivalent Diam. (mm)	R_e^*	f	Tcrt (Pa) (Shields)	$(D_{BFL})_{sed}$ (m)	$(D_{BFL})_{sed}$ (ft)
G. Mean	1.34	34.07					
16th	5.173904	131.42					
50th	9.35	237.45					
75th	11.63351	295.49	5.67E+09	0.047	224.80	1.896	6.221
84th	12.55159	318.81	6.36E+09	0.047	242.54	2.046	6.712
Stnd Dev	2.69	68.21					

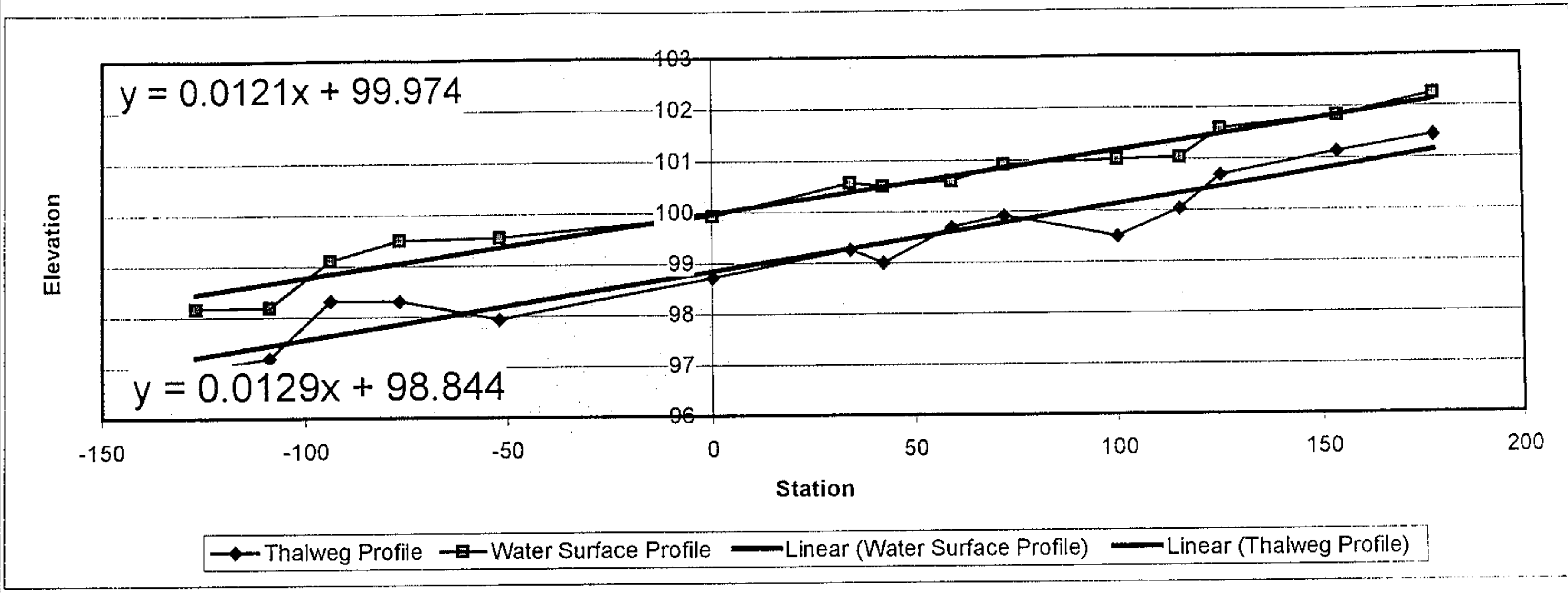
N	Slope	Average Roundness	Average Flatness
125	0.0121	1.39	2.33

Manning's n 0.031 OK

Bankfull Estimate (ft) 3.4

LONGITUDINAL PROFILE : 3

Pot1



Slope Calculations	Points	3	10
Select two data point numbers	Station	-94	72
to determine slope	Bottom Elev	98.31	99.91
	Water Elev	99.11	100.91
Slope from Thalweg Bottom Profile		0.00964	
Slope from Water Surface Profile		0.01084	

