Prepared in cooperation with the
U.S. Department of Homeland Security Federal Emergency Management Agency

Flood Inundation Maps and Water-Surface Profiles for Tropical Storm Irene and Selected Annual Exceedance Probability Floods for Flint Brook and the Third Branch White River in Roxbury, Vermont

Scientific Investigations Report 2014–5118

U.S. Department of the Interior
U.S. Geological Survey

Cover. Digital orthophotograph covering a 1,000-meter corridor centered on Vermont State Route 12A in Roxbury, Vermont, and spanning six other communities; photograph courtesy of State of Vermont, April 2012.

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Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

AEP	annual exceedance probability
FEMA	Federal Emergency Management Agency
lidar	light detection and ranging
NECR	New England Central Railroad
USGS	U.S. Geological Survey
WSE	water-surface elevation

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Abstract

Flint Brook, a tributary to the Third Branch White River in Roxbury, Vermont, has a history of flooding the Vermont Fish and Wildlife Department's Roxbury Fish Culture Station (the hatchery) and surrounding infrastructure. Flooding resulting from tropical storm Irene on August 28–29, 2011, caused widespread destruction in the region, including extensive and costly damages to the State-owned hatchery and the transportation infrastructure in the Town of Roxbury, Vermont. Sections of State Route 12A were washed out, and several bridges and culverts on Oxbow Road, Thurston Hill Road, and the New England Central Railroad in Roxbury were heavily damaged. Record high peak-discharge estimates of 2,140 cubic feet per second (ft^3/s) and 4,320 ft^3/s were calculated for Flint Brook at its confluence with the Third Branch White River and for the Third Branch White River at about 350 feet (ft) downstream from the hatchery, respectively. The annual exceedance probabilities (AEPs) of the peak discharges for Flint Brook and the Third Branch White River were less than 0.2 percent (less than a one in 500 chance of occurring in a given year). Hydrologic and hydraulic analyses of Flint Brook and the Third Branch White River were done to investigate flooding at the hatchery in Roxbury and support efforts by the Federal Emergency Management Agency to assist State and local mitigation and reconstruction efforts.

During the August 2011 flood, the majority of flow from Flint Brook (97 percent or 2,070 ft^3/s) diverged from its primary watercourse due to a retaining wall failure immediately upstream of Oxbow Road and inundated the hatchery. Although a minor amount of flow from the Third Branch White River could have overtopped State Route 12A and spilled into the hatchery, the Third Branch White River did not cause flood damages or exacerbate flooding at the hatchery during the August 2011 flood. The simulated water-surface elevations for August 2011 flood equal the elevations of State Route 12A about 500 ft downstream of Thurston Hill Road adjacent to the troughs between the rearing ponds. The model results indicate that the 10-, 2-, 1, and 0.2-percent AEP flood discharges for the Third Branch White River do not overtop State Route 12A and cause flooding to the hatchery.

Four flood mitigation alternatives (Stantec, Inc., written commun., 2013) being considered by the Vermont Agency of Transportation to improve the hydraulic performance of Flint Brook and reduce the risk of flooding at the hatchery include: (A) no changes to the infrastructure or existing alignment of Flint Brook (existing conditions [2014]), (B) structural changes to the bridges and the existing retaining wall along Flint Brook, (C) realignment of Flint Brook to flow along the south side of Oxbow Road to accommodate larger stream discharges, and (D) a diversion channel for flows greater than 1-percent annual exceedance probability. Although the 10-, 2-, and 1-percent AEP floods do not flood the hatchery under alternative A (no changes to the infrastructure), the 0.2-percent AEP flow still poses a flooding threat to the hatchery because flow will continue to overtop the existing retaining wall and flood the hatchery. Under the other mitigation alternatives (B, C, and D) that include some variation of structural changes to bridges, a retaining wall, and (or) channel, the peak discharges for the 10-, 2-, 1-, and 0.2-percent annual exceedance probabilities do not flood the hatchery.

Water-surface profiles and flood inundation maps of the August 2011 flood and the 10-, 2-, 1-, and 0.2-percent AEPs for four mitigation alternatives were developed for Flint Brook and the Third Branch White River in the vicinity of the hatchery and can be used by the Federal, State, and local agencies to better understand the potential for future flooding at the hatchery.

