Enhancing Flood Resiliency of Vermont State Lands

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Executive Summary

Record flooding on Lake Champlain in the spring of 2011 and widespread damages sustained to Vermont's built infrastructure during Tropical Storm Irene in August 2011 motivated the Agency of Natural Resources (ANR) Lands Stewardship Team to request an evaluation of policies, plans and practices on state-owned lands with a goal to enhance flood resiliency. This report has been prepared by a Project Team consisting of Kristen L. Underwood, hydrogeologist (South Mountain Research & Consulting Services), and David Brynn, consulting forester (Vermont Family Forests).

Flood resilience is defined as "a community's capability to anticipate, prepare for, respond to, and recover from floods with minimum damage to social well-being, the economy, and the environment" (NRC, 2010).

State Lands are defined as those lands held on a fee-simple basis or in terms of non-fee interests (e.g., conservation easements) by one of three departments of the ANR that are represented on the State Lands Stewardship Team: Vermont Department of Forests, Parks, & Recreation; Vermont of Fish and Wildlife Department; and the Vermont Department of Environmental Conservation. State Lands management units make up nearly 8% of the Vermont land area and consist of a wide variety of unit types including state parks, state forests, wildlife management areas, boat/fishing access sites, riparian corridors, fish hatcheries, dams, telecommunications facilities, ski areas, working lands and flood control areas.

The majority (90%) of State Lands are located in forested headwater settings, which are particularly susceptible to generating runoff during storm events, given their topography and geologic setting. This inherent vulnerability to overland flow and soil erosion has been exacerbated by a legacy of land use modifications (deforestation, development of road and trail networks) most often pre-dating State acquisition of the lands. Natural vulnerabilities and legacy impacts have combined to create upland forests particularly sensitive to a rapidly changing climate.

In light of increasing storm frequency, intensity, persistence and magnitude, management for enhanced flood resiliency on State Lands will require greater emphasis on forest health and stewardship of forest ecosystem services, including water retention, infiltration and filtering.

Four management units in south-central Vermont were identified by the ANR Lands Stewardship Team for detailed evaluation during this project. These properties were selected by ANR with a goal that they would be generally representative of the range of conditions characterizing state-owned lands. These properties were also impacted by Tropical Storm Irene. Four management units in Rutland and Windsor Counties were identified, including two Wildlife Management Areas (WMAs), one state park and a state forest.

State Lands Management Unit	Acres	Towns
Camp Plymouth State Park	295	Plymouth
Tinmouth Channel WMA	1,261	Tinmouth
Coolidge State Forest	16,000	
- West		Killington, Mendon, Shrewsbury, Plymouth
- East		Woodstock, Bridgewater, Plymouth, Reading
Les Newell WMA	7,988	Barnard, Bridgewater, Killington, Stockbridge

Each of the selected State Lands was visited during the 2014 field season by the Project Team, accompanied by State Lands Stewardship staff. Through interviews and limited site inspections, as well as document review, a suite of plans, policies, and practices has been offered, in an adaptive management framework, to support forest health and enhanced flood resiliency on State Lands.

A basic Geographic Information Systems (GIS) analysis was performed to characterize the varying soil types and topographic settings on selected State Lands and classify these land areas in terms of their vulnerability to flooding and the enhanced generation of runoff and erosion in response to human landscape modifications and climate change. The mapping approach relies on remote-sensing resources available State-wide, and is practical, easily implemented, and consistent with existing Stewardship Team planning approaches. This "hydrologic lens" for long-range planning on State Lands recognizes those landscape settings with a natural vulnerability to generate runoff – namely, those land areas with steep slopes, shallow (or nonexistent) depths to bedrock or other permeability-limiting layer (e.g., hardpan), and soils with limited infiltration capacity. The proposed mapping approach is intended to help inform the designation of existing Long-Range Management Plan land use classifications, and to "red flag" those lands areas that are more sensitive from a hydrologic standpoint.

Camp Plymouth State Park was chosen to illustrate the mapping approach, wherein lands were classified as *Hydrologic Reserve Zones*, *Hydrologic Conservation Zones*, or *Other Lands*. A *River Corridor* layer was then mapped as an overlay to the full area, following existing guidance from ANR. With respect to climate change and flooding, the *Hydrologic Reserve Zone* and the *River Corridor* are composed of land units that have very limited adaptive capacity. *Hydrologic Conservation Zone* lands have low to moderate adaptive capacity, and *Other Lands* have moderate to good adaptive capacity.

Proposed conservation targets were offered for the four hydrologic resource zones with respect to access networks, including truck roads, forwarding paths, skid trails, and log landings. Collectively, these conservation targets represent actions to remove or reduce the degree of hydrologic modification on State Lands and to disconnect sources of concentrated runoff and sediment from the stream network. More stringent standards for access networks are proposed in those land areas that are most sensitive (i.e., *River Corridor* and *Hydrologic Reserve Zone*) due to steepness of slopes, presence of limited soil infiltration capacity, and proximity to the stream network. Performance in meeting these conservation targets should be measured through regular monitoring efforts.

Several of the proposed conservation measures are already being implemented on State Lands. The mapping approach and proposed conservation targets could be further evaluated and refined in a series of pilot tests implemented by Stewardship staff on a subset of State Lands across the state. Pilot testing would provide an opportunity to address concerns raised by the project Steering Committee that selected State Lands may not adequately represent the diversity of soil types, topographic settings and land covers on State Lands as a whole.

Optimal Conservation Practices (OCPs) were proposed for development to enhance both flood resiliency and water quality in forested headwaters. To date, the primary mechanism for ensuring protection of water resources on State Lands has been the *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs* in Vermont (AMPs). AMPs are designed primarily with the objective of maintaining water quality and reducing the likelihood for direct discharges during historic storm conditions. They are not designed to enhance flood resiliency specifically, or to address more extreme storm conditions experienced with greater frequency in recent years and anticipated in coming decades. Through OCPs, greater protection measures would be applied to those land areas most vulnerable to generating runoff.

Priorities were outlined for addressing legacy impacts by hydrologic resource zone, including down-sizing or re-wilding underused road segments in vulnerable settings, and disconnecting road ditches from stream channels using turn-outs, infiltration basins, or settling ponds.

Inventories of built infrastructure should be undertaken or formalized for each State Land management unit to inform hazard planning, capital budgeting, and flood resiliency planning. It is important to know the position and condition of this infrastructure with respect to the hydrologic resource zones to understand the degree that infrastructure may enhance the sensitivity of the landscape to flooding, so that adequate adaptation actions can be undertaken. Similarly, this mapping process can identify infrastructure at risk from flooding, so that appropriate mitigative actions can be prioritized. Identification of structures on a commonly-available GIS platform and database (e.g., Vermont Natural Resources Atlas platform) can increase networking opportunities with private groups and public agencies to leverage additional funding sources for upgrades, retrofitting, or decommissioning. An example inventory was completed for a subset of the road and trail network at Camp Plymouth State Park.

Implementation of flood resiliency measures will be accelerated through collaboration with other stakeholders. Often projects implemented for other purposes can have overlapping benefits for flood resiliency, opening up other avenues for technical and financial resources to accomplish flood resiliency objectives. Our collective investment in plans, policies and practices to enhance flood resiliency on State Lands will realize greater returns in avoided loss of life, reduced flood damages, improved water quality, and improved forest health for future generations.

1.0 Introduction

The Agency of Natural Resources (ANR) Lands Stewardship Team, in partnership with the Vermont Rivers Program, requested an evaluation to improve flood resiliency on state-owned lands. A primary objective of this project was to evaluate current practices and management plans and to make recommendations for improved management with the specific goal of attenuating flood flows, thereby improving water quality and reducing downstream flooding. A second objective was to identify a process and approach that are transferable to other state-owned lands in Vermont.

In this report, flood resilience is defined as "a community's capability to anticipate, prepare for, respond to, and recover from floods with minimum damage to social well-being, the economy, and the environment" (NRC, 2010).

State Lands are defined as those lands held on a fee-simple basis or in terms of non-fee interests (e.g., conservation easements) by one of three departments of the Agency of Natural Resources that make up the State Lands Committee: Vermont Department of Forests, Parks, & Recreation; Vermont of Fish and Wildlife Department; and the Vermont Department of Environmental Conservation. Four State Lands management units were identified by the ANR Lands Stewardship Team for more detailed evaluation during this report. These properties were selected by ANR with a goal that they would be generally representative of the range of conditions characterizing state-owned lands. State Lands are located in a wide variety of geographic, geologic and land use settings, and it was a difficult task to identify a subset of lands that adequately represented this diversity (see Section 3.2 for further discussion).

Practices and activities undertaken to build flood resiliency on State Lands will have attendant benefits to riparian and forest habitats, as well as increased opportunities for sediment and nutrient attenuation leading to improved water quality. Management of State Lands for their ecosystem services related to flood resiliency will serve as a model of exemplary stewardship practices for other publicly- and privately-held lands.

This summary report has been prepared by Kristen L. Underwood, hydrogeologist (South Mountain Research & Consulting Services), and David Brynn, consulting forester (Vermont Family Forests), both located in Bristol, Vermont.

2.0 Project Motivation and Context

Record flooding on Lake Champlain in the spring of 2011 and widespread damages sustained to Vermont's built infrastructure during Tropical Storm Irene in August 2011 were among the motivations for this report. While the majority of State Lands are in forest cover, significant losses were incurred including trail damage, road washouts, culvert and bridge replacements, and impacts to recreational buildings and facilities. The forested headwaters of many of Vermont's State Lands are particularly susceptible to generating runoff during storm events, given their natural topography and geologic setting. This inherent vulnerability to overland flow and soil erosion has been exacerbated by a legacy of land use impacts dating as far back as the late 1700s, most often pre-dating State acquisition of the lands. Natural vulnerabilities and legacy impacts have combined to create upland forests particularly sensitive to a rapidly changing climate.

2.1 Legacy Impacts

There may be a tendency to assume that lands in forest cover are resilient to the effects of flooding simply by virtue of their forested status. However, forest cover does not necessarily equate to forest health and forest flood resilience. Headwater forests of Vermont include a legacy of human modifications that have left certain land areas with a heightened propensity to generate runoff, accelerate soil erosion, and sediment streams. These legacy impacts affect forest lands across the state, not just State Lands.

Widespread deforestation of the Vermont landscape had occurred by the early- to mid-1880s (Thompson & Sorensen, 2000; Albers, 2002; Foster & Aber, 2004) to support subsistence and sheep farming and the lumber industries. Mill dams were established on headwater streams to harness water power in support of various industrial and manufacturing activities including sawmills, grist mills, potasheries, and iron works (Stilwell, 1948; McGrory-Klyza and Trombulak, 1999; Smith, 1886; Beers, 1871). A network of roads and trails was established to access these upland mills and farms and to retrieve harvested timber. These roads and trails crossed the stream network in many locations.

Deforestation and upland development changed the water and sediment routing on previously-forested lands, making these lands more connected to receiving stream channels. Removal of vegetation reduced the amount of water intercepted, evaporated and transpired by plants. Infiltrative capacity of the soils was reduced through compaction of the soils during harvesting. Where road networks intersected the stream network, road-side ditches (and the roads themselves) have effectively served as an extension of the stream network (Wemple *et al*., 1996; King & Tennyson, 1984). The increased density of flowing channels on the land surface led to increased peak flows and velocities, and substantial turbidity in receiving waters. Thus, more water was available for runoff, leading to a shift from gentler pre-settlement flows to flashier, more intense runoff events ("deforested" line in Figure 1).

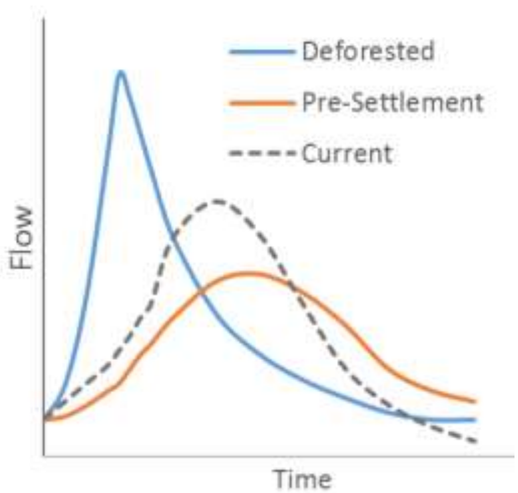

Figure 1. Conceptual diagram of the effects of legacy impacts on watershed hydrology.

Forest cover in the Vermont highlands began to regenerate in the late 1800s and early 1900s, as upland farms and sawmills were abandoned. Forests rebounded to comprise 78% of the landscape by the 1980s, a figure which has remained fairly stable since (NESFA, 2013). However, the quality of those forests is not the same as the pre-Settlement old growth forests. The legacy of early landscape development and a history of channel and floodplain modifications (Kline & Cahoon, 2010) continue to impact water and sediment routing from the land. Landscape modifications have had the effect of increasing the connectedness of land to the river network (Wemple, *et al.,* 1996). It is this enhanced connectivity that needs to be addressed to make our landscape more resilient to flooding and the impacts of a changing climate. Historic access networks of skid trails and forest roads on State Lands were often inherited when the ANR acquired these lands, and are not necessarily representative of current State Lands management practices. Addressing these legacy impacts will require adaptive forest conservation approaches that significantly slow overland flow, increase infiltration, and trap sediment, leading to reduced flood damages.

