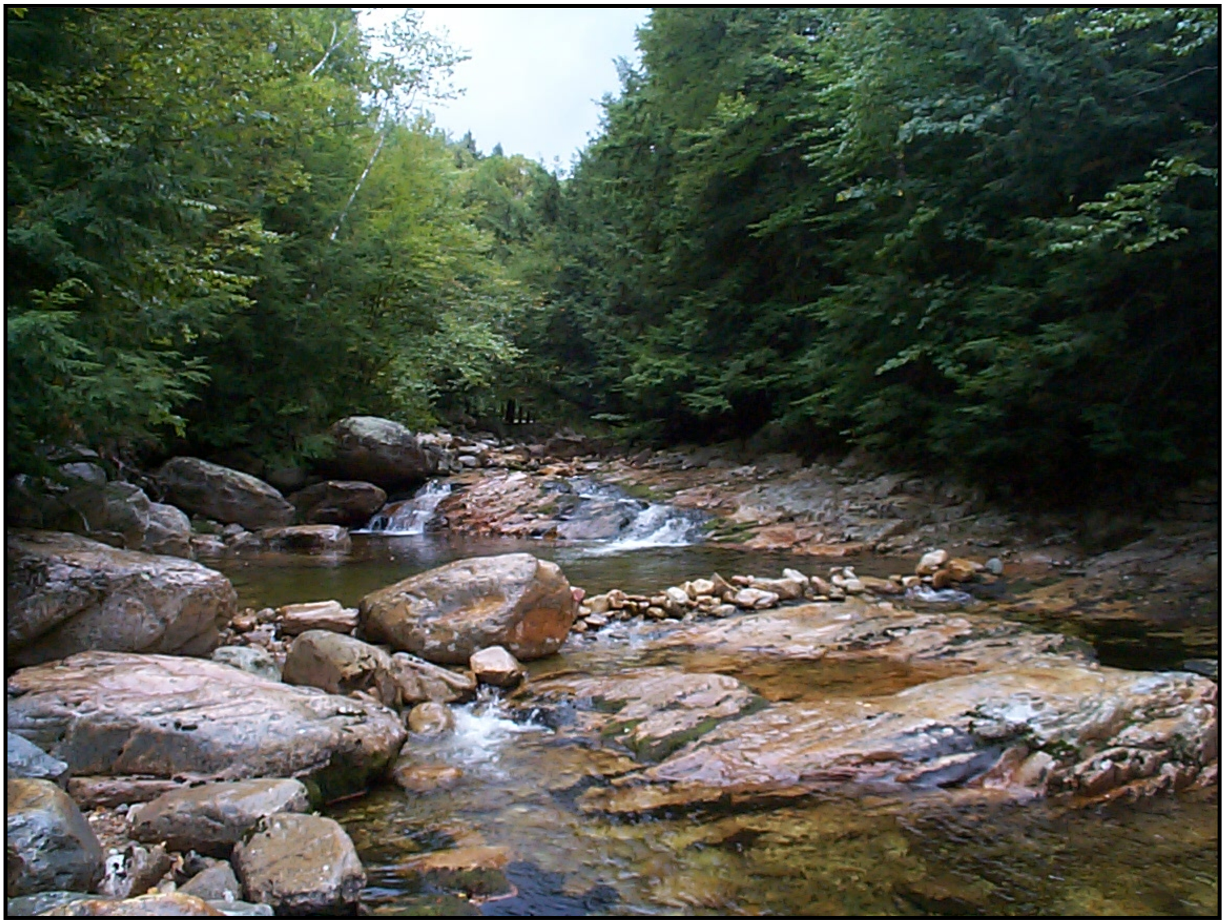
Vermont Stream Geomorphic Assessment

Appendix A



Map, Sketch, and Photo Documentation
&
Data Sheets and Field Forms

Vermont Agency of Natural Resources
May, 2009

Vermont Stream Geomorphic Assessment

Appendix A - Phase 1 Data Sheets

Phase 1 Data Sheets for Steps 1 - 9

Phase 1 Quality Assurance Sheet

Data Sheet 1

Phase 1 - Step 1. Reach Locations

Stream Name: (DMS)________________________________ Watershed: (DMS)______________________ Date:________________

USGS Map Name(s): ________________________________ Organization /Agency: (DMS)____________________________________

Observers: (DMS)__________________________________

Indicate the tools and materials used to collect data in the shaded box at the bottom of each data column.

Reach No. (SGAT)	**1.1 Reach Description**	**1.2 Town**	**1.3 Upstream End of Reach** Latitude/Longitude **(SGAT)**		**Downstream End of Reach** Latitude/Longitude **(SGAT)**	

Phase 1 - Step 2. Reference Stream Types

Data Sheet 2

Reach No. (SGAT)	**2.1 Elevation (ENTER INTO STEP 10 OF SGAT)**			**2.2 Valley Length** (feet) **(SGAT)**	**2.3 Valley Slope** (%) **(DMS)**	**2.4 Channel Length** (feet) **(SGAT)**	**2.5 Channel Slope** (%) **(DMS)**	**2.6 Sinuosity (DMS)**	**2.7 Watershed Size** (Sq. Mi.) **(SGAT)**	**2.8 Channel Width** (feet) **(DMS)**	**2.9 Valley Width** (feet) **(SGAT)**	**2.10 Confinement (Can be manually entered into**		**2.11 Stream Type**	
	Up	Down	Gentle Gradient									Ratio **(DMS)**	Type **(DMS)**	Letter	Bed Materi al

Data Sheet 3

Phase 1 - Step 3. Basin Characteristics - Geology and Soils

Reach No. (SGAT)	3.1 Alluvial Fan (Y / N)	3.2 Grade Controls (menu)	3.3 Geologic Materials (SGAT)			3.4 Valley Side Slopes		3.5 Soil Properties (menus) (SGAT)									
												Water Table					
			Dominant	% Dom	Sub-Dominant	Right	Left	Hydro Group	% Hydro	Flooding	% Flood	Deep	%	Shallow	%	Erod-ibility	% Erod

Phase 1 - Step 4. Land Cover - Reach Hydrology

Reach No. (SGAT)	**4.1 Watershed Land Cover / Use** (Menu)						**4.2 Corridor Land Cover / Use** (Menu)						**4.3 Riparian Buffers** (Menu) **(DMS)**			**4.4 Ground Water Inputs**
	Historic	Current **(SGAT)**				Impact H / L / NS **(DMS)**	Historic	Current **(SGAT)**				Impact H / L / NS **(DMS)**	RB	LB	Impact H / L / NS	High/Low/ None
		Dom	% Dom	Sub-Dom	% Urban Crop			Dom	% Dom	Sub-Dom	% Urban Crop					

Data Sheet 5

Phase 1 - Step 5. Instream Channel Modifications

Reach No. (SGAT)	5.1 Flow Regulation (FIT) (Menu)		5.2 Bridges – Culverts (FIT)			5.3 Bank Armoring (FIT) (Menu)				5.4 Channel Straightening (FIT) (Menu)				5.5 Dredging History (FIT) (Menu)	
	Type/Size/Use	Impact H / L / NS	Length (feet) (FIT)	% Impact (DMS)	Impact H / L / NS (DMS)	Type (FIT)	Length (FIT)	% Impact (DMS)	Impact H / L / NS (DMS)	Type (FIT)	Length (FIT)	% Impact (DMS)	Impact H / L / NS (DMS)	Type	Impact H / L / NS

Phase 1 - Step 6. Floodplain Modifications and Planform Changes

Data Sheet 6

Reach No. (SGAT)	6.1 Berms & Roads (RIT)			6.2 River Corridor Development			6.3 Depositional Features		6.4 Meander Migration		6.5 Meander Width Ratio (B/Wbkf)			6.6 Wavelength Ratio (Lm/Wbkf)		
	One Bank (FIT)	Both Banks (DMS)	% & Impact H / L / NS	One Bank (feet) (FIT)	Both Banks (feet) (FIT)	% & Impact H / L / NS (DMS)	Type	Impact H / L / NS	Type	Impact H / L / NS	Belt Width	MW Ratio	Impact H / L / NS (DMS)	Wave Length	WL Ratio	Impact H / L / NS (DMS)

Data Sheet 7

Phase 1 - Step 7. Bed and Bank Windshield Survey

Reach No. (SGAT)	**7.1 Bank Erosion / Bank Height**			**7.2 Ice & Debris Jam Potential**		**Comments**
	Erosion (H /L /N)	Bank Height (H /M /L)	Impact H / L / NS	Type (Menu)	Impact H / L / NS	

Data Sheet 8

Phase 1 - Step 8. Stream And Watershed Impact Rating

								8.1	(DMS)									8.2	8.3
Reach No.	**Stream Type**	**4.1 Watershed Land Use / Cover**	**4.2 Corridor Land Use / Cover**	**4.3 Riparian Buffer Width**	**5.1 Flow Regulation / Withdrawals**	**5.2 Bridges and Culverts**	**5.3 Bank Armoring / Revetments**	**5.4 Channel Straightening**	**5.5 Dredging / Gravel Mining**	**6.1 Berms, Roads, Railroads, Paths**	**6.2 Floodplain Developments**	**6.3 Depositional Features**	**6.4 Meander Migration**	**6.5 Meander Width Ratio**	**6.6 Wavelength Ratio**	**7.1 Bank Erosion / Bank Height**	**7.2 Ice / Debris Jam Potential**	**Total Impact Score**	**Priority Ranking**

Data Sheet 9

Phase 1 - Step 9. Geomorphic Condition Evaluation

Reach No.	**Stream Type**	**9.1 Channel Adjustment Process**		**9.2 Reach Condition** (DMS)	**9.3 Reach Sensitivity** 9.4 (DMS)
		Adjustment (DMS)	**Concurrent Adjustment** (DMS)		

Phase 1 – Quality Assurance Report

Stream Name:_______________________________________ Watershed: ___________________________ Date:__________
QA Team Leader: ____________________________________ Organization /Agency:___________________________________
ANR Team Leader:___________________________________

Check one or more boxes to indicate the types of ANR sponsored training received by one or more members of your assessment team.		
	Phase 1	
	SGAT	
	QA	

Windshield Orientation Survey completed	
Reach Breaks reviewed by trained team member for consistency	
ANR SGA Handbook Protocols and Database used exclusively	
Other protocols used:	

Phase 1 Step Number	Tool Used to Collect Data	Confidence Level	Date Completed	Date Updated	Date of Local QA Team Review	Date of State QA Team Review	Comments
Step 1		Low to Moderate Moderate Moderate to High High					
Step 2		Low to Moderate Moderate Moderate to High High					
Step 3		Low to Moderate Moderate Moderate to High High					
Step 4		Low to Moderate Moderate Moderate to High High					
Step 5		Low to Moderate Moderate Moderate to High High					
Step 6		Low to Moderate Moderate Moderate to High High					
Step 7		Low to Moderate Moderate Moderate to High High					
Step 8 / 9		Low to Moderate Moderate Moderate to High High					

Phase 1 – Meta Data Documentation

Stream Name: (DMS)________________________________ Watershed: (DMS)____________________ Date:______________

Step	Parameter Name	Meta Data Options (Circle One)
0.1	Reach breaks	1:24K topos
		1:24K topos, 1:5K NHD
0.2	Watershed delineations	1:24K DEM
		1:24K topos, 1:5K NHD
		1:5K DEM
0.3	Valley walls	1:24K topos
		1:24K topos, SG data
		1:24K topos, SG data, field obs.
		1:24K topos, SG data, field - GPS
0.4	Meander centerline	1:24K topos, 1:5K NHD
1.2	Towns that reaches are in	1:24K topos
		SGAT automated
1.3	Latitude and Longitude	SGAT automated
2.01	Downstream and upstream elevations	1:24K topos
2.02	Valley length	SGAT automated
		1:24K topos
		1:24K topos & 1:5K orthos
2.04	Channel length	SGAT automated
		Field - tape measure
		Field - GPS
		Field - survey
2.08	Channel width	HGC - SGAT Automated
		Field - range finder
		Field - tape measure
		Field - survey

Step	Parameter Name	Meta Data Options (Circle One)
2.09	Valley width	SGAT automated
		1:24K topos
		Field - range finder
		Field - tape measure
2.10	Confinement type	1:24K topos
		1:24K topos, SG data
		Field observation
		Field - tape measure
2.11	Stream type	1:24K topos
		Field observation
		Cross-sections, pebble counts
		Profile, cross-sections, pebble counts
3.1	Alluvial fan	1:24K topos
		1:24K topos, SG data
		1:24K topos, SG data, geologic studies
		1:24K topos, field obs.
3.2	Grade controls	1:24K topos
		1:24K topos, bedrock map
		1:24K topos, bedrock map, dam inventories
		1:24K topos, field obs.
3.4	Valley side slopes	1:24K topos
		1:24K topos, soils slope data
		1:24K topos, field obs.
3.5	Corridor soil data	NRCS soil survey maps
4.1	Historic watershed land use - land cover	1:5K orthos (1970s)
		1:5K orthos (1970s), old aerial photos, topos
		Land use - land cover (1990s statewide)
4.2	Historic corridor land use - land cover	1:5K orthos (1970s)
		1:5K orthos (1970s), old aerial photos, topos
		Land use - land cover (1990s statewide)
		Digitial corridor land use - land cover

Step	Parameter Name	Meta Data Options (Circle One)
4.3	Riparian buffer width	1:5K orthos
		Digitial corridor land use - land cover
		1:5K orthos, recent coverages & photos, field obs.
4.4	Groundwater and small tributary inputs	1:24K topos, 1:5K NHD
		1:24K topos, 1:5K NHD, NWI maps
		1:5K NHD, NWI maps, field obs.
5.1	Flow regulations and water withdrawals	1;24K topos, 1:5K NHD & orthos
		1;24K topos, 1:5K NHD & orthos, files
		1;24K topos, 1:5K NHD & orthos, files, field obs.
5.2	Bridges and culverts	1;24K topos, 1:5K NHD & orthos
		1;24K topos, 1:5K NHD & orthos, files
		1;24K topos, 1:5K NHD & orthos, files, field obs.
5.3	Bank armoring and revetments	1;24K topos & orthos
		1;24K topos, orthos, files
		1;24K topos, orthos, files, field obs.
5.4	Channel straightening	1;24K topos, 1:5K NHD & orthos
		1;24K topos, 1:5K NHD & orthos, files
		1;24K topos, 1:5K NHD & orthos, files, field obs.
5.5	Dredging and gravel mining history	Interviews - DEC, NRCS
		Interviews - DEC, NRCS, Towns, others
6.1	Berms and roads	1:24K topos, 1:5K orthos
		1:24K topos, 1:5K orthos, files
		1:24K topos, 1:5K orthos, files, field obs
6.2	River corridor development	1:24K topos, 1:5K orthos
		1:24K topos, 1:5K orthos, files
		1:24K topos, 1:5K orthos, files, field obs
6.3	Depositional features	1:5K orthos
		1:5K orthos, other aerial photos
		1:5K orthos, field obs.
6.4	Meander migration and channel avulsion	1:5K orthos (1990s & 1970s)
		1:5K orthos (1990s & 1970s), other aerial photos
		1:5K orthos (1990s & 1970s), field obs.

Step	Parameter Name	Meta Data Options (Circle One)
6.5	Belt Width	1:5K NHM, 1:5K orthos
		Field - survey
6.6	Wavelength	1:5K NHM, 1:5K orthos
		Field - survey
7.1	Dominant bed form and material	Preliminary estimate
		Field obs. at access point along reach
		Field obs. along entire reach
		Field obs. and detailed notes along entire reach
7.2	Bank erosion - relative magnitude	Field obs. at access point along reach
		Field obs. along entire reach
		Field obs. and detailed notes along entire reach
7.3	Debris and ice jam potential	Field obs. at access point along reach
		Field obs. along entire reach
		Field obs. and detailed notes along entire reach

Phase 1 Task Register 2005

Watershed: ______________________________________ Date:____________

Organization /Agency: _______________________________

Participant Contact Information			
Name (and Agency /Group)	**Telephone**	**E-Mail**	**Mailing Address**

Task to get started **(complete on a paper map first)**				
Task	**Person completing task**	**Schedule**	**Comments**	**Approx time**
Reach Break identification				
Watershed delineation (reach sub-watershed delineation)				
Reach Numbering				

Generate Arcview Themes needed to use SGAT: See attached Phase 1 task document for details				
Task	**Person completing task**	**Schedule**	**Comments**	**Approx time**
1) Watersheds,				
2) Meander Centerline,				
3) Valley Walls				
Upload Themes into DMS for QA review				

SGAT and Database Creation				
Phase 1 steps completed in full or part by SGAT: 1.3; 2.1, 2.2; 2.3; 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.10, 3.3, 3.5, 4.1, 4.2 (see attached document for details)				
Task	**Person completing task**	**Schedule**	**Comments**	**Approx time**
Run SGAT steps 1-10				
Review reach data in step 10; enter elevations; missing valley lengths and widths; towns, orthos; topos, notes				
Export Step 10 table				
Run SGAT steps 11-14 for soils and lulc **(see note below)**				

Parameters clipped in SGAT steps 11-14 for soils and lulc; with Appendix E corridor created in SGAT and/or Watersheds created by user				
Task / Phase 1 step #	**Person completing task**	**Schedule**	**Comments**	**Approx time**
3.3 – Geologic Material				
3.5 – Soils Characteristics				
4.1 Watershed LuLc				
4.2 – Corridor LuLc (this may be more accurate to do with orthophotographs)				

- ***Import tables from SGAT into DMS***
  Run QA check for each table

To assist in steps outside of SGAT it can be useful to print out the reports, for each step and/or the “Data Entry Worksheet”, from the database. This will give the user tables with reach numbers in place for completion of the step. If using the “Data Entry Worksheet” simply fill in the step & parameters being collected at the head of each column.

Steps done without SGAT or SGAT corridor delineation (use Appendix A worksheets to record the data)				
Task / Phase 1 step #	**Person completing task**	**Schedule**	**Comments**	**Approx time**
1.1– Reach Description				
1.2 – Town				
2.11 – Stream Type (steps 2.3 and 2.10 must be completed first)				
DMS – QA step to be completed				
3.1 – Alluvial Fan				
3.2 – Grade Controls				
3.4 – Valley Side Slope				
4.3 – Riparian Buffer Width				
4.4 – Groundwater and Small Tributary Input				
For several parameters in Steps 5-7 it will be necessary to create, and/or modify current, GIS shapefiles. Steps 5.1, 5.3, 5.4, 6.1, 6.2, 6.5, 6.6, 7.2. The type of GIS layer suggested will be noted below, in the step. The Feature Indexing Tool (FIT) is required for steps 5.3, 5.4 and 6.1 (see attached document for details)				
5.1 – Flow Regulations (FIT – point theme)				
5.2 – Bridges (FIT –line theme)				
5.3 – Bank Revetments (FIT – line theme)				
5.4 – Channel Modifications (FIT- line theme)				
5.5 – Dredging and Gravel Mining				
Steps 6.1 & 6.2 are done with Appendix E corridor (created by SGAT) and orthophotographs (use Appendix A worksheets to record the data)				
6.1 – Berms, Roads, Railroads, and Improved Paths (FIT – line theme)				
6.2 – River Corridor Development (FIT – line theme)				

Con't - Steps done without SGAT or SGAT corridor delineation (use Appendix A worksheets to record the data)				
Task / Phase 1 step #	**Person completing task**	**Schedule**	**Comments**	**Approx time**
6.3 – Channel Bars				
6.4 – Meander Migration				
6.5 – Meander Width Ratio (GIS – line theme)				
6.6 – Wavelength Ratio (GIS – line theme)				
7.1 – Dominant Bed Material				
7.2 – Bank Erosion (FIT – line theme)				
7.3 – Debris and Ice Jam Potential				
DMS – QA step to be completed				
8.1 – Impact Rating				
8.2 – Priority Rating				
9.1- Channel Adjustment Process				
9.2- Reach Condition				
9.3- Reach Sensitivity				
10 - Like Reach Evaluation				

Phase 1 Tasks 2005

It is very valuable, and recommended, to take the time to mark all reach breaks, draw all watersheds (reach sub-watersheds, as well as the overall watershed), and to label/number all reaches on a paper map before starting on the computer. This will provide a working map and will help those members of the team who may be completing steps not done on the computer.

*** See protocols for details on collecting the data for all steps.**

Task to get started

1) Reach Break identification
2) Watershed delineation (reach sub-watershed delineation)
3) Reach Numbering

Step done totally or in part by SGAT:

*** Use the SGAT user manual for working through the program. Use the Phase 1 assessment handbook protocols for understanding and evaluating the information for each step listed below.**

The user must generate 3 ArcView themes;

1) **Watersheds,**
2) **Meander Centerline, and**
3) **Valley Walls**

*** The user will also need the 1:5000 stream layer, digital NRCS soils maps, and the digital State-wide Land-use/Land-cover for their area/watershed (data can be obtained from VCGI's web site or by contacting them for a CD).**

***1.3** – Latitude/Longitude*

- Completed for all reaches by SGAT

***2.1** – Elevation*

- User enters elevation, off the topographic map, for each reach point in Step 10 of SGAT)
- **Note:** If the user is unable to distinguish an elevation for the reach break, due to a long reach in a very low slope valley where there are no contour lines crossing the valley, the user may find it difficult to interpolate an elevation. For those reaches where no elevation change is distinguishable on the topographic map, the user can check (on the data sheet and in the database, not in SGAT) the "Gentle Gradient" descriptor for valley and channel slope.

***2.2** – Valley Length*

- Completed by SGAT for reaches where valley wall polygon has been drawn {those reaches that are in Narrow, Broad, or Very Broad valleys}; for reaches in Semi-confined and Narrow-confined valleys, the user must measure the valley length and enter the data in Step 10 of SGAT)

***2.3** – Valley Slope*

- Calculated by SGAT for reaches where valley length and reach elevations have either been generated by SGAT or entered by the user in Step 10 of SGAT.

***2.4**-Channel Length*

- Completed for all reaches by SGAT

***2.5** – Channel Slope*

- Calculated for all reaches by SGAT once elevations have been entered in SGAT Step 10

***2.6** – Sinuosity*

- Calculated for reaches where valley length is provided by either SGAT or entered by the user in SGAT Step 10.

***2.7** – Watershed Size*

- Calculated for all reaches by SGAT

***2.8** – Channel Width*

- Calculated, by SGAT, for all reaches

***2.9** – Valley Width*

- Calculated, by SGAT, for only those reaches where a valley wall polygon has been drawn {typically, those reaches that are in Narrow, Broad, or Very Broad valleys}; the user may choose not to measure confined valley widths due to the inability to discern valley toes on the topographic map, so this parameter may be left blank for confined valleys. If the user measures a confined valley width ,the data can be entered in SGAT Step 10.

***2.10** – Confinement*

- The confinement ratio will be calculated for those reaches where a valley wall polygon has been drawn {those reaches that are in Narrow, Broad, or Very Broad valleys}; if the user entered a valley width for a confined valley in SGAT Step10 then a ratio will be calculated by SGAT. The user will then choose a confinement type in the Phase 1-2 database. For those confined valleys, where no valley wall lines were drawn, use confinement type "1-SC" (semi-confined) as a default choice unless you are aware that the valley is "V" shaped and the stream is narrowly confined, then choose 1-NC.

* SGAT will generate the Appendix E corridor (see Phase 1 handbook for details on the corridor used to determine the information for the following steps)

***3.3** – Geologic Materials*

- Complete steps 11, 12, and 14 in SGAT

***3.5** – Soils Characteristics*

- Complete steps 11, 12, and 14 in SGAT

***4.1** – Watershed Land Cover / Land Use*

- Complete steps 11, 12, **13** and 14 in SGAT

***4.2** – Corridor Land Cover / Land Use*

- Complete steps 11, 12, and 14 in SGAT
-
- **Note: The State-wide LuLc layer is not very accurate at the corridor level. If you have a more detailed LuLc layer (that has the same categories as the State-wide, but has been done for your area more recently) you can clip that layer for your corridor information. Otherwise it is recommended that you get this information from the current orhtophotographs and the windshield orientation survey. (Overlay the corridor generated in SGAT on the orhtophotograph and look for the LuLc that is within the corriodor.)**

Steps 3.3, 3.5, 4.1 and 4.2: **SGAT will clip and sum the information from the NRCS soils data and/or the state-wide Land-use/Land-cover layer. Importing the tables into the DMS will calculate the corrected percents and impact scores for these steps.**

Steps that will be completed once the Appendix E corridor has been created (by SGAT or by hand if not using SGAT)

3.3 –Geologic Material (see SGAT above)
3.5 – Soils Characteristics (see SGAT above)
4.2 – Corridor Land-use/Land-cover (see SGAT above)

6.1 – Berms, Roads, Railroads, and Improved Paths
6.2 – River Corridor Development

Steps that can be done without assistance from SGAT or SGAT corridor delineations:

- Review of orthophotos and topographic maps can be done on the computer, but the paper copies will also be okay for completing these steps, so members of your team who are not computer savvy can work on these tasks while other people do the computer work.
- For all reaches, Complete the Appendix A worksheets for each step. Have a QAQC meeting to review the data before entering it into the database.

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
1.1- Reach Description **1.2** – Town	*** 2.11** – Stream Type	**3.1** – Alluvial Fan **3.4** – Valley Side Slope	*** 4.3** – Riparian Buffer Width **4.4** – Groundwater and Small Tributary Input	**5.1** – Flow Regulations **5.2** – Bridges **5.3** – Bank Revetments **5.4** – Channel Modifications **5.5** – Dredging and Gravel Mining	**6.3** – Channel Bars **6.4** – Meander Migration **6.5** – Meander Width Ratio **6.6** – Wavelength Ratio	**7.1** – Dominant Bed Material **7.2** – Bank Erosion **7.3** – Debris and Ice Jam Potential	**8.1** – Impact Rating **8.2** – Priority Rating	**9.1**- Channel Adjustment Process **9.2**- Reach Condition **9.3**- Reach Sensitivity	**10** - Like Reach Evaluation

* 2.11 – Stream Type

(To complete the stream type for each reach, data from steps 2.3 and 2.10 must be completed first; additional information from steps 7.1 may also be used for a more detailed stream type; but is not necessary for the initial stream type classification, if step 7.1 has not been completed).

* 4.3 – Riparian Buffer Width

(If this is done on the computer, it can be useful to have the various buffer widths displayed, such aa 100 ft "buffer"; polygon created for the stream layer, then overlay it on the orthophoto to help with quickly determining the buffer widths within each category.) When using the centerline, it is more accurate to create the buffer widths based on the equation (channel width / 2) + X ; where channel width comes from SGAT step 8 and X is the widths (25, 50, and 100)

Create the following GIS layers that correspond to Steps 5-7.

- **Step 5.1 Flow Modifications-** identify water withdrawal sites, dams and other features that modify flow (point theme).
- **Step 5.3 Bank Armoring-** locate areas of bank protection (line theme). (**RIT)**
- **Step 5.4 Channel Modification-** document sections of channel that have been modified (line theme). (**RIT)**
- **Step 6.1 Berms and Roads-** identify roads, berms and railroads within stream corridor (line theme). (**RIT)**
- **Ste6 6.2- River Corridor Development-** utilizing 911 site data, locate structures within the river corridor (point theme).
- **Step 6.5 and Step 6.6 Meander Width and Length-** record how and which meanders were measured (line theme).
- **Step 7.2 Bank Erosion-** identify areas of stream bank erosion (line theme).

These GIS layers will be used in the QAQC process, documenting the length and location of the parameter, and identifying where parameters were assessed. These layers are also very valuable for mapping and display purposes.

QAQC Review :

- Review of data collected by QAQC team
- Complete QA steps as required in DMS (shapefiles, SGAT tables, after Step 2, and after step 7)
- Document any questions, concerns, missing data, etc.
- Complete QAQC form for watershed

Database:

* Entering data for all steps

Note: The reach number and VTID, as well as notes and other information from SGAT step 0.0; and from SGAT for steps : 1.3, 2.1, 2.2, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.10; can be imported into the database automatically. Also information from SGAT for Steps: 3.3, 3.5, 4.1, and 4.2 is automatically imported into the DMS.

Information from RIT for steps 5.3, 5.4, 6.1 is automatically uploaded.

Bridge and Culvert Survey:

- Contact town highway department, RPC, and utilize VCGIs' bridge/culvert layer to determine structure numbers (where available)
- Complete Phase ANR Bridge/Culvert Survey
- Enter data into DMS

Vermont Stream Geomorphic Assessment

Appendix C

Channel Evolution Models

Vermont Agency of Natural Resources
May 2007

Channel Evolution Models

F-stage Channel Evolution Process

The capital letters used throughout the following discussions refer to the stream types (Rosgen, 1996) typically encountered as the channel form passes through the different stages of channel evolution. The F-stage adjustment process begins where the streams are not entrenched and have access to a floodplain at the 1-2 year flood stage. Moderately entrenched, semi-confined “B” streams may also go through an F-stage channel evolution. This channel evolution model (CEM) is based on the assumption that the stream has a bed and banks that are sufficiently erodible so that they can be shaped by the stream over the course of years or decades. Streams beginning this process are typically flowing in alluvium or other materials that may be eroded by an increase in stream power. As the incision process continues, they may degrade to bedrock or glacial till materials. When a stream with a low width to depth ratio (“E” stream types) goes through this process, the sequence of stream types may be **E-C-F-C-E** (other forms may include **E-C-G-F-C-E** or **C-G-F-C** or **C-F-C** or **C-B-F-B-C** or **B-G-F-B** or **B-G-F** or **C-B-C**).

Stage I - Channel in regime with access to floodplain or flood prone area at discharges at and above the average annual high flow. Planform is moderate to highly sinuous; supportive of energy dissipating bed features (steps, riffles, runs, pools) essential to channel stability (B, C and E Stream Types). Channel slope (vertical drop in relation to length) generates flow velocities and stream power in balance with the resistance of stream bed and bank materials. Sediment transport capacity in equilibrium with sediment load.

Stage II - Channel has lost access to its floodplain or flood prone area, at its historic bankfull discharge, through a bed degradation process or floodplain build up. Stream has become more entrenched as discharges in excess of the annual high flow are now contained in the channel (B or G or F Stream Type). Channel slope is increased with commensurate increase in velocity and power to erode the stream bed and banks (boundary materials). The result of preventing access to the floodplain and containing greater flows in the channel is to increase the stream’s power that must be resisted by the channel boundary materials; i.e., the rocks, soil, vegetation or man-made structures that make up the bed and banks of the river. Plane bed may begin to form as head cuts move upstream and step/riffle materials are eroded.

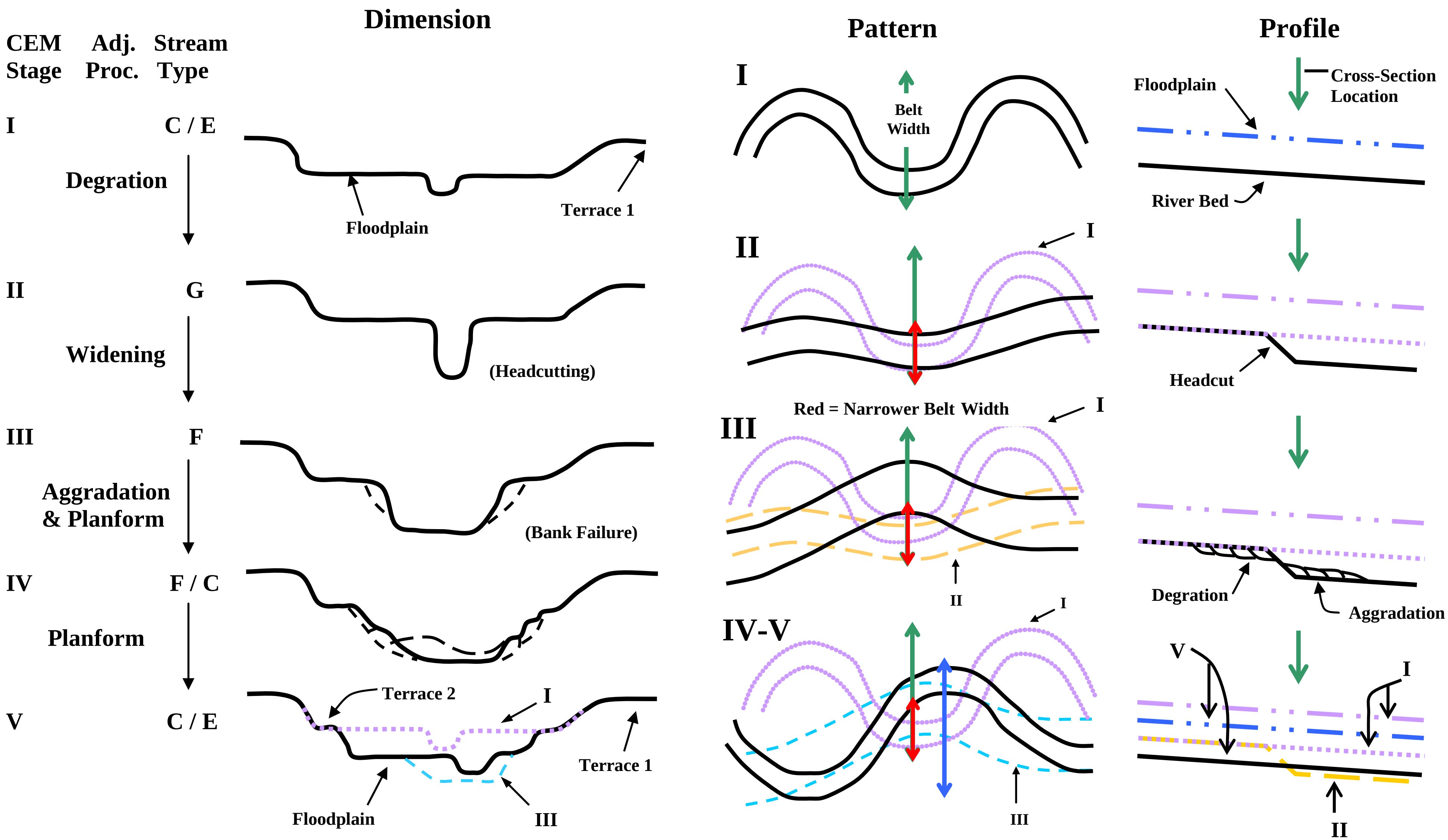
Stage III - Channel is still entrenched, widening and migrating laterally through bank erosion caused by the increased stream power (B or G or F Stream Type). The system regains balance between the power produced and the boundary materials as sinuosity increases and slope decreases. There are profound physical adjustments that occur upstream and downstream from the site of alteration as bed degradation (head cuts) migrates up through the system and aggradation in the form of sedimentation occurs downstream. Stream bed largely becomes a featureless plane bed.

Stage IV - Channel dimension and plan form adjustment process continues. Channel width begins to narrow through aggradation and the development of bar features. The main channel may shift back and forth through different flood chutes, continuing to erode terrace side slopes as a juvenile floodplain widens and forms. Weak step/riffle-pool bed features forming. Transverse bars may be common as planform continues to adjust. At Stage IV, erosion may be severe. Historically, channels have been dredged, bermed, and/or armored at this Stage pushing the process back to Stage II or III.

Stage V - Channel adjustment process is complete. Channel dimension, pattern, and profile are similar to the pre-adjustment form but at a lower elevation in the landscape (B, C and E Stream Types). Planform geometry, longitudinal profile, channel depth, and bed features produce an energy grade that is in balance with the sediment regime produced by the stream’s watershed.

Higher gradient, more entrenched streams (“A” or “B” stream types) with erodible beds also go through channel evolution processes that involves bed degradation. In these cases, the floodplain forming stages may be comparatively minor. A lowering of the bed elevation is more quickly followed by a re-sloping of the banks until the appropriate energy grade is achieved.

F-stage Channel Evolution Process (VTDEC-Modified from Schumm, 1977 & 1984 and Thorne et al, 1997)



D-stage Channel Evolution Process

Only use the D stage CEM where the stream has no opportunity to incise. If the stream has incised and has now hit bedrock or clay and is currently widening, you would still use the F stage CEM.

The capital letters used throughout the following discussions refer to the stream types (Rosgen, 1996) typically encountered as the channel form in the different stages of channel evolution. The difference between F and D-stage channel evolution processes is the degree of channel incision. In D-stage channel evolution, the dominant, active adjustment processes is **aggradation**, widening, and plan form change. In some situations, the stream may not experience any degradation because its bed is significantly more resistant to erosion than its banks. The process may start with limited vertical adjustment and goes right into aggradation and a lateral adjustment processes. Stream with low width to depth ratios ("E" Stream Types) may also go through this process.