Riffle Geometry	Points			
Select two or three data	Station	#N/A	#N/A	#N/A
point numbers to assess	Bottom Elev	#N/A	#N/A	#N/A
riffle distance	Water Elev	#N/A	#N/A	#N/A
Average Riffle Distance		#N/A	ft	

Pool Geometry	Points			
Select two or three data	Station	#N/A	#N/A	#N/A
point numbers to assess	Bottom Elev	#N/A	#N/A	#N/A
pool distance	Water Elev	#N/A	#N/A	#N/A
Average Pool Distance		#N/A	ft	

SLOPE FOR FLOW CALCS 0.0121

0.061	4.80	3.60	3.48	1.92	1.44	0.72	1.92	1.44	0.72	1.35	2.33	0.71	1.43	1.04	5.64	0.12
0.062	4.20	3.72	2.16	1.44	1.92	0.78	1.92	1.44	0.78	1.31	2.15	0.73	1.46	1.13	6.77	0.15
0.063	10.80	7.20	1.92	2.28	1.68	0.84	2.28	1.68	0.84	1.36	2.36	0.84	1.67	1.68	8.48	0.19
0.064	8.40	5.52	2.64	1.92	1.44	1.32	1.92	1.44	1.32	1.10	1.27	0.87	1.75	1.91	10.37	0.23
0.065	6.60	4.80	4.56	1.80	1.44	1.44	1.80	1.44	1.44	1.02	1.13	0.88	1.76	1.95	12.32	0.27
0.066	3.72	3.24	1.80	8.40	0.96	0.48	8.40	0.96	0.48	4.72	9.75	0.89	1.78	2.03	14.35	0.31
0.067	1.32	0.96	0.36	2.04	1.68	1.20	2.04	1.68	1.20	1.12	1.55	0.91	1.82	2.15	16.50	0.36
0.068	0.72	0.60	0.48	3.36	1.56	0.84	3.36	1.56	0.84	1.81	2.93	0.93	1.86	2.31	18.81	0.41
0.069	1.92	1.44	1.32	3.24	2.52	0.72	3.24	2.52	0.72	1.58	4.00	1.02	2.05	3.08	21.89	0.48
0.07	0.96	0.84	0.60	2.64	1.80	1.32	2.64	1.80	1.32	1.26	1.68	1.05	2.09	3.28	25.17	0.55
0.071	0.48	0.36	0.12	2.28	1.92	1.44	2.28	1.92	1.44	1.09	1.46	1.05	2.09	3.30	28.47	0.62
0.072	0.48	0.36	0.36	3.60	2.40	0.84	3.60	2.40	0.84	1.64	3.57	1.10	2.19	3.80	32.27	0.70
0.073	5.28	3.36	3.84	3.84	3.24	0.60	3.84	3.24	0.60	1.73	5.90	1.11	2.22	3.91	36.18	0.79
0.074	1.32	1.20	0.36	2.40	2.04	1.68	2.40	2.04	1.68	1.05	1.32	1.14	2.29	4.31	40.49	0.88
0.075	1.56	0.84	0.60	2.94	2.28	1.32	2.94	2.28	1.32	1.25	1.98	1.17	2.34	4.63	45.12	0.98
0.076	1.20	1.08	0.60	3.24	1.92	1.80	3.24	1.92	1.80	1.28	1.43	1.27	2.54	5.86	50.98	1.11
0.077	5.76	4.80	2.04	4.80	2.52	1.08	4.80	2.52	1.08	1.80	3.39	1.33	2.67	6.84	57.82	1.26
0.078	4.80	4.20	3.24	3.60	2.04	1.80	3.60	2.04	1.80	1.34	1.57	1.34	2.68	6.92	64.74	1.41
0.079	5.40	4.20	1.80	3.00	2.52	1.80	3.00	2.52	1.80	1.11	1.53	1.35	2.71	7.13	71.87	1.57