2.2 Changing Climate

Historic gaging records for Vermont climate stations indicate statistically significant increasing trends in average annual precipitation and temperature over the latter half of the 20th century (Guilbert, *et al.*, 2014). Climate modeling recently performed for the Lake Champlain basin of Vermont projects an increase in mean annual temperature of 4.6°C by late in the 21st century, and a 9.9 % increase in precipitation by late century (Guilbert, *et al.*, 2014).

As average annual rainfall has increased in recent decades, average annual flows in Vermont rivers have also increased. USGS streamflow gages in Vermont show a statistically significant increasing trend in mean annual discharge (Vermont Climate Assessment, 2014; Hodgkins *et al.*, 2010). Based on climate model projections for increased precipitation, we can expect average annual streamflows will continue to increase. High flows are larger in magnitude and are occurring more frequently, often in the winter months associated with earlier thaw dates for snowpack. Records for rivers in New England, including Vermont rivers in particular, indicate a rise in the magnitude of the annual peak discharge over the last several decades (Collins, 2009; Hodgkins & Dudley, 2005; Huntington *et al.*, 2009). A greater fraction of winter precipitation will fall as rain or freezing rain rather than snow, leading to more rain-on-snow events and rain on frozen ground, with associated flooding (Frumhoff, *et al.*, 2007). Up to an 80% increase in the probability of high flows is projected under assumptions of high green-house-gas emissions by the end of the century (Frumhoff *et al.*, 2007; Hayhoe *et al.*, 2007).

Higher magnitude and duration of runoff will generate more flashy flows (Figure 2) and increased stream power leading to increased gullying, and erosion of sediments from the land surface, roads, ditches, landslides and streambanks. It is possible that increased frequency and magnitude of storms in coming decades will rejuvenate erosion processes in headwater regions where hillslopes are closely coupled with stream channels. Such a pattern was evident during TS Irene in the Connecticut River basin (Yellen *et al*., 2014).

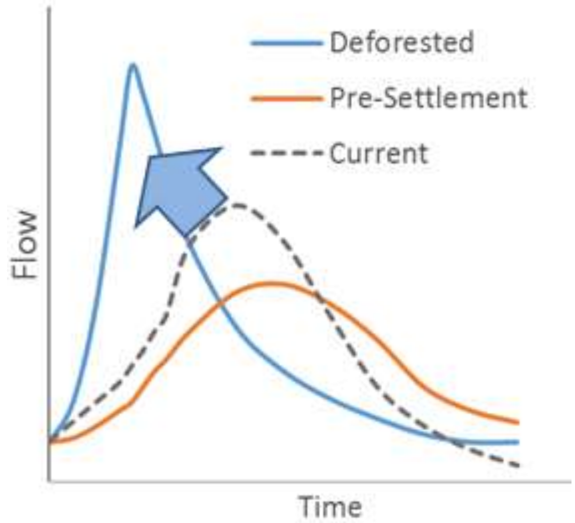

Figure 2. Conceptual diagram depicting expected trend in watershed hydrology with climate change – a return to more flashy flows as noted by the arrow.

3.0 Description of State Lands

As early as 1910, the Vermont State Forester, then Austin F. Hawes, was promoting the importance of acquiring state lands - specifically forest lands - for their role in the protection of water resources (Merrill, 1959). The L.R. Jones State Forest in Plainfield was the first state forest acquired and developed by the State of Vermont in 1909. Since that time, the state has acquired more than 345,000 acres of land and holds conservation easements on more than 44,000 acres of privately-owned lands (Figure 3)[1]. Together these land units comprise nearly 8% of the Vermont land area and consist of a wide variety of unit types including state parks, state forests, wildlife management areas, boat/fishing access sites, riparian corridors, fish hatcheries, dams, telecommunications facilities, ski areas, working lands and flood control areas.

State Lands are managed by three departments of the Vermont Agency of Natural Resources (ANR):

- VT Department of Forests, Parks & Recreation (FPR) "is responsible for the conservation and management of Vermont's forest resources, the operation and maintenance of the state park system, and the promotion and support of outdoor recreation for Vermonters and our visitors"[2]. FPR manages more than 250,000 acres comprising 39 State Forest units and 56 State Parks[1].

- VT Fish and Wildlife Department (VFW) is charged with the conservation of all species of fish, wildlife, and plants and their habitats for the people of Vermont." VFW manages more than 80 Wildlife Management Areas distributed across 109 towns, as well as boat access areas, fish culture stations and pond sites, and river corridor sites in 41 towns.

[1] http://anrmaps.vermont.gov/websites/vgisdata/layers_anr/metadata/CadastralPublands_ANRLANDS.txt
[2] http://www.vtfpr.org/

- VT Department of Environmental Conservation (VDEC) mission is "to preserve, enhance, restore and conserve Vermont's natural resources and protect human health for the benefit of this and future generations".[3] VDEC holdings are limited to lands and infrastructure associated with fourteen flood control dams located in sixteen towns.

State Land management units are distributed in each of the biogeophysical regions of Vermont, although they are somewhat disproportionately representative of the Northern Green Mountains and the Northeastern Highlands (Figure 3). Elevation settings range from 95 feet (e.g., Little Otter Creek WMA adjacent to Lake Champlain) to 4,211 feet above sea level (e.g., flanks of Mount Mansfield).

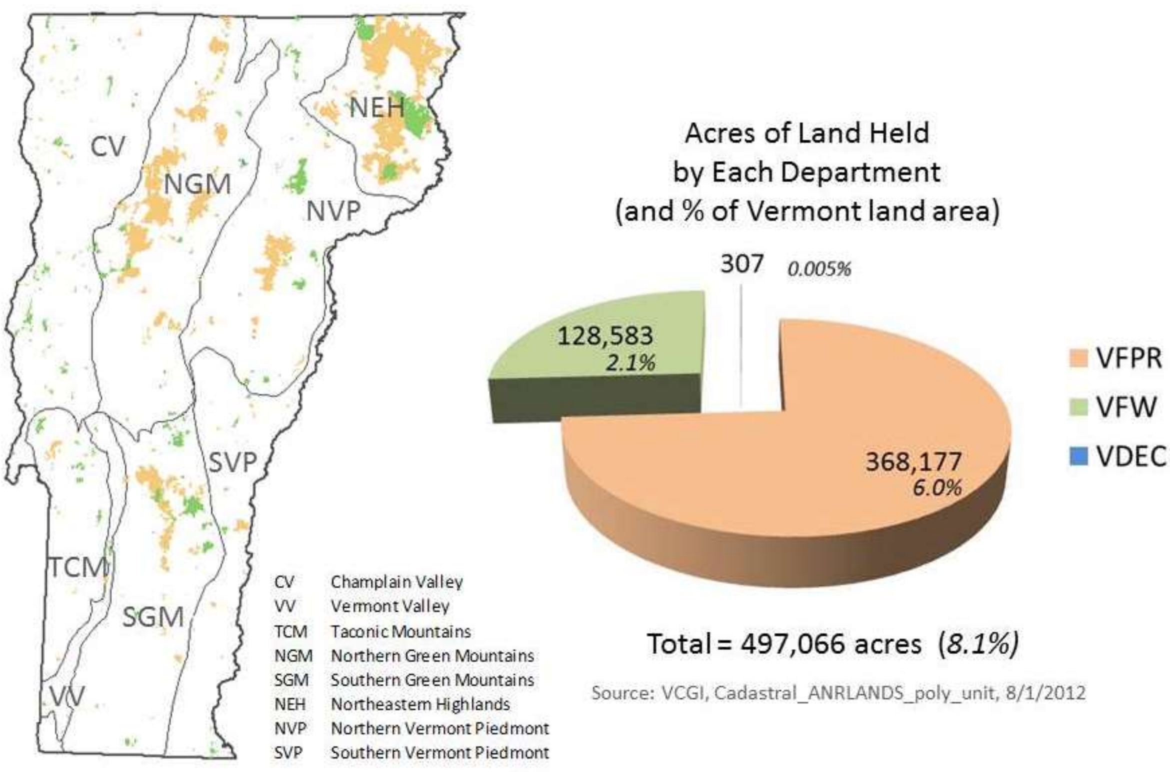

Figure 3. Distribution of State Lands by geographic region and ANR Department .

Land cover and land use on State Lands are dominated by forest cover (Figure 4). State Lands (89.9%) are somewhat more forested than the state as a whole (78%).

[3] http://www.anr.state.vt.us/dec/about.htm

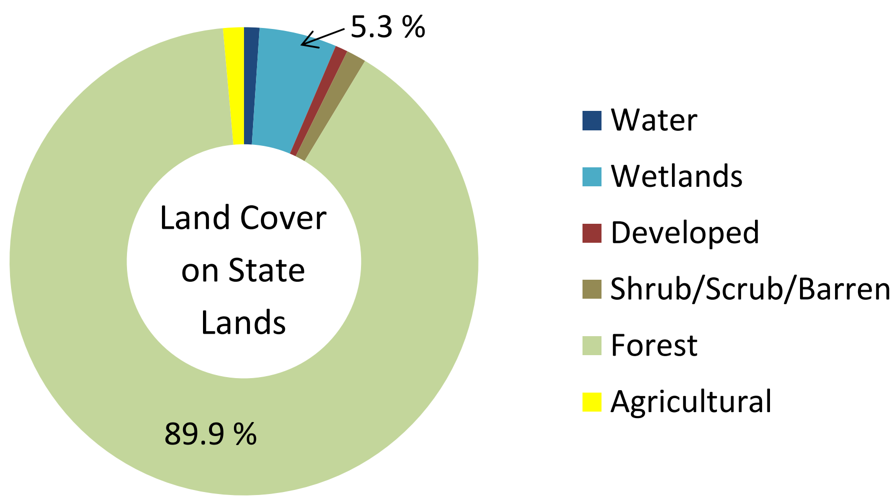

Figure 4. Land cover/ land use distribution for state lands (Source: 2001 NLCD).

Infrastructure on State Lands includes communication towers, camps, state park buildings, parking lots, and associated water and sewer systems. Nearly every State Land management unit includes an access network of roads and trails. In some cases, roads are Class 4 roads owned by the town. In other cases, the relevant department owns a forest access road. Beyond these formal roads, there are informal forest roads, logging access roads and skid trail networks utilized for recreation, hunting, and timber harvest.

Beginning in the early 1940s, seven private ski areas have leased acreage on State Lands for placement of ski lifts, ski trails, and a limited number of buildings (Table 1).

Table 1. Ski areas with lease agreements on State Lands.

Ski Resort	State Lands	Towns	Approx Acreage
Bromley Mountain Resort	Hapgood State Forest	Peru	118
Burke Mountain Resort	Darling State Forest	Burke	1,000
Jay Peak Resort	Jay State Forest	Jay, Westfield	845
Killington Mountain Resort	Calvin Coolidge State Forest	Killington	1,680
Okemo Mountain Resort	Okemo State Forest	Ludlow, Mount Holly	1,223
Smugglers' Notch Resort	Mount Mansfield State Forest	Cambridge, Morristown, Stowe	2,170
Stowe Mountain Resort	Mount Mansfield State Forest	Stowe, Cambridge	1,400

3.1 Forest Resources

Given that the majority of State Lands are in forest cover, the focus of this report has centered on how management of these forests can be modified or adapted to improve flood resiliency. It is informative to review the variety of services and goods provided by our forests, and to evaluate the role of each ANR Department in managing these forest resources.

Forests are composed of a suite of elements, including water, air, wildlife, soil, and vegetation (Figure 5). The recent focus on climate change has directed attention to an additional resource sequestered in the soil and vegetation – i.e., carbon. These forest elements are valued for both their economic (or provisioning) services and their ecosystem (or regulating) services. Ecosystem services include stormwater and floodwater attenuation, water filtering and purification, air filtering, nutrient cycling and habitat provision. Stewardship of these regulating services will support forest health. In the context of flood resiliency, the focus of this report is on water and the flood retention and attenuation roles provided by the forest structure. Provisioning resources provided by our forests include those elements of the forest-based economy, including wood and non-wood products, and the growing importance of forest-based recreation and tourism.

The three departments of VANR are directly involved with these forest resources in two primary ways: Ownership and Trusteeship (Figure 5). FPR and VFW hold the majority of State Lands – either on a fee-simple basis or in non-fee interests (e.g., conservation easements). In administering those state lands, FPR and VFW own and manage those physical public goods including the soil and vegetation, and the carbon stored in each of those elements. FPR and VFW do not own those elements of the commons – including water, air, and wildlife. On the other hand, VFW and VDEC are ***trustees*** of these commonly-held elements.

Protection of ecosystem services promotes forest health while exploitation of the economic services provided by forests connotes forest use. Our forests have the capacity to provide both ecosystem and economic services. However, to promote flood resiliency in the face of a changing climate will require greater emphasis on forest health and stewardship of forest ecosystem services. Forest utilization will need to be optimized to ensure the mutual goals of improved forest health and resiliency to flooding and other impacts of climate change. At the same time, promoting forest health will also ensure the sustainability of our forest-based economy.