Stage I - Channel in regime with access to floodplain or flood prone area at discharges at and above the average annual high flow (B, C and E Stream Types). Plan form is moderate to highly sinuous; supportive of energy dissipating bed features (steps, riffles, runs, pools) essential to channel stability. Channel slope (vertical drop in relation to length) generates flow velocities and stream power in balance with the resistance of stream bed and bank materials. **Then either of the following Stage II scenarios may occur:**

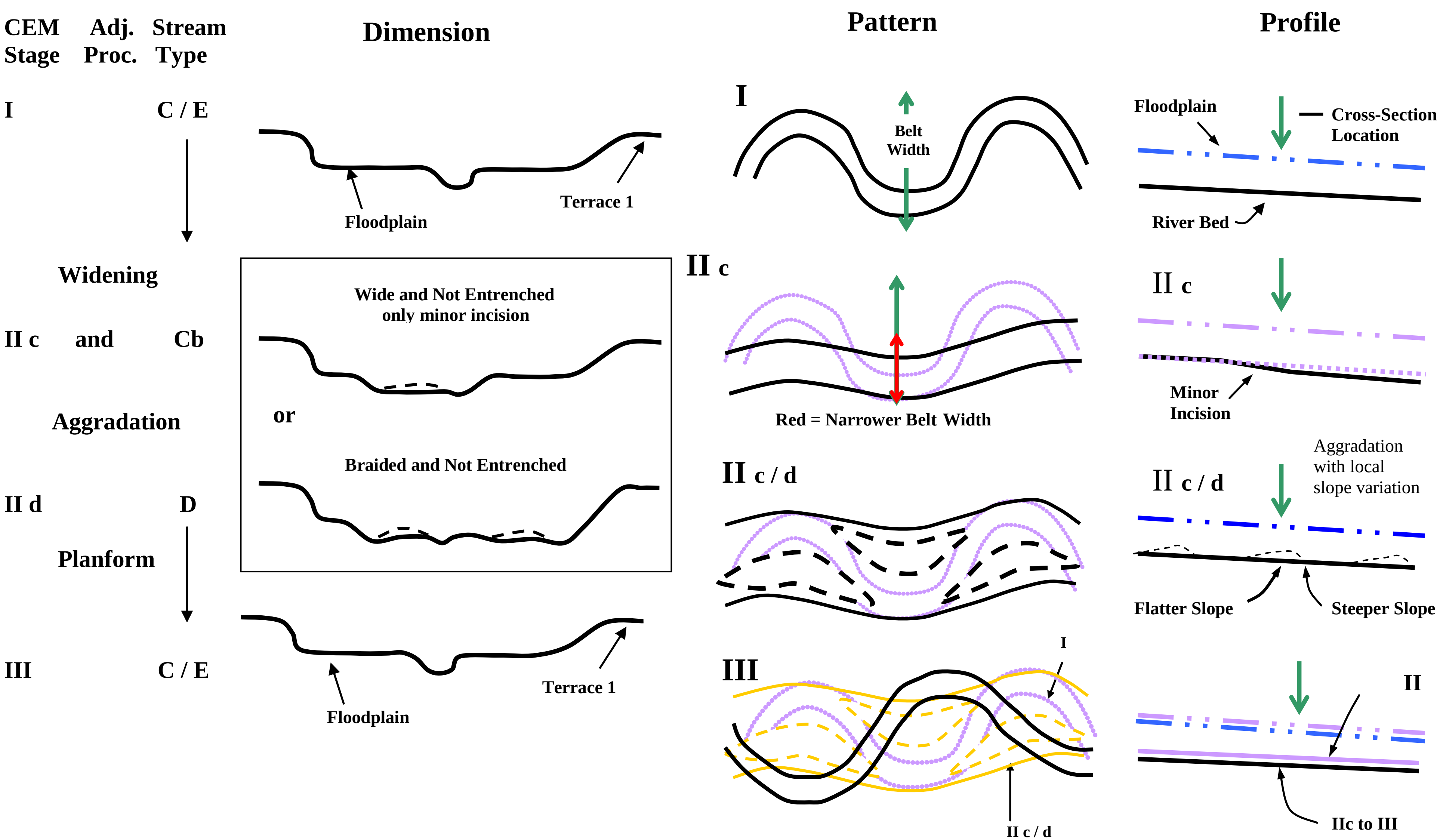
Stage IIc Steeper gradient may be imposed through activities such as channelization, but due to the resistance of the bed material, the stream has not incised significantly or lost access to its floodplain (remaining a "C" Stream Type). Channel is widening and migrating laterally through bank erosion caused by the increased stream power. The balance between stream power and boundary materials is re-established when the slope flattens after a process of channel lengthening and increased sinuosity. Stream bed may be a combination of poorly defined riffle-pool and plane bed features.

Stage IId Channel becomes extremely depositional and becomes braided with water flowing in multiple channels at low flow stage ("D" stream type). Dimension and plan form adjustment processes continue. Channel width begins to narrows through aggradation and the development of bar features. The main channel may shift back and forth through different channels and chute cut-offs, continuing to erode banks or terrace side slopes. Riffle-pool bed features develop as single thread channel begins forming. Transverse bars may be common as planform continues to adjust.

Stage III Channel adjustment process is complete (back to a B, C or E stream type). Channel dimension, pattern, and profile are similar to the pre-adjustment form. May or may not be at a lower elevation in the landscape. Planform geometry, longitudinal profile, channel depth, and bed features produce an energy grade (sediment transport capacity) that is in balance with the sediment regime produced by the stream watershed.

Important Notes: 1) The imposition of new constraints or changes at watershed, reach, or local scales, especially those related to large floods that energize the stream system with high flows of water, sediment, and debris, will affect the time scales associated with each stage of channel evolution. They may also have dramatic effects on the direction of a channel evolution process. The overlapping pulses of channel adjustment moving upstream and downstream in a watershed often makes the pinpointing of a specific channel evolution stage complicated. 2) Bedrock-controlled reaches in Vermont are presumed to be relatively fixed for the purposes of these protocols as little bed or back erosion can be expected even over a century. Such reaches may, however, dramatically change or evolve due to rapid or catastrophic avulsions of the flow onto more erodible sediments nearby, leaving the bedrock channel wholly or partially abandoned.

C-D-C Channel Evolution Process (VTDEC-Modified from Schumm, 1977 & 1984 and Thorne et al, 1997)



Vermont Stream Geomorphic Assessment

Appendix D

Delineating Watershed Drainage Area

Topographic Maps And Aerial Photography

Vermont Agency of Natural Resources
April, 2004

Delineating Watershed Area

Watershed areas can be drawn with map and pencil or with computer mapping tools; however, it is highly recommended that you use paper topographic maps to first draw watershed areas and complete reach numbering. Digitizing on-screen from scratch can be inefficient, as the user must switch back and forth between a small scale in order to see topographic features and a larger scale to see drainage patterns. It is also extremely valuable to have the paper maps as a backup and for educational display.

Materials needed

- USGS 1:24,000 topographic maps
- tape
- pencil and eraser

Procedure

1. Tape together a composite of the all the topographic maps on which the watershed is located. To determine which maps these are, you will need to have a general sense of where the mainstem river or stream flows and which larger tributaries flow into it. Each USGS topographic map covers about 53 square miles of land area.

2. On the map, mark the watershed outlet, which is the most downstream end of the stream, river, lake, or reach you are assessing. Examine the map to identify all land area that directs water to the watershed outlet. Look for the blue lines, which indicate surface water, that flow to the watershed outlet, and visually follow these blue lines upstream until they end. All of these blue lines that drain to the watershed outlet make up the drainage network (Figure D.1). From the most upstream ends of the blue lines, follow the contour lines uphill until reaching the ridge tops of the drainage divide. The contour lines along a stream make a V with the point of the V facing uphill, and ridges make a U (sometimes V-shaped) with the bottom of the U facing downhill.

3. Draw the watershed boundary by connecting all the ridge tops and highpoints from which the land slopes down to the river (or lake) and eventually to the watershed outlet. Watershed boundary lines are drawn at right angles to the contour lines on the topographic maps'. Start at the watershed outlet and work upstream, drawing the watershed boundaries on one side of the watershed; and continue to follow the ridges around until you come back to the watershed outlet on the opposite side of the watershed. The watershed boundary line you draw should encircle the entire drainage network of the watershed. Sometimes it is easier to visualize watershed boundaries by first looking for the tops of hills and mountains and "connecting the dots", ridge top to ridge top, around the waterbody.

Notes

- If a wetland sits on a drainage divide between two watersheds, divide the wetland in half with the watershed boundary line. It is likely that the wetland drains in both directions, into the watershed you are delineating and into the adjacent watershed.

- Be careful in urban areas because stormwater drainage and water supply systems can sometimes significantly change the locations of drainage divides. Contact the city engineer for information.

- Check your work by examining the contour lines within the watershed boundaries to make sure that there are no points, other than the outlet, where water flowing off the land could cross the watershed boundary lines and leave the watershed.

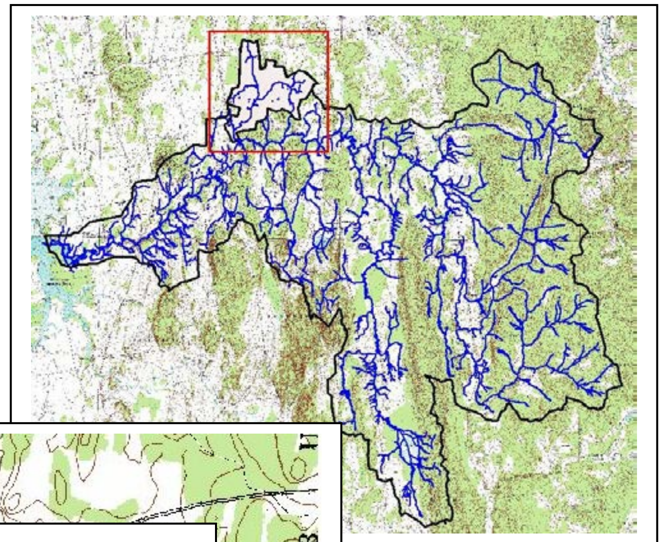
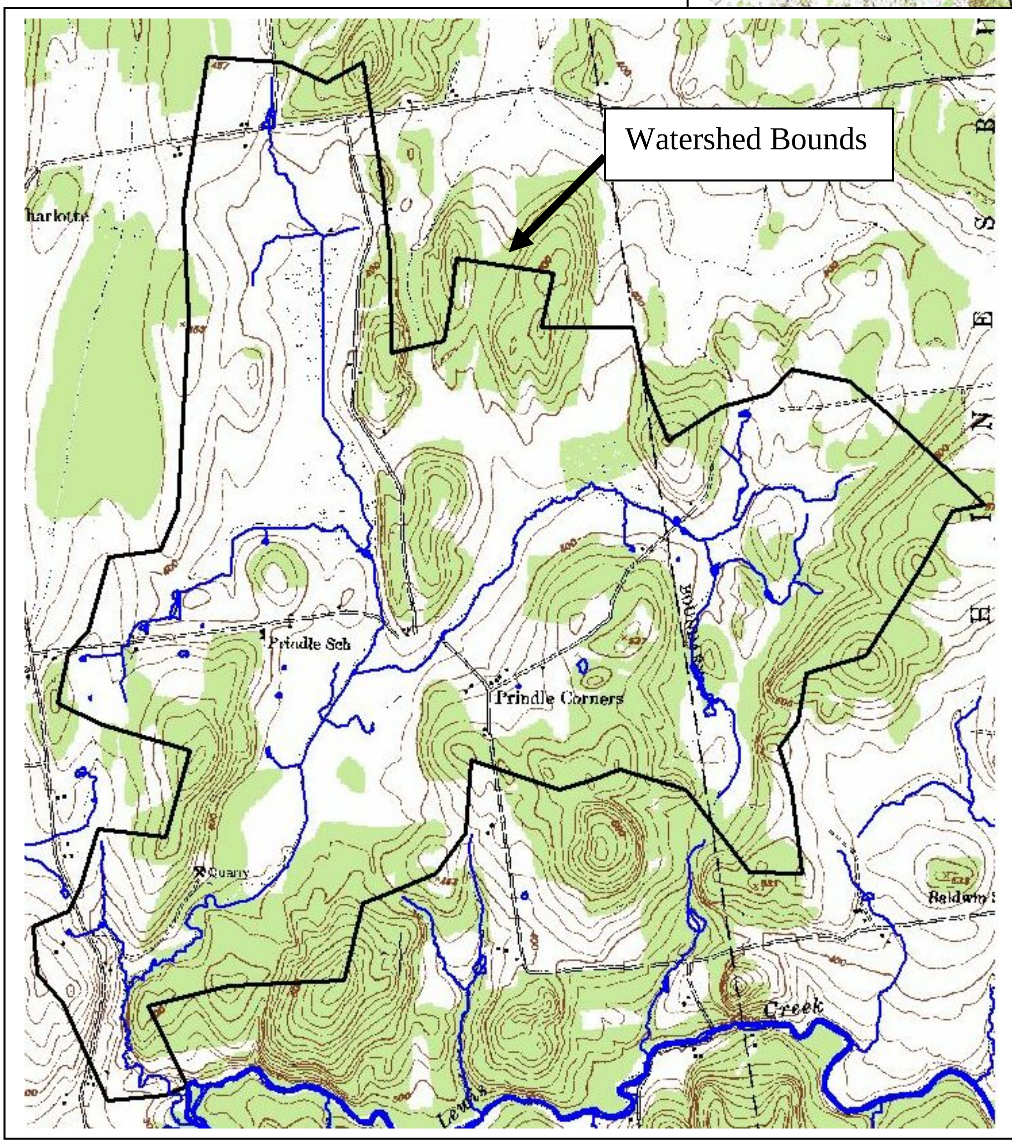


Figure D.1 Below, the watershed area drawn for a tributary stream. Inset on right shows the location of the tributary watershed within the larger mainstem watershed. The drainage network is shown in blue.



Topographic Maps and Aerial Photography

Reading a Topographic Map

Becoming familiar with the topographic map is essential for understanding a watershed. Two features used frequently are the scale, which can be read at the bottom of the map, and the contour lines. The scale relates the distance between two points on the map ad the actual distance. The United States Geological Survey (USGS) produces several series of topographic maps with different scales. The two most common are the 1:24,000 and the 1:100,000 series. On a 1:24,000 map, a distance of one unit on the map equals 24,000 units in the field.; For example, 1 (map) inch = 24,000 (field) inches or 2000 feet. Contour lines are lines of equal elevation, typically 20 feet or 6 meters apart on the 1:24,000 series map. Every fifth contour line is darkened and this helps to make reading the map easier. Since contour lines are lines of equal elevation, when they are closer together, it indicates steeper terrain, and when they are further apart, the land is flatter. Many stream features such as channel slope, valley slope, sinuosity, valley width, basin slope, location of alluvial fans, drainage area etc. can be read from a topographic map.

The list below includes some of the most common features that you will see when reading a topographic map.

Note that while some valleys on the map show streams flowing through them, others do not. This does not mean that there is no stream there, it means that a perennial stream was too small to detect when the map was made or the stream is ephemeral (not flowing all the time). The dotted blue lines indicate larger ephemeral streams, solid blue lines indicate perennial streams.

Guide to main features on a topographic map

Hill summit: closed round circle
Depression: closed round circle with small lines pointing to the center of the circle.
Valley: V shaped contours with the point of the V facing UPHILL.
Ridge: U or V shaped contours with the point of the U facing DOWNHILL.
Steep terrain: contour lines close together
Flat terrain: contour lines farther apart
Slope breaks: These are areas where alluvial fans, or multiple channels may occur.

Using Aerial Photographs and Orthophotos

Introduction

Aerial photograph interpretation is an easy and low-cost way to view a large area of land in its entirety. With the right photos and a small amount of training, aerial photographs can reveal a tremendous amount of information about rivers and watersheds.

As the subject is a broad one, this section can only provide a brief introduction. Anyone seriously interested in photo interpretation should refer to Avery and Berlin (1992) and Philipson (1997).

Aerial photos can be divided into two broad categories: Vertical photos are taken with a camera which is pointing approximately straight down and oblique photos are taken at some angle other than vertical. The typical photo taken by pointing a handheld camera out an airplane window is an oblique photo. Oblique photos can themselves be divided into two categories: low obliques, which do not show the horizon, and high obliques, which are so slanted from vertical that they include the horizon. Although these photos can be very helpful for evaluating a stream corridor it is not usually practical to make any actual measurements off of oblique photos.

Vertical aerial photos are usually taken with a special mapping camera which is mounted in the belly of an airplane. The actual film is about 10 inches wide and the lenses vary in focal length from 6 to 12 inches. A gyroscopically stabilized mounting keeps the camera vertical as the plane flies along and a special forward motion compensation device may be used to reduce blurring caused by the motion of the plane during the time the shutter is opening and closing.

A series of aerial photos taken as the plane is flying along on a constant heading is called a flight line. Ideally the photos line up in an exactly straight line. In practice, the photos may be somewhat canted to the line of flight or else the line may drift sideways relative to the intended line of flight. Flight lines are most often oriented north-south, although small projects may use other orientations so as to cover a project area with the least amount of reversals of the plane. The photos in a flight line are usually taken so as to overlap by about 60 percent. Photos in adjacent flight lines typically overlap by 25 to 30 percent. The overlap along flight lines allows stereoscopic viewing of adjacent pairs of photos. This is the single most important technique to master in order to interpret aerial photos.

The Geometry of Aerial Photos

Although aerial photos are often thought of as being maps, this is not really correct. Simple maps can be thought of as what are known as orthographic projections. In an orthographic projection all features are located in their correct horizontal positions and are depicted as though they are being viewed from directly overhead. Angles and distances can be easily measured on such maps. Aerial photos, by contrast, are central projections. In a central projection all features are viewed from a single central point that is a finite distance above the scene. This results in the images of most objects being shifted from their proper map positions, a phenomenon known as radial displacement or image displacement. Most of this displacement is caused by the shifting of images radially towards or away from the center of the photo depending on whether the features are lower or higher than the elevation of the land at the center of the photo.

Other sources of distortion in aerial photos are camera tilt and distortion due to the camera lens itself, both of which are usually quite minor. Lens distortion is usually greatest at the edges of the photo, so its good practice to avoid working at the edges of the photos.

Scale of Aerial Photos

The scale can vary significantly over a single aerial photo. First, the hills are closer to the camera than the valleys and thus the hills are shown at a larger scale while the valleys appear at a smaller scale. Second, the distance from the camera to the edge of the scene is larger than the distance from the camera to the center of the scene. In hilly terrain scale variations within a single photo can sometimes exceed 5%.

The scale also varies from one photo to the next due to the changing height of the airplane above the ground surface.

The simplest way to determine the scale of an aerial photo is to measure the distance between two points on the photo and compare that to the distance between the corresponding points on a map of known scale. If the distance between two points on a photo of unknown scale is 2.1 inches and the corresponding distance on a 1:24,000 scale map is 1.6 inches, then solve the following ratio to find the scale of the photo:

Distance on photo/ Denominator of photo scale =
Distance on map / Denominator of map scale

$$1.6/x = 2.1/24{,}000$$
$$x = (1.6)(24{,}000)/2.1$$
$$x = 18{,}286$$

Photo scale = 1:18,286

Types of Film

The three types of film most commonly used for aerial photography are black-and-white, color infrared, and color films.

Black-and-white or panchromatic film is usually shot with a yellow filter for increased haze penetration. Black-and-white photos are excellent for general land use and land cover mapping and have moderately good depth penetration in water.

Color infrared film has been around since World War II but has only come into widespread use in the last 30 years. This is a false-color film that is always shot with a yellow filter. This film-filter combination is sensitive to the green, red, and near-infrared parts of the spectrum and is excellent for distinguishing different types of vegetation. Water and wet soils stand out in strong contrast to surrounding drier soils but color infrared film has poor depth penetration in water bodies (clear water tends to look black). It is not a heat-sensitive film (heat radiation is in the far-infrared portion of the spectrum).

A third type of film is normal color film. Colors correspond roughly to colors seen by the human eye, although haze often seems to wash out the colors a bit. Normal color film has better depth penetration in water than color infrared film but vegetation has a smaller range of colors on normal color film than on color infrared. Table 1 gives examples of the colors that a variety of objects have on both normal color and color infrared film.

Any of the films described above can be useful for a watershed study. However, if wetland mapping is to be done, color infrared film flown in the springtime is the film to have.

Stereoscopic Viewing

The key to extracting the maximum amount of information out of aerial photos is stereoscopic viewing. Stereo viewing more than doubles the amount of information available from a pair of photos. With this technique you can determine the heights of objects and the shape of the land surface.

Stereoscopic vision is achieved by having each eye view an object from slightly different angles. When the eyes are viewing an actual scene in the landscape, the eyes can only use stereoscopic vision out to around 1000 feet. Beyond that, all distance determinations are based on context. That is why distances in deserts and other large open areas are so hard to estimate. If our eyes were spaced farther apart, we would be able to view the landscape stereoscopically out to greater distances.

The stereoscope, in effect, gives you a very widely spaced pair of eyes. Although aerial photos are usually taken at altitudes of from 6,000 to 20,000 feet above the land surface, the spacing between successive photos in a flight line is usually several thousand feet. The stereoscope is a device that allows each eye to view one of a pair of aerial photos, each of which shows a scene from a different angle. Because the ground spacing between photos is so large, the brain is fooled into interpreting the stereo image as that of a nearby scene with very high relief. Thus, hills appear overly steepened and low features stand out above their surroundings. Depending on the scale of the photos, the focal length of the lens, and the ratio of the height of the plane above the land surface to the horizontal distance between photo centers, height differences as low as two to 10 feet may be readily visible.

To view aerial photos with a standard folding pocket stereoscope, line up a pair of adjacent photos from the same flight line, allowing them to overlap so that common features are directly on top of one another (for example, if a pond is shown on both photos, the images of the pond should be one right on top of the other. Next, spread the photos roughly 2.4 inches apart (the distance between the eyes of an average person), parallel to the flight line. Next, set the width of the lenses of a pocket stereoscope to this same distance. Place the stereoscope on top of the parts of the photo pair that overlapped. The long dimension of the stereoscope should be parallel to the flight line. When the scope and the photo pair are properly oriented, the landscape will stand out in exaggerated relief.

If you can get the view into stereo but the images swim around before settling in, or your eyes begin to hurt after a brief viewing, you do not have the photos aligned quite right. Keep adjusting the photos until they come immediately into stereo view when your eyes are placed on the scope. Sometimes you will find that the photos need to be canted a little in order to come into stereo properly. This is because the photos were crabbed when they were taken. For more details on how to line up photos see Soil Survey Staff (1966).

Once the photos are properly aligned, it may help to tape one or both of the photos down to keep them from moving out of alignment. To view parts of the photos with a pocket stereoscope you will need to gently bend (not crease) parts of the photos.

Photo Interpretation

Many people take a more or less casual look at an aerial photo and believe that they have seen all there is to see in it. An experienced interpreter of aerial photos knows that any given photo (or especially any given stereo pair of photos) contains an enormous amount of information regarding landscape history, vegetation, soils, streams, cultural features, etc. The key is to go beyond passively viewing the photos and to begin to actively interpret them.

The distinctive set of characteristics that describe a feature on an aerial photo is called its signature. Signatures are composed of the following elements (adapted from Avery and Berlin, 1992): tone or color, texture, shadow, pattern, association, shape, and size.

Tone refers to the various shades of gray seen on a black-and-white photo and color refers to the range of colors seen on a color photo. It is important to realize that tone or color by themselves will not uniquely identify any feature. For example, on spring-time color infrared photos a dry sand pit, a sandbar in a river, a dry field covered with stubble, and a wet meadow dominated by reed canary grass may all have the same color (white).

Texture is the roughness or smoothness of a feature. An old field growing up in shrubs and saplings has a very rough texture while pavement or a mowed lawn has a very smooth texture.

Shadows often obscure important features but it is useful to remember that the shadow can also reveal information about the object which is casting it. The dark shadow of a shrub on grassy vegetation may be easily visible while the shrub itself has little contrast with its surroundings and is difficult or impossible to discern. Note that on color infrared film shadows tend to be very black and they can completely obscure features, while on black-and-white film one can commonly see some detail in the shadows.

Pattern refers to the arrangement of objects, such as the grid pattern of trees in an orchard, contour plowing on a hillside, or a trellis drainage pattern in a river system.

Association refers to the general association between features, such as the association of toppling trees with an eroding river bank. Trees topple over for many reasons at many different spots on the landscape but if one observes several trees toppling over into the river at a site it is quite likely that the cause is an eroding bank.

Shape is often a very obvious clue to the identity of a feature. The shape of an abandoned oxbow in a floodplain is quite distinctive. Also, on a large-scale photo the shape of an elm tree is very different from that of a sugar maple.

Size is another obvious signature element. Relative size can be estimated by comparison with known objects such as roads, houses, cars, etc. If the scale of the photo is known accurately then actual measurements can be made.

Some of the features that can be spotted on aerial photos when they are viewed in stereo:

a. Shadows of deciduous trees on river
b. Road
c. Riffles, runs, and pools
d. Old channel, now partly abandoned
e. Tree leaning over river
f. Former channels
g. Rip-rap on bank
h. Bedrock
i. Farmstead
j. Culvert under road
k. Conifer woodland
l. Pasture
m. Hayfield
n. Unvegetated bars
o. Vegetated bar
p. Eroding bank with no buffer
q. Large log on bar
r. Tree which has slumped into river
s. Boulder in river

Many further examples of the features which can be discerned on aerial photos are shown in Avery and Berlin (1992) and Soil Survey Staff (1966).

Height Measurement

Using a stereoscope it is possible to roughly measure the height of features such as stream banks or trees, either by comparison with objects of known height (such as houses, cars, or telephone poles), or else by analytical methods involving parallax calculations. For information on making parallax calculations see Avery and Berlin (1992). Using a stereoscope you should easily be able to distinguish differences in height between grasses, shrubs, and trees.

The Need for Field Work

In order to get the maximum amount of information out of a set of aerial photos, a certain amount of field work is necessary. For a large project, a recent set of photos should be obtained early on and reviewed prior to field work. The photos can provide a good overview of land use and land cover in the corridor and may reveal possible locations of alluvial fans, former channels, flood chutes, eroding banks, etc. After going out in the field, again review the photos. This is a good time to review older sets of photos to look for changes in stream planform, etc. This second round of aerial photo study can also help you see the full extent of features seen in the field. For example, a low terrace that you overlooked in the initial photo review may now be easily visible since you encountered it in several spots.

If your organization owns the aerial photos, you may choose to take them out in the field, although it is probably better to make copies and leave the originals in the office (good copies can actually be viewed in stereo, although there is certainly some loss of fine detail). As it can be difficult to keep photos clean and dry, do not take borrowed photos into the field.

Common Flaws Seen on Photos

On some prints of aerial photos the edges are quite dark. Because wide-angle lenses are used for this work, there is significantly less light falling on the edges as compared to the central region of the photos. Therefore, if a simple contact print is made, the edges come out dark and it is difficult or impossible to see details. If you are considering using photos which are dark on the edges, it may be possible to use modern printing techniques to reprint them and eliminate the dark edges.

A large fuzzy white spot on an aerial photo is referred to as a hot spot. This is caused by sunlight being reflected directly back at the camera, causing an overexposed spot. Aerial photographers usually plan their photography to avoid times of day when hot spots are likely to occur. Again, modern printing techniques can at least partly reduce these spots.

No two sets of color infrared photos of the same area ever seem to show the same exact color range. This is partly due to the sensitivity of such film to variations in vegetation and partly due to the fact that the color balance in these photos is sensitive to the temperature and freshness of the developing chemicals. Two prints from the same original made by the same lab on two different days usually have visibly different color balance. If you are unsatisfied with the quality of a photo order, have the processor try again.

Finding Vermont Aerial Photos

Hundreds of aerial photo flights have been made over Vermont since at least as far back as the late 1930s. Some were contracted by the federal government, some by the state, and others by private companies or individuals. The available photo sets range from statewide coverages to sets of a dozen or less photos flown for an engineering project. As an example, at least 18 separate sets of photos of various scales have been flown over all or part of the Town of Plainfield, Vermont.

Since the late 1930s at least eight complete statewide sets of aerial photos have been taken over Vermont (Table D-1)

Table D-1 Statewide aerial photo coverages.

Date	Original Contracting Agency	Current Source	Scale	Emulsion
1939-1942	USGS and USDA	EROS Data Center, APFO	1:48,000	Black-and-white
1962-1964	State of Vermont	Aero Graphics	1:18,000	A
1974-1976	State of Vermont	Aero Graphics	1:20,000	A
1974-1985	Vermont Mapping Program	Vermont Mapping Program	1:30,000	A (first round of orthophoto production)
1978-1980	US Army Corps of Engineers	EROS Data Center, APFO	1:80,000	Black-and-white or color infrared
1985-1987	USGS NHAP	EROS Data Center, APFO	1:58,000	Color infrared
1988-present	Vermont Mapping Program	Vermont Mapping Program	1:30,000	Black-and-white (second round of orthophoto production)
1992-1994	USGS NAPP	EROS Data Center, APFO	1:40,000	Color infrared

EROS = U.S.G.S. EROS Data Center, Mundt Federal Building, Sioux Falls, SD 57198, phone (800) 252-4547, web site <http://edcwww.cr.usgs.gov/eros-home.html>.

APFO = USDA Aerial Photography Field Office, P.O. Box 30010, South Salt Lake City, UT 84130-0010, phone (801) 524-5856, web site <http://www.apfo.usda.gov>.

Aero Graphics Corporation, Box 248, Bohemia, NY 11716, phone (516) 589-6045.

NHAP = National High Altitude Program

NAPP = National Aerial Photography Program

The 1962-64 statewide photos are probably the most widely used set of photos in the state. The photos are of fairly large scale (1:18,000) and most of the frames have very good contrast. Because more of the land was in agricultural use than at the present time, the land was more open and therefore these photos are excellent for studying landforms. They are still being used today by soil mappers and geologists. As part of the project, large-scale photos (1:6,000 scale) were taken of many of the town and village centers.

There are many aerial photo collections in Vermont. The Bailey Howe Library at the University of Vermont maintains a large collection. Several offices in the Vermont Agency of Natural Resources maintain collections. The local NRCS offices usually have particularly good aerial photo collections.

Although these organizations do not loan out photos, they are usually available for public viewing (be sure to call ahead first).

Ordering Aerial Photos

To order photos from the federal government, contact either the USGS EROS Data Center or the USDA Aerial Photography Field Office. The EROS Data Center (phone 800-252-4547, web site <http://edcwww.cr.usgs.gov/eros-home.html>) maintains an aerial photography collection going back to the 1930s. A search of their archives for Plainfield, Vermont turned up 10 sets of photos from 1939 to 1993. The USDA Aerial Photography Field Office (phone 801-975-3503, web site <http://www.apfo.usda.gov>) maintains an archive of aerial photography going back to the 1950s. A catalog of their recent Vermont holdings is in Appendix 2.

Aerial photos can be obtained as either prints or transparencies. Prints are more convenient to use but if maximum resolution is needed, transparencies are best. Prints can be made on heavy or light paper, with the heavy paper being much less subject to curling.

The standard size for aerial photos is the 9 x 9 inch direct contact prints. Although because of the large negative size, high-resolution enlargements up to 36 x 36 inches can also be obtained, the cost is considerably more than for contact prints.

When ordering photography try to make sure that prints are made with a printer that can electronically dodge the prints. This can reduce hot spots and eliminate light fall-off on the edges. Because the EROS Data Center uses these higher quality printers while the Aerial Photography Field Office (APFO) does not, photos should be ordered from EROS Data Center rather than APFO whenever possible.

Storing Aerial Photos

All photos should be kept in clear mylar sleeves. This protects them from fingerprints. The oil from fingerprints makes dust stick on them and the dust then scratches the emulsion, reducing the resolution of the photos. For long term storage, the sleeved photos should be in acid-free folders and should be kept out of direct sunlight. If properly processed and stored, black and white photos should last for many decades without significant fading. Color photos of all sorts will undoubtedly fade over time.

Orthophotos

Aerial photos can reveal an incredible amount of detail about the landscape. However, it is difficult to make accurate measurements on them because the scale continuously changes from the center to the edge of the photo and as the elevation of the ground changes. A special type of aerial photo product known as an ortho-photograph remedies this problem. An ortho-photograph shows much of the detail of an aerial photo but, like a map, it has a constant scale. This enables the user to make reasonably accurate measurements of angles and distances.

Orthophotos are available for all of Vermont at 1:5,000 scale and more detailed 1:1,250 scale orthophotos are available for selected urban areas. The ortho-photography program began in 1974 and most areas have been covered twice since then. Since 1994 the orthophotos have been produced using digital methods and are available in digital format as well as the traditional printed map format. Digital orthophotos are currently available for most of the state. To obtain orthophotos, contact the Vermont Mapping Program at 43 1/2 Randall St., Waterbury, VT 05676, phone (802) 241-3507.

There are limits to what can be seen on orthophotos. They are very useful for determining land use, land cover, and the locations of prominent features and it is easy to measure sizes, distances, and angles. However, many features that can be easily discerned by viewing a pair of aerial photos in stereo are simply not visible on an orthophoto. Also, even though the newer digital orthophotos have very good resolution, they still do not have as fine a resolution as the original photos that the orthophotos were made from. Thus, an orthophoto can show you the location of a stream bank but you will not be able to tell the height of the bank and you probably will not be able to see logs stranded on a sandbar.

Historical Analysis With Aerial Photos and Orthophotos

Aerial photos and orthophotos are powerful sources of historical information for documenting how landscapes have changed over time. They are especially well suited for studies of change in stream channel planform because the stream banks are usually reasonably clear, even on single aerial photos or orthophotos.

Assuming that the features of interest are easily visible on the images, the primary difficulty is to get all of the different images at the same scale so that comparisons can be made. If all of the sources of data were orthophotos, then it would be a fairly simple matter to enlarge or reduce them all to a common scale. Because we do not have orthophoto coverage prior to the 1970s, and because of the distortions inherent in all aerial photos, it is usually not quite that easy. For a small area it is most practical to enlarge or reduce small areas of the photo, one at a time, registering them into position by using landmarks which show up on both the photo and the base map. This can be done either by using an optical instrument such as a Zoom Transfer Scope or vertical sketchmaster or by making overlays of the aerial photos and enlarging the overlays using a copy machine so they match the scale of the base map and then shifting them around on top of the base map on a light table until the landmarks on the overlay match up with their positions on the base map. This is a slow and tedious method but it can yield reasonably accurate results. For large areas, it may be more efficient to use GIS software to produce a digital orthophoto of each date of photography. Possible software for such work includes ERDAS Orthbase and an ArcView extension called Orthrec. Either of these programs would require a digital elevation model of the terrain and scanned images of the aerial photos.

Summary

- The stereoscope is a very powerful tool for photo interpretation.
- Interpret objects by looking at all the signature elements, not just tone or color.
- Field work and photo interpretation go hand-in-hand.
- Statewide aerial photo coverages date back to the late 1930s and early 1940s.

References

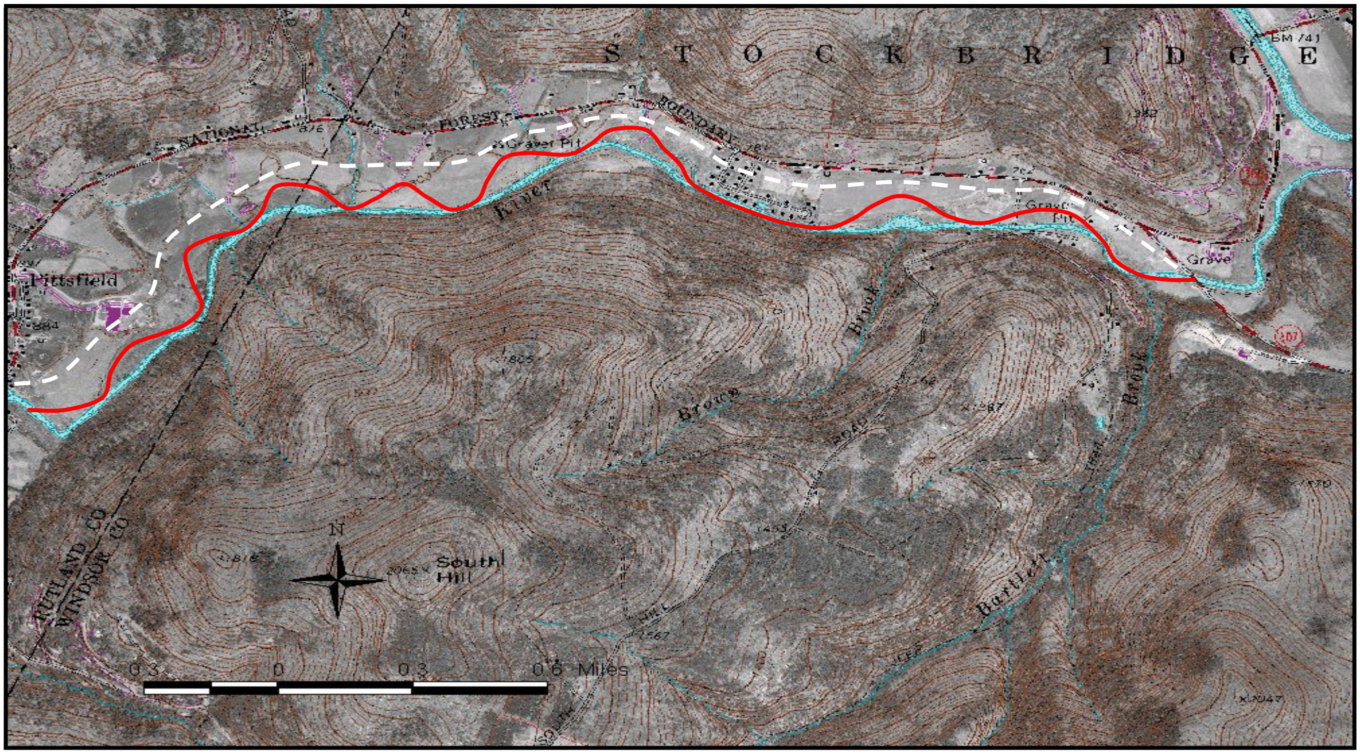
1. Avery, T.E., and G.L. Berlin. 1992. Fundamentals of remote sensing and air photo interpretation: Macmillan Publishing Company, New York, 472p.