0.08	4.92	3.72	2.76	4.80	2.40	1.56	4.80	2.40	1.56	1.62	2.31	1.48	2.97	9.41	81.28	1.77
0.081	6.00	6.00	2.16	4.44	2.16	1.92	4.44	2.16	1.92	1.48	1.72	1.50	2.99	9.64	90.92	1.98
0.082	10.80	6.00	3.60	4.32	3.00	1.44	4.32	3.00	1.44	1.44	2.54	1.50	3.01	9.77	100.69	2.19
0.083	12.00	8.40	6.00	3.24	2.88	2.04	3.24	2.88	2.04	1.07	1.50	1.51	3.03	9.97	110.66	2.41
0.084	7.20	3.00	2.64	3.60	2.76	2.16	3.60	2.76	2.16	1.14	1.47	1.57	3.15	11.24	121.90	2.66
0.085	21.60	10.80	4.80	3.72	3.24	1.80	3.72	3.24	1.80	1.18	1.93	1.58	3.16	11.36	133.26	2.90
0.086	13.20	8.40	4.80	5.28	2.40	1.80	5.28	2.40	1.80	1.64	2.13	1.61	3.21	11.94	145.20	3.16
0.087	9.60	8.64	4.20	4.80	2.40	2.04	4.80	2.40	2.04	1.48	1.76	1.62	3.25	12.31	157.50	3.43
0.088	10.20	4.80	4.44	4.44	3.00	1.92	4.44	3.00	1.92	1.33	1.94	1.67	3.34	13.39	170.89	3.72
0.089	5.64	4.32	1.44	6.00	2.40	1.80	6.00	2.40	1.80	1.79	2.33	1.68	3.35	13.57	184.47	4.02
0.09	10.80	8.40	3.00	3.96	3.96	1.92	3.96	3.96	1.92	1.12	2.06	1.76	3.53	15.76	200.23	4.36
0.091	5.40	3.24	2.40	4.20	3.72	2.16	4.20	3.72	2.16	1.15	1.83	1.83	3.66	17.67	217.90	4.75
0.092	3.60	2.76	2.16	4.32	3.84	2.04	4.32	3.84	2.04	1.18	2.00	1.83	3.67	17.72	235.62	5.13
0.093	5.40	4.80	2.40	5.64	4.32	1.44	5.64	4.32	1.44	1.52	3.46	1.86	3.71	18.37	253.99	5.53
0.094	18.00	15.60	7.20	6.60	3.72	1.44	6.60	3.72	1.44	1.77	3.58	1.86	3.72	18.51	272.50	5.94
0.095	22.80	7.20	5.40	6.00	2.88	2.16	6.00	2.88	2.16	1.58	2.06	1.89	3.79	19.54	292.05	6.36
0.096	4.80	2.40	1.56	5.40	4.20	1.80	5.40	4.20	1.80	1.38	2.67	1.95	3.90	21.38	313.42	6.83
0.097	8.40	8.40	4.20	5.40	3.24	2.40	5.40	3.24	2.40	1.37	1.80	1.97	3.94	21.99	335.41	7.31
0.098	6.60	4.20	1.80	5.76	3.84	1.92	5.76	3.84	1.92	1.46	2.50	1.98	3.95	22.24	357.64	7.79
0.099	4.32	3.00	1.44	6.60	4.20	1.80	6.60	4.20	1.80	1.58	3.00	2.09	4.17	26.13	383.77	8.36
0.1	8.40	5.40	4.20	4.92	3.72	2.76	4.92	3.72	2.76	1.17	1.57	2.09	4.19	26.45	410.22	8.94
0.101	5.76	3.84	1.92	5.76	4.80	2.04	5.76	4.80	2.04	1.33	2.59	2.17	4.35	29.53	439.75	9.58
0.102	3.36	1.56	0.84	7.20	3.00	2.64	7.20	3.00	2.64	1.65	1.93	2.18	4.36	29.86	469.61	10.23
0.103	3.24	2.88	2.04	4.80	3.60	3.48	4.80	3.60	3.48	1.08	1.21	2.22	4.44	31.49	501.10	10.92