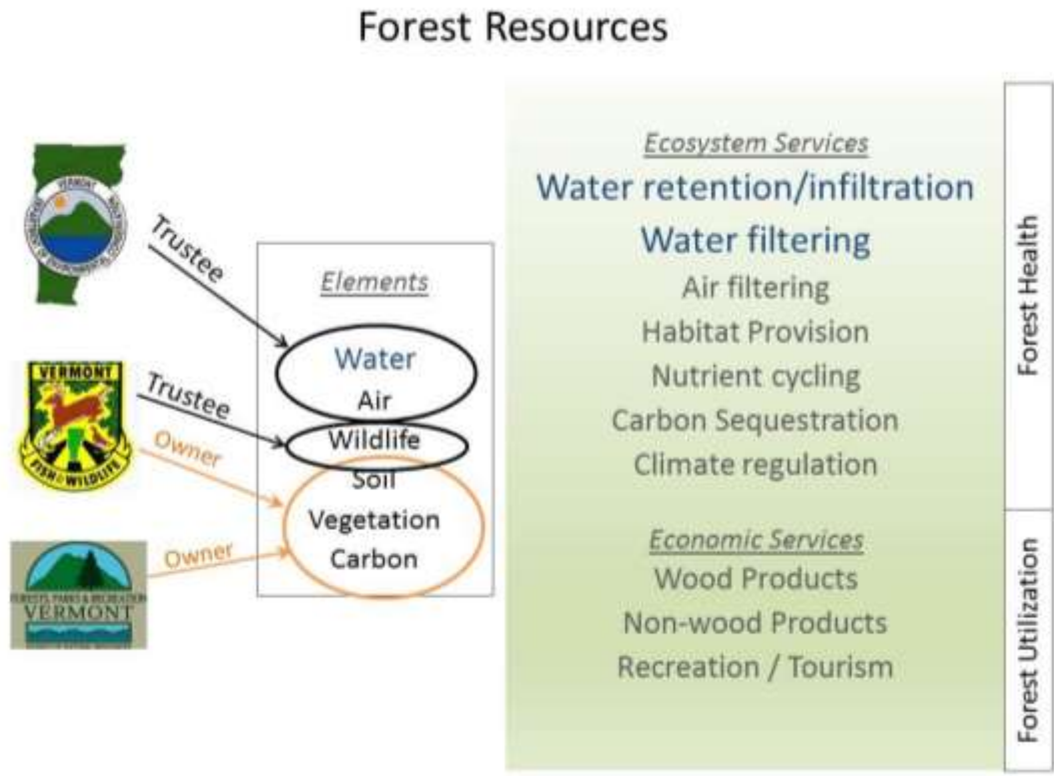

Figure 5. Ecosystem (regulating) services and economic (provisioning) services provided by forest resources and the trustee versus ownership role of VANR Departments over forest elements.

3.2 Selected State Lands

This report focused on a subset of State Lands selected by the ANR Lands Stewardship Team to be representative of the natural settings, land covers and uses of State Lands as a whole (Figure 6) – and yet to be reasonably centralized for easy access by the assessment teams. Four management units in Rutland and Windsor Counties were identified, including two Wildlife Management Areas (WMAs), one state park and a state forest (Table 2).

Table 2. Selected State Lands Management Units

State Lands Management Unit	Acres	Towns
Camp Plymouth State Park	295	Plymouth
Tinmouth Channel WMA	1,261	Tinmouth
Coolidge State Forest	16,000	
- West		Killington, Mendon, Shrewsbury, Plymouth
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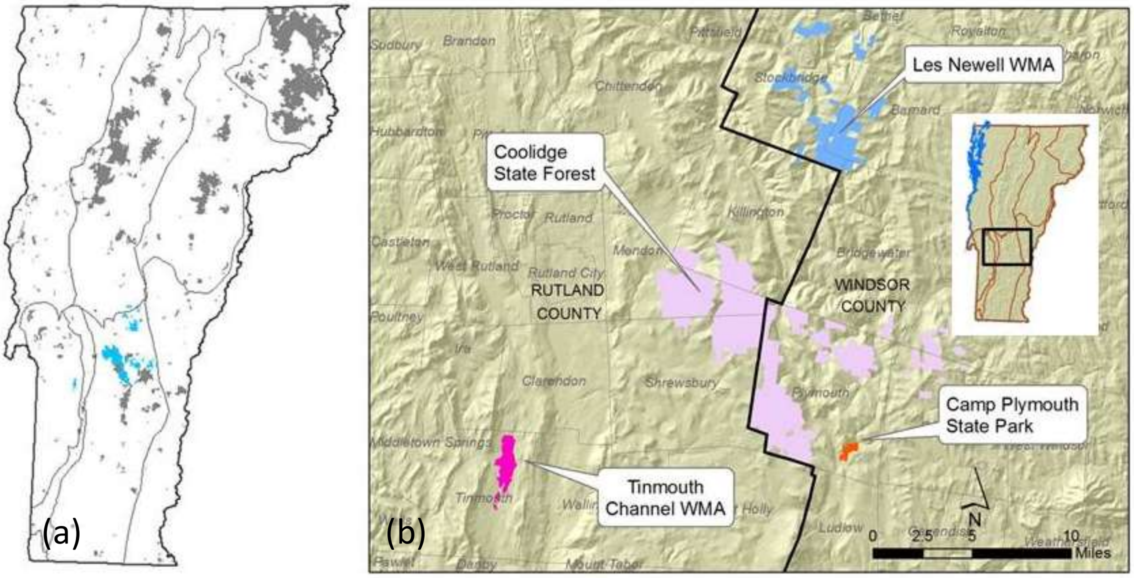
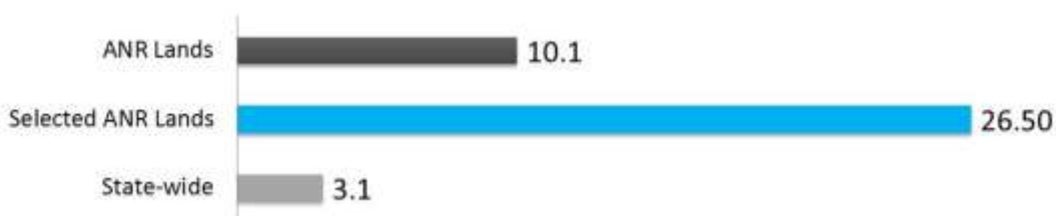


Figure 6. Location of Selected State Lands:
(a) Selected lands (shaded turquoise) vs State Lands as a whole (shaded gray);
(b) detailed view of selected State Lands located in Rutland and Windsor Counties.

Selected lands are 94.3% forested, similar to the 90% forest cover on State Lands as a whole. On the four properties assessed, 26.5% of the land area is above an elevation of 2,500 feet which exceeds and may over-represent high-elevation settings when compared to ANR Lands as a whole (Table 3). Yet, these higher elevation settings are particularly vulnerable to the effects of climate change as they generally receive greater amounts and intensities of precipitation.

Table 3. Percent of land area above 2,500 feet elevation



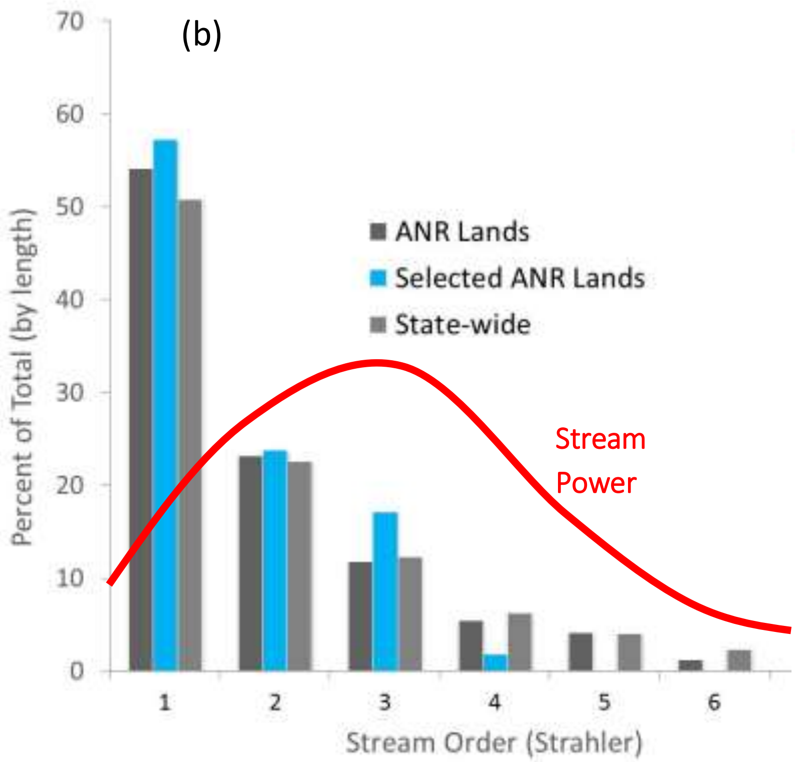
State Lands were evaluated with regard to the stream networks that drain them and the frequency of stream segments of a particular stream order (after Strahler, 1952). First-order streams represent those smallest channels that are generated when runoff or groundwater seepage combines to form concentrated flow in a defined stream channel. First order stream segments are most often located in the headwaters of a catchment. A second-order stream is formed when two first-order streams come together; a third-order stream is formed by two second-order streams, and so on (Figure 7a). Generally speaking, the width and depth of stream channels increases with increasing stream order, as the upstream drainage area grows in size.

Figure 7b shows the distribution of stream segments by Strahler stream order on all State Lands in comparison to the state of Vermont as a whole. Approximately 50.8% of the total length of mapped stream segments in Vermont (VHD_CARTO) are classified as first-order streams. State Lands and the subset of State Lands selected for this report contain somewhat higher percentages of first-order streams (54.1% and 57.3%, respectively). This finding is not unexpected considering that the distribution of State Lands tends to over-represent the mountainous settings of the Northern Green Mountain and Northeastern Highlands biogeophysical provinces (Figure 3).

Thus, in a watershed context (Figure 8), State Lands are generally located in the headwaters and less frequently along middle-order to large-order segments. The maximum order of stream segments represented on the selected State Lands is fourth-order (e.g., Great Roaring Brook, Calvin Coolidge SF in Plymouth; Broad Brook, Coolidge SF East).

Based on a separate study being undertaken by the Vermont Land Trust, stream power has been estimated for mapped stream networks in the state (Fitzgerald, 2013; Schiff, 2014). Stream power refers to the ability of streams to erode sediments and move debris and is primarily a function of water volume and channel slope. At a given stream reach, stream power is greater at high flows than at low flows, due to the larger volume and velocity of water passing through the channel reach. In a watershed context, stream power will generally be greater on steeper reaches than on low-gradient reaches, for a given storm event. Stream power is maximized along those mid-order stream segments (Figure 7b) – usually located near the transition from the headwaters to the transfer zone of a watershed (Figure 8). Here, the volume of water carried in the channel has increased (due to increased drainage area) and channel slopes are generally still steep enough to generate high stream powers sufficient to exceed thresholds for erosion. Notably, many of the damages sustained on selected State Lands during Tropical Storm Irene, were located along these mid-order segments, such as the Buffalo Brook at Camp Plymouth State Park (3rd order; see Appendix A) and the Roaring Brook at Killington Resort in Coolidge SF West (2nd order; Appendix A).

The selected State Lands were chosen by ANR to be generally representative of the range of conditions characterizing state-owned lands. State Lands are located in a wide variety of geographic, geologic and land use settings, and it is a difficult task to identify a subset of lands that adequately represent this diversity. For example, soil types and slope settings of Northeast Highland headwater properties are somewhat different than the soils and slope settings of the headwater lands in the Northern and Southern Green Mountains. Given the location of the selected State Lands in south-central Vermont, these units were more significantly impacted by flooding during Tropical Storm Irene than were State Lands in the northern part of the state. Yet, a focus on how these selected areas fared during TS Irene is informative for all regions of the state, since we can expect more frequent storms with impacts similar to TS Irene in future decades in light of a changing climate.