2. Philipson, W.R., *editor*. 1997. Manual of photographic interpretation: American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 689p.

3. Soil Survey Staff. 1966. Aerial-photo interpretation: Agriculture Handbook 294, U.S. Department of Agriculture, Soil Conservation Service, 89p.

Vermont Stream Geomorphic Assessment

Appendix E



River Corridor Delineation Process

Vermont Agency of Natural Resources
April, 2007

River Corridor Delineation Process

Purpose

A stream and river corridor delineation process has been developed as part of the Phase 1 Stream Geomorphic Assessment (SGA) protocol to create a map overlay area and assess:

- Surficial geologic materials and soils (Steps 3.3 and 3.5)
- Land cover / land use (Step 4.2)
- Berms, roads, and developments (Steps 6.1 and 6.2)

The corridor will also be used in the Phase 2 SGA protocols to evaluate parameters in the field.

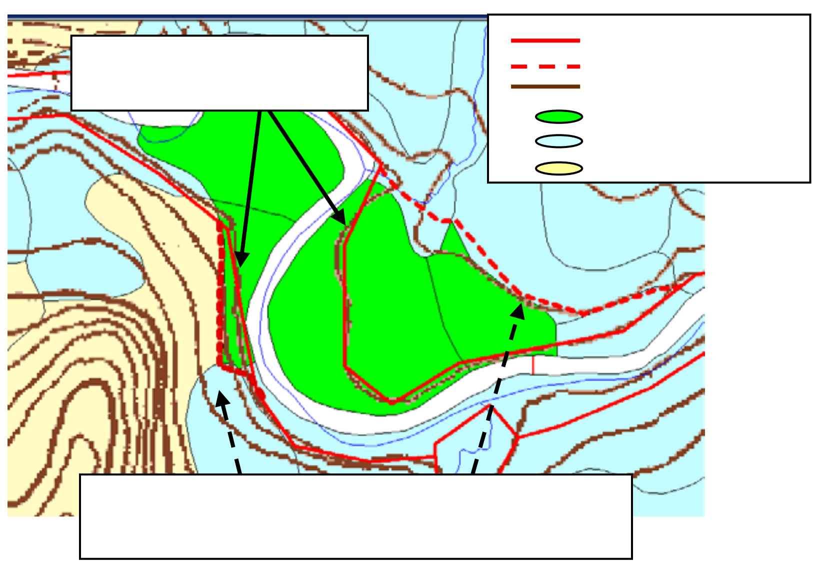
- River corridor encroachments (Step 1.3)
- River corridor land use (Step 3.3)

The delineation process recognizes that in some cases, the geologic and land use factors influencing runoff and erosion may extend beyond the toe of the side slope in a narrow valley. The process also recognizes that in wider valleys, human structures on the valley floor do not always alter floodplain characteristics. The process defines a width of land on either side of the river, together called the river corridor, that will capture:

- Factors influencing runoff and erosion;
- Factors influencing floodplain function; and
- A minimum width of land within the overall valley width that may be occupied by the active stream channel, as slope and dimension remain in balance with the watershed inputs.

SGAT and the Corridor Delineation Process

The SGAT extension designed for use with GIS is a significant time-saving tool in delineating the river corridor. For those stream reaches where you have used GIS to draw valley toe and meander centerlines, SGAT can be used to carry out the four-step process described below in a matter of minutes. For stream reaches where no valley toes and meander center lines were drawn, a default corridor of either 2.5 times the channel width (for a total of 5 channel widths) either side of the centerline or 100 ft (for a total of 200 feet) either side of the centerline, which ever is greatest, will be drawn by SGAT. Note, that this width is determined off the stream centerline; the 2.5 times the channel width is an attempt to recognize a portion of the channel width inherent in buffering off the stream centerline. If you are drawing the corridor from the top of the stream bank; than the calculation will be 2 times the channel width (for a total of 4 channel widths) either side of the stream bank or 100 ft (for a total of 200 ft), which ever is greatest.



A method for defining meander centerlines is described in Step 2 of the river corridor delineation process. A method for defining the toes of valley walls is described below. Draw the valley toes as a polygon theme and the meander centerlines as a line theme. See SGAT User Manual (Steps 7 and 9) for details on theme requirements and uses within the SGAT program.

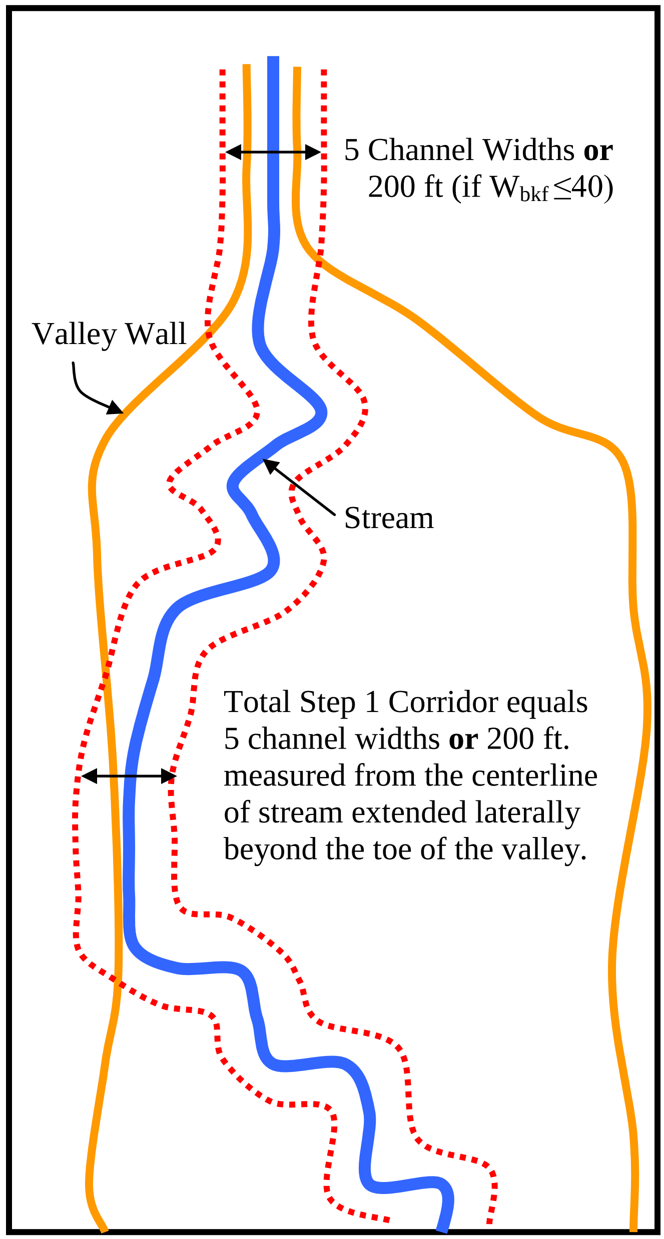
Defining the Toe of the Valley:

Using soils maps and data in conjunction with topographic maps determine the location of the toe of the right and left valley walls. Generally, the toe of a valley wall can be identified by looking for the break in slope as the steeper valley wall turns into the gentle sloped valley floor. Soils data help with identifying changes in slope and include other soil characteristics that may indicate the need to adjust a valley wall line one way or the other. Starting at the mouth of the main stem and tributaries, draw right and left valley wall toes as continuous lines to an upstream point where distinguishing between the valley toes and the stream line becomes difficult (in confined valleys). Additional valley wall delineation tips and rules of thumb are offered at the end of this Appendix.

Four Step Corridor Delineation Process

For the purpose of a Phase 1 and Phase 2 Assessment, river corridors are defined using the following 4 step process:

Step 1.



This delineation process requires the use of the most recent orthophoto and topographic map of the reach. The orthophoto is used to draw the corridor and the topo map is used as a guide to determine the proximity of the channel and the toe of the valley walls. The ideal mapping base to work on is an orthophoto with topographic lines overlain using a computer mapping tool such as GIS.

Shown as the dotted red lines in the example to the right, the Step 1 corridor lines are drawn parallel to the stream at a distance from the centerline of the stream of:

2.5 x channel widths, where the bankfull width is > 40 feet (for a total Step 1 Corridor of 5 channel widths);

or

100 feet, where the bankfull width is ≤ 40 feet (for a total Step 1 Corridor of 200 feet)

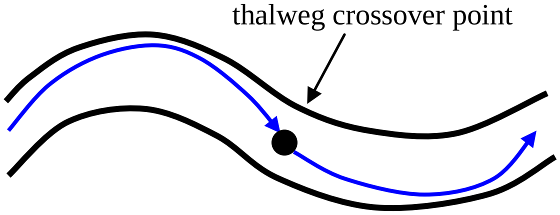
The stream can be used as a centerline where it appears, as with small streams, to be a single line. Where the valley is narrow it is important to draw the corridor lines so that they extend laterally beyond the toe of the valley walls.

Rationale: This step identifies those land areas beyond the toe of the valley wall that, may or may not be important to the stream for planform and slope adjustment, but involve land uses that significantly change runoff patterns and sediment discharges to streams in confined valleys .

Step 2.

Shown as the dashed brown lines in the example below, the Step 2 corridor lines are drawn parallel to a line that is drawn down-valley through meander crossover points. For the purposes of this delineation process this line is called the meander centerline.

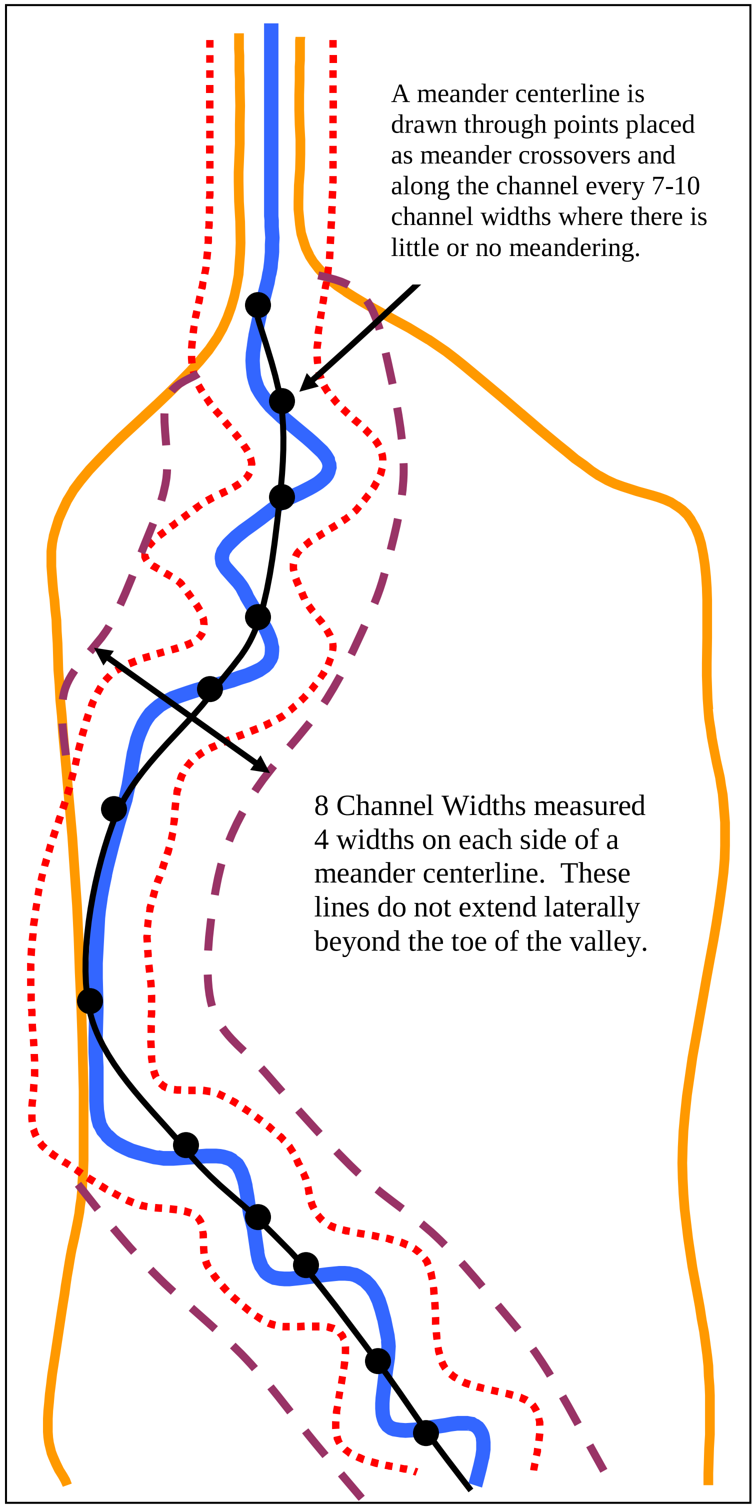
Complete Step 2 of the corridor delineation process for streams and rivers flowing in valleys measured to be at least 4 channel widths wide (valley types NW, BD, and VB). To draw the meander centerline, first place crossover points on the channel. These points are generally located in the center of the channel where the deepest thread of water (or thalweg) "crosses over" from the outside bank of one meander to the opposite bank on the next meander downstream.



Where there are no discernible meanders (in a straight or straightened reaches of channel), continue to add points along the centerline of the stream at a 7-10 channel widths interval. Draw corridor lines 4 channel widths either side of and parallel to a meander centerline drawn through the crossover points. The total corridor in an unconfined valley is 8 channel widths.

Since this stream corridor delineates lands that may influence runoff patterns and sediment discharges, as well as planform and slope adjustments in unconfined, depositional streams, the corridor lines should not extend laterally beyond the toe of the valley. As shown in the example to the right, discontinue the corridor line where the stream is close to the valley wall.

Rationale: In addition to lands affecting runoff, the Step 2 corridor includes the belt width (4-8 channel widths, depending on the stream type). The belt width is an area critical to unconfined streams as they adjust their slope consistent with their sediment regime.

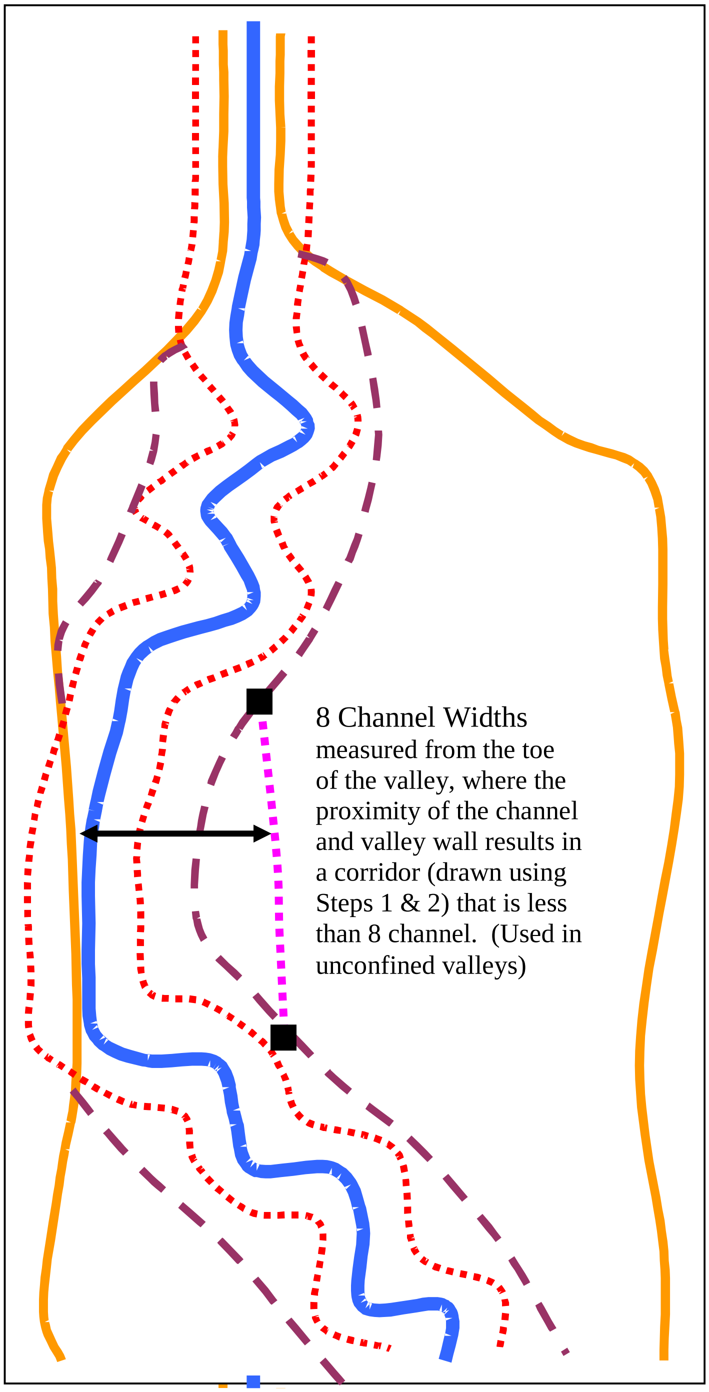


Step 3.

Shown as the dotted purple lines in the example below, a Step 3 corridor line is drawn parallel to the valley wall at a distance of 8 channel widths from the toe of the valley. Complete Step 3 of the corridor delineation process for streams and rivers flowing in valleys greater than 4 channel widths wide (Step 2-10: valley types 2 and 3).

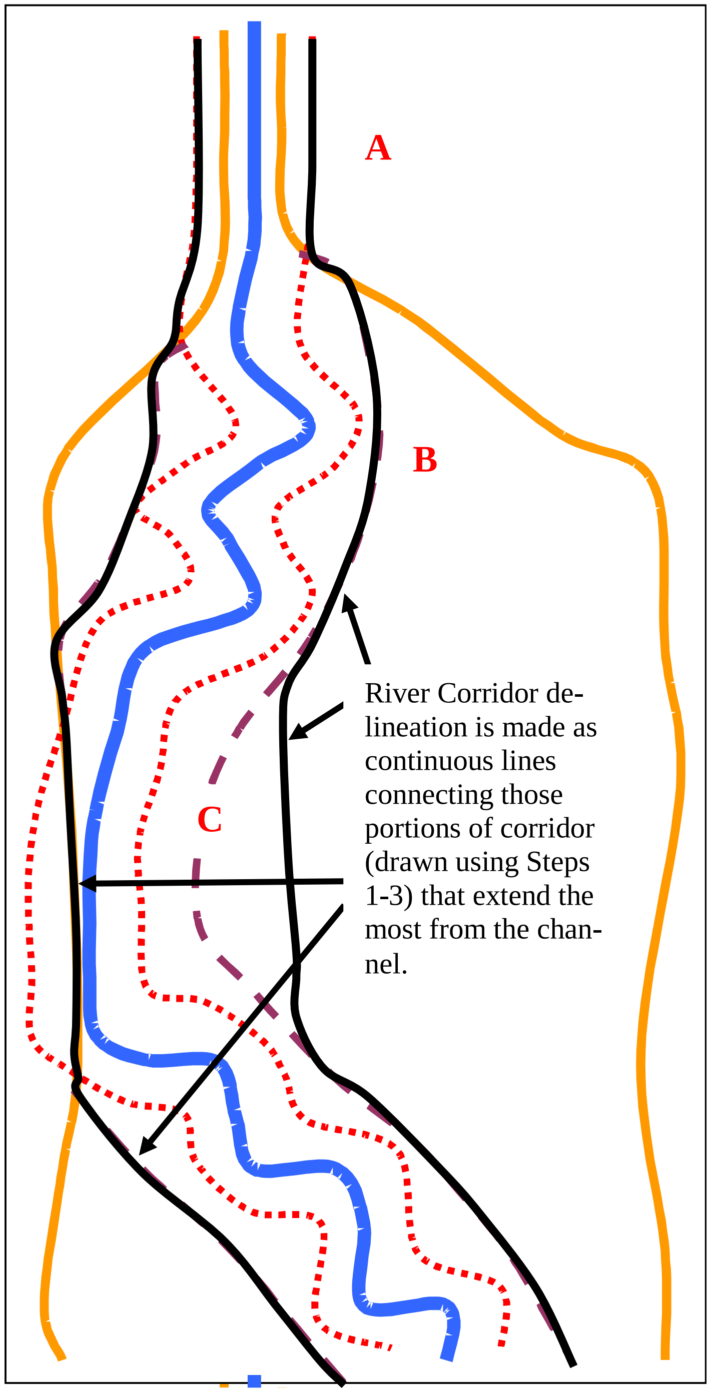
The Step 3 delineation process is necessary only in those situations where the stream or river reach is in a broad unconfined valley and flowing within a distance of 4 channel widths from the valley wall. In reaches where the stream comes close to the valley wall, draw a line parallel to the toe of the valley at a distance of 8 channel widths. This line need not extend longitudinally (upstream or downstream) beyond lines drawn during Step 2 of this process.

Rationale: In lieu of any geologic information that may explain the straighter course of a stream, this Step assumes that a straight reach in a wide, shallow-sloped valley may attempt to adjust its planform and slope. The channel will become more sinuous to regain equilibrium with the large supply of fine grained sediments typically found in unconfined valley segments. The Step 3 delineation process attempts to include those land areas into the corridor that may be important to this adjustment process.



Step 4.

If more than one of the Steps 1 through 3 were required for a given reach, then you will want to complete Step 4 of this river corridor delineation process. The Step 4 corridor lines encompass all corridor lines drawn in Steps 1 through 3 to form a single stream or river corridor delineation.



Shown as the solid black lines in the example to the right, the Step 4 corridor lines follow those segments of the Step 1-3 lines that extend laterally away from the channel.

The only corridor lines to be included outside the toe of the valley walls are Step 1 corridor lines; for streams in confined valleys where a valley wall and meander centerline could not be drawn.

In the example to the right, the corridor for the stream reach in the valley segment labeled **A,** the stream corridor follows the Step 1 corridor lines. This follows because Step 2 and 3 lines are drawn for streams flowing in broader valleys at least 4 channel widths wide.

Step 1 and 2 corridor lines were both drawn for the stream in valley segment **B**. The Step 2 lines were followed for the final corridor delineation (solid black line) because they extend further laterally than the Step 1 lines. Had there been an atypical meander with a larger amplitude (not shown) the Step 1 lines may have extended beyond the Step 2 lines around the meander.

Step 1, 2, and 3 corridor lines were drawn for the stream in valley segment **C**. The Step 1 corridor line (on the right side) and Step 3 corridor line (on the left side) were followed from the final corridor delineation because they extend further laterally than any other line drawn in this valley segment.

NOTE: The stream and river corridors delineated for the Phase 1 and Phase 2 Stream Geomorphic Assessment are determined for the purposes of evaluating the possible impacts of various factors influencing runoff (i.e., land use/cover) and floodplain modifications. They are not intended to empirically show floodplains, flood prone areas, or flood hazard areas. These delineations are determined through Phase 2 **and** Phase 3 field assessments.

Valley wall delineation tips and rules of thumb

Background and Need:
Polygon shape files showing the location of the toes of valley walls are one of the user-created inputs to the Stream Geomorphic Assessment Tool (SGAT) and are used in Step 7 of SGAT to determine valley length and average valley width (used to calculate sinuosity and confinement).

For Phase 1 uses, relatively crude valley walls are generally sufficient. In Phase 1 you are looking at the natural valley setting, and not including any man made changes to the width of the valley. During the Phase 2 geomorphic assessment a more accurate delineation of the natural valley walls can be determined; the field assessment will also allow for any potential human made changes to the valley width to be noted and used for modifications to the valley walls for FEH corridor delineation.

During the development of Fluvial Erosion Hazard (FEH) corridors in SGAT (Part E, Step FEH03), the corridor is clipped to the valley wall, as erosion hazards do not extend outside the valley floor (see Appendix H for a more detailed look at corridor development). As a result, the valley wall locations often define the limits of the FEH corridor, making an accurate valley wall shape file essential to the process. This is especially true in many of Vermont's narrower valleys, where the valley walls often define one or even *both* sides of the FEH corridor. Review the additional criteria for valley wall consideration, under "Phase 2 and FEH valley wall guidance" below.

While identifying valley walls is generally a simple task, it can be complicated by the presence of features both manmade (road and railroad beds, development), and natural (terraces, abandoned floodplains, etc) which may act as confining features . The purpose of this guidance document is to clarify both the purpose and application of the valley wall shape file in the VTANR Stream Geomorphic Assessment and related applications, and to provide guidelines that will help assessors develop the best possible valley wall shape files.

The valley walls are used, in part, to help define the lateral constraints on the river. In delineating the valley walls it is important to try to establish reasonable estimates of valley toe locations. In certain valleys it will be necessary for the user to make a reasonable best guess; erring on the side of conservative to define wider valleys where remote sensing data presents uncertainties. The user may not delineate valley walls in steeper, more confined valleys where it is harder to distinguish the toes of the valley from the stream itself.

The 20 foot contour lines on topographic maps may not be detailed enough to give a clear indication of where the toe of the valley wall may be. To assist in determining the outer limits or toes of the valley wall, it may be valuable to use the NRCS soils in conjunction with the topographic map. The soils can be linked in ArcView to the NRCS Top20 table; then displayed on parent material. One of the key parent materials to look for is alluvium. Using the surficial geology maps to locate bedrock outcrops will also provide insight into where the geology is restricting the river from moving laterally across a valley.

Once delineated as a shape file in ArcView, print out the valley walls on a topographic map and/or orthophoto, and conduct a field review of valley walls. First, field check those areas where you had questions, then if time and funds permit review the valley walls in other reaches. During your time in the field, verify the location of the valley wall whenever possible. If the valley wall location differs from your original delineation, make note of the true location on your map and change it when you return to the office. Some people like to take a laptop into the field to cut out this intermediate step. Another approach is to capture toe of valley wall locations with a GPS unit. If using this approach, be aware of the accuracy of the GPS unit being used. Given the margin of error for many handheld GPS units in many situations, it is often possible to more accurately identify locations manually using orthophotos.

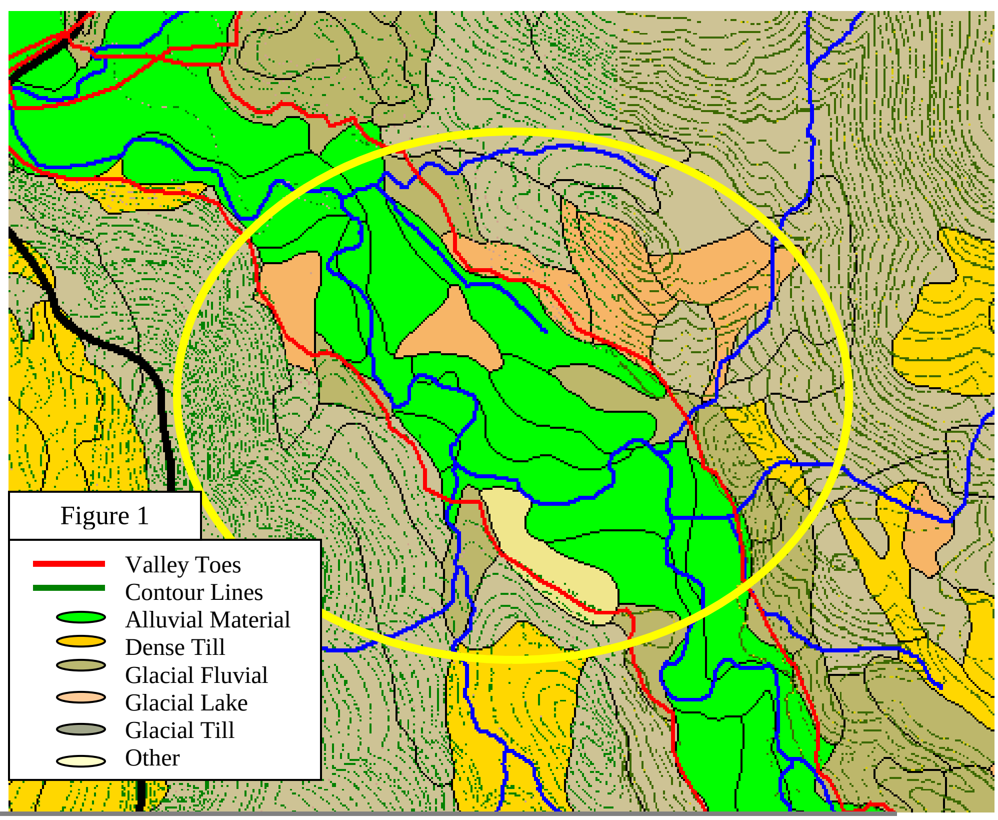
On those reaches where it is not possible to field check the location of valley walls, you may consider completing a stereoscopic analysis of air photos, which allows the user to view the landscape in 3D. It is possible to see rises as low as 5 to 10 feet. This process may only be necessary where there are concerns or issues that dictate the need for more accurate valley walls and a field visit is not possible.

** In locations where LIDAR (Light Detection and Imaging) has been flown (much of Chittenden County, see the Vermont Mapping Program's website for the latest: http://www.state.vt.us/tax/mapping.shtml) and an accurate digital elevation model has been produced, it may be possible to develop a very accurate valley wall based solely on remotely sensed data.*

Guidelines

1) If SGAT is to be used; review Step 7 "*Requirements for Digitizing Valley Walls*" for additional information on the data requirements for valley walls used in SGAT. (There are a few examples below that address SGAT issues.)
2) Include all alluvial material, except unreasonable rises, as indicated by topography
3) Use the outer limits of the valley as indicated by the contour lines (where topographic map indicates a wide valley), even if the alluvial material does not fill the valley. Overlaying the topographic contours on the soils map can be a good way of reviewing both topographic features and soils at the same time.
4) Delineate the toe of the valley wall at changes in elevation greater than 20 feet (indicated by 2 or more contour lines within a short distance of each other), as this is a good indicator that the river is not likely to utilize the taller, steeper feature.
5) Include alluvial fans that are within the mainstem valley

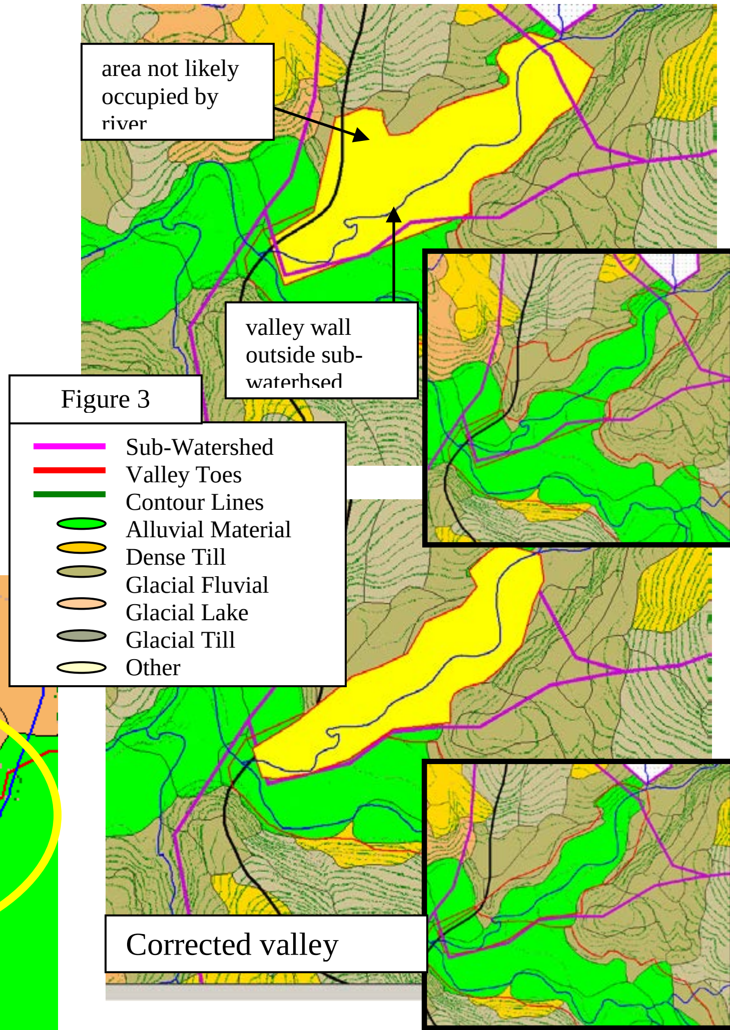
An often asked questions is whether to include or not include pockets of other (non-alluvium) material within the valley wall? In Figure 1, the material was included, due to the location of the contour lines indicating the valley walls may be further back then what the alluvial material indicates. This is appropriate until field verification can be done.

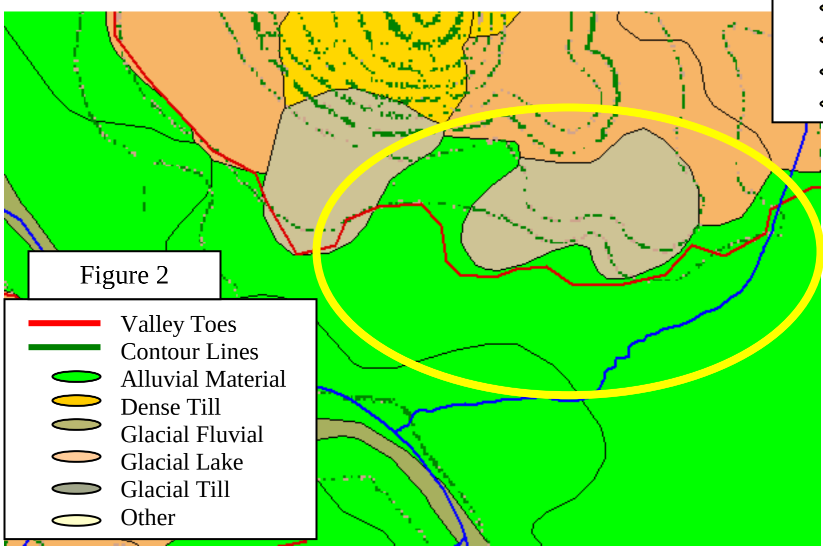


The valley wall in Figure 2 was not extended up to the outer extent of the alluvial depicted on the soils map. Alluvial material in the surrounding area did not extend up the contours in the same way as this lobe of alluvium. To keep the valley wall more consistent, and to not create an odd "point" in the valley, the valley wall bisected the lobe. A compromise was also made in the valley wall, where the contour lines indicated a change in elevation of greater than 20 feet. The valley wall was drawn to include as much of the alluvial material as possible without extending up the slope significantly.

In Figure 3, the small tributary had a separate polygon drawn for the valley walls (highlighted in yellow for ease of viewing). In the downstream portion the valley walls are outside of the sub-watershed for that reach. This can cause an error in the calculation of the valley width, because the program will not recognize the valley wall outside of the sub-watershed.

The walls also appear to occupy an area that is not likely accessed by the river; due to elevation change indicated by contours. Until field verified, the valley wall was moved into a lower elevation.





Be careful with valley walls outside of the sub-watershed boundaries. In SGAT, if the valley line is outside of the sub-watershed it will not be counted for the reach. In some cases it is not possible to contain both valley walls within the sub-watershed for the reach; and in those cases the user will have to manually measure the valley data for that reach (see Figure 4).