0.104	6.60	5.76	3.60	5.40	4.80	2.40	5.40	4.80	2.40	1.20	2.13	2.25	4.49	32.57	533.67	11.62
0.105	6.00	3.60	3.00	6.00	3.60	3.00	6.00	3.60	3.00	1.32	1.60	2.28	4.55	33.93	567.60	12.36
0.106	6.60	3.72	1.44	4.80	4.20	3.24	4.80	4.20	3.24	1.05	1.39	2.28	4.56	34.20	601.80	13.11
0.107	5.64	5.40	3.36	5.28	3.36	3.84	5.28	3.84	3.36	1.14	1.36	2.31	4.63	35.67	637.47	13.89
0.108	3.60	2.04	1.80	6.00	6.00	2.16	6.00	6.00	2.16	1.24	2.78	2.42	4.84	40.72	678.18	14.77
0.109	6.00	2.40	1.80	6.60	3.96	3.60	6.60	3.96	3.60	1.28	1.47	2.58	5.15	49.27	727.45	15.85
0.11	1.80	1.44	1.44	5.64	5.40	3.36	5.64	5.40	3.36	1.08	1.64	2.65	5.30	53.58	781.03	17.01
0.111	2.40	2.04	1.68	8.40	5.52	2.64	8.40	5.52	2.64	1.49	2.64	2.81	5.63	64.09	845.12	18.41
0.112	4.80	2.40	2.04	6.60	5.76	3.60	6.60	5.76	3.60	1.13	1.72	2.92	5.84	71.66	916.78	19.97
0.113	2.64	1.80	1.32	6.60	4.80	4.56	6.60	4.80	4.56	1.11	1.25	2.97	5.95	75.64	992.42	21.62
0.114	2.28	1.92	1.44	10.80	7.20	1.92	10.80	7.20	1.92	1.80	4.69	3.01	6.01	78.17	1070.60	23.32
0.115	3.00	2.52	1.80	8.40	5.40	4.20	8.40	5.40	4.20	1.29	1.64	3.26	6.52	99.75	1170.35	25.49
0.116	8.40	0.96	0.48	10.20	4.80	4.44	10.20	4.80	4.44	1.50	1.69	3.41	6.81	113.82	1284.17	27.97
0.117	4.44	3.00	1.92	10.80	6.00	3.60	10.80	6.00	3.60	1.55	2.33	3.49	6.98	122.15	1406.31	30.63
0.118	4.44	2.16	1.92	10.80	8.40	3.00	10.80	8.40	3.00	1.47	3.20	3.67	7.34	142.50	1548.82	33.74
0.119	3.24	1.92	1.80	8.40	8.40	4.20	8.40	8.40	4.20	1.11	2.00	3.78	7.56	155.17	1703.99	37.12
0.12	3.96	3.96	1.92	9.60	8.64	4.20	9.60	8.64	4.20	1.20	2.17	3.99	7.97	182.40	1886.39	41.09
0.121	2.04	1.68	1.20	13.20	8.40	4.80	13.20	8.40	4.80	1.44	2.25	4.59	9.18	278.67	2165.06	47.16
0.122	1.08	1.08	0.36	12.00	8.40	6.00	12.00	8.40	6.00	1.25	1.70	4.79	9.58	316.67	2481.74	54.06
0.123	3.84	3.24	0.60	22.80	7.20	5.40	22.80	7.20	5.40	2.09	2.78	5.44	10.89	464.15	2945.89	64.17
0.124	1.44	1.08	0.36	21.60	10.80	4.80	21.60	10.80	4.80	1.84	3.38	5.88	11.77	586.30	3532.19	76.94
0.125	0.96	0.72	0.12	18.00	15.60	7.20	18.00	15.60	7.20	1.26	2.33	7.16	14.33	1058.59	4590.78	100.00
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