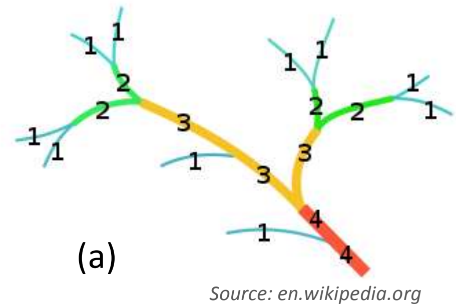
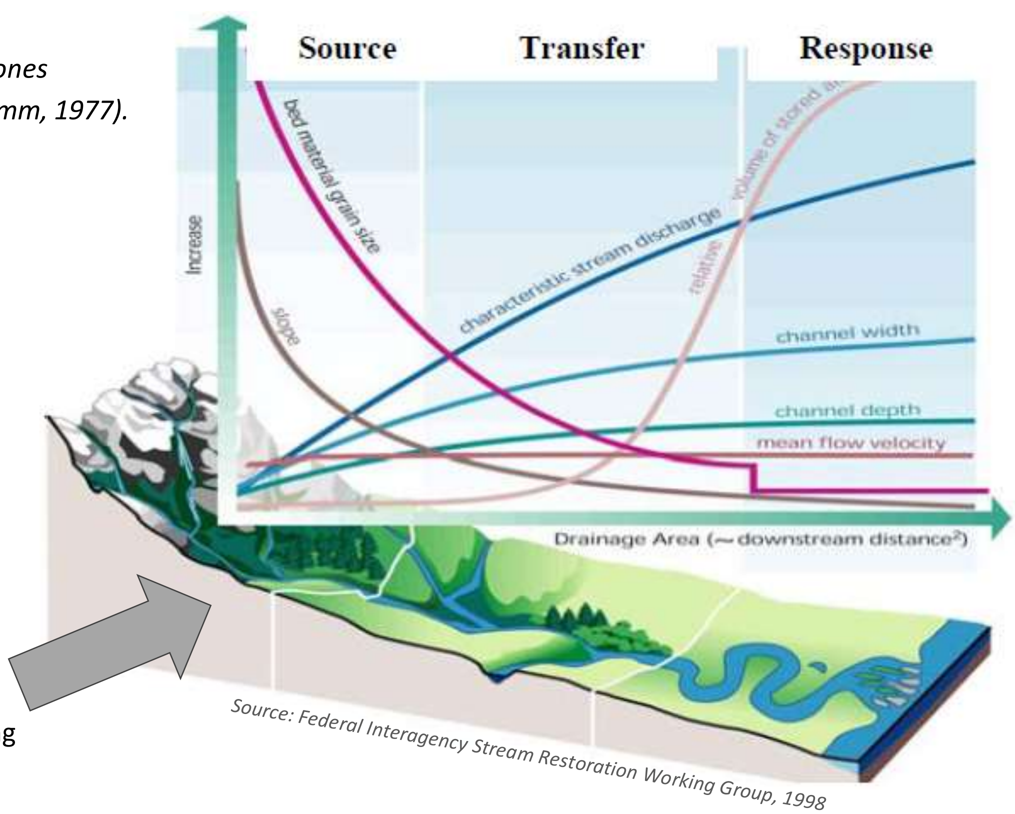


Figure 7. Stream networks on State Lands : (a) stream order graphic *(after Strahler, 1952)*; (b) *distribution of stream segments on State Lands by Strahler stream order. Stream power line conceptualized after findings of Milone & MacBroom, Inc. and Fitzgerald Environmental Associates in a recent study for the Vermont Land Trust (Fitzgerald, 2013; Schiff, 2014).*

Figure 8. Three sediment zones of a watershed (after Schumm, 1977).



Majority of
State Lands in
Headwater setting

4.0 Assessment Methods

The consideration of flood resiliency on State Lands was accomplished through a variety of assessment methods, as outlined in the project proposal.

4.1 Meetings and Presentations

The Project Team attended meetings with Steering Committee members including an initial scoping meeting in Rutland on 3 February 2014 to clarify project goals and expectations and a progress meeting in Rutland on 22 September 2014. A presentation of draft findings was delivered to the State Lands Stewardship Team in Montpelier on 22 January 2015. Proposed GIS mapping methods were delivered to the State Lands Stewardship Team for review during a subsequent meeting on 26 March 2015. A final presentation was made to the 8 April 2015 State Lands Stewardship staff meeting in Waterbury, Vermont. Final comments from the Steering Committee were discussed in a meeting with the State Lands Stewardship Team on 28 May 2015.

4.2 Limited Site Visits and Interviews

Each of the selected State Lands was visited during the 2014 field season by the Project Team, accompanied by various members of the Steering Committee, as summarized in Table 4. Appendix A provides a summary of major findings from these site visits.

Table 4. Field visits to selected State Lands

Camp Plymouth SP	June 5, October 20
Tinmouth Channel WMA	June 18
Coolidge West - Killington	July 31
Coolidge West	September 8
Coolidge East	September 29
Les Newell WMA	December 1

4.3 Review of Documents

A limited review was conducted of select plans relating to management of State Lands, including:

- Long Range Management Plan Documentation
- Long Range Management Plans for the selected State Lands (available for all management units except Les Newell WMA and Coolidge East)
- Water Resources Assessment (no date, internal document)
- Timber/ Vegetative Management Prescriptive Worksheets (select)
- Annual Work Plans (select)
- Vermont State Lands Riparian management Guidelines (March 2015 Draft)
- ANR Policy: Riparian Area Management on ANR Lands (March 2015 Draft)

Several recommendations gleaned from review of these documents are presented in subsequent sections.

4.4 GIS analysis

A basic Geographic Information Systems analysis was performed to characterize the varying soil types and topographic settings on State Lands and classify these land areas in terms of their vulnerability to flooding and the enhanced generation of runoff and erosion in response to human landscape modifications and climate change. The goal of this analysis was to develop a methodology that relies on remote sensing resources available State-wide, and that is practical, easily implemented, and consistent with existing planning approaches for State Lands. Essentially, this mapping approach defines an additional planning "lens" specific to the hydrologic resources of State Lands.

Under this mapping approach (Figure 9), State Lands are mapped into zones including "Hydrologic Reserve" areas, "Hydrologic Conservation" areas and "Other Lands", and a "River Corridor" layer is then mapped as an overlay to the full area.

This "hydrologic lens" for long-range planning on State Lands recognizes those landscape settings with a natural vulnerability to generate runoff – namely, those land areas with steep slopes, shallow (or nonexistent) depths to bedrock or other permeability-limiting layer (e.g., hardpan), and soils with limited infiltration capacity.

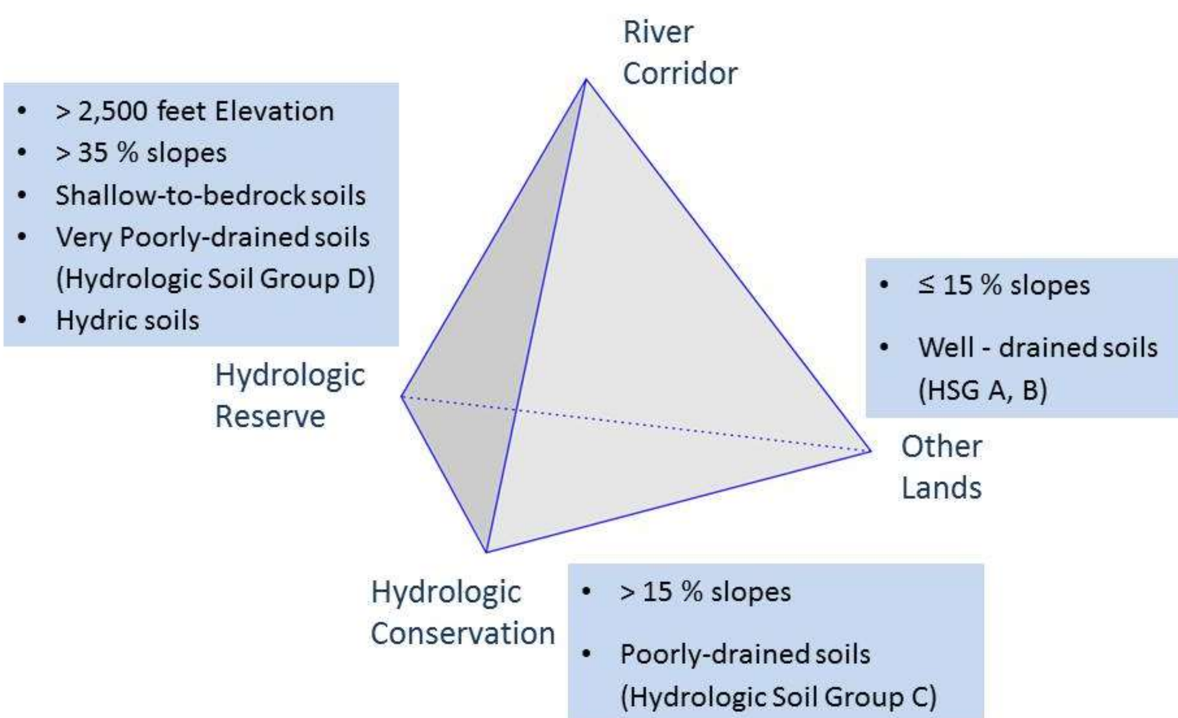


Figure 9. Hydrologic Resource Mapping Approach

A coarse-resolution GIS analysis was completed to classify land areas on select State Lands into the above Hydrologic Resource Zones, so that Steering Committee members could visualize how this hydrologic layer could be incorporated alongside other attributes such as wildlife, natural communities, and recreational and historic resources. This analysis utilized 1:24,000-scale coverage of resource layers readily available through the Vermont Center for Geographic Information in a step-by-step query process carried out in ArcGIS 10.1 with Spatial Analyst extension. The **Hydrologic Reserve Zone** is composed of lands with elevations above 2500 feet; slopes exceeding 35%; shallow-to-bedrock soils; and poor infiltrative capacity identified as Hydrologic Soil Group D and hydric soils using a join of the *Table 20 attributes* from NRCS (Table 5). The **Hydrologic Conservation Zone** is a union of lands with slopes exceeding 15% and soils in Hydrologic Soil Group C (excluding those lands delineated in the Hydrologic Reserve) (Table 5). Remaining areas on State Lands are simply classified in the **Other Lands** category for purposes of delineating the hydrologic resources.

The **River Corridor** overlay follows the stream network, intersecting all three hydrologic mapping zones. The river corridor is delineated by the VDEC based on physical (geomorphic) assessments of Vermont's stream and rivers. A river corridor overlay is a footprint in the landscape, which encompasses the dynamically-adjusting river channel. The corridor varies in width along its length, accounting for the actual width of the river channel at various locations, the size and nature of the watershed draining to that particular reach, the sensitivity of the reach to physical adjustment processes, knowledge of historic migration patterns of the river, and the position of the valley walls adjacent to the channel. For drainage areas greater than two square miles, the river corridor includes a meander belt width component as well as a 50-foot setback as an extension on either side of the meander belt to accommodate a vegetated riparian buffer. For small streams draining an area less than or equal to two square miles, the 50-foot setback from each bank serves both the meander and riparian buffer functions. Further details of the delineation procedure for river corridors are provided in several ANR publications, including the *Flood Hazard Area and River Corridor Protection Procedure* (2014) and *River Corridor Protection Guide* (2008). The updated river corridor layer is accessible via the ANR Natural Resources Altas web page[4] or by contacting VTDEC Rivers Program personnel in the appropriate district.

Where available as GIS files, the **Built Infrastructure** on State Lands was then overlaid on the above mapped elements. Built infrastructure includes the access network of roads, skid trails, parking areas and landings as well as culvert and bridge structures, and buildings and other facilities. In this way, the position of this infrastructure with respect to the natural Hydrologic Resource Zones can be visualized to understand the degree that infrastructure may enhance the sensitivity of the landscape to flooding or be at risk of impacts from flooding.

[4] http://anrmaps.vermont.gov/websites/anra/

Table 5. Hydrologic Resource Mapping Elements

HYDROLOGIC RESERVE ZONE

Variable	Description	GIS Source Layer (vcgi.org)	Data Type	Scale
Elevation	Land areas greater than 2500 feet in elevation	ElevationOther_CON2500	vector	1:24,000
Steepness	Land areas of slope greater than 35%	ElevationSlope_SLOPE24 (generated from USGS 30-m DEM)	raster	1:24,000
Infiltration Capacity	Shallow-to-Bedrock - Soils composed of exposed bedrock or of shallow thickness to bedrock or other permeability-limiting layer	GeologicSoils_SO (NRCS) joined with Table 20 attributes – select ROCKSHALLOW ≤ 20 inches and ROCKDEEP ≤ 20 inches	vector	1:24,000
	Soils of Hydrologic Soil Group D	GeologicSoils_SO (NRCS) joined with Table 20 attributes - select for HSG D soil mapping units	vector	1:24,000
	Hydric Soils	GeologicSoils_SO (NRCS) joined with Table 20 attributes - select for Hydric soil mapping units	vector	1:24,000

HYDROLOGIC CONSERVATION ZONE

Variable	Description	GIS Source Layer (vcgi.org)	Data Type	Scale
Steepness	Land areas of slope greater than 15%	ElevationSlope_SLOPE24 (generated from USGS 30-m DEM)	raster	1:24,000
Infiltration Capacity	Soils of Hydrologic Soil Group C	GeologicSoils_SO (NRCS) joined with Table 20 attributes - select for HSG C soil mapping units	vector	1:24,000

4.4.1 Hydrologic Resource Mapping Elements

The mapping elements which define these Hydrologic Resource Zones relate to the topographic setting and infiltrative capacity of surface sediments.

- **Elevation**

Due to orographic effects, highest elevations of Vermont receive greater amounts of precipitation, and are projected to receive precipitation of increasing magnitude and intensity in future decades (Guilbert, *et al.*, 2014). Available research for Vermont is not conclusive as to a specific threshold elevation above which sensitivity to climate change is enhanced. An elevation of 2500 feet was chosen to be consistent with Vermont Water Quality rules which require greater water quality protections for waters above this elevation (VWMD, 2014).

- **Slope**

All other factors being equal, steeper-gradient hillslopes are likely to yield more runoff at higher velocities than lesser-gradient hillslopes. With greater flow velocities comes greater energy (stream power) to entrain and erode sediments. Where legacy impacts include historic road and skid trail networks established on steep slopes, these former road networks are serving as conduits for concentrated runoff, rill and gully erosion. Often, drainage along these road networks terminates at stream crossings without being adequately disconnected from the stream through turnout structures or infiltration basins. Roads developed on steep slopes disturb wider areas of soil and forest on cut and fill areas adjacent to the road to achieve suitable slopes than do roads traversing lesser-gradient hillslopes (Weist, 1998). Our mapping approach involved a threshold of greater than 35% slopes for Hydrologic Reserve areas and greater than 15% slopes for Hydrologic Conservation areas, consistent with a USDA publication for silvicultural suitability of Vermont soils (USDA, 1991).