Figure 4 is an example where the user would not be able to include both sides of the valley (highlighted in yellow for ease of viewing) for one of the mainstem reaches. A tributary enters the valley and divides the valley into "two" sub-watersheds. The user will get an error in SGAT – Step 7 that the valley information can not be calculated for this reach. The user will be able to have SGAT skip this reach and continue with calculating data for the remaining reaches. Be sure to note the reach number indicated in the error message, then come back and manually measure the valley information.

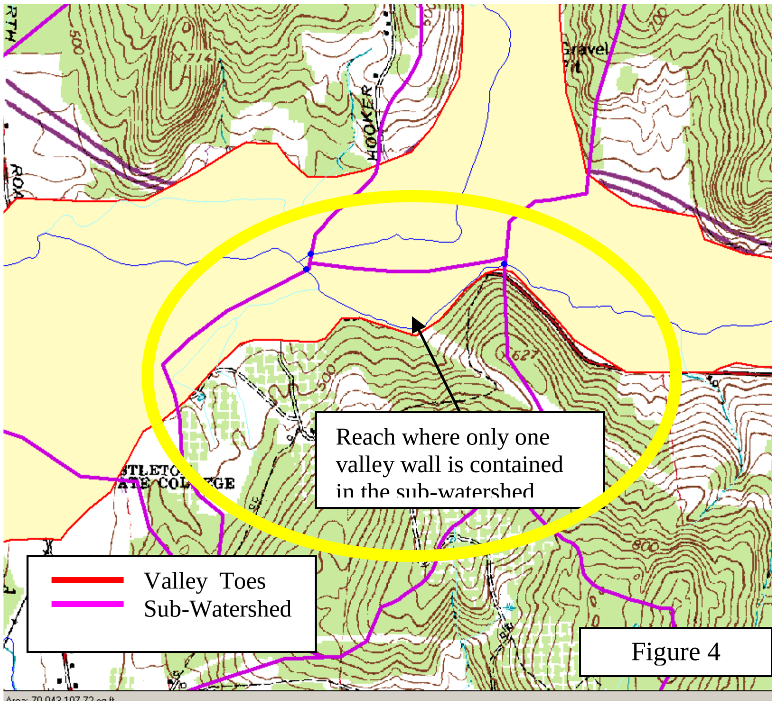


Figure 4

PHASE 2 AND FEH VALLEY WALL GUIDANCE

Phase 2 and FEH

For the purposes of Phase 2 assessments and Fluvial Erosion Hazard mapping, the goal is to adjust the valley wall shape file to reflect the presence of natural and man made features which act as barriers to lateral migration of a river.

Identifying Valley Walls in the Field

Identifying the location of the toe of the valley walls is usually straightforward. In most cases, the toe of the valley wall is located at the break in slope between the steeper valley walls and the flatter valley floor. However, there are situations that are much less straightforward, several of which are discussed in more detail below.

Terraces

As a result of heavily glaciated nature of the landscape, many types of glacial, glaciofluvial, and glaciolacustrine terraces can be found in the river valleys of Vermont, as well as more recent terraces of fluvial origin.

For the purposes of fluvial erosion hazard mapping we are concerned with whether or not a terrace is a confining feature for a stream. In other words, does (or will) the terrace act as a barrier to lateral migration of the stream channel? In general, most high (greater than 20 ft. high) glacial terraces do act as confining features, and should be mapped as the valley wall. Dense tills, and fine grained glaciolacustrine deposits are generally quite resistant to fluvial erosion, and terraces made up of these materials do act as confining features. On the other end of the spectrum, large terraces made up of unconsolidated alluvium are often very erodible and do not act as confining features. Time scale is an important factor in the decision as to whether a landform confines a stream. In geologic time scales, nothing is truly "confining" to a river. However, all of the management applications of geomorphic assessments are concerned with human time scales (several decades to hundreds of years), and this should be the time scale of concern when mapping valley walls.

It is essential that smaller alluvial terraces that are actually abandoned floodplains are not mapped as valley walls. While these features can be fairly large in deeply incised streams (like the West Branch Little River, where the old floodplain is now nearly 20' above the present day channel bed in places), such features can be easily eroded, and do not confine the lateral migration of a river.

Manmade Features

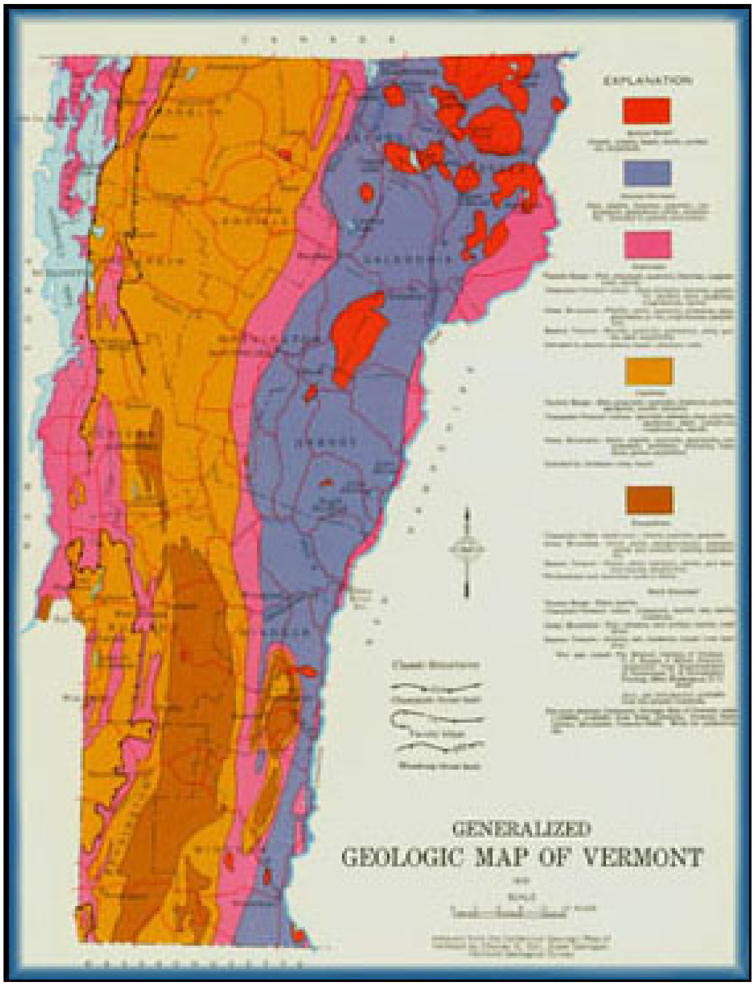
Significant human-constructed features can also act as a confining feature to lateral stream migration and should be mapped as valley walls. Major railroads and highways often act as valley walls, as can rows of structures built on fill, especially along our smaller streams. In general, smaller roads and other manmade features should not be mapped as valley walls, as they often fail due to fluvial erosion during large flow events and are not truly confining features. While communities may choose to replace Berms, levees, and floodwalls should not be mapped as valley walls. Past experience shows us that such structures are prone to failure, often with catastrophic results.

"When in doubt, leave it out"

If in doubt as to whether a manmade feature should be mapped as a valley wall, err on the side of caution and use the actual topographic or "natural" valley wall. There are many opportunities for fine-tuning river corridors (in the FEH mapping and river corridor planning processes) to account for human investments.

Vermont Stream Geomorphic Assessment

Appendix F



Geologic Information

Vermont Agency of Natural Resources
April, 2004

Geologic Information

Common Geologic Materials Found in Vermont

Alluvium (river sediments):
Alluvium is sediment deposited by a stream. It may consist of boulders, cobbles, gravel, sand, or silt. Alluvial deposits may be modern or ancient, although all of the alluvial deposits in Vermont post-date the last glaciation. These are the materials that are called postglacial fluvial deposits on the *Surficial Geologic Map of Vermont* (Doll, 1970). Modern deposits are found in active stream channels and in floodplains, and they may also occupy low terraces which are occasionally flooded during high flows. If a stream has been incising down into a valley, old alluvial deposits may be evident in the recently abandoned floodplain, out of reach of current flood levels. Alluvium deposited in floodplains is typically fine sand or silt. On steep streams the cobble and boulder alluvial deposits are typically imbricated, that is they are stacked like dominoes leaning upstream.

Figure F-1: Imbricated alluvium

Ice-contact Deposits:
Ice-contact deposits are composed of sediments which accumulated in lakes, ponds, or streams in contact with glacial ice. Ice-contact deposits are associated with the landforms known as kames, kame terraces, and eskers. In contrast to glacial till, ice-contact deposits show evidence of sorting and layering due to the action of flowing water. The grain size of the material can range from silt and clay up to cobbles and boulders, although most of the material is usually of sand-size or coarser. When we look at these deposits today, the layers of sediment are commonly folded or faulted because they were deposited on or next to blocks of stagnant glacial ice, which subsequently melted away, causing the sediment deposits to collapse.

A kame is a small, isolated hill of stratified sand or gravel. Kames form as streams deposits sand and gravel in depressions on the ice surface. When the ice melts away, the collapsed remnant of the deposit is left standing alone as a small, lumpy hill.

A kame terrace is similar to a kame in that it is a stratified deposit composed mostly of sand and gravel. However, the kame terrace is typically a long terrace on the edge of a valley, formed between the stagnant remnant of a glacier in the valley and the valley side. Streams wash material off of the glacier and the hills into an ice-marginal lake. In some deposits, considerable amounts of silt or clay may be included. When the ice melts away, a terrace consisting of collapsed, stratified material is left behind.

An esker is a long, narrow, often winding ridge composed of water-lain deposits of sand, gravel, and boulders which formed as a stream deposit in a tunnel within or at the base of a retreating glacier. When the glacier melts away, the snake-like ridge remains behind. These ice-contact fluvial deposits are also known as glaciofluvial deposits. The coarse cobble and boulder deposits which are often seen in eskers formed as point bar and channel deposits and are indicators of the tremendous volumes of water which once flowed through these glacial meltwater streams.

Glacial Lake Deposits (Glacio-lacustrine):

As the ice melted back northward at the close of the last glaciation lakes formed in many of the valleys in Vermont. Glacial meltwater and runoff from the surrounding hills poured into these lakes. Deltas of sand and gravel formed where streams entered the lakes and beach deposits of sand and gravel formed along the shorelines. Out in the deeper waters of these lakes fine sand, silt, and silty clay accumulated. The fine-grained deposits often have layers called varves. Varves are annual layers of fine-grained sediment deposited into lakes in the vicinity of glacial ice. One pair of light and dark layers forms over the course of each year, the light layer being a relatively coarser-grained warm season deposit and the dark layer being a relatively finer-grained winter deposit.

Glacial Marine Deposits (Glacio-marine):

After glacial ice melted out of the St. Lawrence River valley an arm of the Atlantic Ocean extended up into the Champlain valley to form the Champlain Sea. The deposits consist of beach gravels and sands that formed on the margins of the sea and fine-grained deposits that formed in deeper waters. The fine-grained material is typically a sticky, dark-gray silty clay although it is sometimes varved. Fossil marine shells are locally common.

Till:

The most widespread surficial deposit in Vermont is glacial till. As the glacial ice flowed over Vermont, it scraped up everything in its path. As the ice melted back, tremendous quantities of sediment were produced, some of which washed away with the rushing melt-waters and some of which was left behind. The material that was left behind is glacial till. It contains a mix of grain sizes, from tiny clay-sized particles up to huge boulders. In Vermont, glacial till has been crudely divided into two classes, basal till and ablation till. Basal till is perhaps more accurately called lodgement till, as it appears to be material that has been lodged or plastered under the ice as the glacier flowed over it. This material has enough silt and/or clay in its matrix so that it is very compact and firm. When it is freshly exposed, lodgement till is so firm that it is difficult to dig up, even with a pick, thus leading to the name “hardpan”. Ablation till also contains a wide variety of grain sizes, but it is much sandier and looser than lodgement till. It seems to have pretty much dropped out in place as the ice wasted away. It is thought that most of the silt and clay in the ice washed away as the ice melted, leaving behind a till with a sandy matrix. Ablation till is far more erodible than unweathered lodgement till, although if stream flows are high enough, serious erosion can also occur in lodgement till.

Colluvium:
Colluvium is material that accumulates at the base of a slope as the result of gravity or sheet-flow (runoff from the land which has not been concentrated into channels). The term includes rockfall deposits that accumulate beneath steep rock faces (talus), as well as landslide, slump, and debris flow deposits formed from any of the surficial materials described above. Thus, if a slump occurs in a steep bank of lodgement till, then the material in the slide is considered to be colluvium.

Bedrock:
The most stable streams are those with bedrock beds and banks. In areas where streams are cutting through bedrock, the rates of bank and bed erosion are much lower than in areas where none is exposed. Although streams have the power to dramatically erode even the hardest bedrock over centuries or millennia, bedrock in stream beds and banks is not usually severely eroded over the course of a few years or decades. Thus, waterfalls, cascades, and ledges in rivers provide relatively permanent controls on the grade (elevation) of rivers. Where bedrock is not exposed in the bottom of a stream valley, the stream may cut down into the surficial materials dramatically, particularly if the equilibrium of the stream is disturbed. Although bedrock outcrops in a bank or bed usually contribute to the stability of the stream, a ledge on one bank may deflect stream flow against the opposite bank downstream, leading to increased erosion.

Bedrock also is the source of the material found in the surficial deposits such as till and alluvium. Different bedrock types have different qualities. For example, granites are low in calcium and do not contain biological material. Rivers that drain from granitic bedrock are usually not highly productive in terms of aquatic habitat. On the other hand, marbles and dolomites are common in the Champlain Valley, and throughout much of Central Vermont. Rocks of the Waits River and Gile Mountain Formations are formed from sediments deposited in a tropical ocean. There was a lot of biological activity in these warm oceans, and the rocks contain a lot of calcium. This calcium is an important nutrient, and it also keeps the pH (a measure of acidity) higher in the streams, thus buffering the affects of acid rain. Streams draining through this kind of bedrock often have high biological productivity, supporting large and healthy populations of aquatic insects, amphibians, and fish.

Where To Find Geologic Information

There are several sources for geologic information about Vermont watersheds, notably the publications of the Vermont Geological Survey (VGS), the U.S. Geological Survey (USGS), and the Natural Resources Conservation Service (NRCS).

The VGS has a variety of information about the bedrock geology and surficial geology of the state. Besides the statewide maps of the bedrock and surficial deposits (Doll and others, 1961; Doll, 1970), detailed bedrock geologic maps are available for most of the state at either 1:62,500 or 1:24,000 scale. The 1961 bedrock geologic map is now out of print, but scanned images of the map are available from the Survey on CD-ROM and a new edition is in preparation by the VGS and the USGS. Scanned images of the 1:62,500 scale maps used to compile the 1970 surficial geologic map are available from the VGS and several areas have recently been remapped. Bulletin 31 (Stewart and MacClintock, 1969) provides descriptions of the surficial materials in the state. A series of environmental geology reports covers much of the state. These reports include information on surficial and bedrock geology, groundwater potential, and cross sections that show the thickness of surficial deposits. For more information on these and other publications contact the VGS at 103 South Main St., Laundry Building, Waterbury, VT 05671-0301, phone (802) 241-3608, web site <http://www.anr.state.vt.us/geology/vgshmpg.htm>. A publication list is available both in printed form and on the web site.

The USGS also has many publications dealing with Vermont geology. Check for publications related to water resources at the web site of the New Hampshire-Vermont USGS Office at <http://bowdnhbow.er.usgs.gov/ >. These include a series of bridge scour studies performed for the Vermont Agency of Transportation. The USGS also maintains a search engine for its publications at <http://usgs-georef.cos.com/>. The VGS can also help direct researchers to some of the USGS publications.

The Soil Surveys of the NRCS (formerly Soil Conservation Service) contain a wealth of information, including interpretations of the surficial geologic materials. Every soil series (the basic soil subdivision) has been assigned a parent material classification. The parent material is defined by NRCS as "...the unconsolidated material, mineral or organic, from which the soil develops" (Natural Resources Conservation Service, 1999, Part 618.40). In Vermont the parent materials are broadly broken down into six categories: alluvial, glaciolacustrine, glaciofluvial, glacial till, dense till, and organic deposits. The glaciolacustrine category includes glacial lake deposits as well as marine deposits from the Champlain Sea. The glacial till listing appears to include some materials which geologists would classify as ablation till and some which may correspond with weathered basal till. The dense till corresponds with basal till.

Because soils are classified based on the characteristics of the materials encountered in the first 60 inches in depth, soil maps do not always accurately portray the dominant parent material at a site. For example, if a hole is augured down into a flat terrace and passes through six feet of recent stream alluvium overlying 20 feet of lacustrine silt and silty clay, then the soil would be mapped as one which has an alluvial parent material. The lacustrine material would only show up on a soil map if erosion has exposed a considerable thickness of it on a steep slope below the terrace. The soil surveys are thus best at portraying the materials at the surface and do not fully show the three-dimensional nature of the deposits.

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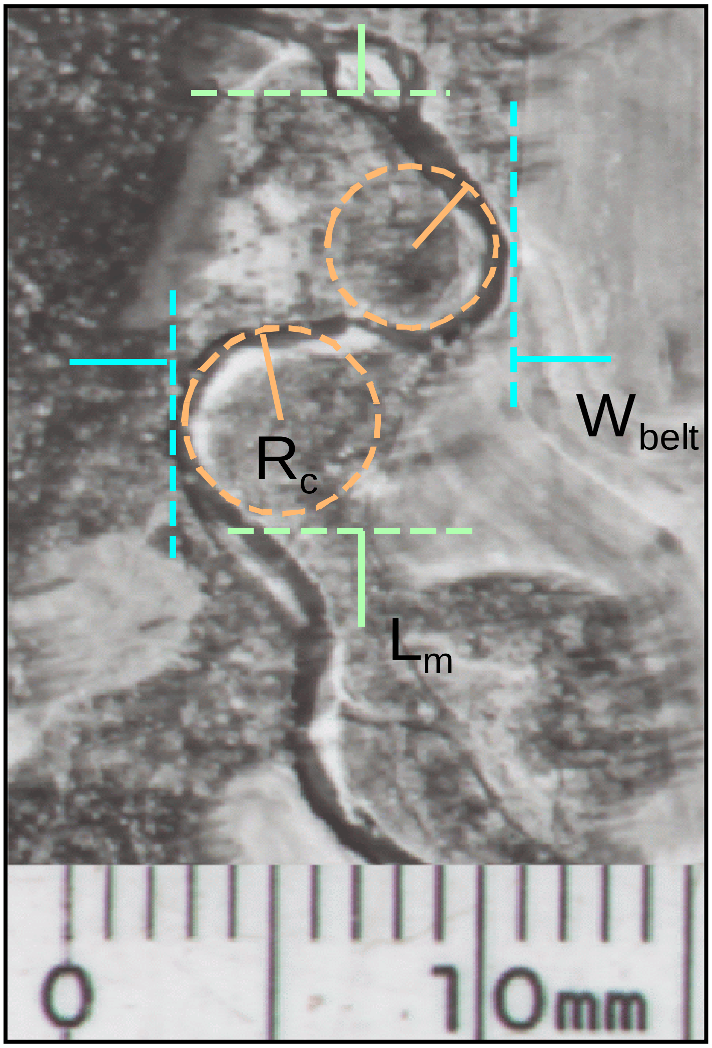
Vermont Stream Geomorphic Assessment

Appendix H



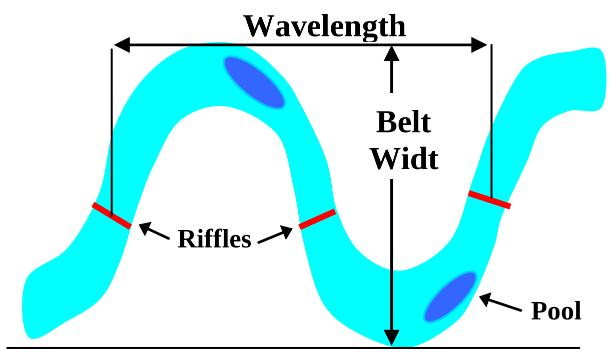
Meander Geometry

Vermont Agency of Natural Resources
April, 2004

Meander Geometry Formulas & Measurements

Meander Geometry Formulas

Rivers are in a dynamic equilibrium between their sediment loads and the energy available from stream flow to perform work and transport the sediment load. The meander geometry (patterns) of rivers develop naturally to provide for the dissipation of the energy of moving water and the transportation of sediment. Rivers exhibit continual adjustments in channel length (sinuosity) that result in maintaining a slope such that the stream system neither degrades nor aggrades. When the alignment of the river is changed, by reducing natural sinuosity, the reach length is decreased, increasing local slope, and setting in motion a series of channel adjustments (Rosgen, 1996)



Naturally straight, alluvial channels are very rare. Even within straighter channels, the deepest thread or thalweg follows a sinuous course between the straight alignment of the banks (Thorne, 1997). The fact that unconfined, single thread streams follow a sinuous or meandering course is related to the vertical oscillations of the stream bed (i.e., pools and riffles). Flow characteristics (turbulence and secondary or lateral currents) cause the selective entrainment, transport, and deposition of bed materials which produces systematic sorting of grain sizes between scour pools and riffle bars. Riffles are the topographic high points in the undulating profile (with symmetrical cross-sections), and pools are the intervening low points. The high velocity flow, scour, and secondary currents work against the one bank in the asymmetrical pool generating bank instability and retreat. This process leads directly to the development of a sinuous channel, with riffles becoming points of inflection, where the flow switches from one side of the channel to the other (Thorne, 1997).

Researchers have developed meander geometry formulas to relate channel dimensions with plan form measurements. Leopold et.al. (1964) noted that riffles were spaced 5 to 7 channel widths apart and that meander wavelengths measured 10 to 14 channel widths (as wavelengths are comprised of 2 riffle-pool sequences). Thirty years of further observations and measurements have not yielded different results (Thorne, 1997). Williams (1986) using data collected from 153 rivers around the world found that the relationship between channel width and the meander belt width is expressed by the formula $B=3.7W^{1.12}$ (measuring width in feet and for channels ranging from 5 to 13,000 ft wide). This formula results in a meander width ratio approximately equal to six (i.e., the belt width is equal to about 6 bankfull channel widths). Calculating the regime meander belt width for a meandering type stream is particularly valuable for evaluating the lateral channel adjustments that are likely to occur in the channelized reach.

Meander geometry is not only related to channel width (which correlates with discharge) but also to sediment load and boundary materials. For instance, stream banks having greater resistance to erosion (i.e., consisting of cohesive clay materials) may result in a narrower channel and tighter, shorter wavelength bends (Knighton, 1998). Clay plugs and other resistant outcrops, that are frequently encountered by rivers meandering across alluvial flood plains, may distort or deform meander bends. This is often the reason why perfectly formed meanders are rarely encountered (Thorne, 1997). Streams with very high sediment loads generally have shorter wavelengths and larger belt widths. If in a high bed load stream, the stream banks are resistant to erosion (i.e., with cohesive soils and vegetation), then channel width is typically found to be narrower.

Where a meandering stream has planform dimensions that are much larger than what would be expected, the stream may be meandering in a confined or narrow valley formed by a much larger stream that existed at a time when the watershed hydrology was very different. For example, a number of valleys in Vermont were formed after the glaciers receded by rivers that meandered and worked through and landscape with much larger flows and sediment transport capacity than the rivers that flow there today. The current day rivers flow “passively” in meandering valleys without sufficient power to readily erode the valley walls.

Meander Geometry Measurement

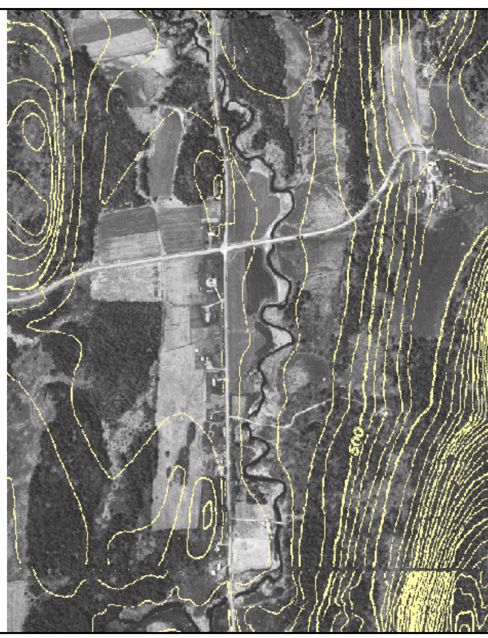
The following reaches are shown as examples of where to measure representative channel wavelengths and belt widths. Example 1 also includes an example of calculating average values which are then divided by the estimated or measured reference channel width to generate values for wavelength and meander width ratios.

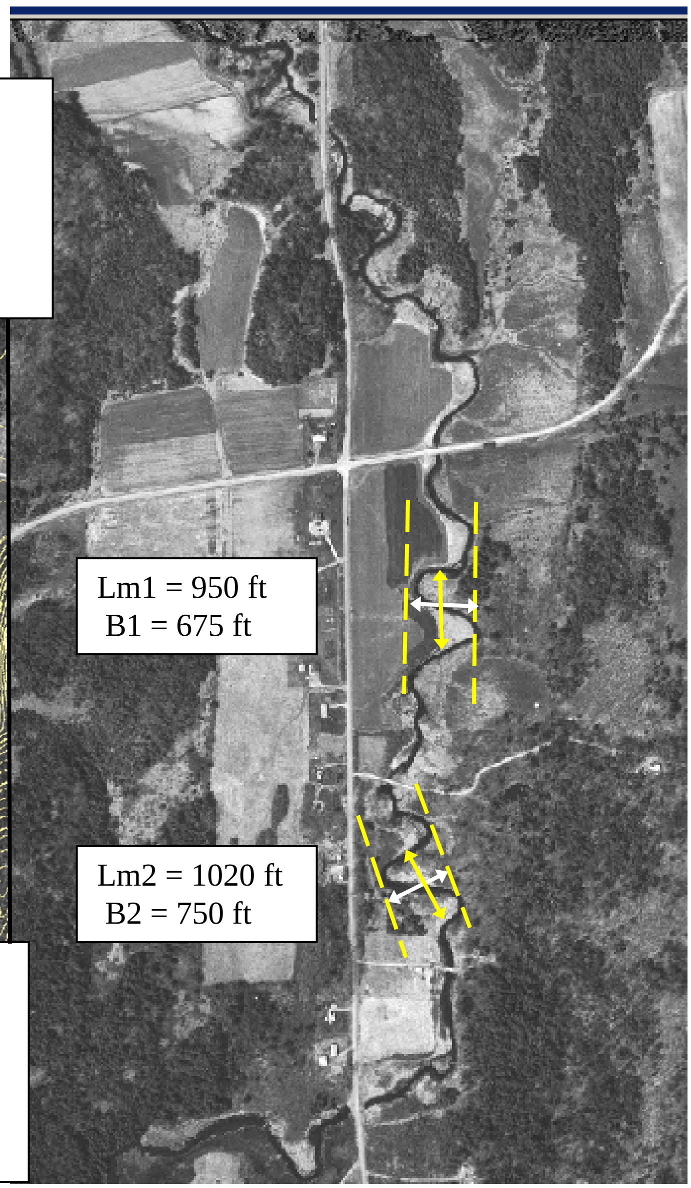
Example 1.

The areas selected for measuring representative wavelengths (Lm) and belt widths (B) were those unaffected by the 4 bridges in this reach. Average values for the reach would be calculated as:

Lm = (950 + 1020) / 2 = 985

B = (675 + 755) / 2 = 715



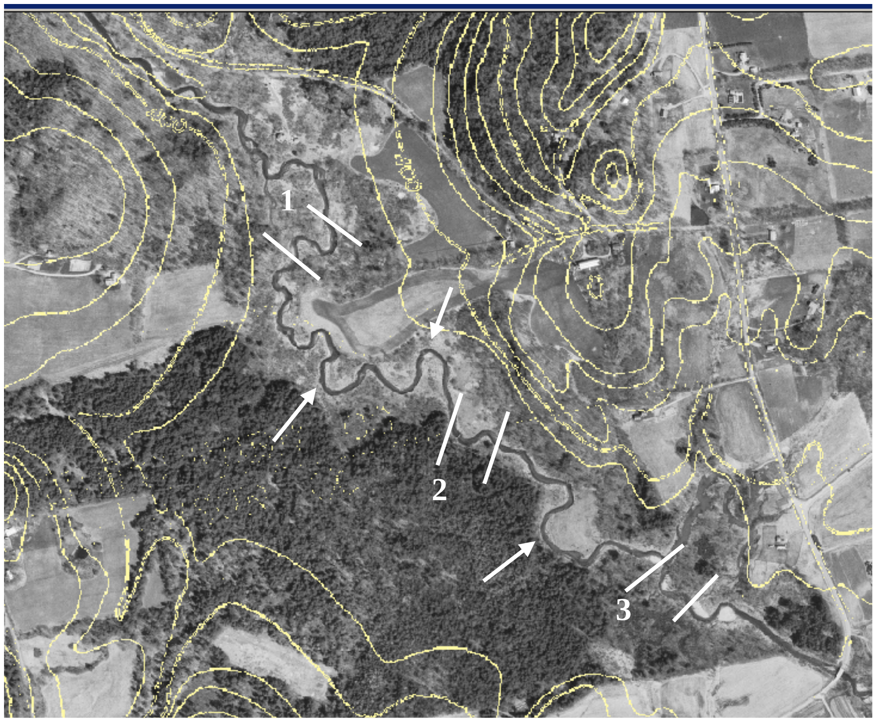


If the bankfull width estimated by the VT hydraulic geometry curves equals 75 ft. The wavelength and meander width ratios would be:

Lm / W = 985 / 75 = 13.1

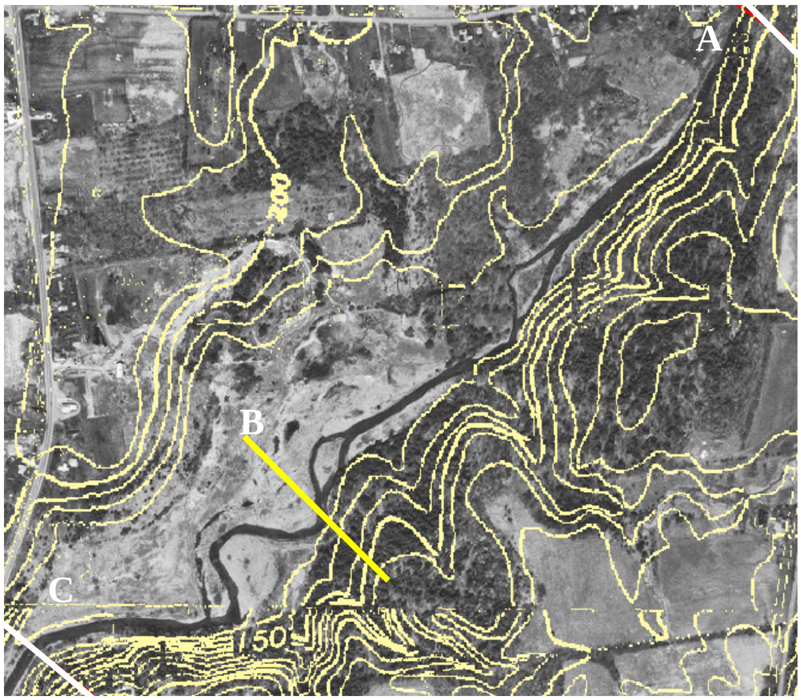
B / W = 715 / 75 = 9.5

Example 2. Three meanders have been bracketed as representative of the reach. Three other bendways are noted with an arrow to show the type of large irregular meander that you may encounter. In this case, these large meanders do not dominate the reach and therefore should not be the basis of your Phase 1 assessment of meander width and wavelength ratios. Had they been the dominant feature, then you would have measured them and determined impact ratings as described in Phase 1, Steps 6.5 and 6.6.



The references below offer excellent reading on the complex subject of meander development and are highly recommended.

Example 3. The reach in this example flows between Lines A and C. Over half of the reach (from Line A to Line B) has been straightened. Therefore, as part of the Phase 1 assessment of wavelength and meander width ratios you would enter the channel width (the value recorded in Step 2.8) into the data base for the wavelength and belt width values. This will generate ratios of "1.0" and impact ratings of "High." The seemingly well formed bendway downstream, from Line B to Line C, may serve as reference during Phase 2 and Phase 3 assessment.



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Vermont Stream Geomorphic Assessment

Appendix I

Stream Classification Systems

Vermont Agency of Natural Resources
April, 2004

Stream Classification Systems

Rosgen Stream Channel Classification System

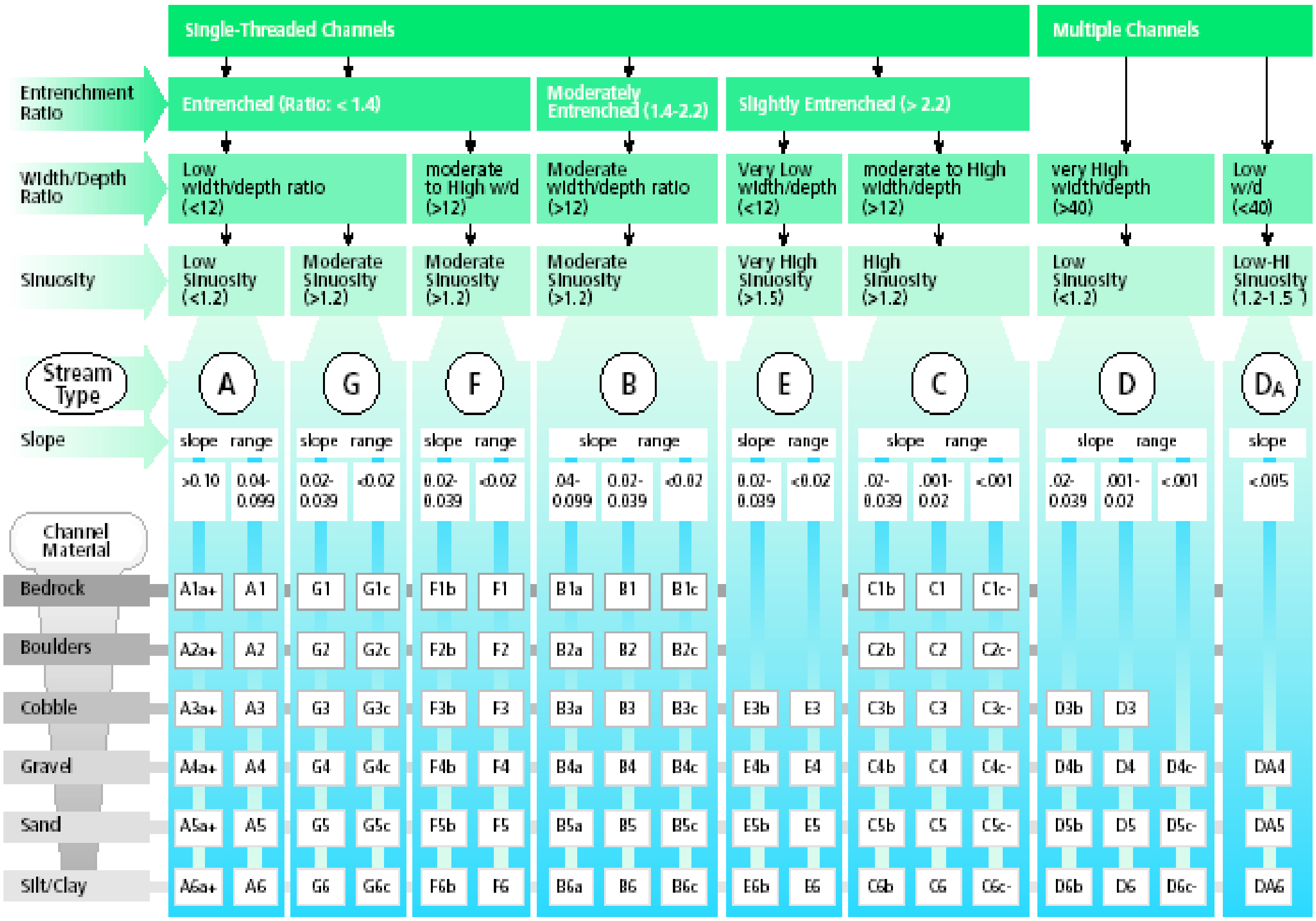
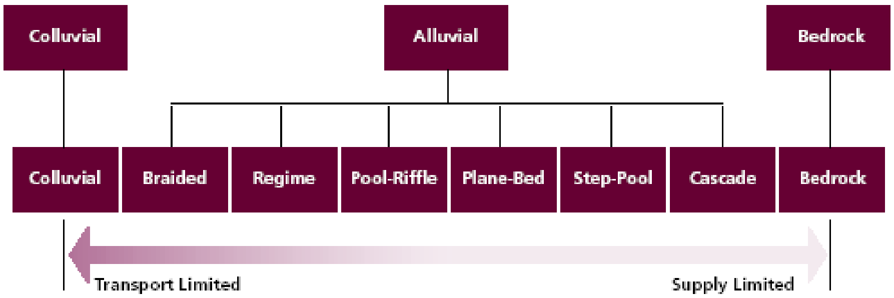


Figure 1 Rosgen Classification System, (Rosgen, Dave, 1996. Applied River Morphology) Copyright 1996 by Wildland Hydrology. All illustrations copyright 1996 by Hilton Lee Silvey. Excerpted from the Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration Manual: Principles, Processes, and Practices. Reproduced here by written permission of Wildland Hydrolgy.

Montgomery – Buffington Stream Classification System

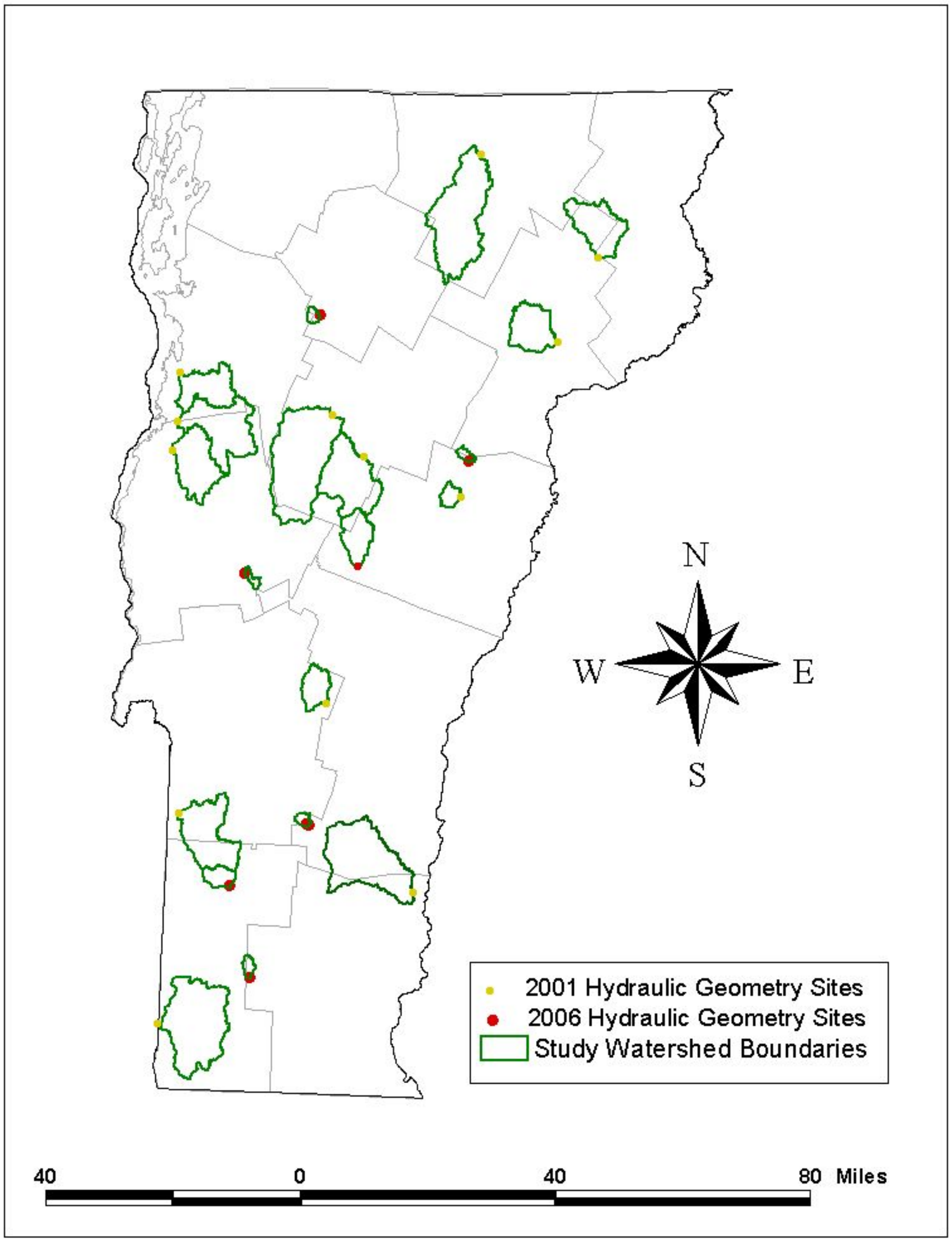


	Braided	Regime	Pool-Riffle	Plane-Bed	Step-Pool	Cascade	Bedrock	Colluvial
Typical Bed Material	Variable	Sand	Gravel	Gravel, cobble	Cobble, boulder	Boulder	N/A	Variable
Bedform Pattern	Laterally oscillary	Multi-layered	Laterally oscillary	None	Vertically oscillary	None	•	Variable
Reach Type	Response	Response	Response	Response	Transport	Transport	Transport	Source
Dominant Roughness Elements	Bedforms (bars, pools)	Sinuosity, bedforms (dunes, ripples, bars) banks	Bedforms (bars, pools), grains, LWD, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, LWD, banks	Grains, banks	Boundaries (bed & banks)	Grains, LWD
Dominant Sediment Sources	Fluvial, bank failure, debris flow	Fluvial, bank failure, inactive channel	Fluvial, bank failure, inactive channel, debris flows	Fluvial, bank failure, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flow	Hillslope, debris flow
Sediment Storage Elements	Overbank, bedforms	Overbank, bedforms, inactive channel	Overbank, bedforms, inactive channel	Overbank, inactive channel	Bedforms	Lee & stoss sides of flow obstructions	•	Bed
Typical Slope (m/m)	S < 0.03	S < 0.001	0.001 < S and S < 0.02	0.01 < S and S < 0.03	0.03 < S and S < 0.08	0.08 < S and S < 0.30	Variable	S > 0.20
Typical Confinement	Unconfined	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Pool Spacing (Channel Widths)	Variable	5 to 7	5 to 7	none	1 to 4	< 1	Variable	Variable

Figure 2. Suggested stream classifications for Pacific Northwest. Source: Montgomery and Buffington 1993. Table excerpted from the Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration Manual: Principles, Processes, and Practices.

Vermont Stream Geomorphic Assessment

Appendix J



Vermont Regional Hydraulic Geometry Curves

River Management Program
Vermont Agency of Natural Resources
January, 2006

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Abstract

Hydraulic geometry data from six ungaged streams in Vermont, ranging from four to 13 square miles of drainage area, were gathered and added to hydraulic geometry curves previously developed by the Vermont Department of Environmental Conservation (Vermont DEC, 2001). Four of the surveyed stream reaches have entrenchment ratios less than 2.2 and width to depth ratios greater than 12 which places them in the Rosgen B-stream type category (Rosgen, 1998). Two of the stream reaches have entrenchment ratios greater than 2.2 and width to depth ratios greater than 12 which places them in the Rosgen C-stream type category (Rosgen, 1998).

To verify that the flow frequency of the identified bankfull stage at each reach was within reasonable proximity to the theoretical value of 1.5 years the discharge associated with the identified bankfull stage was determined using stage discharge relations developed during this study and compared to the predicted 2-yr. recurrence interval flow as calculated using a regression equation developed by the United States Geological Survey (Olson, 2002) to calculate peak flow frequency characteristics of Vermont streams. Bankfull values extrapolated from the stage discharge curves fell within the standard error of prediction of the Olson equation.

Addition of the new data points to the previously developed Vermont Hydraulic Geometry Curves (Vermont DEC 2001) significantly strengthened the regressions describing the relation between drainage area and bankfull hydraulic geometry. Considering the typical application of and standard error of prediction associated with the regional curves, the change in predicted bankfull dimension values (cross section, width and depth) resulting from the addition of the 2006 data points are not substantial.

Flow measurement and hydraulic geometry data was used to test the applicability of an equation relating friction factor to relative roughness presented in Rosgen (1998). The test showed that the Rosgen (1998) friction factor equation does not accurately predict friction factor of the study streams. Velocities calculated using the Rosgen (1998) based friction factor vary from measured velocities by 33% on average. The equation was revised using flow measurement data from this study and used to recalculate velocities. The average variation between calculated and measured velocity decreased to 16%. These results are encouraging in that they suggest locally derived relative roughness friction factor relationships may lead to improved accuracy in velocity calculations. The revised relation should be tested on streams outside of the study streams.

Study Objectives

Bankfull hydraulic geometry relationships, otherwise known as regional curves were presented by Dunne and Leopold (1978). Regional hydraulic geometry curves describe the relation between drainage area of a channel and the bankfull hydraulic characteristics of discharge, cross-sectional area, width and depth of the channel. Hydraulic geometry curves developed by the Vermont Department of Environmental Conservation (VT DEC, 2001) have proven to be a useful tool in predicting the equilibrium condition hydraulic geometry of streams in Vermont.

Use of the hydraulic geometry curves has assisted in: geomorphic assessment, regulatory activities, flood recovery, fluvial conflict management and stream corridor protection and restoration design. Empirical evidence has verified that the curves' accuracy of prediction when applied to streams of the same size and morphologic type as those used to develop the curves is sufficient for the intended applications. Users of the curves have reported that the curves appear to under predict hydraulic geometry characteristics, particularly width, when applied to higher gradient streams draining an area less than the lower limit of the range of those used to develop the curves. The primary purpose of this study was to obtain and add data points from small streams in Vermont to improve the accuracy of prediction of the 2001 Vermont Hydraulic Geometry Curves when applied to small streams.

Flow velocity is strongly related to flow resistance (Knighton, 1998). Boundary resistance is the component of flow resistance that has been shown to have the most affect on velocity. Grain roughness is a component of boundary resistance and has been shown to be a function of relative roughness wich is the ratio of mean flow depth (d) to D84 (the diameter at which 84 percent of the particles are finer). Rosgen (1998) presents a plot of the relation between relative roughness and the ratio of velocity to shear velocity (v/v*). The data on the plot is from Leopold et. al (1964) and Limerinos (1970). The equation describing the line fit to the data is given as:

$$v/v^* = 2.83 + 5.7\mathrm{Log}(d/D84).$$

The Vermont DEC Phase 3 stream geomorphic assessment spreadsheet calculates flow velocity using the above equation. Because the data sets used to develop the equation do not originate in the north eastern U.S. the applicability of this relationship to Vermont rivers has been questioned. A secondary purpose of this study is to verify the applicability of the above relationship to Vermont Rivers.

Site Selection

Several criteria were established for use in site selection. To qualify as study sites, candidate sites needed to: be of reference condition (see, 2001 Vermont Regional Hydraulic Geometry Curves), drain an area of less than 15 square miles, have a slope less than three percent and have well developed bankfull indicators. Data for the development of the 2001 Vermont regional curves was collected near active flow gages. Because of the lack of active USGS flow gages on small streams in Vermont we decided that study sites did not need to be in the vicinity of active gages.

Because sites were not required to be in the proximity of active flow gages possible site locations included nearly any reach of river in Vermont that met the above criteria. Remote screening data used to iteratively reduce the number of candidate sites included: Emergency 911 GIS data as an indicator of existing development, Vermont Biophysical Regions Data (Sorenson and Thompson, 2000) as an indicator of bedrock surficial geology and topographic characteristics, Vermont Road data (Vermont Center for Geographic Information) as an indicator of roadway encroachments, ortho-photographs (1990's) as an indicator of surrounding land use and information on Vermont's flood history (Cahoon, 2004 personal communication) as an indicator of potential historic flood damage and mitigation related alterations. Information provided by the Green Mountain National Forest helped to identify sites with a high probability of meeting the established criteria. A list of likely study sites was developed and field visits made to each to verify the suitability of each as a study site.

Verifying Correct Identification of Bankfull Stage

Data for the development of hydraulic geometry curves is typically collected at locations of flow gages with a period of record longer than 20 years. This allows for the bankfull stage selected by observation of field indicators to be correlated to a flow recurrence interval as calculated from the long term flow data. It has been shown that the bankfull or channel forming flow of different streams within a hydrophysiographic region will have a common recurrence interval which is typically in the proximity of 1.5 years (Leopold, etc, etc). Using this principle the researchers are able to verify that they have correctly identified the bankfull stage by comparing the flow frequency of the bankfull discharge to the theoretical value of 1.5.

Of the six sites selected only the Ranch Brook site, which has been in operation for four years, is in the proximity of an active USGS flow gage. None of the remaining study sites were located in the proximity of a gaging station. The absence of long term flow gages near the study sites prevented the standard practice of using long term flow data to calculate a recurrence interval for the field identified bankfull stage at each site. As an alternative means of providing some level of verification that the recurrence interval of the field identified stage was within the proximity of that which was expected the Vermont Flow Frequency Tool (Olson, 2003) was used to predict the 2-year discharge for each site. Stage discharge rating curves were developed and used to determine bankfull discharge and the bankfull discharge was then compared to the 2-year flow predicted by the Vermont Flow Frequency Tool (Olson, 2003).

Stage Discharge Rating Curves

Table 1 presents flow measurement data that was collected during the study. Because the Ranch brook site was in close proximity to a gage it was unnecessary to make flow measurements there. Two to three flow measurements were made at each of the other sites. This allowed for development of preliminary stage-discharge rating curves from which bankfull discharge could be extrapolated. Because the two measurements from the Waits river site were made during very similar discharges a rating curve could not be developed for this site.

Table 1. Flow Measurement Data.

Stream	Date	Stage	Mean Depth (ft.)	Width (ft.)	Cross Sectional Area (sq.ft.)	Velocity (ft/sec)	Discharge (cfs)	Manning's n
Battenkill W. Br.	10/11/2005	7.07	1	29	28.89	1.45	41.9	0.06
Battenkill W. Br.	10/25/2005	7.61	1.55	31	48.05	2.75	132.1	0.07
Deerfield	5/25/2004	10.02	1.04	22.3	23.2	1.28	29.8	0.12
Deerfield	10/11/2005	9.83	0.78	21	16.4	1.12	18.3	0.11
Greendale Brook	10/11/2005	11.25	0.36	23	8.21	1.19	9.77	0.084
Greendale Brook	10/25/2005	12.1	1.22	23.5	28.69	3.53	101.37	0.063
Sucker Brook	5/25/2004	9.32	0.54	16.75	9.06	0.8	7.22	0.19
Sucker Brook	8/13/2004	9.87	1.07	17.4	18.58	1.68	31.25	0.14
Sucker Brook	9/1/2005	9.4	0.45	15	6.8	0.8	5.43	0.16
Waits River	4/28/2005	6.28	0.82	22.6	18.62	2.11	39.39	0.08
Waits River	10/17/2005	6.22	0.9	21	18.95	2.18	41.24	0.09

Figure 1 shows the four stage discharge rating curves that were developed for the remaining sites. These curves should be considered preliminary. Due to the few data points on each plot there can be little confidence in discharge values both interpolated and extrapolated from these curves. The presentation of these curves and use of values extrapolated from them in this report is done out of absolute necessity. As more data points are added to these plots this report will be updated.

Figure 1. Stage-discharge rating curves for study sites.

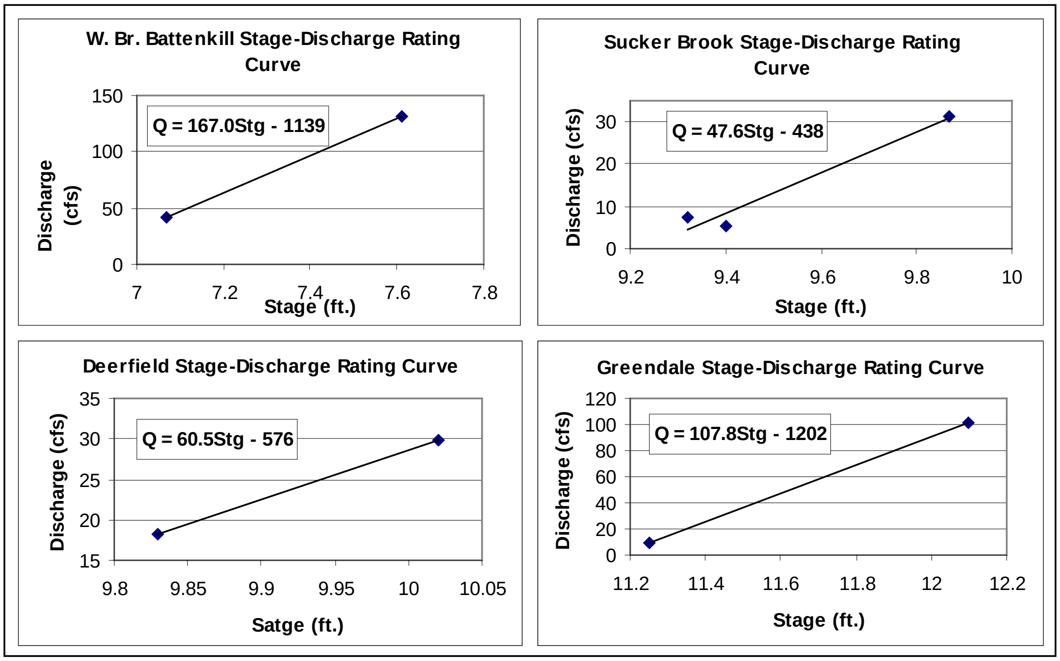


Table 2 presents the bankfull values derived by extrapolation from the preliminary state discharge rating curves, the 2-year flow calculated using the Olson equation, and the difference between the two as a percentage of the Olson Q2 prediction for each site. The data neither verifies nor disproves the accuracy of the field determination of bankfull stage.

Table 2. Difference between bankfull discharge determined by extrapolation of preliminary rating curves and calculation using Olson, 2003 regression equations.

Stream	Qbkf from Rating Curve (cfs)	Q2-Olson (cfs)	Difference as % of Q2-Olson
Sucker Brook	79	98	-19
Greendale Brook	171	157	9
Ranch Brook	*N/A	147	N/A
Waits River	N/A	131	N/A
Deerfield	104	189	-45
Battenkill W. Br.	206	320	-36

*The reason that there is no bankfull for Ranch brook is that the need to correlate flow stage at the measurement cross section to flow stage at the USGS gage was overlooked. This data will be gathered in the upcoming field season.

While there is up to 45 percent difference between the bankfull discharge and predicted 2-yr discharges it must be noted that the typical standard error of prediction for the 2-year discharge using the Vermont Flow Frequency Tool (Olson, 2003) is +48.2 percent and -32.5 percent and the probability that the actual 2 year discharge falls within this range is only 68 percent. Table 2 shows that the bankfull values fall within this standard error of prediction. The fact that the identified bankfull discharge falls within the standard error of prediction of the 2-yr flow does indicate a good probability that the bankfull stage was correctly identified.

Channel Morphology of Study sites

Hydraulic geometry and several morphologic characteristics of the study sites and surrounding valleys were surveyed in the field following established protocols and using standard laser level survey equipment. See, 2002 Vermont Regional Hydraulic Geometry Curves (VT DEC, 2002) for further description of field survey techniques.

Table 3. Compiled 2001 and 2006 hydraulic geometry dataset.

Table 4 presents the primary parameters that describe stream morphology for each of the sites. Research has shown that channel geometry has an influence on hydraulic geometry. For this reason it is common practice to use streams of a single valley type and boundary condition when developing regional hydraulic geometry curves. The Rosgen stream classification system (Rosgen, 1996) provides a useful method for identifying streams of similar type. In developing the 2002 Vermont regional hydraulic geometry curves (VT DEC, 2001) an effort was made to obtain data from unconfined streams with slopes less than three percent (Rosgen C-type streams) because in Vermont these are the types of streams that are most frequently degraded and in need of restoration. Due to topographic characteristics of Vermont it is uncommon for small catchments to be drained by C-type streams. For this reason the common morphology criterion was relaxed to allow for streams of narrower valleys and steeper slopes to be included in the study.

Table 4. Morphologic characteristics of 2006 study sites.

Stream Name	Entrench-ment Ratio	W/D Ratio	Reach Slope (ft./ft.)	D50 (mm)	Rosgen Stream Type
Greendale Brook	1.64	20.78	0.0184	31	B4c
Sucker Brook	1.74	16.50	0.0292	32.00	B4
Ranch Brook	1.48	24.88	0.0193	53.00	B4
Waits River	4.18	16.00	0.0195	35.00	C4b
Deerfield River	1.88	21.00	0.0104	74.00	B3c
W Br. Bkill	4.89	25.22	0.0070	43.00	C3

Site Name**	Drainage Area (sq.mi.)	Bankfull Discharge (cfs)*	XS Area (sq.ft.)	Width (ft.)	Depth (ft.)
Sucker Brook	3	79	27	22	1.25
Greendale Brook	4	171	30	20	1.49
Ranch Brook	4	147	37	27	1.40
Waits River	4	131	34	25	1.34
Deerfield	5	104	57	32	1.8
East Orange Br.	9	187	53	28	1.9
W Br. Bkill	13	206	63	40	1.58
Ottaquechee	23	661	201	63	3.2
Ayers	31	621	146	41	3.6
Sleepers R.	43	1312	214	69	3.1
Laplatte E Br	45	734	197	77	2.5
Passumpsic	54	854	224	72	3.1
Little Otter	57	1122	265	92	2.9
Mettawee	70	3300	337	95	3.5
Dog	76	1537	277	78	3.6
Lewis	77	1850	244	89	2.7
Walloomsac	111	1879	410	110	3.7
Williams	112	5490	650	133	4.9
Black River	122	1726	304	71	4.3
Mad River	139	4960	559	138	4.0

* For 2006 sites except Ranch brook and Waits river bankfull discharge was determined by extrapolation from preliminary stage discharge rating curves. Bankfull discharge for Ranch brook and Waits river were calculated using the VT Flow Frequency Tool. For all other sites bankfull discharge was determined using USGS stage discharge relation for the particular gage.
** Sites in bold were used for development of 2001 Regional Hydraulic Geometry Curves. All other sites were surveyed in 2004

2006 Hydraulic Geometry Curves

The complete 2001 and 2006 hydraulic geometry dataset is presented in Table 3. The 2001 and the new 2006 curves (the 2006 curves are based on the compiled 2001 and 2006 data sets) are shown in Figure 2. Plotting both the 2001 and the 2006 curves on the same graph allows for a visual analysis of the affect that the 2006 data has on the previously plotted 2001 regressions. Because the discharge data collected for the 2006 sites is unreliable bankfull discharge data was not plotted. The addition of the 2006 data to the 2001 data set resulted in a:

- 0.17 increase in intercept and no change in slope and of the area regression,
- 2.92 increase in intercept and a 0.16 decrease in slope of the width regression, and
- 0.26 increase in intercept and a 0.05 increase in slope of the depth regression.

Addition of the 2006 data to the 2001 VT Hydraulic Geometry Curves resulted in a rise in r-squared values for each curve. R-squared values increased from:

- 0.85 to 0.95 for the area regression,
- 0.78 to 0.91 for the width regression and
- 0.59 to 0.87 for the depth regression.

These high r^2 values reveal that drainage area is a very good predictor of bankfull width, depth and cross-sectional area.

To quantify the effect of the 2006 data on bankfull dimension predictions, an analysis of prediction difference was conducted. The results of the analysis are presented in Table 5.

- The difference in predicted cross sectional area, ranges from 0.57 square feet at five square miles to 6.16 square feet at 120 square miles.
- The difference in predicted width decreases from 3.83 feet at five square miles to zero at 66 square miles and then increases to 3.84 feet at 120 square miles.
- The difference in predicted depth decreases from 0.27 feet at five square miles to zero at 120 square miles.

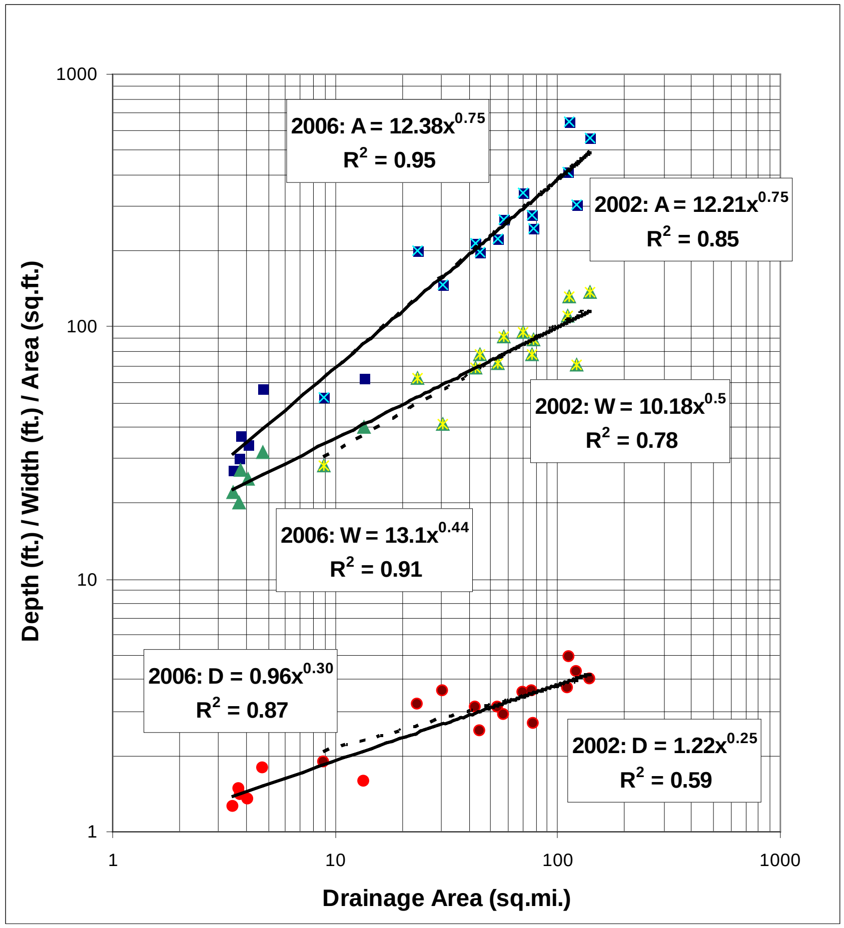


Figure 2. 2001 and 2006 Vermont Hydraulic Geometry Curves. The 2001 curves are presented as dashed lines and 2006 curves as solid lines. 2001 data are presented as dual-colored points and 2006 data as mono-colored points.

Table 5. Analysis of difference in geometry predictions between 2001 and 2006 curves.

	Area (sq. ft.)			Width (ft.)			Depth (ft.)		
Drainage Area	2006 Prediction	2001 Prediction	Diff.	2006 Prediction	2001 Prediction	Diff.	2006 Prediction	2001 Prediction	Diff.
5	41.40	40.83	0.57	26.60	22.76	3.83	1.56	1.82	-0.27
10	69.62	68.66	0.96	36.08	32.19	3.89	1.92	2.17	-0.25
20	117.08	115.48	1.61	48.95	45.53	3.42	2.36	2.58	-0.22
40	196.91	194.21	2.70	66.40	64.38	2.02	2.90	3.07	-0.16
60	266.89	263.23	3.66	79.37	78.85	0.52	3.28	3.40	-0.12
80	331.16	326.61	4.55	90.08	91.05	-0.97	3.57	3.65	-0.07
100	391.49	386.11	5.38	99.37	101.80	-2.43	3.82	3.86	-0.04
120	448.86	442.69	6.16	107.67	111.52	-3.84	4.04	4.04	0.00

The increase in predicted width that resulted from addition of the 2006 is in agreement with past reports that the 2001 curves under-predict channel width when applied to small streams. Yet the increase in predicted width is at only 3.83 feet for streams draining five square miles.

The 95% interval confidence bands around the width curve are shown in Figure 3. The figure shows that the possible prediction values associated with a 95% confidence level range from:

- 15 to 33 feet at four square miles,
- 51 to 68 feet at 30 square miles,
- 79 to 95 feet at 70 square miles and
- 105 to 134 feet at 143 square miles.

Considering this range of predicted values within the 95% confidence limits and the typical applications of the curves the change in predicted bankfull geometry values when the 2006 data is added to the 2001 curves is not substantial.

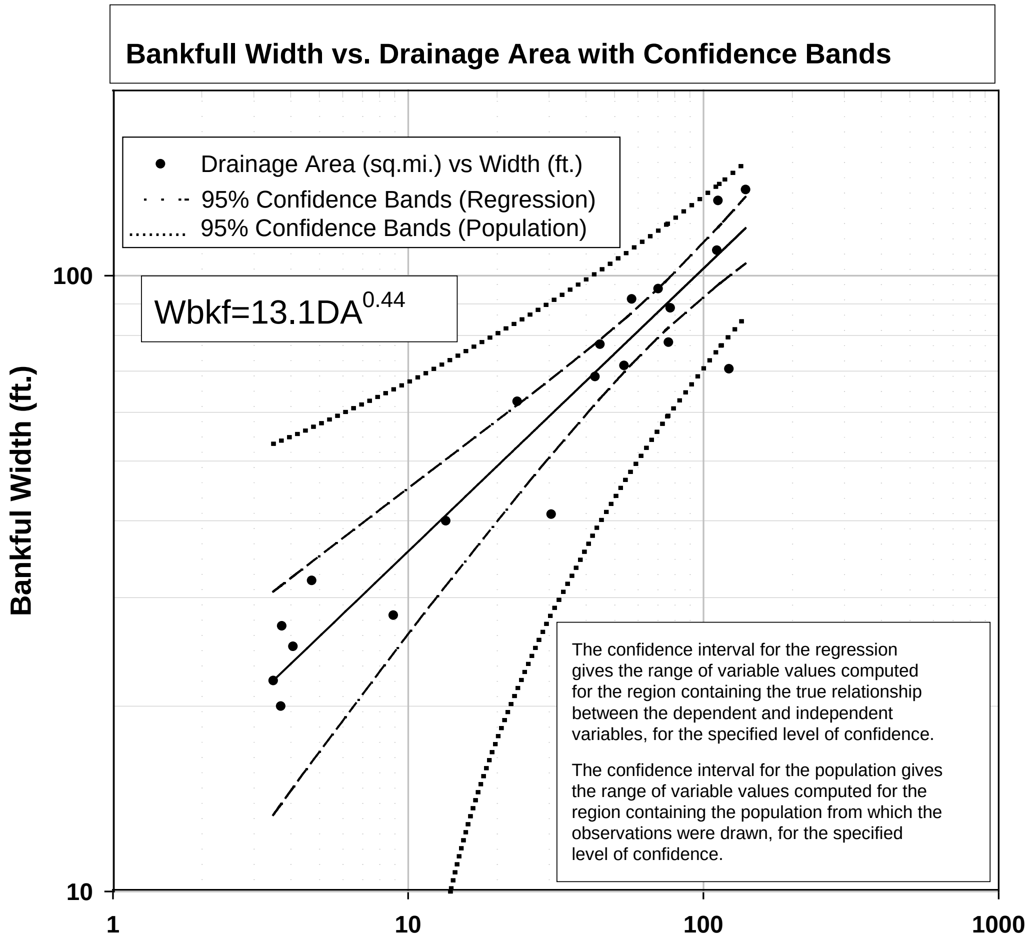


Figure 3. Width vs. drainage area data and regression lines with confidence

Testing the Rosgen (1998) Friction Factor Equation

The flow measurement and hydraulic geometry data gathered during this study provided an opportunity to test the applicability of the friction factor relative roughness relation presented in Rosgen (1998) and used in the Vermont DEC Phase 3 stream geomorphic assessment spreadsheet to Vermont streams. The relationship is of the form,

$$v/v^* = 2.83 + 5.7\log(d/D84)$$

Where; v is velocity, and
d is mean depth and
v* is shear velocity.

The calculation of shear velocity is possible with basic channel geometry data.

$$V^* = (gSR)^{0.5}$$

Where, g = the acceleration due to gravity,
S = channel slope, and

R= hydraulic radius.

The friction factor relative roughness relationship can be used in combination with the equation for shear velocity to calculate mean velocity at the cross-section. Using this friction factor relation for Vermont streams is likely to provide inaccurate results due to the fact that the equation was developed using empirical data from regions other than northern New England.

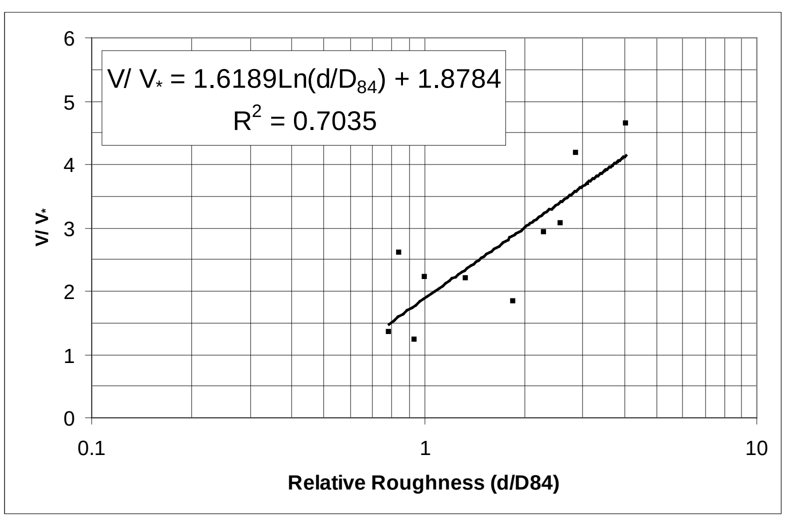
As a test of the Phase 3 velocity calculations velocities were calculated for each stream for every stage at which velocity measurements were made. Table 6 shows a comparison of velocities measured at the study sites during various flow stages and velocities calculated by the Vermont DEC Phase 3 spreadsheet for those same flow stages. Velocities calculated using the Phase 3 spreadsheet differ from measured velocities by an average of 35%.

Table 6. Comparison of measured to calculated velocities.

				d	e
Stream Name	**Measured Velocity (cfs)**	**Calculated Velocity (cfs) (Rosgen, 1998)**	**Percent difference (a and b)**	**Calculated Velocity (cfs) (VT friction factor relation)**	**Percent difference (a and d)**
Battenkill W. Br.	1.45	2.40	40	1.61	10
Battenkill W. Br.	2.75	3.63	24	2.45	-12
Deerfield	1.28	2.08	38	1.36	6
Deerfield	1.12	1.45	23	0.94	-19
Greendale Brook	1.19	1.10	-8	0.73	-63
Greendale Brook	3.53	4.40	20	3.01	-17
Sucker Brook	0.8	1.87	57	1.15	30
Sucker Brook	1.68	4.32	61	2.62	36
Sucker Brook	0.8	1.44	44	0.87	8
Waits River	2.18	3.56	39	2.39	9

A plot showing friction factor versus relative roughness values calculated using data from this study is shown in Figure 4. The relationship of the relative roughness and friction factor data is best described by the equation v/v* = 1.62Ln(d/D84) + 1.88. Velocities for the study sites were recalculated using the revised relationship and are shown in column d of Table 6.

Figure 4. Resistance to flow as a function of relative roughness.



As is expected the velocities calculated for the study streams using the revised friction factor relative roughness relation are much more accurate than velocities calculated using the relationship incorporated into the phase 3 spreadsheet. Velocities calculated using the revised curve vary from measured velocities by an average of 21%. If the value of greatest variance for each set of calculated velocities is considered an outlier and discarded the average variation of the Rosgen based velocities becomes 33% and the average variation of the VT based velocities becomes 16%.

It is to be expected that the relation developed from a particular data set will better predict the related values for that data set than a relation developed on another data set. A true test of the usefulness of the revised relation for predicting friction factor of Vermont streams will require comparison of predicted to measured velocities on other streams in Vermont. It is expected that the accuracy of this curve for calculating friction factor on other Vermont streams will be highly dependent on the stream's similarity to those used in this study. Because of this fact it may become desirable to develop curves for each major stream morphology found in Vermont.

Further Study

Flow measurements will continue at all six sites in order to increase confidence in the stage-discharge rating curves. A stage-discharge relation will be established at the Ranch brook site so that the discharge associated with the identified bankful stage can be determined. When enough stage-discharge data are collected to establish reliable stage-discharge curves the bankfull discharge curve for the complete data set will be added to the regional curve plot.

Flow measurement data collected for the discharge-rating curves will also be added to the relative roughness friction factor plot to increase confidence in the established relative roughness friction factor relationship. Flow measurements will also be made at sites not included in this study to test the accuracy of prediction provided by the relative roughness friction factor relationship when applied to streams outside those included in this study. Exploration into the use of existing data from USGS flow gages for addition to the relative roughness friction factor relationship will also be conducted.