- **Shallow-to-Bedrock Soils**

Soils with shallow depths to bedrock or other permeability-limiting layers such as clay or "hardpan" have very limited infiltration capacity. Precipitation and snowmelt will generate a greater amount of runoff from shallow soils as the limited thickness of soils is quickly saturated.

- **Hydrologic Soil Groups D and C**

The Natural Resources Conservation Service (USDA, 1986) classifies soils by their infiltration capacity into four groups (A through D), ranging from a high (A) to very low (D) capacity. Hydrologic Soil Groups D and C have been selected as elements of the Hydrologic Reserve and Hydrologic Conservation Zones, respectively, in the mapping approach recommended for this report:

  - "**Group D** soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material [e.g., bedrock]. These soils have a very low rate of water transmission (0-0.05 in/hr)" (USDA, 1986).

- **"Group C** soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr)". (USDA, 1986).

- **Hydric Soils**

Hydric soils are saturated by water, either on a seasonal or year-round basis and are often associated with wetlands. In headwater settings of Vermont, hydric soils tend to be distributed in isolated pockets associated with vernal pools, or along upper-elevation floodplains, ponds, or wetlands. In lowland settings, hydric soils tend to be more wide-spread. In the Champlain Valley physiographic province, hydric soils are frequently associated with glaciolacustrine deposits of the former Lake Vermont and Champlain Sea. In agricultural and developed areas, hydric soils may be mapped where wetlands were previously converted to other uses through installation of drainage ditching and/or tile drains. This prior-converted status of wetlands is not expected to be a condition representative of the majority of State Lands, which are predominantly forested. Often hydric soils are classified as HSG D soils, though not always.

4.5 Field Application

Camp Plymouth State Park in Plymouth was chosen by the Project Team to serve as a demonstration site for application of recommended measures to enhance flood resiliency on State Lands. For example, limited site assessments were conducted in the Fall of 2014 in the Buffalo Brook watershed upstream of the park to evaluate conformance to AMPs and to visualize the placement of infrastructure and the access network alongside a mapping of hydrologic zones outlined in Section 4.4. This task also leveraged data developed under a separate project by SMRC contracted to the Lake Rescue Association (SMRC, 2014) with funding from a VDEC Ecosystem Restoration Grant. Results of these assessments are summarized in Appendix B.

4.6 Summary Report and Presentations

A presentation of draft findings was delivered to the State Lands Stewardship Team in Montpelier on 22 January 2015. Proposed GIS mapping methods were delivered to the State Land Stewardship Team for review during a subsequent meeting on 26 March 2015. The draft summary report was presented at the 8 April 2015 State Lands Stewardship staff meeting in Waterbury, Vermont, with review comments incorporated in this final summary report.

5.0 Guiding Strategies to Enhance Flood Resilience

Overall strategies to improve flood resilience on State Lands are analogous to those of the EPA and VDEC for treatment of stormwater on developed lands (i.e., Low Impact Development and Green Infrastructure initiatives). Treatment strategies for stormwater involve practices to "slow it, spread it, sink it" (EPA, 2013).

- Slow stormwater runoff
  - increase roughness
  - decrease slopes
  - dissipate energy

- Spread stromwater and disconnect it from stream networks
  - disperse flow paths
  - interrupt flow paths with flow diversion structures (water bars, broad-based dips, turnouts)
  - direct runoff to infiltration or detention ponds

- Store and detain water allowing it to sink into the subsurface
  - Increase infiltration
  - minimize disturbance
  - minimize imperviousness & soil compaction

These strategies should be considered in the development of plans, policies and practices to enhance flood resilience on State Lands. Agency plans and polices should seek to protect river corridors and vulnerable land areas from further modification and encroachments. Implementation of optimal conservation practices will significantly increase infiltration, slow overland flow, trap sediment, and reduce downstream flood damage.

6.0 Findings and Recommendations

In consideration of these overall strategies, a suite of planning, policy and practice recommendations has been compiled to achieve greater flood resiliency on State Lands. Implementation of these recommendations can occur in a phased approach and will demonstrate exemplary practices for adoption by other public and private landowners. Section 7 outlines an implementation plan for these recommendations and addresses cost constraints as well as partnerships that can be leveraged to afford these measures.

Recommendations are organized below within the framework of an adaptive management cycle following *Open Standards for the Practice of Conservation*[5] (CMP, 2013) .

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[5] http://cmp-openstandards.org/

Figure 10. Adaptive Management Cycle after CMP, 2013.

6.1 Conceptualize

The State Lands Stewardship Team has taken important steps to plan for flood resiliency including commissioning this report. The team is identified and has a strong collaborative history of managing State Lands for various public uses and the protection of natural resources. Previous sections of this report have identified the project context, including critical threats of flooding related to climate change and a legacy of landscape and river network modifications.

To more comprehensively address flood resiliency, additional working sessions could be convened to further align the scope, vision, and conservation and management targets of the three ANR Departments that make up the State Lands Stewardship Team. Proposed conservation targets relevant to flood resiliency are presented in Section 6.2.1 (Table 7).

In keeping with its role as the trustee of Vermont's water resources, the VDEC should take a more active role in the management of State Lands. VDEC should be consistently represented on the district-level Stewardship Teams that meet approximately monthly to identify management priorities and that generate the annual work plans and LRMP for each State Lands management unit. Integration of VDEC staff within the Stewardship Teams has been achieved to varying degrees across the State in recent years. Basin Planners from the VDEC Watershed Management Division have been included in ANR District Stewardship Teams in Springfield, Rutland and Northeast Kingdom districts and have recently co-authored sections of the LRMPs pertaining to water resources. VDEC should take on an expanded role in monitoring land use practices on State Lands with respect to conservation targets and compliance with Vermont Water Quality Standards.

6.2 Plan Actions and Monitoring

In this new day of increased flood magnitude and frequency, the management approach for State Lands should incorporate water resources and water-related forest ecosystem services (i.e., retention, infiltration, filtering) more explicitly in its short-term and long-term planning efforts. Plans and policies should articulate specific targets and objectives for State Lands and Hydrologic Resource Zones in particular to achieve the overall goal of improved flood resiliency.

6.2.1 State-wide application

Update Acceptable Management Practices

To date, the primary mechanism for ensuring protection of water resources on State Lands has been the *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs* in Vermont (adopted in 1987 and last printed in 2011). "The AMPs are the proper method for the control and dispersal of water collecting on logging roads, skid trails and log landings. …The AMPs are intended to prevent discharges" to receiving waters (AMPs, 2011).

With regard to improved flood resiliency, and in light of a changing climate, the Project Team sees significant challenges in relying solely on AMPs. AMPs were designed to address runoff conditions during historic storm conditions, if structures are installed properly and at the recommended density. However, there are no regular practices to quantitatively measure conformance with the AMPs (e.g., appropriate number and spacing of drainage structures on forest access roads or skid trails). State Lands Stewardship Team members report that AMP compliance is more qualitatively measured as the absence of an observed or reported discharge to the waters of the State. This standard for measuring AMP compliance is subjective and contingent upon the conditions at the time of inspection. During spring runoff or intense storms when conditions are such that discharge will be possible, it may be less likely for Stewardship staff or others to be inspecting projects. And yet these are exactly the conditions that contribute most to erosion, downstream flooding and water quality impacts. Improving flood resiliency (and water quality) requires managing for these infrequent, but significant, storm conditions.

Also, in light of increasing storm frequency, intensity, persistence and magnitude, AMPs will not be sufficient for those land areas most vulnerable to generating stormwater runoff (i.e., Hydrologic Reserve Zones and River Corridors). AMPs are designed primarily with the objective of maintaining water quality and reducing the likelihood for direct discharges during historic storm conditions. They are not designed to enhance flood resiliency specifically, or to address more extreme storm conditions experienced with greater frequency in recent years and anticipated in coming decades. Our recommendation is that Optimal Conservation Practices (OCPs) be developed for enhancing both flood resiliency and water quality in forested headwaters (Figure 11). OCPs are outlined in Appendix C. Through OCPs, greater protection measures would be applied to those land areas most vulnerable to generating runoff.

OCPs would apply to all access networks regardless of whether or not they are actively being used for timber harvest . All roads and trails on State Lands have the potential to serve as conduits of stormwater, and flood resiliency is enhanced by ensuring that drainage structures are properly spaced and maintained.

Figure 11. Recommended Optimal Conservation Practices

OCPs should be an element of a proposed *Silvicultural Guide to Understanding, Preserving, and Enhancing the Capacity of Vermont's Headwater Forests to Attenuate Flood Damage and to Produce High Quality Waters in a Rapidly Changing Climate*.

Incorporate Flood Resiliency in Long-range Management Plans

As stated in the ANR Long Range Management Planning Support Document (2001), "the development of the … LRMP for agency lands represents a key step in providing responsible stewardship of these valued public assets. Each LRMP identifies areas where different uses are to be allowed and describes how these uses will be managed to ensure protection of natural resources. The … over-arching management standards further both agency and department missions and are applied to the development of long-range management plans for all ANR lands" . As trustees of water and wildlife, VDEC and VFW, in particular, have a responsibility to oversee land management activities on all State Lands to ensure compliance with State regulations and policies that are designed to protect water quality and reduce flood erosion and inundation hazards.

The management objective of enhanced flood resiliency should be more consistently incorporated within the Long-range Management Plan (LRMP) for each State Lands management unit. Historically, the LRMP has reflected management objectives for those public forest resources that are owned - i.e., timber harvest, habitat provision, wood products, non-wood products, cultural resources and recreational use. There is some discussion and planning for protection of wildlife – particularly rare, endangered, and threatened species – in terms of management of the habitat for those species. However, there is variable treatment of water and those practices and policies that are protective of water quality and which build flood resilience. Those LRMPs which have been updated in more recent years tend to have addressed water resources to a greater degree. The Natural Resource Assessment process should be adapted to more explicitly identify flood resiliency as a management objective. Forest resources should be recognized as part of the stormwater management infrastructure on State Lands, and activities should be managed to further enhance forest health.

The mapping approach outlined in Section 4.4 can be incorporated directly with the Natural Resource Inventory process that is undertaken during the development of the LRMP for each state-owned unit. This mapping approach is intended to help inform the designation of existing LRMP land use classifications, and is not intended as a stand-alone land use classification system. For example, the *Hydrologic Reserve Zone* would be the hydrologic resource component of those lands which are deemed Highly Sensitive Management Areas (Table 6). *Hydrologic Conservation Zones* or *Other Zones* would span those Special Management Areas, General Management Areas, and Intensive Management Areas delineated on the remaining lands. The *River Corridor* overlay would then intersect all planning units. Thus, with respect to climate change and flooding, the *Hydrologic Reserve Zone* and the *River Corridor* are composed of land units that have very limited adaptive capacity. *Hydrologic Conservation Zone* lands have low to moderate adaptive capacity, and *Other Lands* have moderate to good adaptive capacity.

It is clear from interviews with VFPR staff (e.g., Morton, 2014; Thornton, 2014; Lones, 2014) that hydrologically-sensitive areas are being considered during planned activities on State Lands, such as the layout of harvest areas for pending timber sales. However, this has been an informal process to date. Hydrological resources should be explicitly called out and given at least equal weighting among the list of sensitive resources considered in the inventory process.

Table 6. Relationship of Hydrologic Planning Approach to Existing Land Management Classification system used by ANR

<table>
<tr><th>Category</th><th>Description</th><th>Hydrologic Unit</th></tr>
<tr><td>Highly Sensitive Management Areas</td><td>“areas with uncommon or outstanding biological, ecological, geological, <<add hydrological >>, scenic cultural or historic significance…”</td><td>Hydrologic Reserve Zone</td></tr>
<tr><td>Special Management Areas</td><td>areas “where protection and or enhancement of those resources is an important consideration for management…”</td><td rowspan="3">Hydrologic Conservation Zone

Or

Other Lands</td></tr>
<tr><td>General Management Areas</td><td>areas where “dominant uses include vegetation management for timber and wildlife habitat, concentrated trail networks, and dispersed recreation…”</td></tr>
<tr><td>Intensive Management</td><td>areas characterized by a “high level of human activity and high intensity development on or adjacent to State land.”</td></tr>
</table>

Establish Conservation Targets

Plans and policies should articulate specific targets and objectives for State Lands, and Hydrologic Resource Zones in particular, to achieve the overall goal of enhanced flood resiliency. For example, Table 7 presents proposed conservation targets for the four Hydrologic Resource Zones on State Lands with respect to the access network, including truck roads, forwarding paths, skid trails, and log landings. Road and trail networks are generally “regarded as one of the most hydrologically active areas within a logged forest” (Croke & Hairsine, 2006). A recent study of Vermont stream reaches in forested headwater settings found that proximity between roads and streams and density of stream crossings were the best predictors of geomorphic instability – itself a reflection of increased stormwater and sediment delivery (Pechenick *et al.,* 2014).

Table 7 defines default conditions for each of the hydrologic resource zones, which vary in their propensity to generate stormwater runoff. More stringent standards for access networks are proposed in those land areas that are most sensitive (i.e., River Corridor and Hydrologic Reserve Zones) due to steepness of slopes, presence of limited soil infiltration capacity, and proximity to the stream network. Collectively, these conservation targets represent actions to remove or reduce the degree of hydrologic modification on State Lands and to disconnect sources of concentrated runoff and sediment from the stream network. Performance in meeting these conservation targets should be measured through regular monitoring efforts (see Sections 6.3 and 6.4).