Currently Rosgen E-type channels are not well represented in the Vermont regional curve dataset. E-channels have a much lower width to depth ratio than the C and B-channels that make up a large portion of the Vermont hydraulic geometry dataset (Rosgen, 1998). It is expected that the both the 2001 and 2006 regional curves over-predict the width and under-predict the depth of E-channels. There is interest in adding data from E-channels to document the difference in hydraulic geometry between E and C and B-channels. Identification of appropriate study sites will begin in the 2006 field season.

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6. Vermont Regional Hydraulic Geometry CurvesVermont Department of Environmental Conservation 2001

Partners and Supporting Agencies

United States Forest Service, Green Mountain National Forest.
United States Geological Survey, New Hampshire/Vermont District.
Vermont Department of Fish and Wildlife.

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Mike Kline mike.kline@state.vt.us (802) 241- 3774

Vermont Stream Geomorphic Assessment

Appendix L

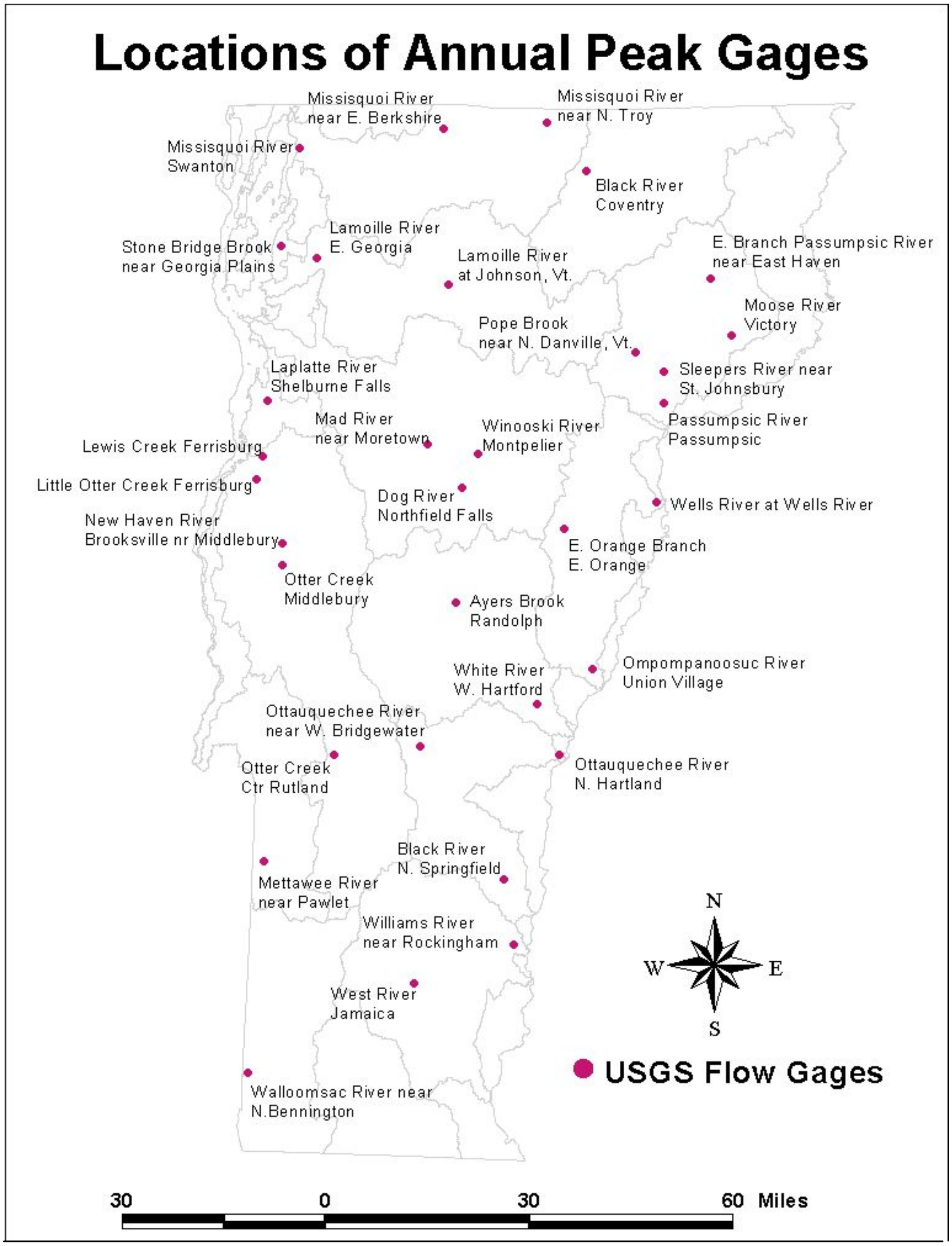
Flood History of Vermont Rivers

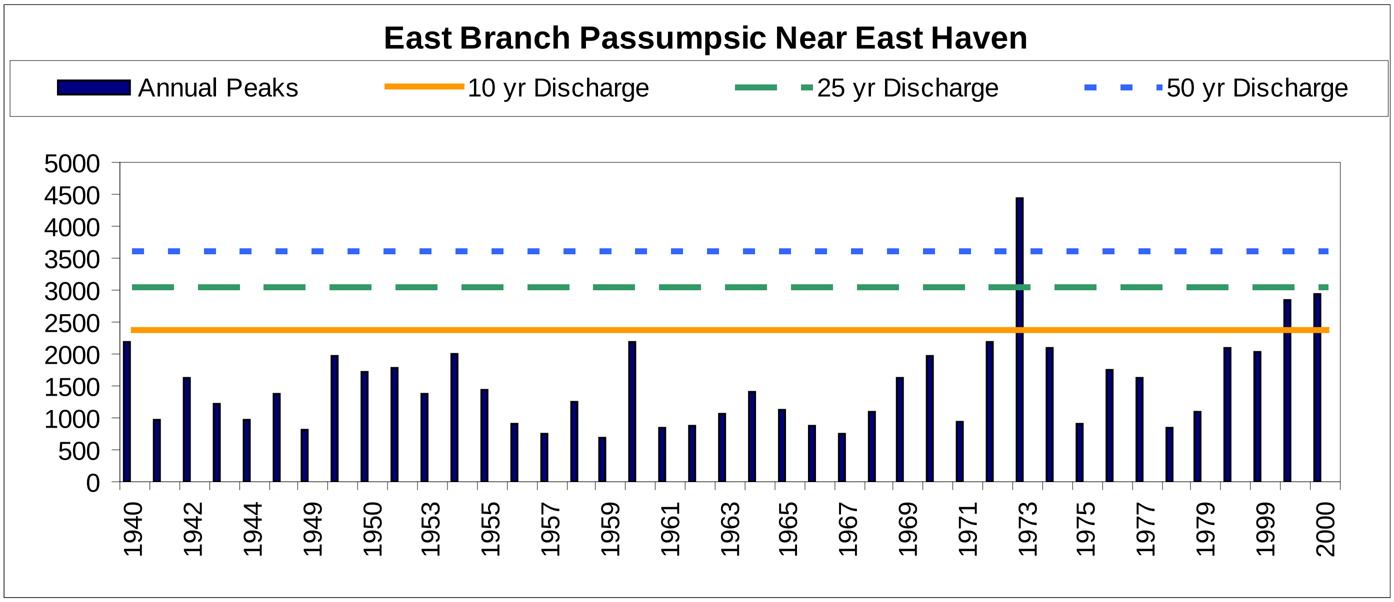
Vermont Agency of Natural Resources
April, 2004

Flood History of Vermont Rivers

Use the map of Vermont USGS river gage site to locate the gage nearest to the reach or site of interest. Then refer to the plots on the following pages to learn the history of floods during the period of record for each gage site. Reminders:

- Some gage sites are below dams that regulate flow which explains why large floods in these watershed did not result in a high flow recorded at the gage.
- Annual peak data used to generate these plots do not include more recent years.
- Annual Peak data from USGS and listed by that agency as provisional.
- Recurrence interval data taken from USGS (2002).
- Visit the USGS web page (listed at the end of this Appendix) for more information about the data used in this aapendix.