Ideally, the network of road and trail access to a management unit would be laid out such that the most vulnerable land areas are avoided to the greatest extent possible. This may mean longer roads and trails with more switch backs to achieve ideal road gradients (less than 7%). The resulting percentage of land area developed with an access network may, in these cases, exceed conservation targets for percent imperviousness. However, to the degree that stormwater is disconnected from the stream network through adequately constructed and appropriately spaced drainage structures, a higher percentage of imperviousness can be tolerated.

Road gradients of 7% or less are ideal, as they more effectively dissipate stormwater runoff (with the proper density of functioning broad-based dips), cost less to install, and will require less frequent maintenance. At road gradients exceeding 10% the outsloped broad-based dip cannot be effectively used to control drainage. Water bars can be used but are much less effective, and require more frequent maintenance, than when installed on lesser-gradient road segments. The higher density of drainage structures required on steeper road gradients increases installation and maintenance costs.

Conservation targets could be applied, evaluated and refined in a series of pilot tests implemented by Stewardship staff on a subset of State Lands management units across the state. Several of the proposed conservation measures are already being implemented on State Lands, as depicted in Figure 12.

Table 7. Conservation Targets for Enhanced Flood Resiliency by Hydrologic Resource Zone

	River Corridor	Hydrologic Reserve Zone	Hydrologic Conservation Zone	Other Lands
Access Network Targets [1]				
Access Standards	Site-specific design	Site-specific design	OCPs	AMPs
Road density	Site-specific design	Site-specific design	<2 miles/100 acres [4]	-----
Maximum impervious area	5% [2]	0%	5% [2]	10% [3]
Average access segment slope	Site-specific design	Site-specific design	7% [4]	AMPs
Maximum access segment slope/length	Site-specific design	Site-specific design	10%/200 feet	AMPs
Erosion control structures	Site-specific design	Site-specific design	Primarily BBDs	AMPs
Erosion control structure spacing	Site-specific design	Site-specific design	{[100-(6.4*slope)]*3.281} [4] e.g., 118 ft for 10% slope	AMPs
Log landings	None	None	None	AMPs
Construction Season	Site-specific design	Site-specific design	Dry Summer	Dry Summer
Monitoring	VDEC	VDEC	FPR	FPR

[1] Including truck roads, forwarding paths, skid trails, and log landings.
[2] Fitzgerald, 2007 - Recent Vermont-based studies linking percent imperviousness to geomorphic and biologic condition of streams suggests that low-order streams (headwaters tributaries) may experience impacts from stormater runoff at thresholds lower than 5% impervious cover.
[3] Booth, 1991; Center for Watershed Protection, 2003.
[4] Swift, Jr., L.W, 1988. Forest Access Roads: Design, Maintenance, and Soil Loss

Abbreviations: BBDs = Broad-based dips; AMPs = Acceptable Management Practices; OCPs = Optimal Conservation Practices

Figure 12. Exemplary practices implemented at State Lands management units to enhance flood resiliency.

(a) Corduroy stream crossing at Tinmouth Channel WMA reduces sediment erosion and dissipates stormwater runoff along road approaches to the creek.

(b) broad-based dips installed on forest road in Plymsbury WMA off Old Shrewsbury Road.

(c) Road segments have been down-sized, vegetated, and culverts removed in a portion of the access network at Curtis Hollow drainage in Coolidge State Forest East.

Address Legacy Impacts

Often, the state has acquired lands with a legacy of road and trail networks that do not meet the conservation targets recommended in Table 7. Over time, legacy roads and trails located in the most vulnerable land settings should be downsized or decommissioned to reduce the degree to which they may continue to serve as a source of concentrated runoff. Downsizing involves narrowing the road and installing appropriate densities of drainage structures, and would reduce the degree to which stormwaters draining along these networks are directly connected to streams.

Downsizing legacy roads and use of broad-based dips (<10%) or water bars (>10% slopes) at a frequency appropriate to the road grade will still permit recreational and hunting access to State Lands, while discouraging All-Terrain-Vehicle (ATV) access (where ATV access is not allowed). For example, a segment of forest road has recently been downsized and culverts removed in the Coolidge Hollow drainage in Coolidge State Forest East (Figure 12c).

Table 8 identifies priorities for addressing legacy impacts by Hydrologic Resource Zone.

Table 8. Priorities for addressing legacy impacts by Hydrologic Resource Zone

	River Corridor	Hydrologic Reserve	Hydrologic Conservation	Other Lands
Address Legacy Impacts				
Decomission/Replace Road Segments parallel to the Streams	✓✓✓	✓✓✓	✓✓	✓
Rewild Road Segments steeper than…	--	10% ✓✓✓	25% ✓✓✓	25% ✓✓✓
Downsize/optimize access network to meet Conservation targets		✓✓	✓✓	✓
Remove Unused culvert/ bridge crossings	✓✓✓✓	✓✓✓	✓✓	✓
Disconnect roads & trails from stream channels using turn-ups, broad-based dips (active use) or water bars (inactive)	✓✓✓✓	✓✓✓	✓✓	✓
Disconnect road ditches from stream channels using turn-outs, infiltration basins, settling ponds	✓✓✓✓	✓✓✓	✓✓	✓
Buildings, parking areas, lifts/ski trails, recreational structures	Plan for removal or flood-proof	Incorporate Green Infrastructure and LID retrofits		

✓ *Higher number of check marks indicates higher priority*

6.2.2 Unit-specific application

Inventory and Map Hydrologic Resource Zones

At each State Lands management unit, areas most vulnerable to generating runoff should be inventoried and mapped following a procedure such as the mapping approach outlined in Section 4.4. This inventory process is a way to visualize those portions of the management unit more prone to generating stormwater, so that these areas can be avoided to the greatest extent possible when considering new access networks and other built infrastructure. Mapping of these hydrologic resource zones also serves as a way to prioritize restoration and decommissioning activities to address legacy impacts. It may not be practical to apply this inventory and mapping task at all State Lands management units, since not all units will be large enough or have the relevant composition to warrant application of this approach. For those larger management units across the state, however, this can be a useful characterization and prioritization tool.

For example, Figure 13 displays the mapping of Hydrologic Resource Zones at the Buffalo Brook watershed draining to Camp Plymouth State Park. This catchment includes portions of the Arthur Davis Wildlife Management Area in Plymouth and Reading. See Appendix B for an illustration of the individual mapping elements comprising these zones. A majority of the land area in the upstream drainage area to Camp Plymouth State Park is mapped as either Hydrologic Reserve Zone or Hydrologic Conservation Zone, in which proposed conservation targets would include measures somewhat more stringent than AMPs. This finding reflects the mountainous terrain and predominance of infiltration-limiting soils in this watershed. Appendix A illustrates the application of this mapping approach in the other State Lands selected for this project. (Note that a large area of Tinmouth Channel WMA mapped as Hydrologic Reserve Zone was already protected by virtue of its classification as a Class I wetland).

The mapping approach as outlined (Section 4.4), and the related conservation targets for enhanced flood resiliency (Table 7), should be field-truthed. District stewardship teams could select one State Lands management unit in each district to pilot test this inventory and mapping approach. Pilot testing would provide an opportunity to address concerns raised by the project Steering Committee that selected State Lands may not adequately represent the diversity of soil types, topographic settings and land covers on State Lands as a whole. For example, soils in the Northeastern Highlands and Northern Vermont Piedmont can be dominated by Hydrologic Group D soils, but on level or lesser-gradient (<15%) slopes (Bushey, 2015). Given this situation, the mapping approach could be refined such that land areas to be mapped as *Hydrologic Reserve* require both HSG D soils AND steep (>35%) slopes, rather than either HSG D soils OR steep slopes. Further application and testing of the mapping approach could also incorporate variable weighting of mapping elements (Pytlik, 2015).

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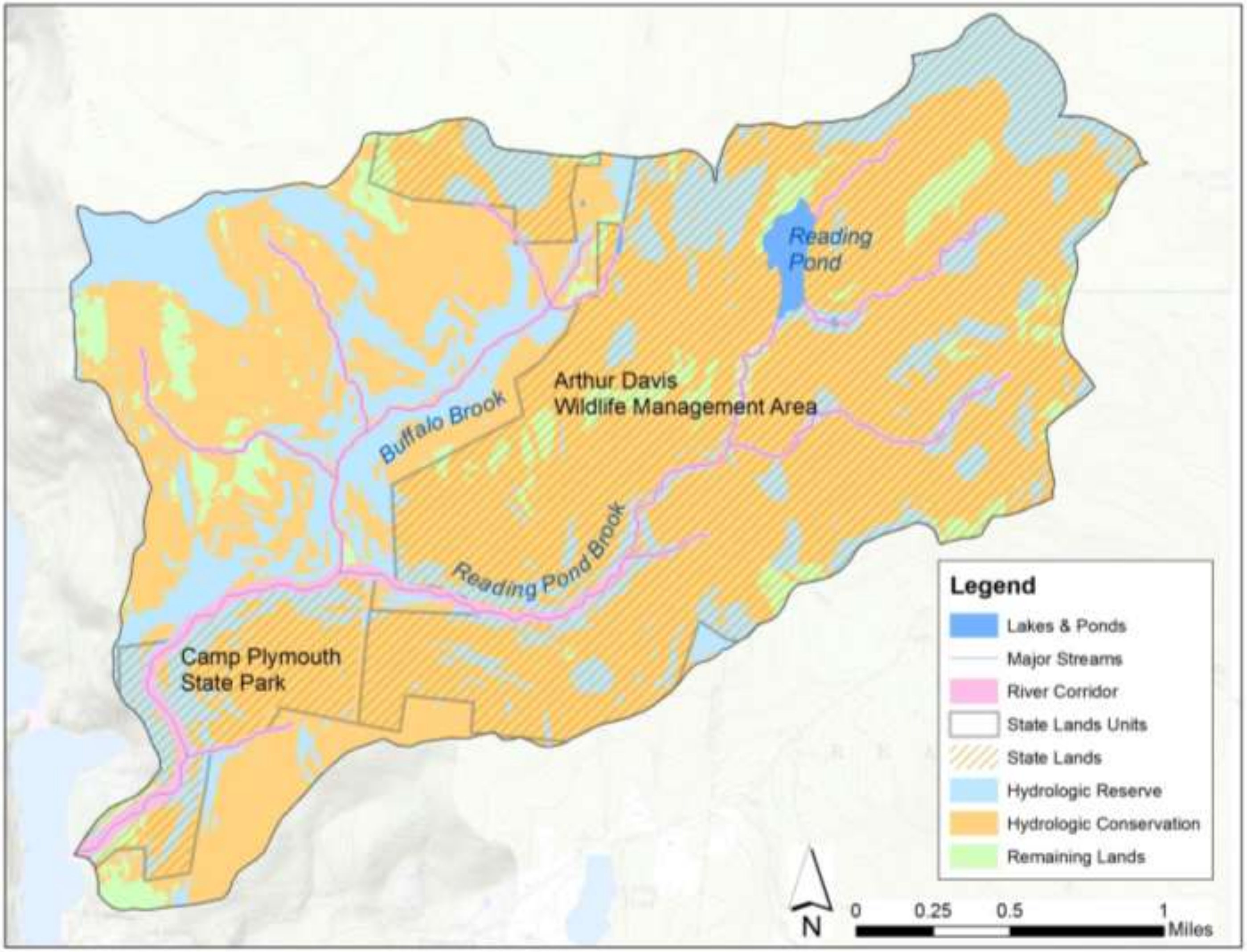


Figure 13. Application of the Hydrologic Resource Mapping Approach to Buffalo Brook watershed draining portions of the Arthur Davis Wildlife Management Area in Plymouth and Reading, joining Echo Lake at Camp Plymouth State Park.

Inventory and Map Built Infrastructure

Inventories of built infrastructure should be undertaken or formalized for each State Land management unit to inform hazard planning, capital budgeting, and flood resiliency planning. It is important to know the position and condition of this infrastructure with respect to the natural Hydrologic Resource Zones to understand the degree that infrastructure may enhance the sensitivity of the landscape to flooding, so that adequate adaptation actions can be undertaken. Similarly, this mapping process can identify infrastructure at risk from flooding, so that appropriate mitigative actions can be prioritized. Identification of structures on a commonly-available GIS platform and database (e.g., Vermont Natural Resources Atlas platform) can increase networking opportunities with private groups and public agencies to leverage additional funding sources for upgrades, retrofitting, or decommissioning.

- Road and Trail Networks - Mapping and assessment of access networks should be conducted, including roads, skid trails, and parking areas and landings. Access networks should be evaluated for conformance with Acceptable Management Practices, and ultimately for conformance with Optimal Conservation Practices. These are rapid assessments, easily implemented using a recreational-grade GPS unit, tape measure and inclinometer in a simple tally system such as the Benchmark Tally published by Vermont Family Forests (Figure 14). Figure 15 and Table 9 provide an example of an assessment performed on trail networks upstream of the Camp Plymouth State Park during this project. Forest logging trails were assessed for gradient and number/ spacing of drainage structures (see Appendix B).