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1500
2000
2500
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4500
5000
1940
1942
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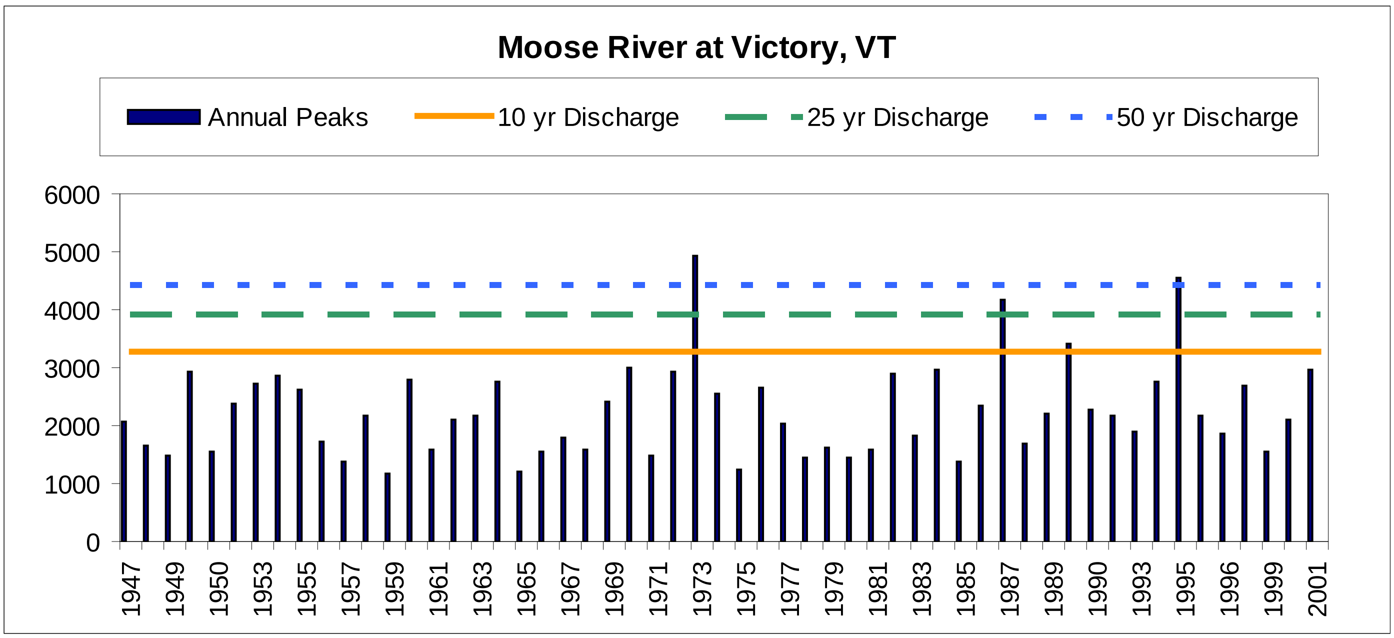
Moose River at Victory, VT
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1000
2000
3000
4000
5000
6000
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1953
1955
1957
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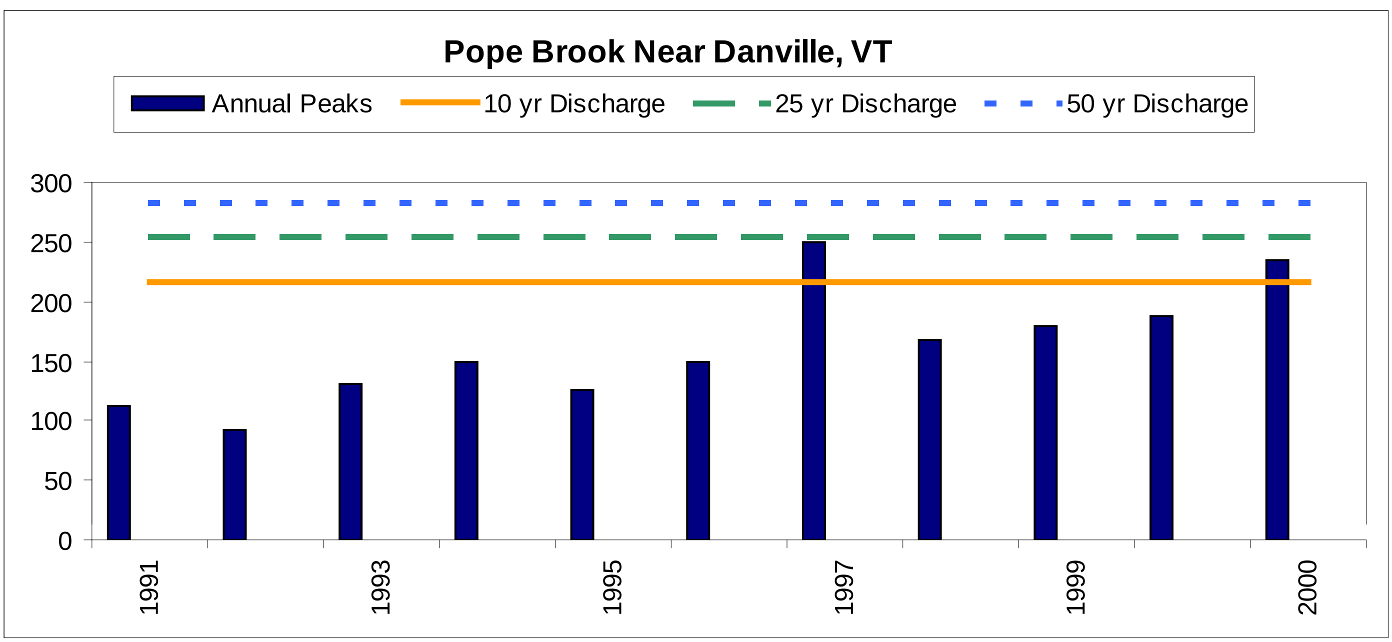
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1993
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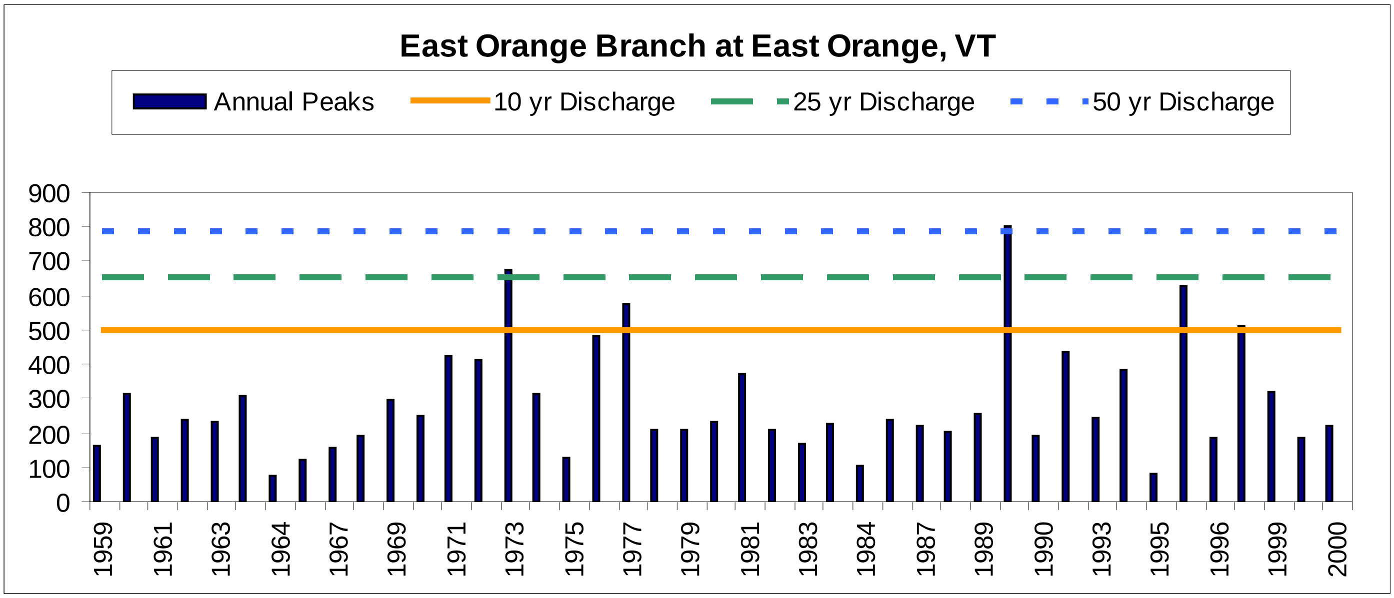
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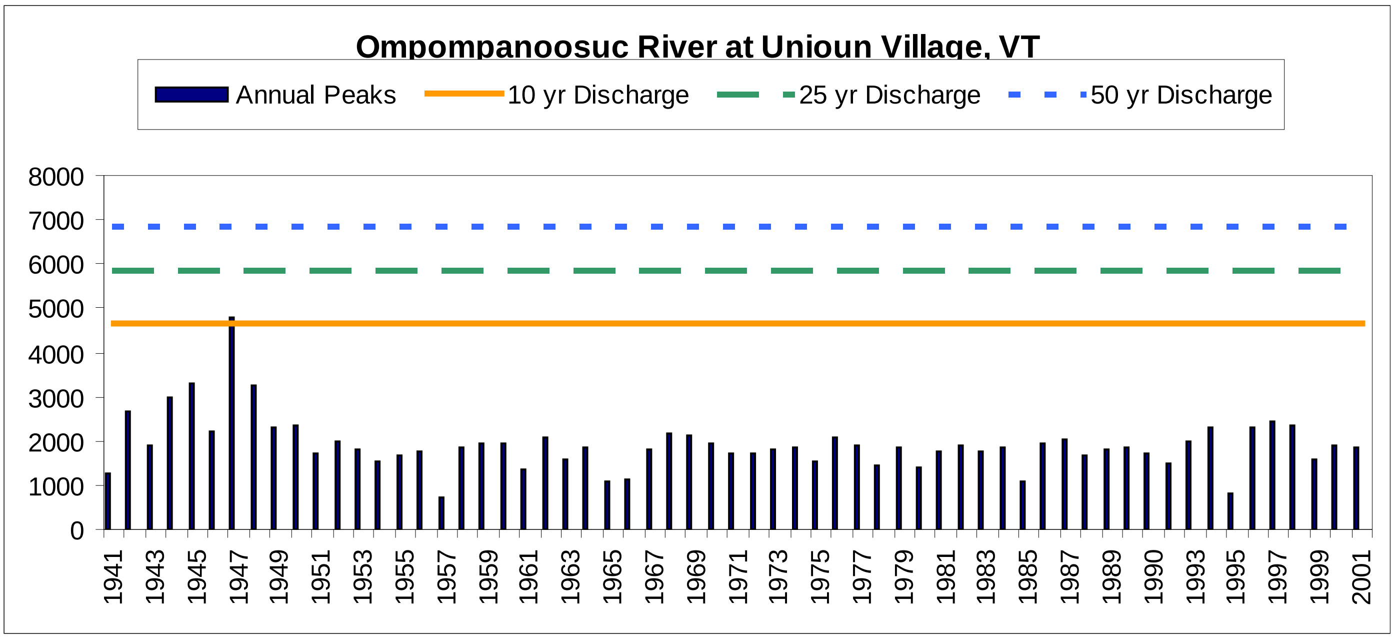
Ompompanoosuc River at Unioun Village, VT
Annual Peaks
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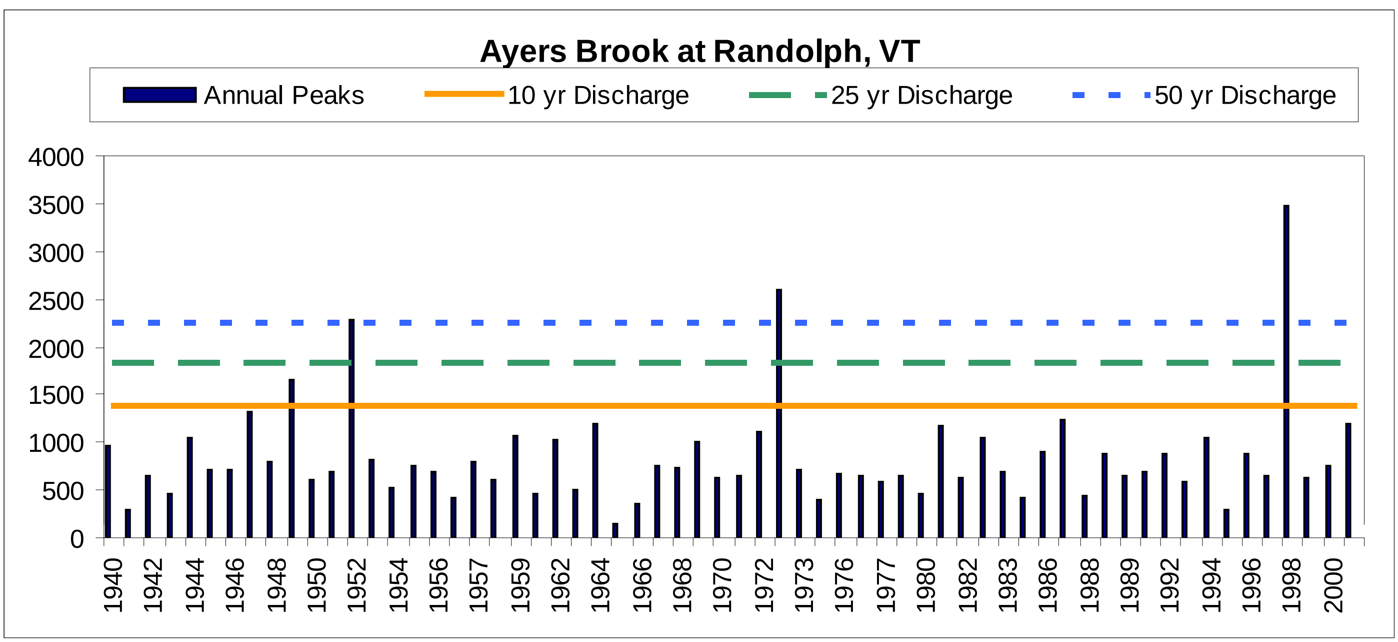
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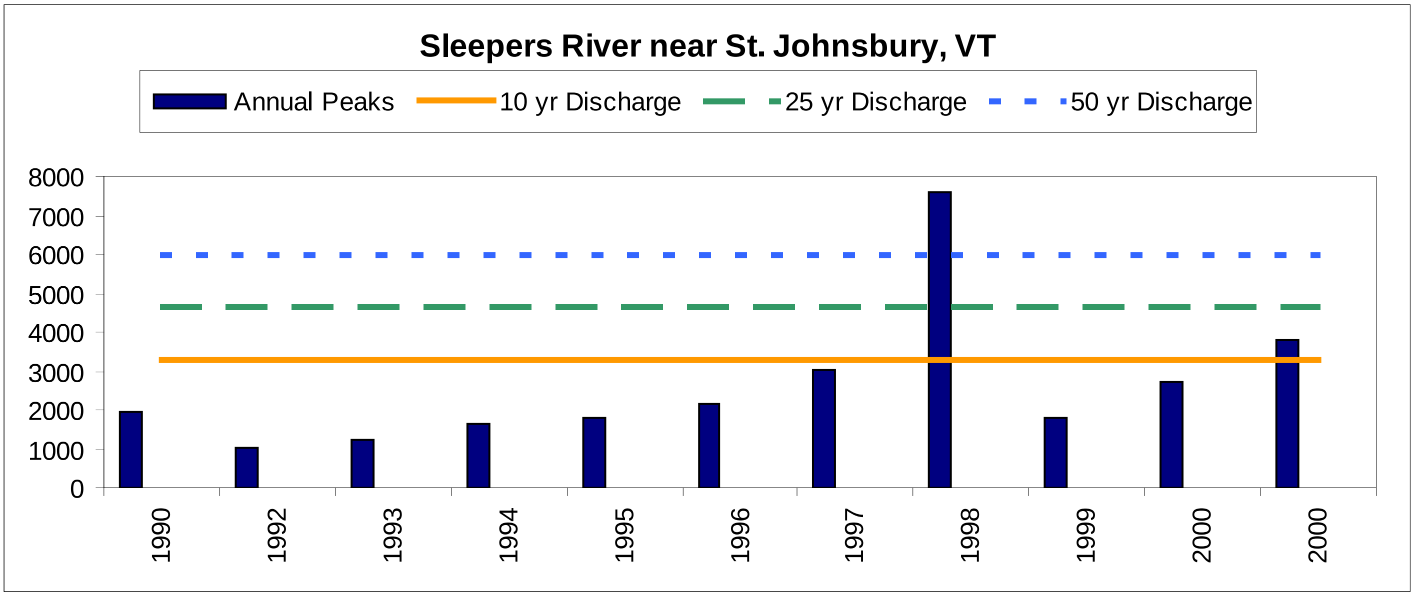
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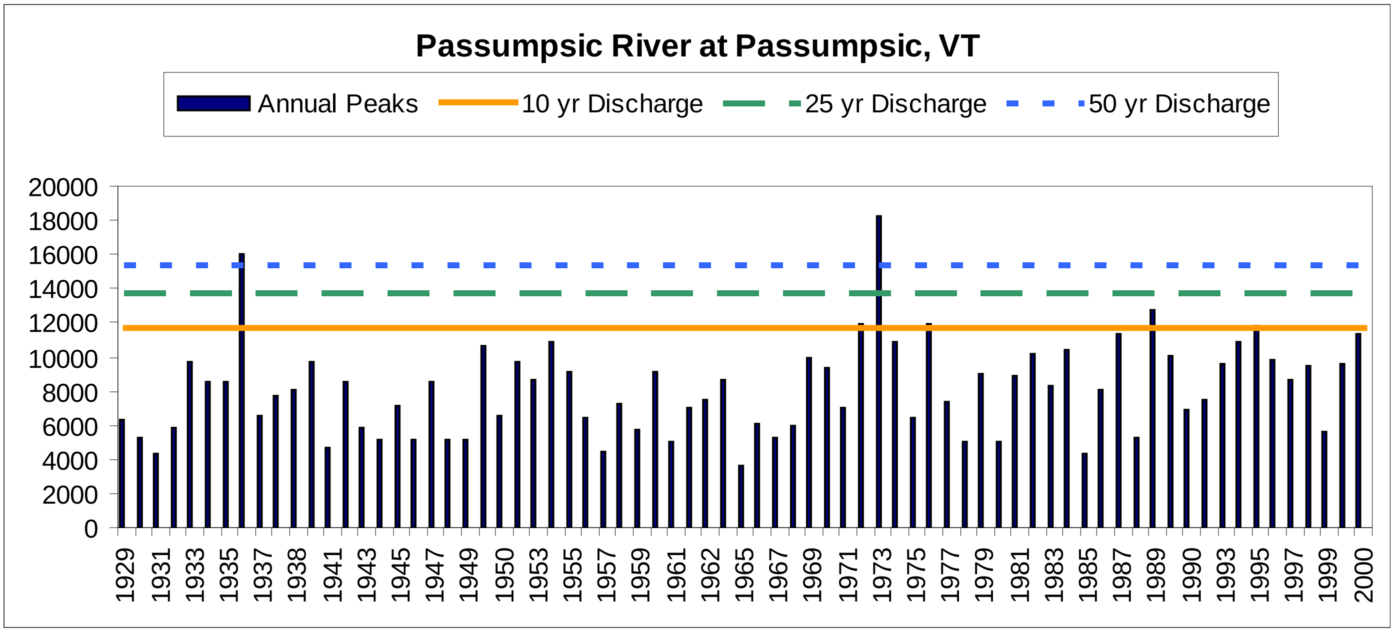
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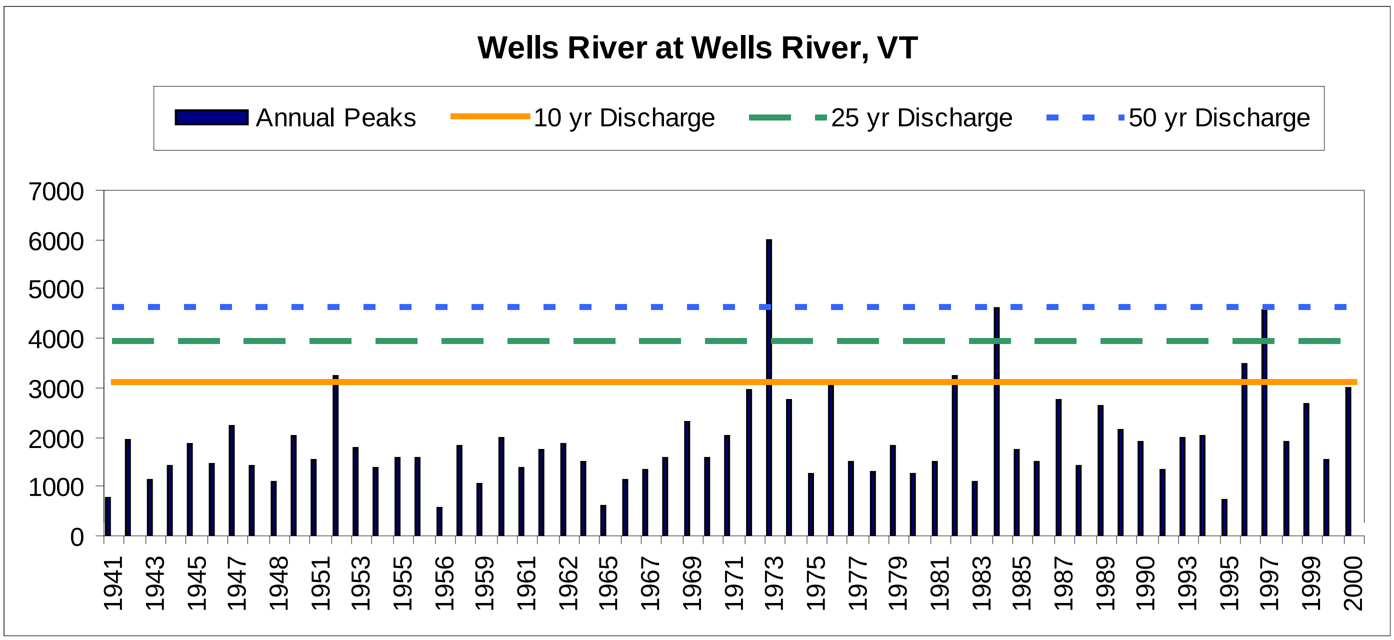
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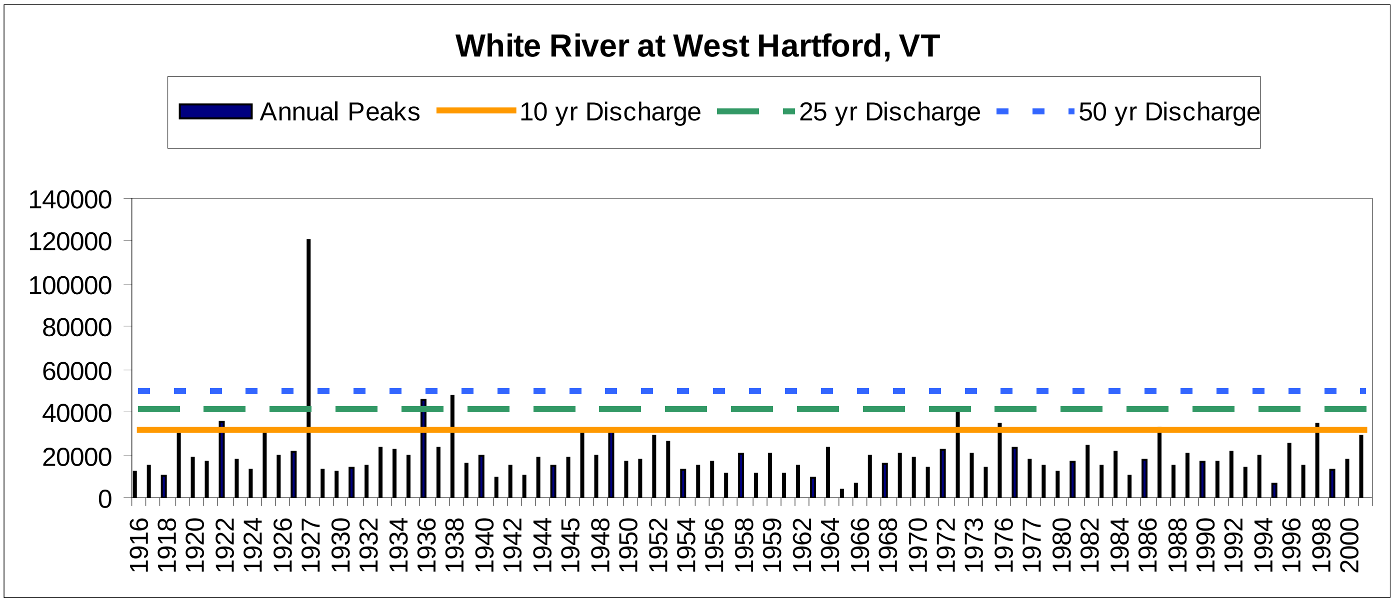
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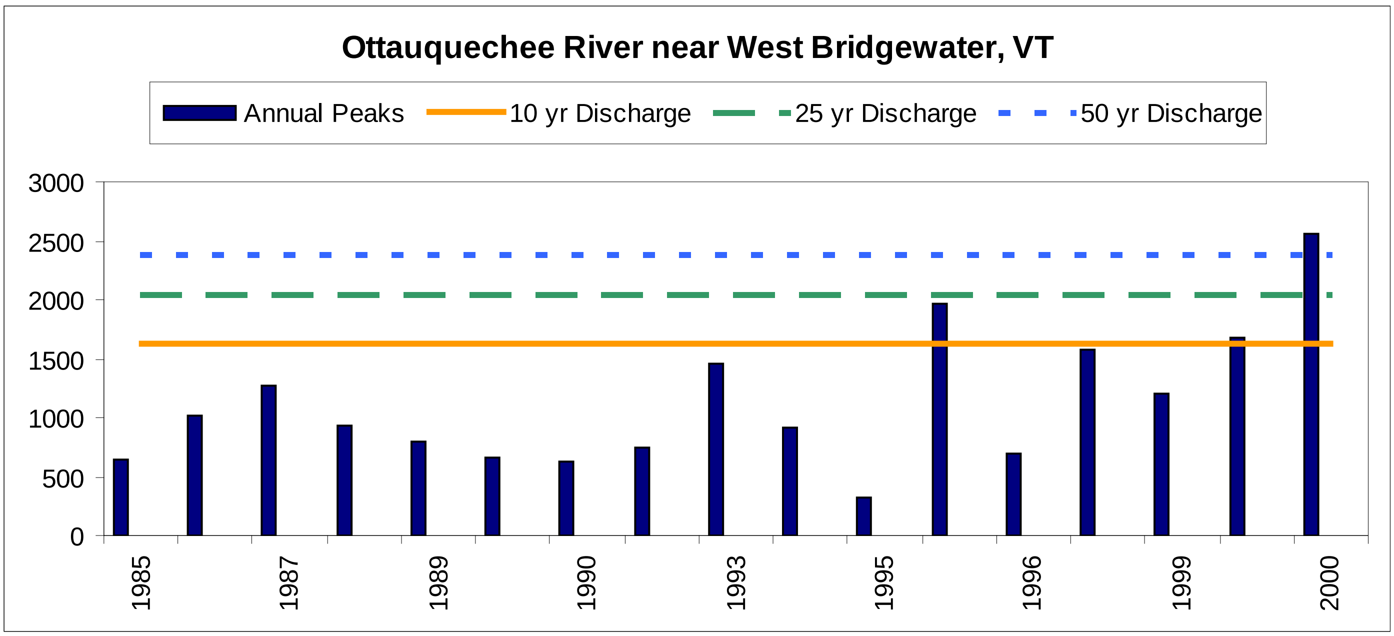
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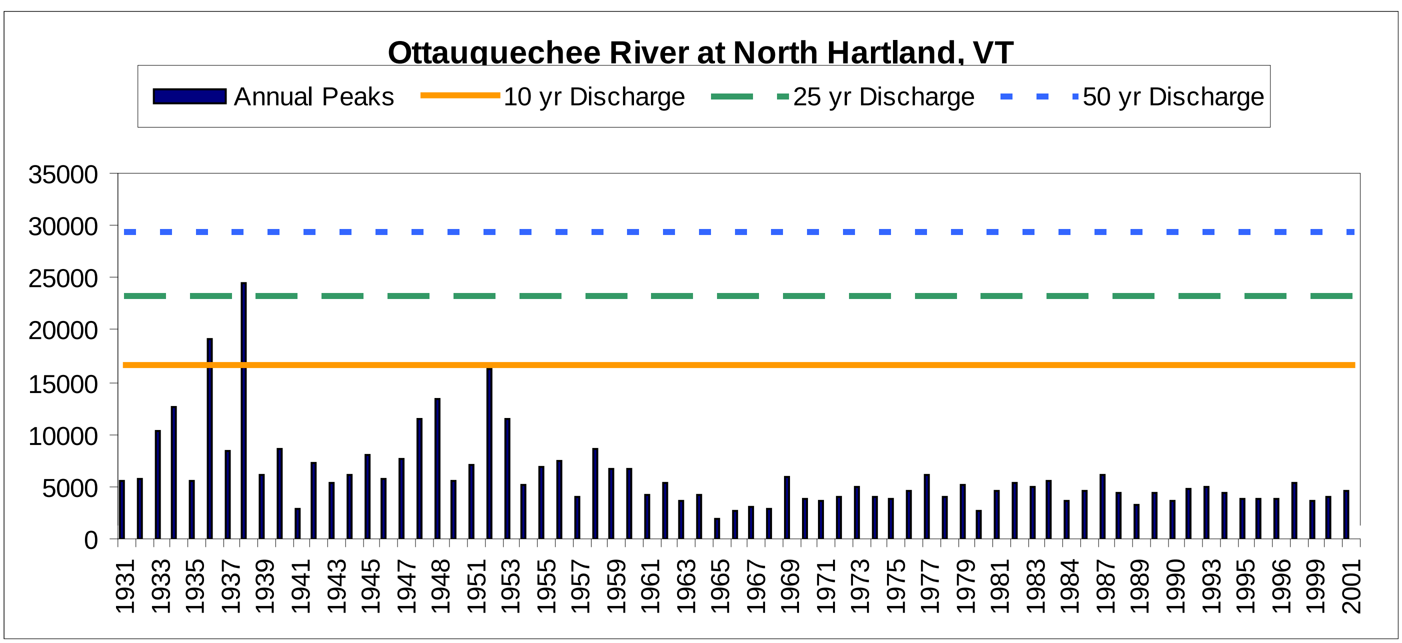
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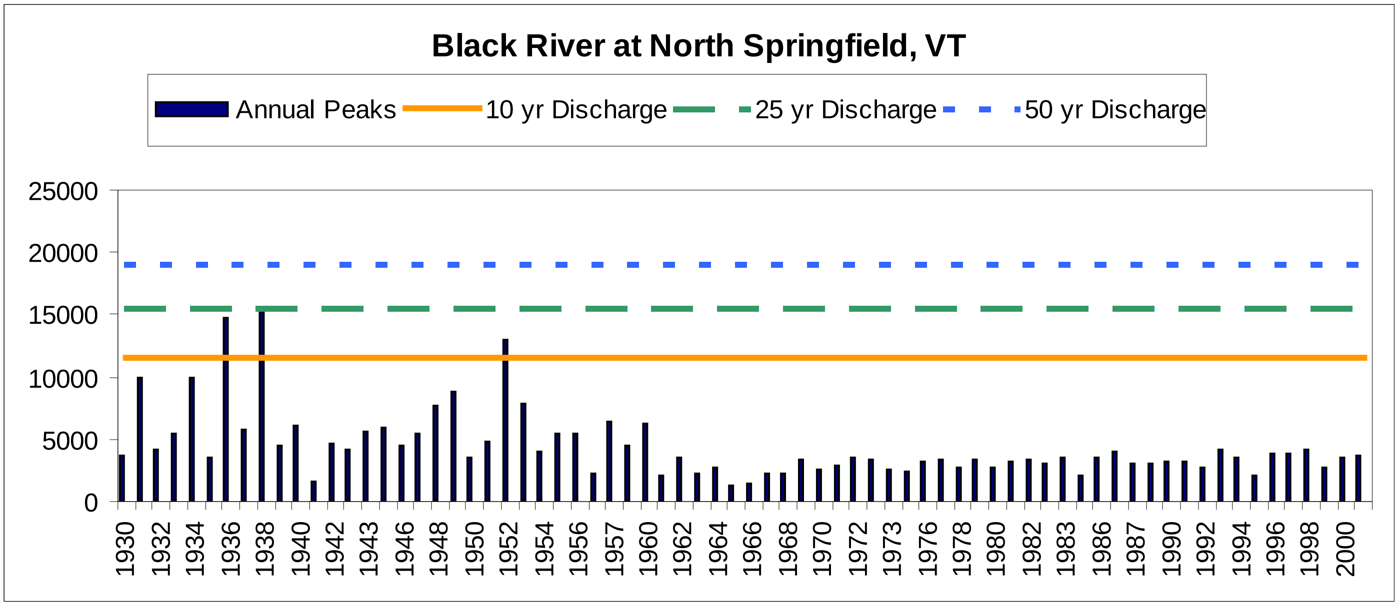
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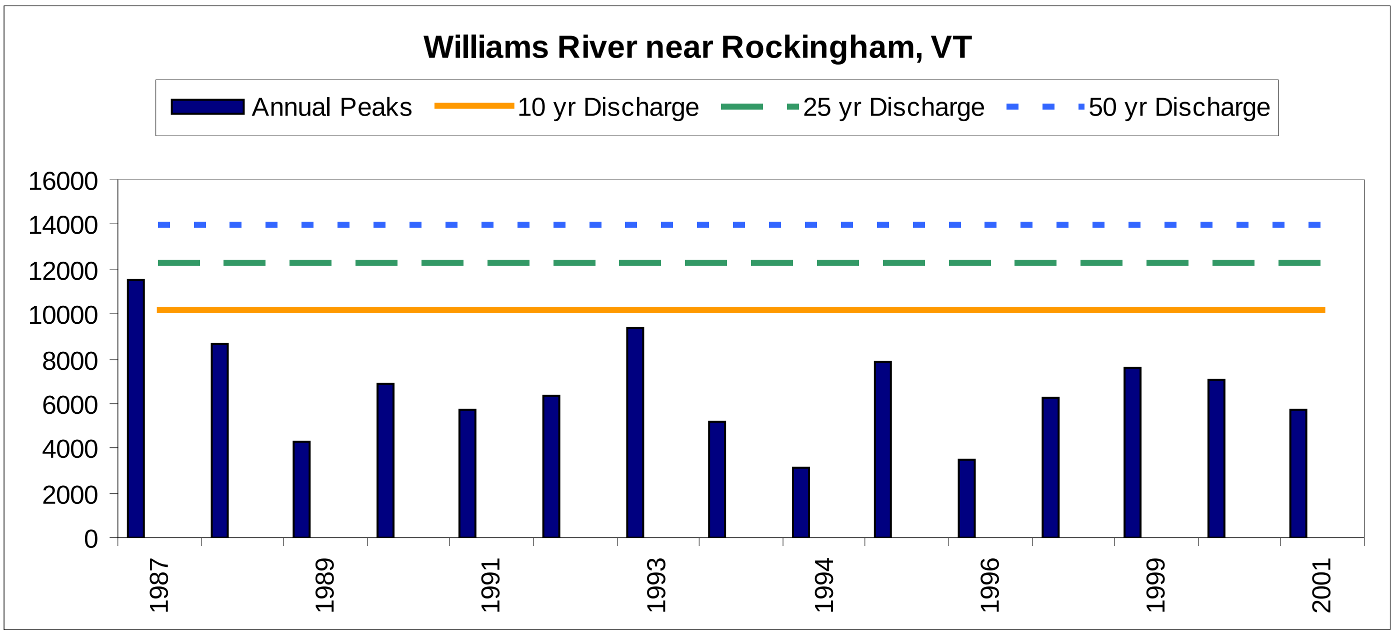
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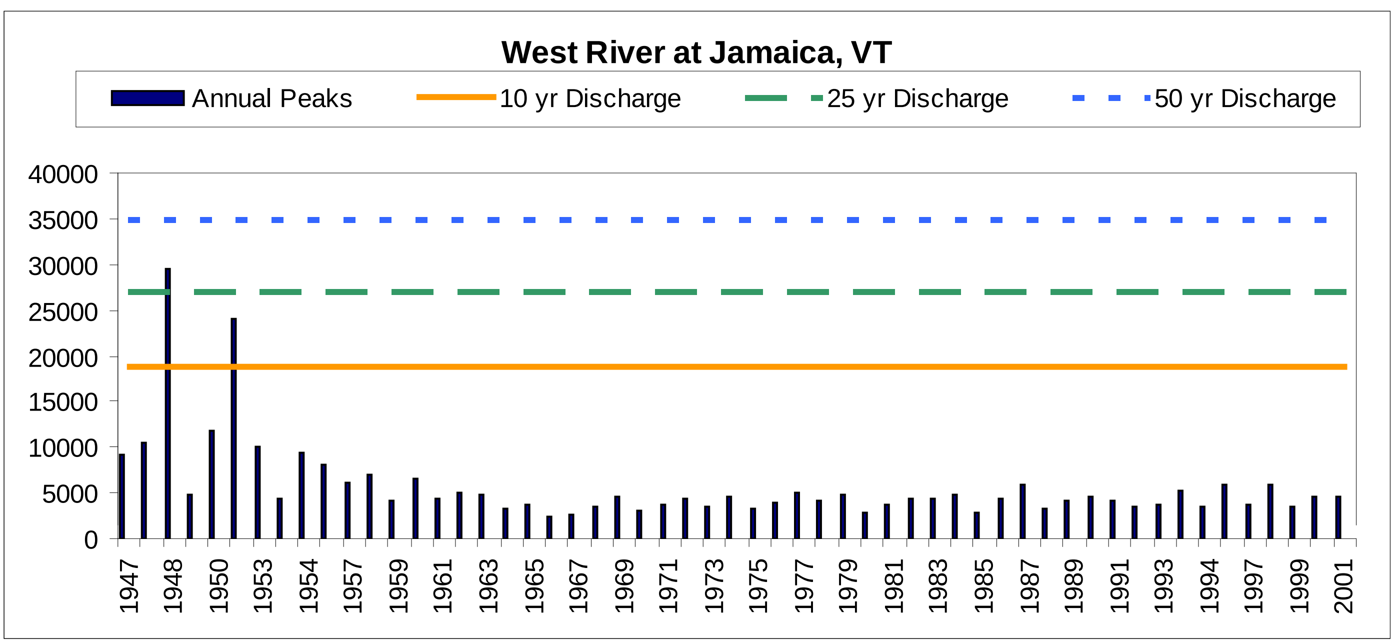
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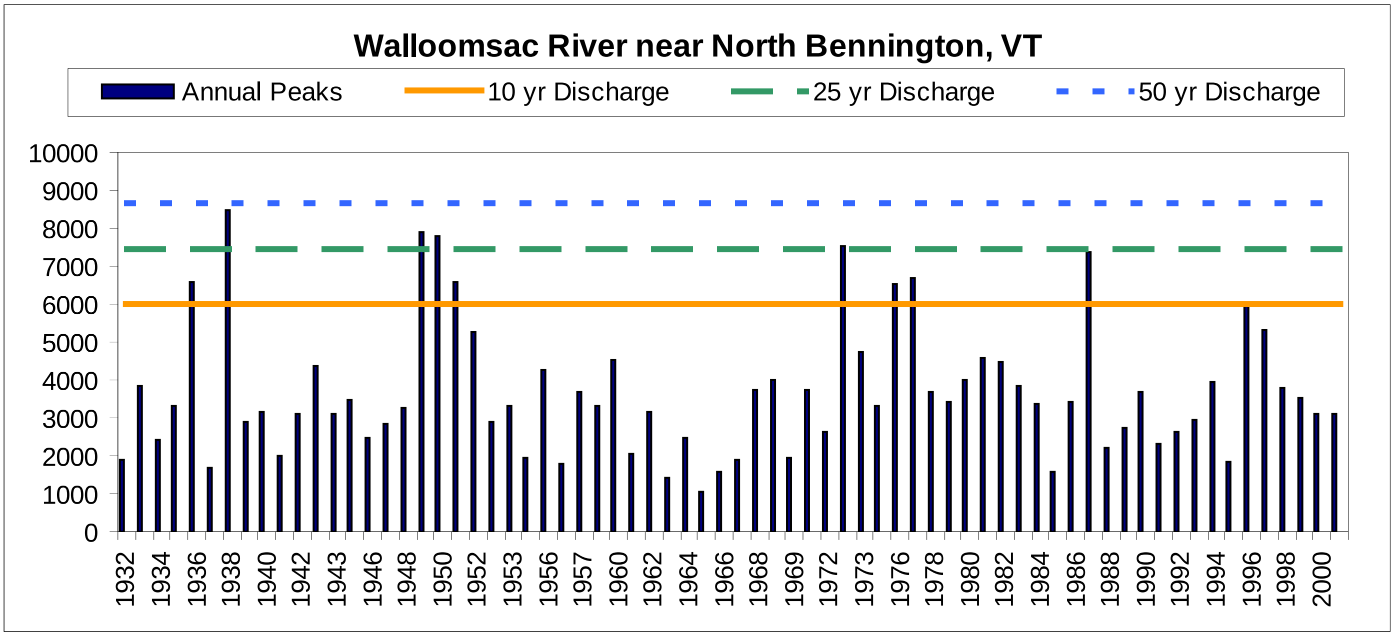
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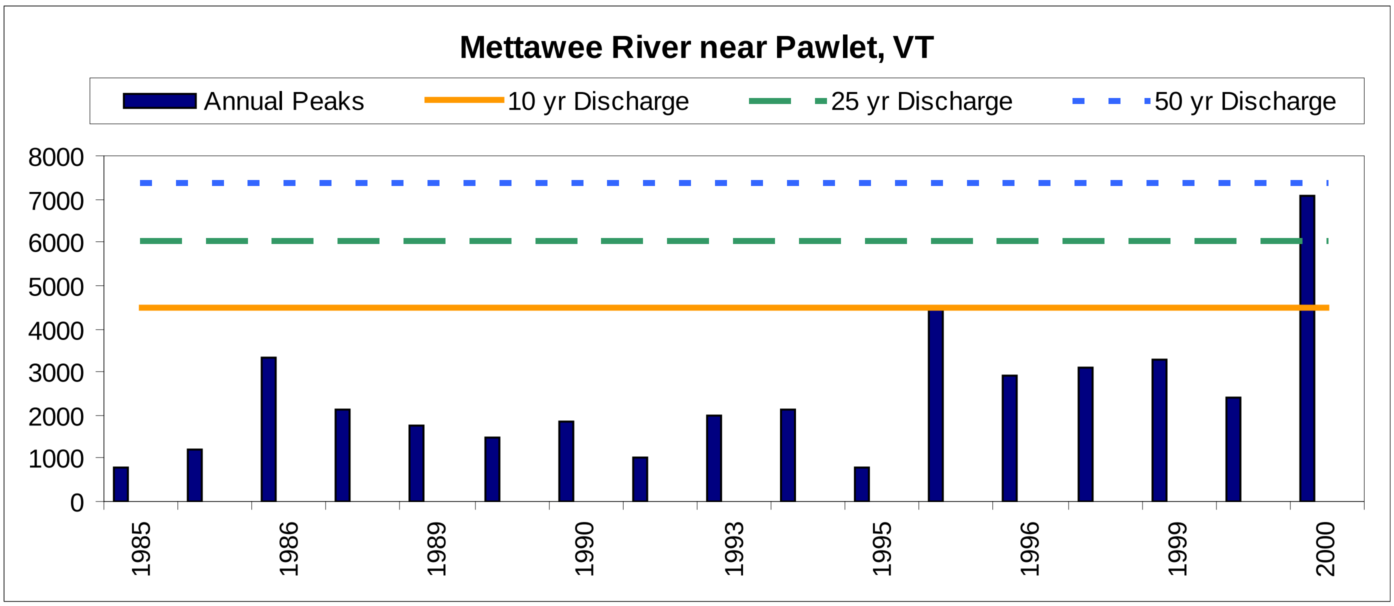
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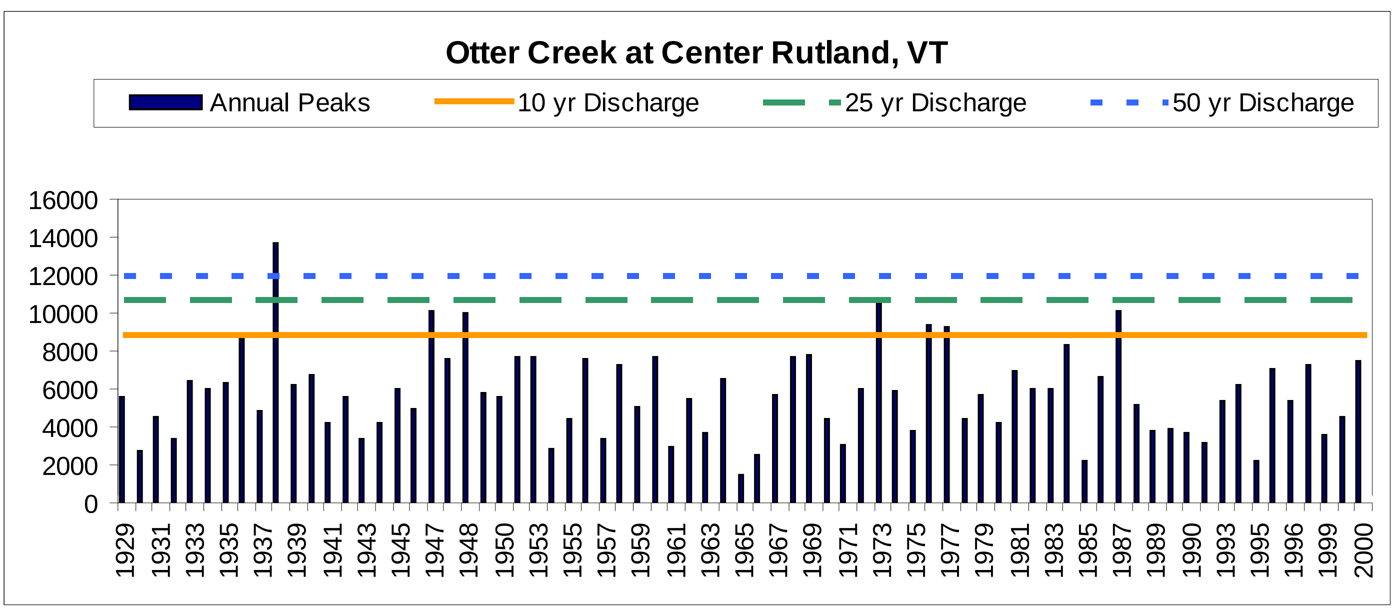
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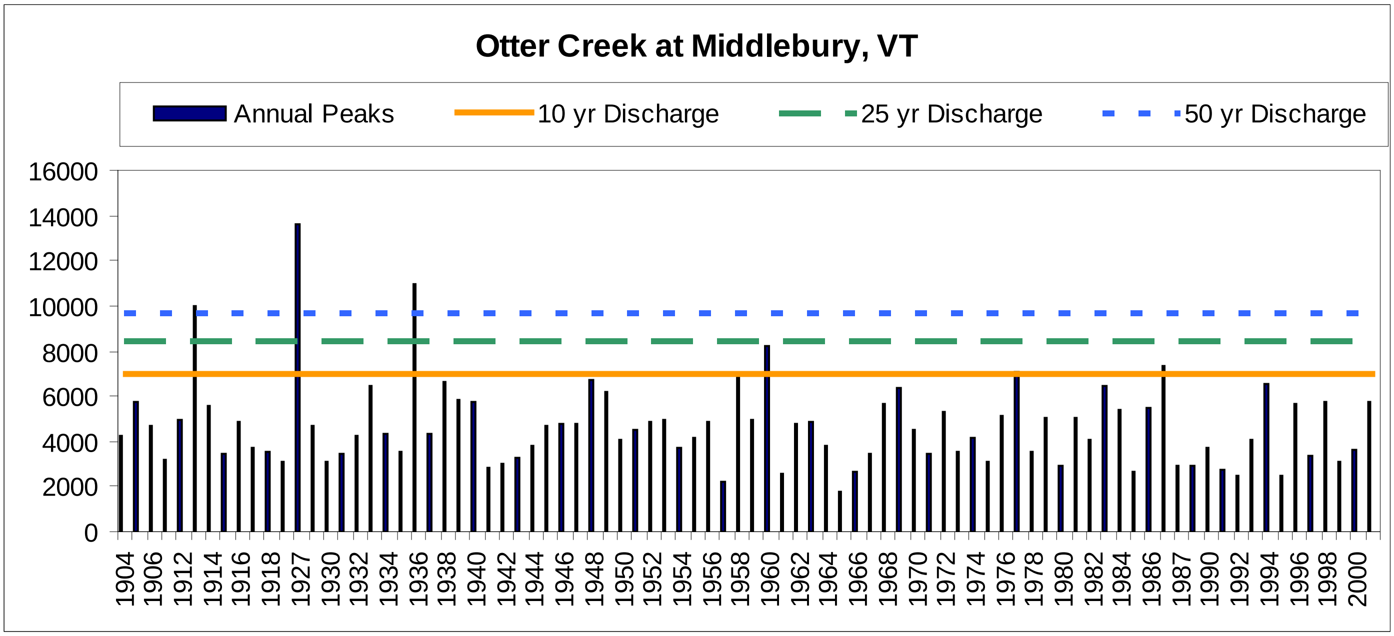
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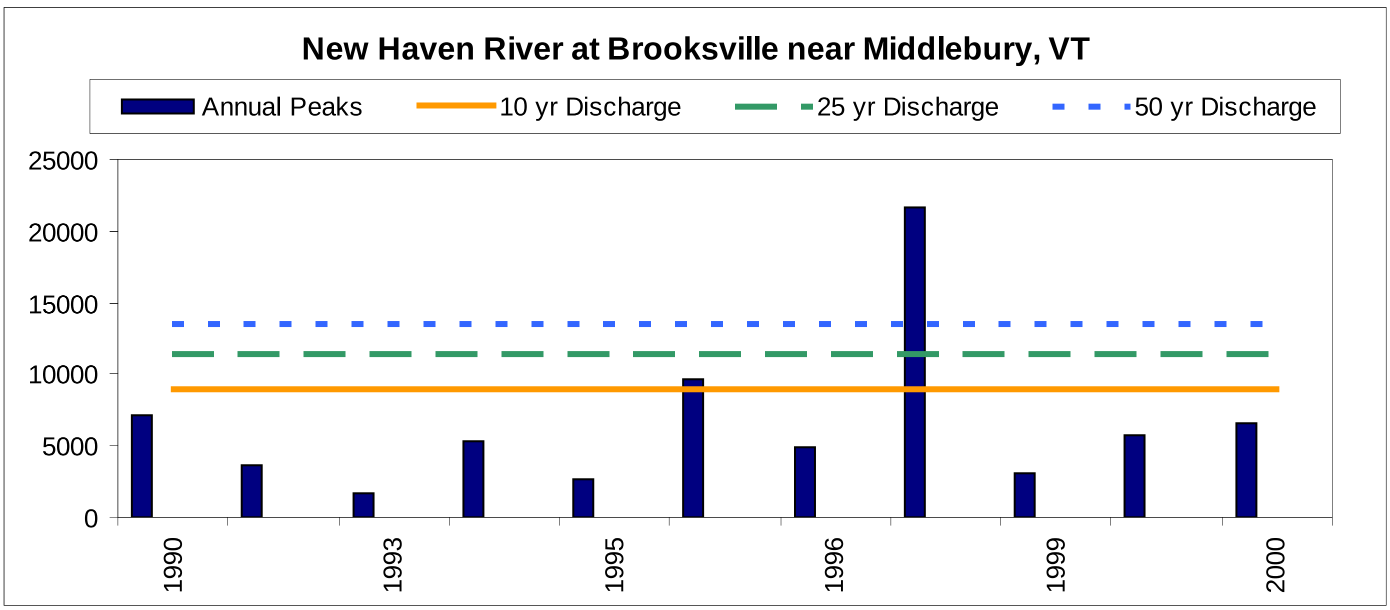
New Haven River at Brooksville near Middlebury, VT
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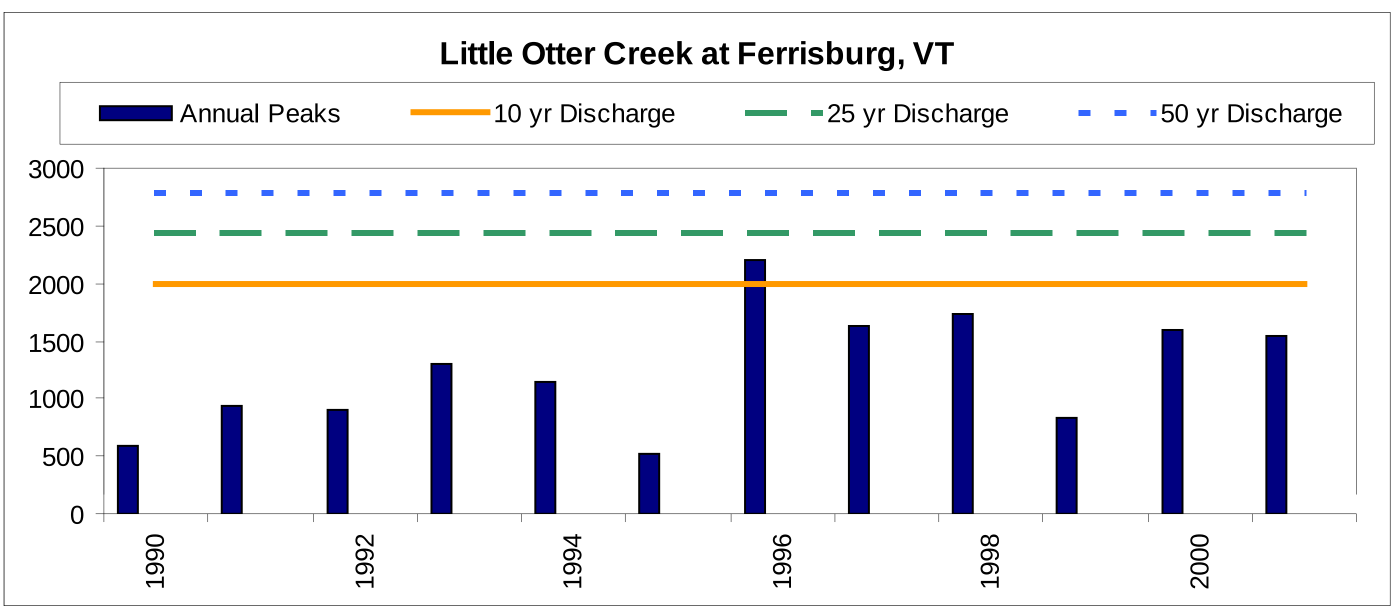
Little Otter Creek at Ferrisburg, VT
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1500
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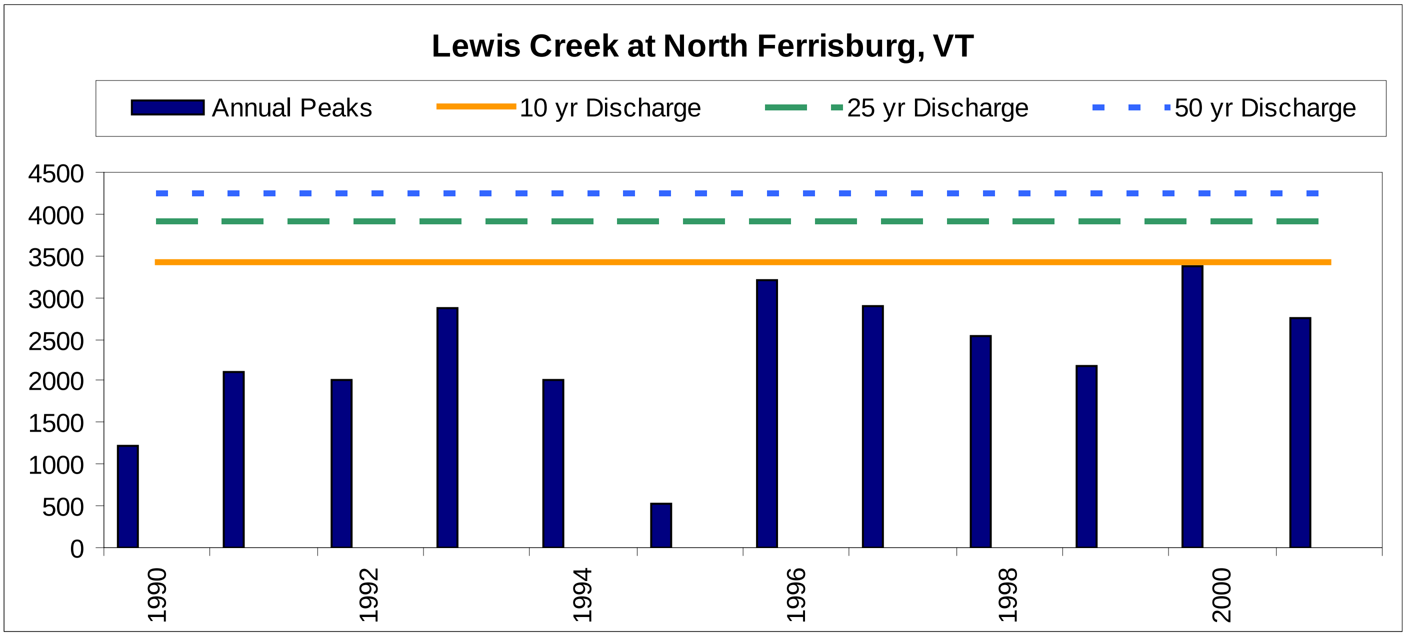
Lewis Creek at North Ferrisburg, VT
Annual Peaks
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1500
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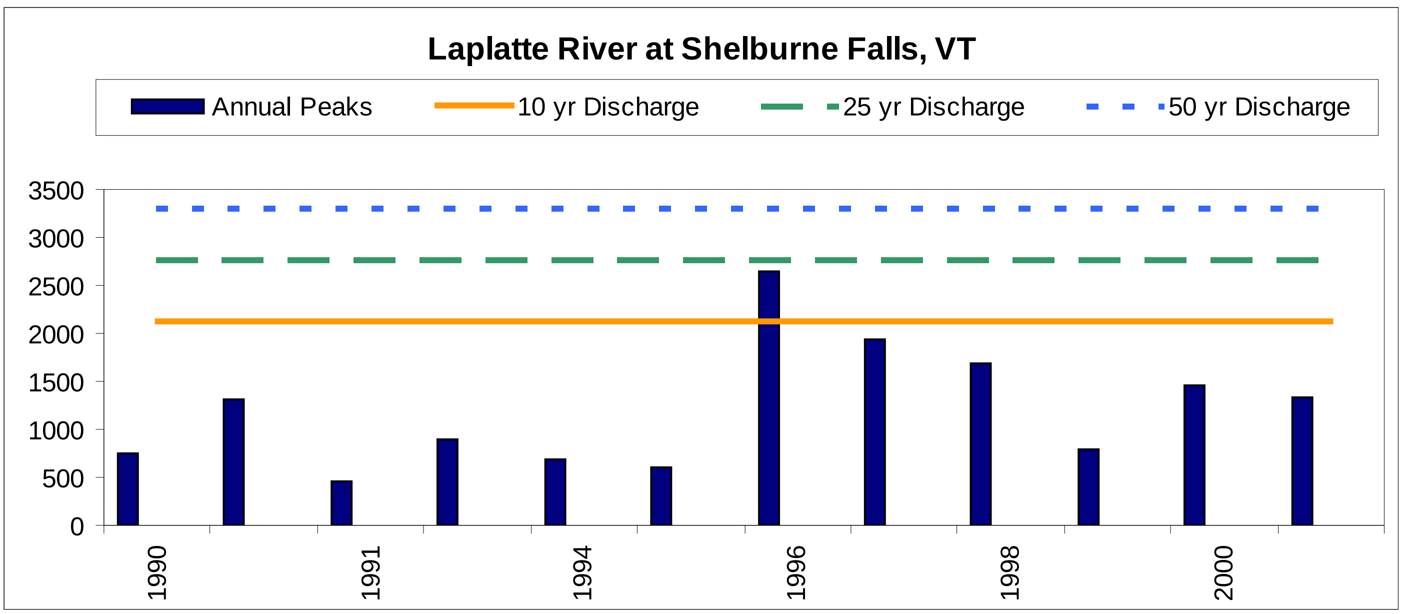
1992
1994
1996
1998
2000


Laplatte River at Shelburne Falls, VT
Annual Peaks
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1991
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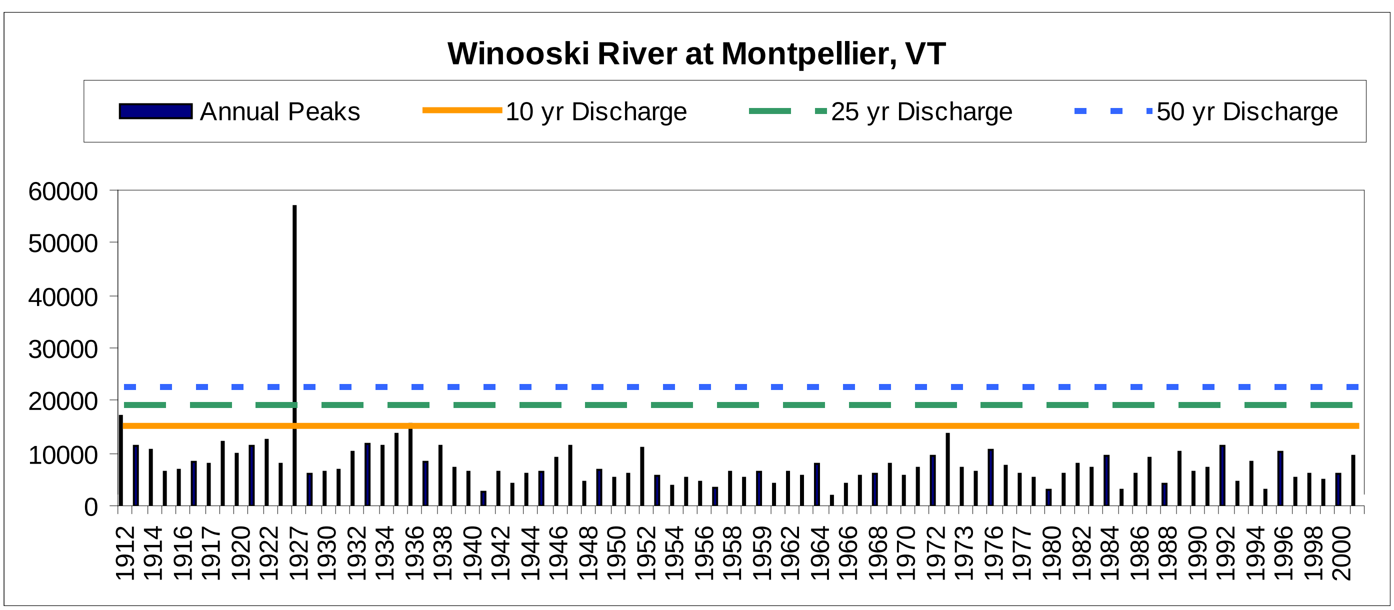
Winooski River at Montpellier, VT
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40000
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0
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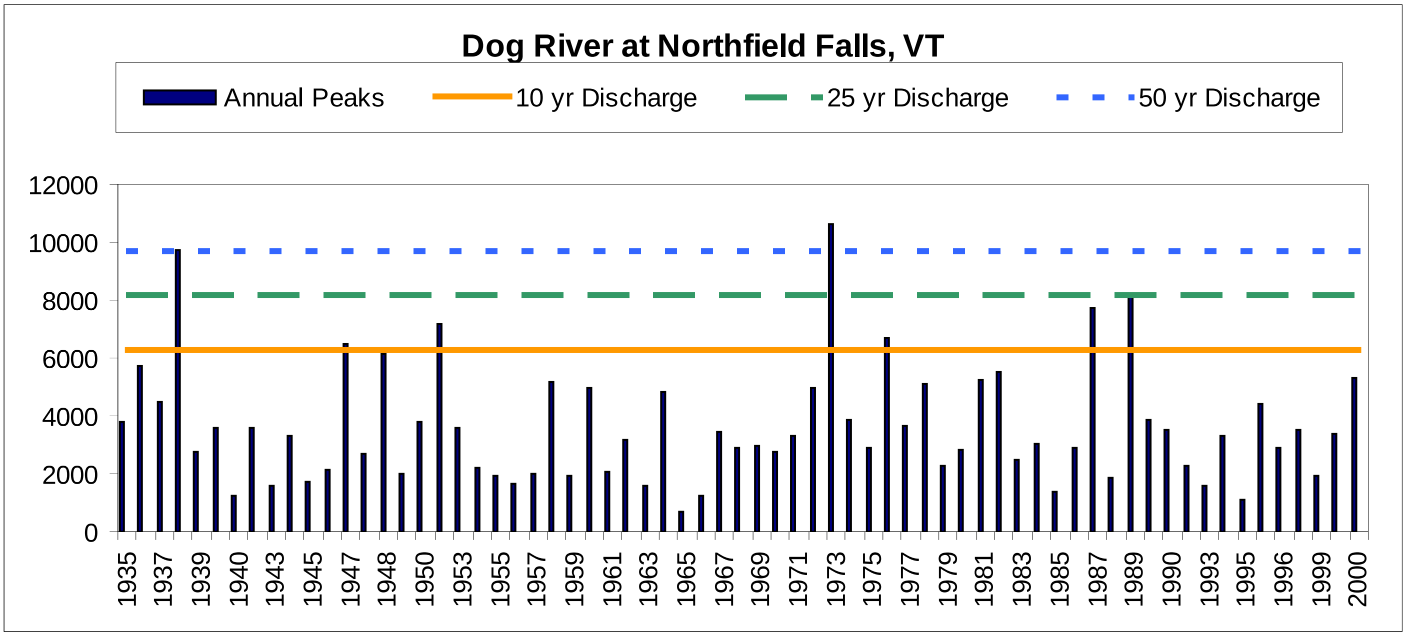
Dog River at Northfield Falls, VT
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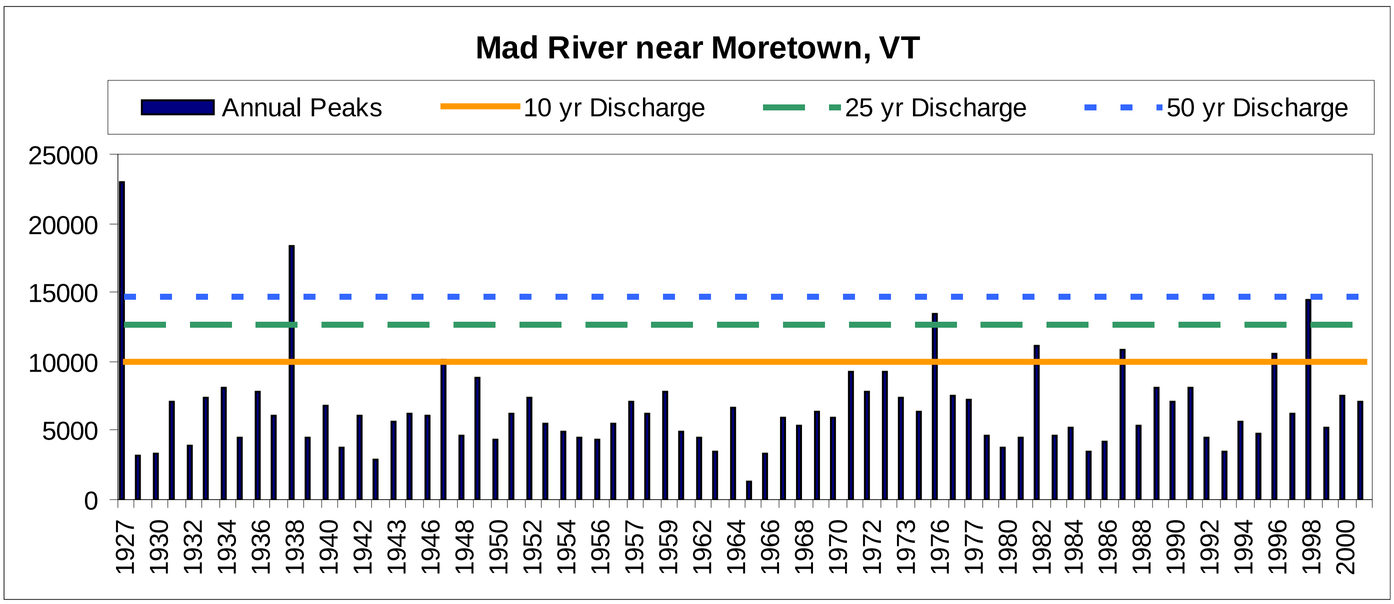
Mad River near Moretown, VT
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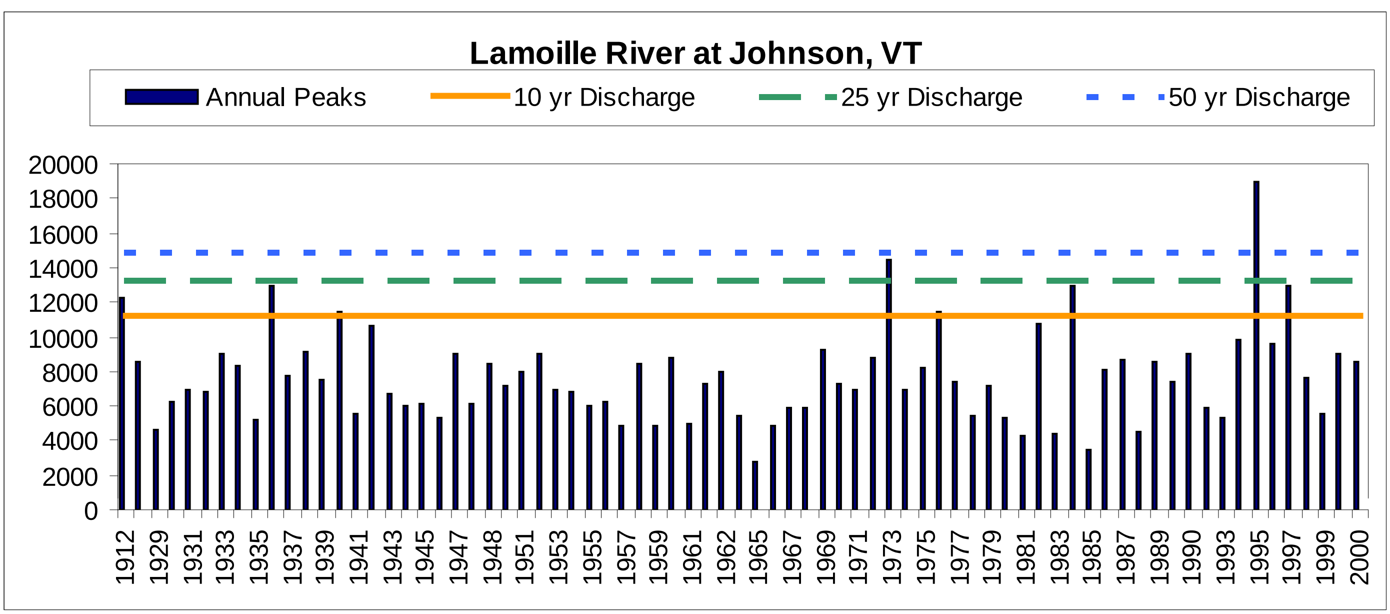
Lamoille River at Johnson, VT
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16000
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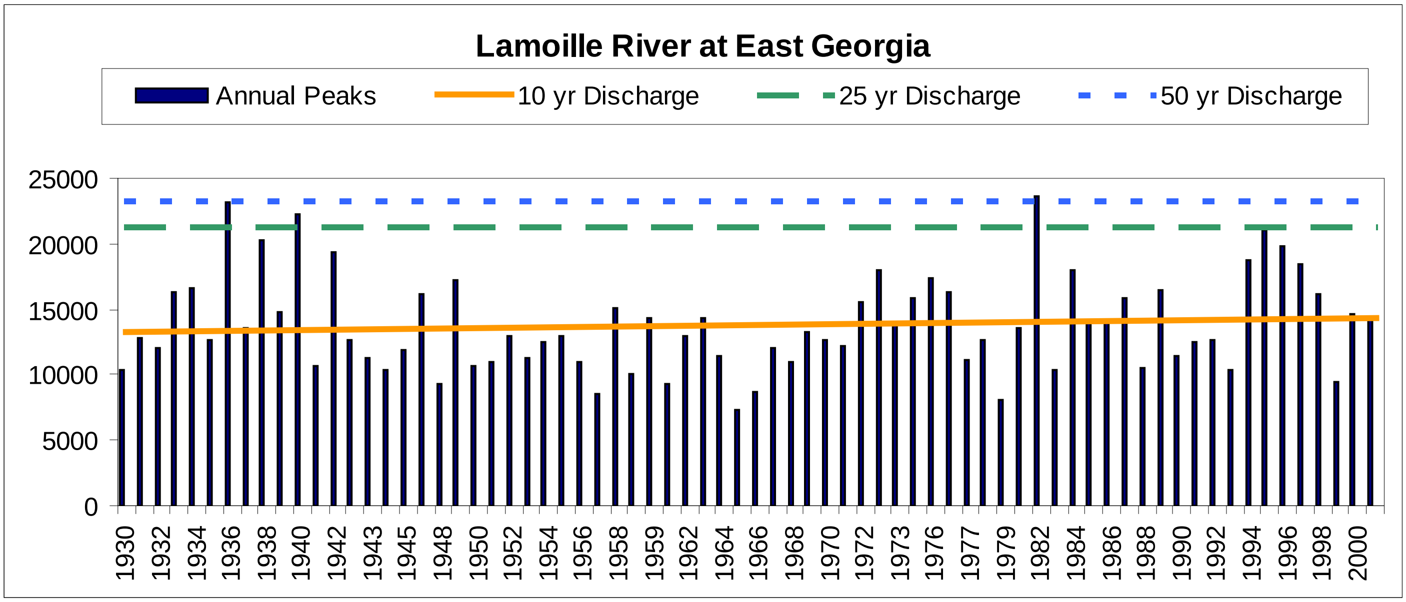
Lamoille River at East Georgia
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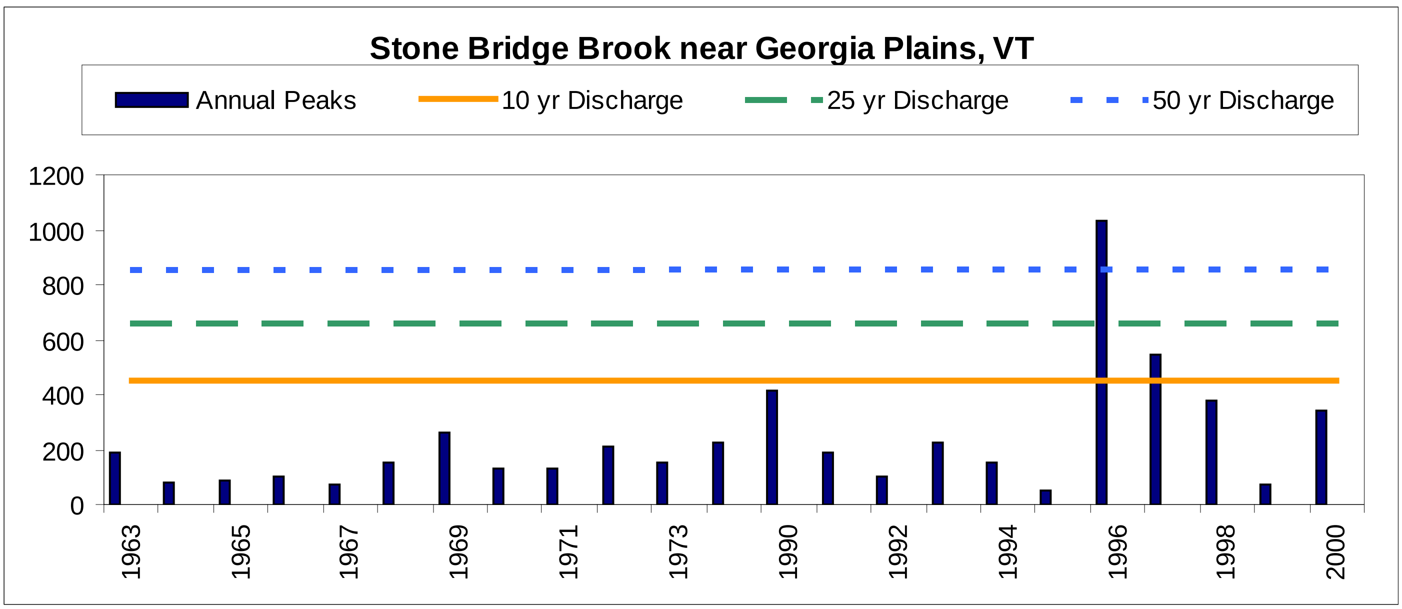
Stone Bridge Brook near Georgia Plains, VT
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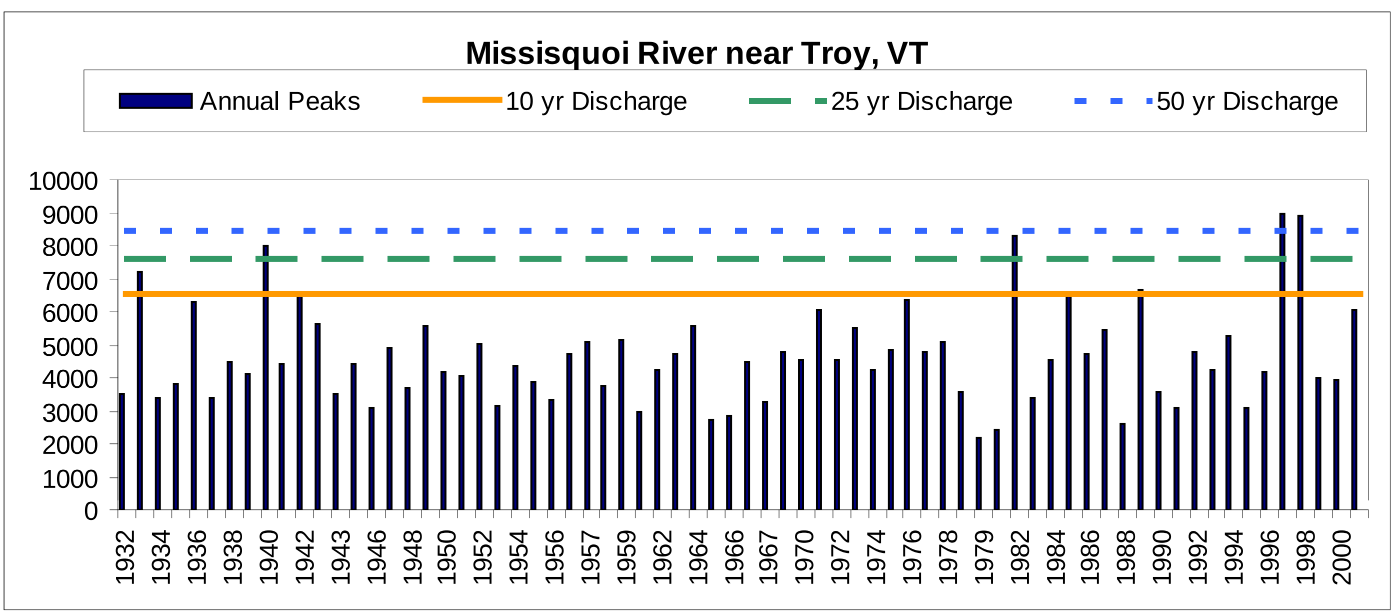
Missisquoi River near Troy, VT
Annual Peaks
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50 yr Discharge
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9000
8000
7000
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3000
2000
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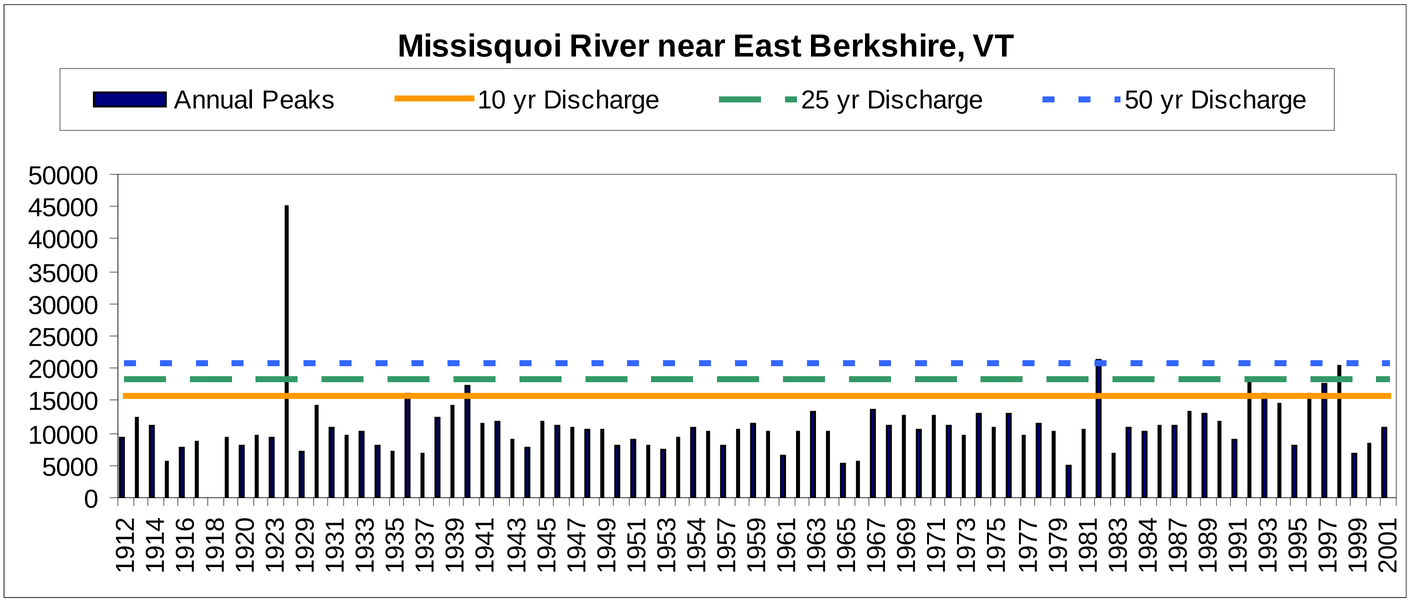
Missisquoi River near East Berkshire, VT
Annual Peaks
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25 yr Discharge
50 yr Discharge
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45000
40000
35000
30000
25000
20000
15000
10000
5000
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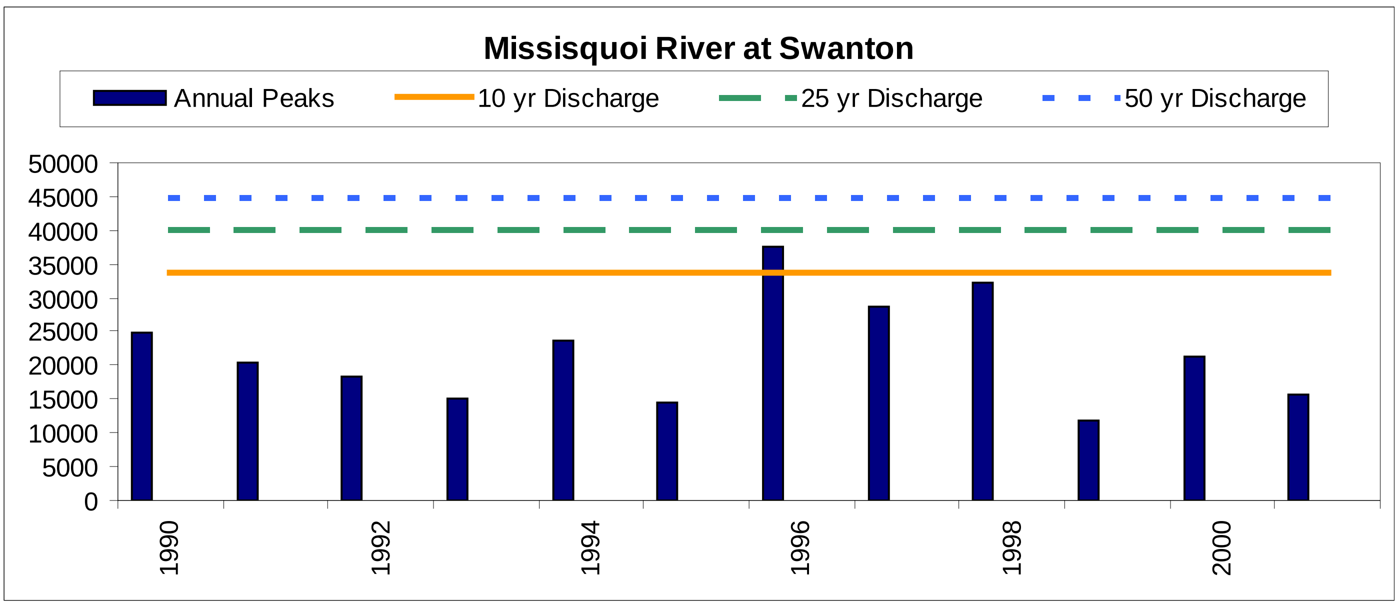
Missisquoi River at Swanton
Annual Peaks
10 yr Discharge
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45000
40000
35000
30000
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20000
15000
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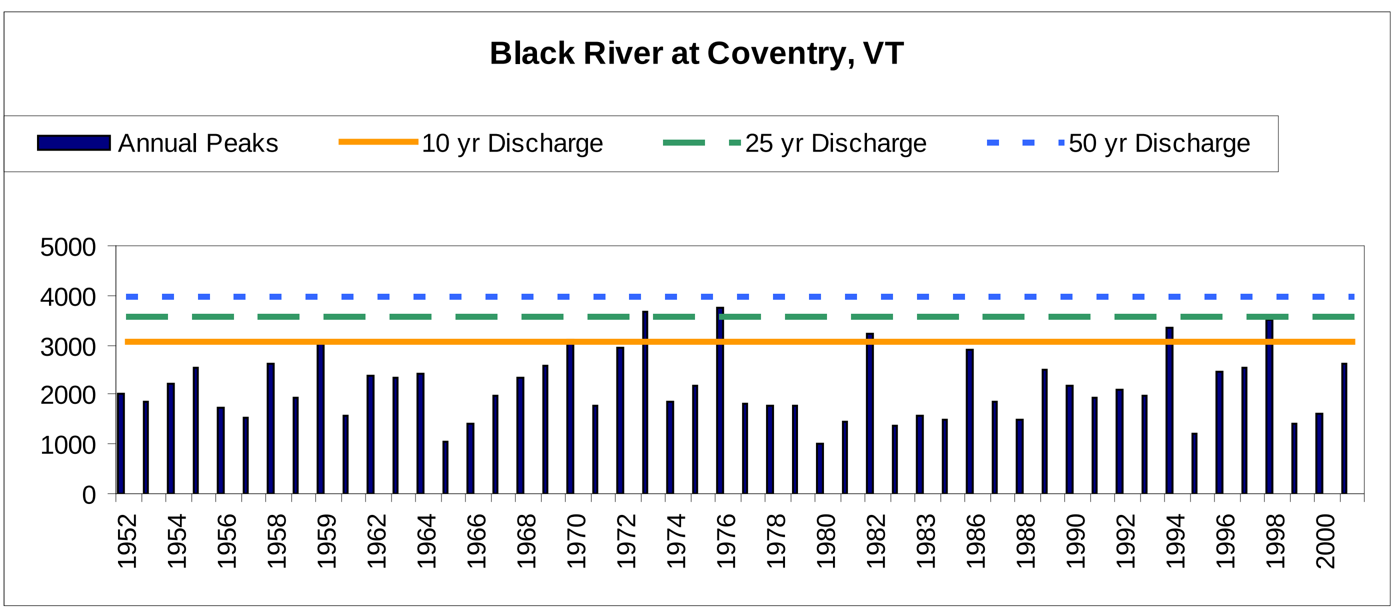
1990 1992 1994 1996 1998 2000


Black River at Coventry, VT
Annual Peaks
10 yr Discharge
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50 yr Discharge
5000
4000
3000
2000
1000
0
1952 1954 1956 1958 1959 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980 1982 1983 1986 1988 1990 1992 1994 1996 1998 2000

Web page links to Vermont Hydrology Data

Use the following web sites to obtain other facts and data related to the hydrology of Vermont rivers and streams:

Vermont River Gages

http://waterdata.usgs.gov/vt/nwis/sw

Interactive Climate Map for the State of Vermont

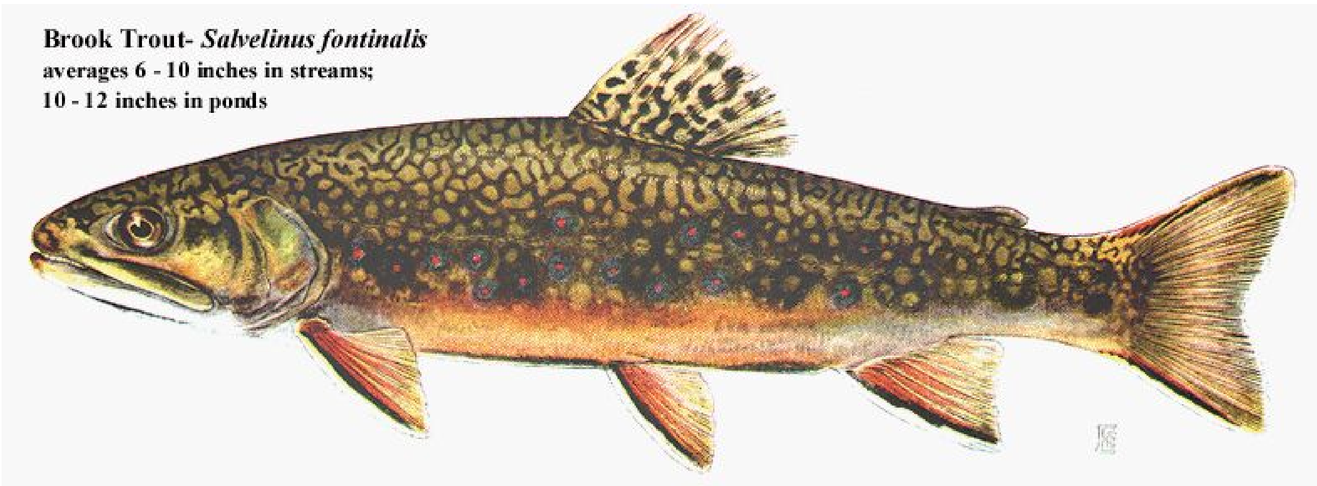
http://academics.smcvt.edu/vtgeographic/textbook/map_images/Vermont_map_precipitation.htm

Flow Frequency Characteristics of Vermont Streams

http://pubs.water.usgs.gov/ofr02494/

Vermont Stream Geomorphic Assessment

Appendix Q



Glossary of Terms

Vermont Agency of Natural Resources
April, 2004

Glossary of Terms

Adapted from:
ERDC TN-EMRRP-SR-01 1
Glossary of Stream Restoration Terms
by Craig Fischenich.. February 2000
USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180

OVERVIEW
Following is a glossary of terms commonly used in stream geomorphic assessment.

TERMS
Acre -- A measure of area equal to 43,560 ft 2(4,046.87 m2). One square mile equals 640 acres.
Adjustment process --or type of change, that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)
Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.
Algae -- Microscopic plants that grow in sunlit water containing phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain.
Alluvial -- Deposited by running water.
Alluvium -- A general term for detrital deposits make by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.
Anadromous -- Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn.
Aquatic ecosystem -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.
Armoring -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth.
Augmentation (of stream flow) – Increasing flow under normal conditions, by releasing storage water from reservoirs.
Avulsion -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.
Backwater -- (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.
Backwater pool -- A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.
Bank stability -- The ability of a streambank to counteract erosion or gravity forces.
Bankfull channel depth -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.
Bankfull channel width -- The top surface width of a stream channel when flowing at a bank-full discharge.
Bankfull discharge -- The stream discharge corresponding to the water stage that first overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years.
Bankfull width -- The width of a river or stream channel between the highest banks on either side of a stream.
Bar -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.

Barrier -- A physical block or impediment to the movement or migration of fish, such as a waterfall (natural barrier) or a dam (man-made barrier).
Base flow -- The sustained portion of stream discharge that is drawn from natural storage sources, and not affected by human activity or regulation.
Bed load -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.
Bed material -- The sediment mixture that a streambed is composed of.
Bed material load -- That portion of the total sediment load with sediments of a size found in the streambed.
Bed roughness -- A measure of the irregularity of the streambed as it contributes to flow resistance. Commonly expressed as a Manning "n" value.
Bed slope -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.
Benthic invertebrates -- Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples: clams, crayfish, and a wide variety of worms.
Berms -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.
Biota -- All living organisms of a region, as in a stream or other body of water.
Boulder -- A large substrate particle that is larger than cobble, 256 mm in diameter.
Braided channel -- A stream characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.
Braiding (of river channels) -- Successive division and rejoining of riverflow with accompanying islands.
Buffer strip -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.
Canopy -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand. Leaves, branches and vegetation that are above ground and/or water that provide shade and cover for fish and wildlife.
Cascade -- A short, steep drop in streambed elevation often marked by boulders and agitated white water.
Catchment -- (1) The catching or collecting of water, especially rainfall. (2) A reservoir or other basin for catching water. (3) The water thus caught. (4) A watershed.
Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.
Channelization -- The process of changing (usually straightening) the natural path of a waterway.
Clay -- Substrate particles that are smaller than silt and generally less than 0.003 mm in diameter.
Coarse woody debris (CWD) -- Portion of a tree that has fallen or been cut and left in the woods. Usually refers to pieces at least 20 in. in diameter.
Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally 64-256 mm in diameter. Can be further classified as small and large cobble.
Confluence -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.
Conifer -- A tree belonging to the order Gymnospermae, comprising a wide range of trees that are mostly evergreens. Conifers bear cones (hence, coniferous) and have needle-shaped or scalelike leaves.
Conservation -- The process or means of achieving recovery of viable populations.
Contiguous habitat -- Habitat suitable to support the life needs of a species that is distributed continuously or nearly continuously across the landscape.

Cover – "cover" is the general term used to describe any structure that provides refugia for fish, reptiles or amphibians. These animals seek cover to hide from predators, to avoid warm water temperatures, and to rest, by avoiding higher velocity water. These animals come in all sizes, so even cobbles on the stream bottom that are not sedimented in with fine sands and silt can serve as cover for small fish and salamanders. Larger fish and reptiles often use large boulders, undercut banks, submerged logs, and snags for cover.
Critical shear stress -- The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.
Crown -- The upper part of a tree or other woody plant that carries the main system of branches and the foliage.
Crown cover -- The degree to which the crowns of trees are nearing general contact with one another.
Cubic feet per second (cfs) -- A unit used to measure water flow. One cubic foot per second is equal to 449 gallons per minute.
Culvert -- A buried pipe that allows flows to pass under a road.
Debris flow -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.
Deciduous -- Trees and plants that shed their leaves at the end of the growing season.
Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.
Detritus -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.
Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.
Dissolved oxygen (DO) -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.
Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.
Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.
Drainage basin -- The total area of land from which water drains into a specific river.
Dredging -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.
Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.
Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.
Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.
Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is **not** embedded has loose rocks that are easily removed from the stream bottom, and may even "roll" on one another when you walk on them.
Entrenchment ratio --The width of the flood-prone area divided by the bankfull width.

<u>Epifaunal</u> – “epi” means surface, and “fauna” means animals. Thus, “epifaunal substrate” is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other “bugs”). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen “green” logs and trees.

Ephemeral streams -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.

Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

Eutrophic -- Usually refers to a nutrient-enriched, highly productive body of water.

Eutrophication -- The process of enrichment of water bodies by nutrients.

Flash Flood -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.

Floodplain -- Land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.

Floodplain (100-year) -- The area adjacent to a stream that is on average inundated once a century.

Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).

Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).

Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.

Fry -- A recently hatched fish.

Gabion -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.

Gaging station -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

Gallons per minute (gpm) -- A unit used to measure water flow.

Geographic information system (GIS) -- A computer system capable of storing and manipulating spatial data.

Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

Glide -- A section of stream that has little or no turbulence.

Gradient -- Vertical drop per unit of horizontal distance.

Grass/forb -- Herbaceous vegetation.

Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.

Groundwater -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.

Groundwater basin -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.

Groundwater recharge -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.

Groundwater table -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Habitat -- The local environment in which organisms normally live and grow.

Habitat diversity -- The number of different types of habitat within a given area.
Habitat fragmentation -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.
Headwater -- Referring to the source of a stream or river.
High gradient streams -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.
Hydraulic gradient -- The slope of the water surface. See also streambed gradient.
Hydraulic radius -- The cross-sectional area of a stream divided by the wetted perimeter.
Hydric -- Wet.
Hydrograph -- A curve showing stream discharge over time.
Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time.
Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.
Hydrologic unit -- A distinct watershed or river basin defined by an 8-digit code.
Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.
Hyporheic zone -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.
Improved paths – Paths that are maintained and typically involve paved, gravel or macadam surfaces.
Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.
Incision ratio -- The low bank height divided by the bankfull maximum depth.
Infiltration (soil) -- The movement of water through the soil surface into the soil.
Inflow -- Water that flows into a stream, lake,
Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.
Instream flows -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.
Instream use -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.
Intermittent stream -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.
Irrigation diversion -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.
Islands – mid-channel bars that are above the average water level and have established woody vegetation.
Lake – An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam
Landslide -- A movement of earth mass down a steep slope.
Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull channel.
Levee -- An embankment constructed to prevent a river from overflowing (flooding).
Limiting factor -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.
Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools. These streams are usually found in the large valley bottoms of the Champlain Valley and occasionally in high wet meadows. The lower reaches of the Otter Creek,

Lewis Creek, and Poultney River are all areas you are likely to find low gradient streams.
Macroinvertebrate -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.
Macrophytes -- Aquatic plants that are large enough to be seen with the naked eye.
Mainstem -- The principal channel of a drainage system into which other smaller streams or rivers flow.
Mass movement -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).
Mean annual discharge -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.
Mean velocity -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.
Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.
Meander amplitude -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.
Meander belt width -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.
Meander length -- The lineal distance downvalley between two corresponding points of successive meanders of the same phase.
Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.
Milligrams per liter (mg/l) -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.
Natural flow -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.
Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.
Oxbow -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.
Peat -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.
Perched groundwater -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.
Perennial streams -- Streams that flow continuously.
Permeability -- The capability of soil or other geologic formations to transmit water.
pH -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.
Point bar -- The convex side of a meander bend that is built up due to sediment deposition.
Pond -- A body of water smaller than a lake, often artificially formed.
Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.
Pool/riffle ratio -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.
Potential plant height -- the height to which a plant, shrub or tree would grow if undisturbed.

Probability of exceedence -- The probability that a random flood will exceed a specified magnitude in a given period of time.
Railroads – Used or unused railroad infrastructure.
Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.
Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.
Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.
Regime theory -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.
Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.
Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.
Riffle/step frequency -- ratio of the distance between riffles to the stream width.
Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains.
Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses.
Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).
Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.
Riparian -- Located on the banks of a stream or other body of water.
Riparian vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.
Ripple -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.
Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.
River channels -- Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.
River miles -- Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.
River reach -- Any defined length of a river.
River stage -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).
Riverine -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.
Riverine habitat -- The aquatic habitat within streams and rivers.
Roads - Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.
Rock -- A naturally formed mass of minerals.
Rootwad -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.

Run (in stream or river) -- A reach of stream characterized by fast-flowing, low-turbulence water.
Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.
Sand -- Small substrate particles, generally from 0.06 to 2 mm in diameter. Sand is larger than silt and smaller than gravel.
Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.
Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.
Sedimentation -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.
Seepage -- The gradual movement of a fluid into, through, or from a porous medium.
Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.
Sensitivity --of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.
Shoals – unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.
Silt -- Substrate particles smaller than sand and larger than clay (3 to 60 mm).
Siltation -- The deposition or accumulation of fine soil particles.
Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.
Slope -- The ratio of the change in elevation over distance.
Slope stability -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.
Snag -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.
Spawning -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.
Spillway -- A channel for reservoir overflow.
Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.
Stone -- Rock or rock fragments used for construction.
Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.
Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal.
Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.
Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.
Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.
Stream morphology -- The form and structure of streams.
Stream order -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.
Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.
Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.
Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.
Streambank erosion -- The removal of soil from streambanks by flowing water.
Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.
Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.
Streamflow -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).
Step (in a river system) -- A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the steps it takes various flow paths thus dissipating energy during high flow events.
Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.
Surface erosion -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.
Surface water -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.
Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.
Suspended sediment load -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.
Tailwater -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.
Thalweg -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.
Tractive Force --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.
Transpiration -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.
Tributary -- A stream that flows into another stream, river, or lake.
Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one

component of turbidity.

Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.

Variable stage stream -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.

Velocity -- In this concept, the speed of water flowing in a watercourse, such as a river.

Washout -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.

Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Waterfall -- A sudden, nearly vertical drop in a stream, as it flows over rock.

Watershed -- An area of land whose total surface drainage flows to a single point in a stream.

Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.

Watershed project -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.

Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.

Weir -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.