Figure 14. Benchmark tally on skid trail at Camp Plymouth State Park

- Culvert & Bridge Inventories - inventories of culvert and bridge structures located on State Lands, should be conducted, including lands on which timber management rights are owned by private parties. Structure inventories should be evaluated for geomorphic compatibility as well as Aquatic Organism Passage (AOP) in accordance with VTANR Stream Geomorphic Assessment protocols (VTANR, 2009). Unused structures should be identified for removal with appropriate stream restoration. Road ditches should be disconnected from stream networks through turnouts and infiltration and detention basins. Inventory information can be used for capital budget planning and to inform priorities for structure removal, rehabilitation or replacement. Figures 16 and 17 provide examples from the Coolidge State Forest East off Curtis Hollow Road.

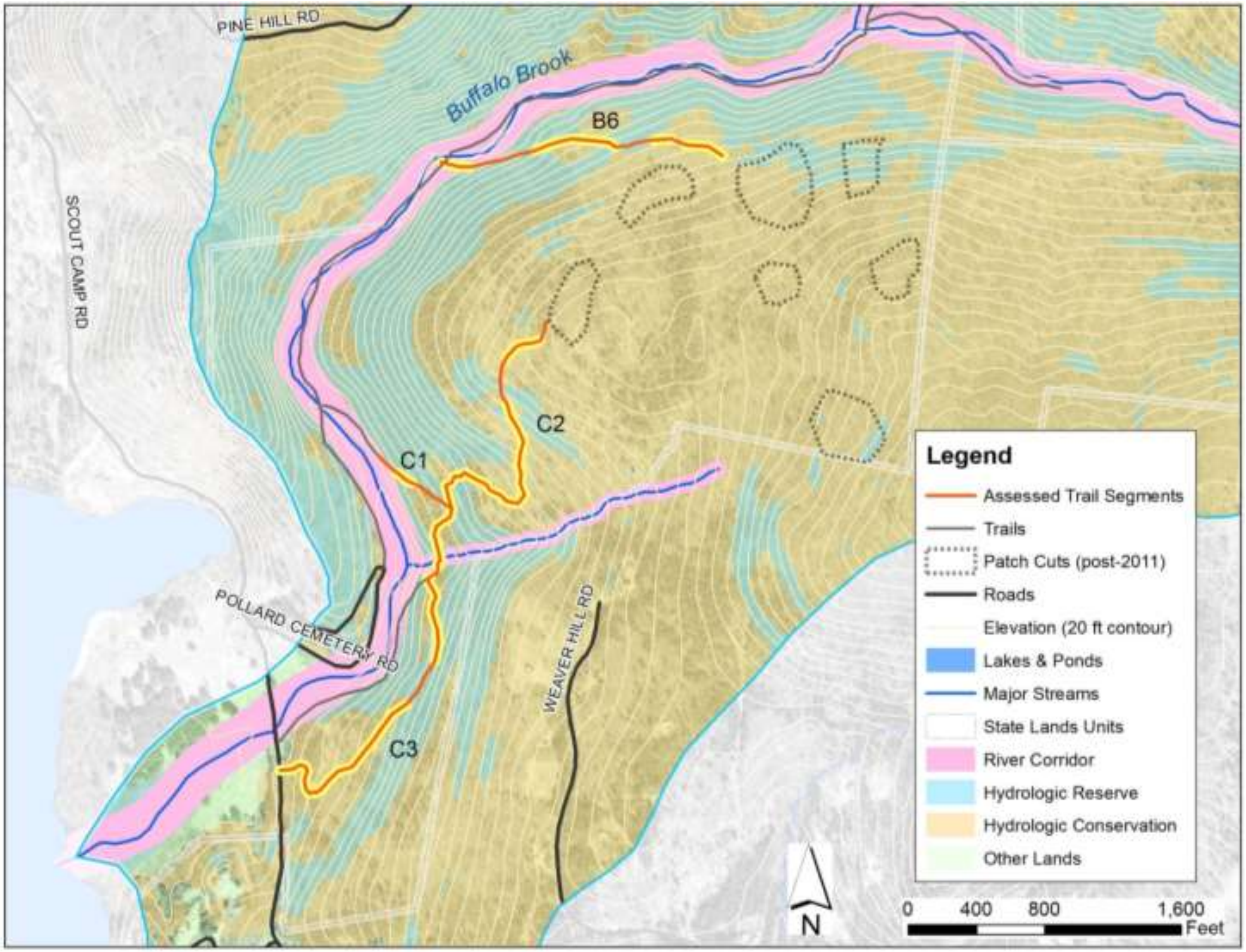


Figure 15. Road Segments Evaluated at Camp Plymouth State Park for Conformance with AMPs. Yellow highlighting indicates road segments exceeding 10% gradient.

Table 9. Evaluation of Forest Road Segments for Conformance to AMPs – Camp Plymouth State Park, Plymouth

Seg-ment	Length Assessed ft	Average slope of segment %	# functional drainage structures in place	# Drainage Structures Recom-mended	Percent Compliant with AMPs %	Percent of Length with Gradient >10% %	Percent of Length with Gradient >15% %
B6	1700	12.8	1	26	4%	59%	29%
C1	500	12.2	5	7.4	68%	40%	20%
C2	1800	16.3	15	32	47%	78%	61%
C3	2244	14.0	26	37.2	70%	85%	36%

Note: Road gradients of 7% or less are ideal, as they cost less to install, require less frequent maintenance, and more effectively dissipate stormwater runoff (with the proper density of fully-functioning broad-based dips). At road gradients exceeding 10% the outsloped broad-based dip cannot be effectively used to control drainage. Water bars can be used but are much less effective than when installed on lesser-gradient road segments, and require frequent maintenance. The higher density of drainage structures required on steeper road gradients increases installation and maintenance costs.

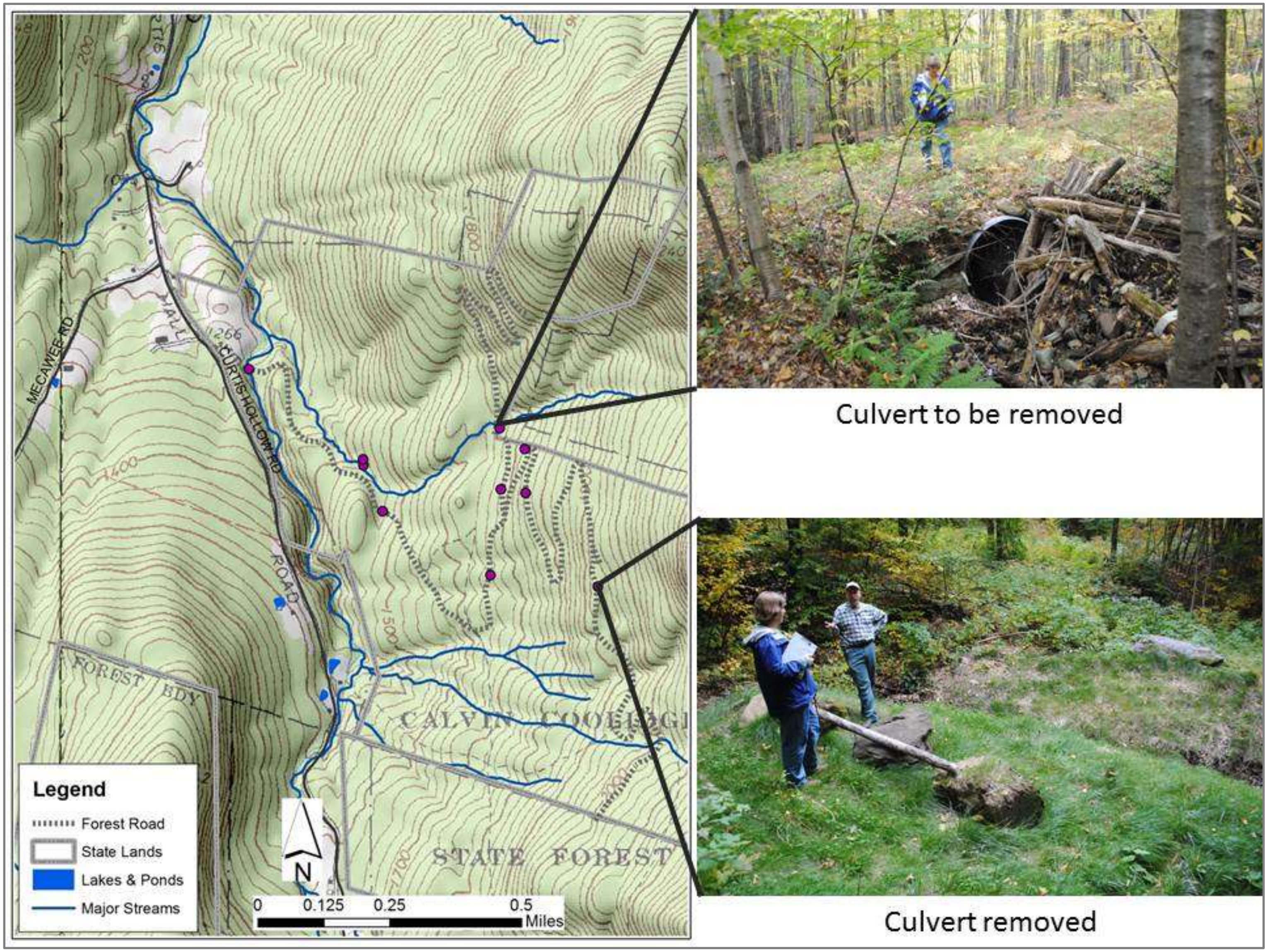
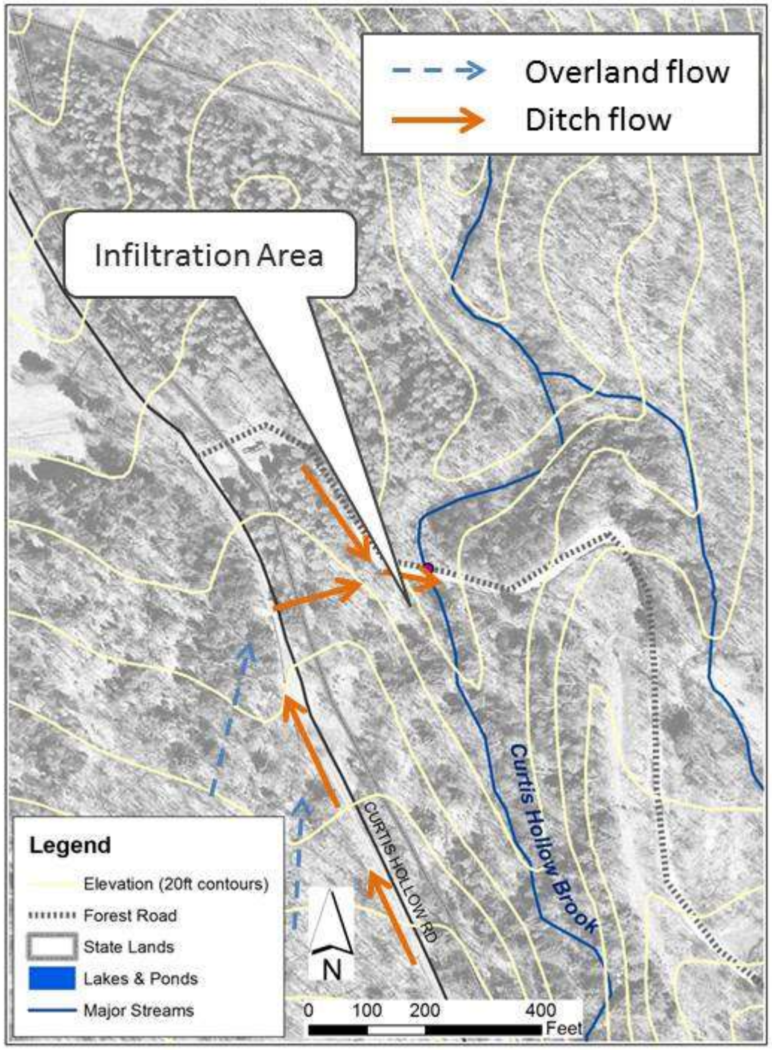


Figure 16. Example of culvert inventories at Calvin Coolidge State Forest – East, off Curtis Hollow Road, Woodstock



Abutment replaced after TS Irene

Opportunity to Disconnect Road Ditch

Figure 17. Example of Opportunity to Disconnect Road Ditch Runoff from Curtis Hollow Brook, Calvin Coolidge SF – East, Woodstock. Ditch network receives stormwater from ditches along Curtis Hollow Road. Opportunity for town collaboration and possible Better Backroads grant – a possible demonstration and training site.

- Buildings / Facilities - inventories should be conducted of buildings and facilities located within mapped river corridors. A record of repeat damages sustained during past flooding events and associated costs should be maintained and included in a life-cycle estimate of building or facility maintenance. Through these inventories, priorities can be assigned to those structures which could be relocated or removed from the corridor, and plans developed for relocation/removal following the next significant flood-damage event, including a cost threshold above which the structure will not be repaired. For those structures which – due to cultural or historical significance or other constraints – cannot be relocated or removed, emergency management plans and possible flood-proofing measures should be developed. Figure 18 depicts several structures at risk from flooding on the alluvial fan of Buffalo Brook at Camp Plymouth State Park.

Develop River Corridor Plans

River corridor plans should be developed for those stream reaches on State Lands draining greater than two square miles in area. Protocols and methods have been published by the VTANR (2009, 2011). Approved data reside in the Stream Geomorphic Assessment Data Management System and are available for viewing on the Vermont Natural Resource Atlas. A subset of these reaches on State Lands has already been assessed. For those unassessed reaches, the State Lands Stewardship Teams could collaborate with towns, Regional Planning Commissions, Conservation Districts and/or local watershed groups to secure funding for technical support services to carry out these assessments.

River corridor plans involve the physical assessment of the stream reach following Stream Geomorphic Assessment protocols. Based on the condition of each reach and the overall sensitivity of adjustment in response to changing water and sediment volumes, various stream and corridor restoration and conservation projects are identified and prioritized.

These existing protocols provide a framework for inventory and evaluation that can be leveraged by ANR on State Lands. Completed river corridor plans should be referenced within the LRMP for the respective management unit. These data will also be incorporated in VDEC Basin Plans as part of the Tactical Basin Planning[6] approach of the VDEC Watershed Management Division. This process opens the door to many more financial and technical resources to implement recommended restoration and conservation projects. An example is the Ecosystem Restoration Grant secured by Lake Rescue Association in Plymouth to accomplish rewilding of forest road segments within the private lands and State Forest lands of Buffalo Brook watershed upstream of Camp Plymouth State Park (to be implemented in 2015).

Stream and river corridor restoration projects could be incorporated in timber harvest contracts on State Lands. For example, directional felling of large woody debris into the stream channel (“chop and drop”) can trap sediment and add roughness elements to the channel bed that serve to attenuate flow velocities (Figure 18). Timber sales could incorporate the hydrologic restoration needs of a State Lands unit – a “Hydrologic Restoration Sale” in addition to a “Timber Harvest Sale”.

[6] http://www.vtwaterquality.org/wqd_mgtplan/swms_ch4.htm

Figure 18. Example of mapping to identify infrastructure at risk of erosion and inundation flooding, Camp Plymouth State Park.

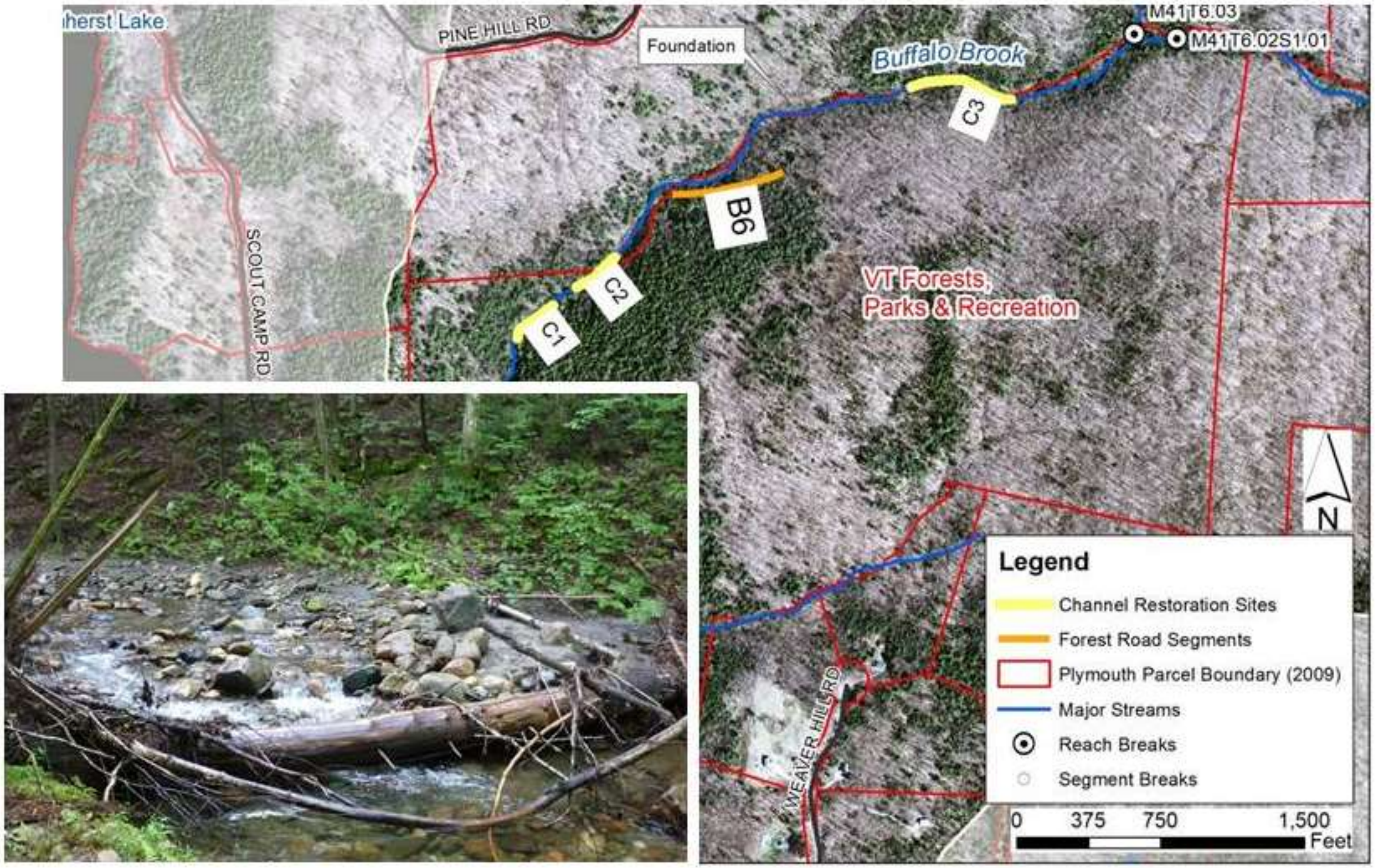


Figure 19. Example of a "chop and drop" stream restoration technique to attenuate flows, trap sediment, and improve aquatic habitats. This strategy was proposed for select segments of the Buffalo Brook upstream of Camp Plymouth State Park as part of a separate project. A similar project could be accomplished on State Lands through a "Hydrologic Restoration Sale".

6.3 Implement Actions and Monitoring

Practices to improve flood resiliency should be incorporated within the existing framework for managing State Lands, including:

- Annual Work Plans
- Lease Agreements (e.g., ski areas)
- Timber Sale Contracts

Forwarders should be used and incentivized where possible on State Lands. In general, they result in less soil compaction and less disturbance than skidders (Figure 20). As a consequence, forwarders are useful in a greater variety of weather conditions and require narrower and fewer access roads.

Skid Path, Camp Plymouth State Park Forwarding Path, Coolidge East

Figure 20. Comparison of land disturbance from use of skidder versus forwarder to harvest timber.

(Note: Other factors contribute to the difference in site conditions between the skid path site and the forwarding path site, including different years and seasons of logging operations, shaded versus full sun setting, aspect and slope setting) .

6.4 Analyze Data, Use the Results, and Adapt

Inventories and monitoring data should be used to evaluate compliance with conservation targets. Results should be used to update mapping and help to prioritize subsequent project phases. LRMP and annual work plans can be modified and adapted, accordingly.

6.5 Capture and Share Learning

As implementation of flood resiliency measures progresses, State Lands Stewardship Teams should document major findings. Successful projects can serve as demonstration projects for other Districts and for the public. Sharing can also occur in the setting of public outreach meetings convened during development of the Long-Range Management Plans.

Stewardship staff reported a strong interest in training in flood resiliency techniques. Training could be accomplished within the Agency (VFW, VDEC) and with other partners (e.g., US Forest Service, US Fish & Wildlife, Regional Planning Commissions, Ski Areas). For example, the VDEC Rivers Program and VFW have organized training sessions with VTrans and local road crews on how to design, construct and maintain roads and bridges to create greater river stability and more flood resilient transportation infrastructure[7]. A similar model could be employed to train State Lands staff and logging contractors to incorporate conservation practices and various stream and river corridor restoration techniques for improved flood resiliency on State Lands. Projects might include infiltration basins to disconnect ditch drainage from streams, gully stabilization projects utilizing large woody debris harvested during the logging project, or "chop and drop" projects to enhance stream habitats and attenuate sediment. Such projects could involve partnership with other state and federal agencies, utilizing grant funding sources to afford professional design, permitting and construction.

Possible training opportunities

- Use of Planning Tools – VT Natural Resources Atlas, USGS Streamstats, Stream Simulation Design of crossing structures for Aquatic Organism Passage
- Design of flood resiliency techniques/ practices
- Design of access networks to meet conservation targets for flood resiliency
- Measurement techniques for AMPs and OCPs

Citizens should be engaged in basic mapping and monitoring tasks on State Lands, such as GPS mapping of road and trail networks and benchmark tallies to quantify density of drainage structures. This will increase public awareness of the challenges and strategies for addressing flood resiliency. It can be a way to afford necessary monitoring efforts in a context of limited ANR budgets and staffing, and it represents a way to enable the transfer of these techniques to private lands. Citizen science can be coordinated through collaboration with local watershed groups or other non-profits including the Green Mountain Club or local universities and high schools.

7.0 Implementation Plan

This section broadly outlines a plan to implement enhanced flood resiliency on State Lands. It has taken over 225 years to significantly alter the hydrology of Vermont's forests through a legacy of landscape and stream network modifications. Restoring the hydrology will take time, but is not impossible if we support the forest's capacity for self-renewal by minimizing our activities in the most vulnerable settings and by optimally siting our access to the forest for recreational use and wood-product harvest.

[7] http://www.watershedmanagement.vt.gov/rivers/docs/rv_Tier2_Overview.pdf;

Recommended actions should be phased in over time (Table 10). Implementation and refinement of Optimal Conservation Practices and conservation targets for Hydrologic Resource Zones could start small, applying these practices in a pilot project on one management unit in each District or river basin.

Restoration / conservation projects should be implemented according to priorities developed during the LRMP and River Corridor Plans. Greater priority should be placed on projects that disconnect road and trail networks from the stream network. Start with management units that experienced most significant losses in Tropical Storm Irene (in central and southern Vermont) and during the floods of the 1990s (in northern Vermont). Prioritize those areas for river corridor plans and implementation projects.

Table 10. Phased Plan to Implement Recommended Flood Resiliency Measures.

	Year						
	1	2	3	4	5	5 to 10	10 to 20
Align missions and objectives	■						
Update State-wide Plans/Policies to include Flood Resiliency	■						
Refine Conservation Targets for New Projects	■						
Develop Optimal Conservation Practices (OCPs)	■						
Develop Silvicultural Guide for Improved Flood Resiliency	■	■					
Conduct Monitoring and Evaluation - Engage Citizens	■	■	■	■	■	■	■
Conduct Training in Flood Resilience Practices	■	■	■	■	■		
Reach out to Partners to Collaborate on Implementation	■	■					
Implement Restoration / Conservation Projects w/Partners	■	■	■	■	■	■	■
Phase in OCPs			■	■	■	■	■
Address Legacy Impacts		■	■	■	■	■	■

Most importantly, implementation of flood resiliency measures will be accelerated through collaboration with other stakeholders. Often projects implemented for other purposes can have overlapping benefits for flood resiliency, opening up other avenues for technical and financial resources to accomplish flood resiliency objectives. For example:

<u>State and Federal agencies</u>

- US Forest Service - Precedent for USFS technical and/or financial resources to support projects located in the same watershed where USFS holds land.
- US Department of Agriculture, Natural Resources Conservation Service
- US Fish & Wildlife – particularly culvert / bridge crossings for AOP
- FEMA – post-disaster recovery, and hazard mitigation planning (cooperate with towns)
- Department of Homeland Security (e.g., forest road and trail mapping for emergency management purposes)

- VDEC – Ecosystem Restoration Grants, Vermont Watershed Grants (e.g., in collaboration with town or watershed groups)
- Better Backroads grants (improve road networks, collaboration with towns/watershed groups)

Public / private partnerships

- Watershed groups (e.g., citizen science for mapping, monitoring, planting)
- Colleges and Universities (service learning projects including mapping, monitoring)
- Municipalities (towns, conservation districts, RPCs)
- The Nature Conservancy (conservation of forested headwaters and attenuation assets in mid- to low-lands)
- Vermont Land Trust (conservation of forested headwaters)
- Vermont River Conservancy (conservation and restoration of river corridors)
- Private foundations

Given economic constraints, it will be necessary to work collaboratively to accomplish restoration and conservation objectives, relying to a greater extent on private-public partnerships. Our collective investment in plans, policies and practices to enhance flood resiliency on State Lands will realize greater returns in avoided loss of life, reduced flood damages, improved water quality, and improved forest health for future generations.

8.0 Conclusions

State Lands serve as useful demonstration sites to showcase exemplary practices that address the challenges of a changing climate and a legacy of landscape and river network modifications.

A suite of plans, policies, and practices for improved flood resiliency has been offered, in an adaptive management framework, to support forest health and enhanced flood resiliency on State Lands. These public lands are predominantly located in forested headwater settings. This presents an opportunity to address stormwater generation and sediment production at the source, leading to reduced flood damages along downstream reaches.

The recommended approach is not intended to discourage forest utilization for recreational and harvesting purposes, but rather to accommodate these uses through optimally-designed access networks, while supporting and enhancing forest health and structure to slow, spread, and sink stormwater.

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"Health is the capacity of the land for self-renewal.
Conservation is our effort to understand and preserve that capacity." Aldo Leopold

North American Maple Plot, Coolidge East, October 2014