Introduction

Flood information is needed by Federal, State, and local agencies to make informed decisions in meeting mission requirements related to flood hazard mitigation, planning, and response. The flood of August 28–29, 2011, due to tropical storm Irene caused extensive damages to the Vermont Fish and Wildlife Department's Roxbury Fish Culture Station (the hatchery) and the transportation infrastructure in the Town of Roxbury, Vermont (fig. 1). The hatchery, which began operations in 1891, is the oldest fish hatchery system in Vermont and is listed on the National Register of Historic Places (undated). During the August 2011 flood, Flint Brook, at the north end of the hatchery, breached its banks and washed out a retaining wall. The brook flowed through and around the hatchery, damaging the rearing ponds and causing extensive damage to the grounds and several buildings. The transportation infrastructure near the hatchery, which includes State Route 12A, the New England Central Railroad (NECR), Oxbow Road, Thurston Hill Road, and Carrie Howe Road, also was damaged. Annual exceedance probabilities (AEPs) for the August 2011 flood were between 0.2- and 1 percent for nearby U.S. Geological Survey (USGS) streamgages on Ayers Brook (01142500) White River, (01144000), and Mad River (04288000) and exceeded the 0.2-percent AEP on Dog River (04287000; fig. 1–1; Olson and Bent, 2013). The 0.2-percent AEP flood has a 0.2-percent chance of being equaled or exceeded in any given year. Damage caused by the flooding resulted in a presidential disaster declaration on September 1, 2011, for the 12 counties in Vermont affected by the August 2011 flood (Federal Emergency Management Agency, [2011]).

Flint Brook originates in the Northfield Mountains, flowing east, then north under Oxbow Road, and then east under the NECR and State Route 12A at the brook's confluence with the Third Branch White River. As Flint Brook flows through the sharp bend near Oxbow Road, the water velocity causes bank instability, undercutting, and erosion. A retaining wall was built to minimize erosion and stabilize the bank upstream of the bridge at Oxbow Road. The Third Branch White River originates in the Northfield Mountains and flows adjacent to the hatchery, crossing State Route 12A about 0.4 miles (mi) north of the hatchery and again immediately south of the hatchery.

When Flint Brook breached its banks during the August 2011 flood, its flow diverged along a straight path south to converge with the Third Branch of the White River. Although the mapped alignment of the lower reach of Flint Brook appears to be natural under most streamflow conditions, the natural channel alignment, particularly during major floods (1998, 2006, and 2011), is a straighter reach oriented in a southeasterly direction to the confluence with the Third Branch White River. During the August 2011 flood, Flint Brook followed the same divergent path as it did during the June 1998 and December 2006 floods. Although little information is available on the peak discharges or the high-water elevations at the hatchery for the 1998 and 2006 flood events, damages were less extensive and less costly than the August 2011 flood (Jeremy Whalen, supervisor, Roxbury Fish Culture Station, written commun., 2014). The rearing ponds were damaged (filled with gravel and debris) in the 1998 and 2006 floods, whereas they were completely destroyed and several buildings sustained significant damages in the 2011 flood.

After the August 2011 flood, State and local officials requested an investigation of flooding problems and mitigation measures at the hatchery. The Federal Emergency Management Agency (FEMA) retained Stantec, Inc., to propose and design several alternatives to reduce the risk of future flood damages to the hatchery infrastructure. In 2014, the USGS entered into an agreement with FEMA to provide hydrologic and hydraulic analyses in support of the efforts by FEMA to (1) compute flood profiles and produce a flood inundation map of the August 2011 flood in the vicinity of the hatchery, (2) investigate divergent flow conditions that affect the magnitude and extent of flooding along Flint Brook affecting the hatchery, and (3) compute flood profiles and produce flood inundation maps for floods of selected AEPs for the proposed mitigation design alternatives (Stantec, Inc., written commun., 2013).

Purpose and Scope

This report documents the magnitude and extent of flooding from the August 2011 flood (tropical storm Irene) at the hatchery in Roxbury and the hydrologic and hydraulic analyses of peak discharges in Flint Brook and the Third Branch White River near and around the hatchery. Water-surface profiles and the flood inundation area observed during the August 2011 flood and for the modeled 10-, 2-, 1-, and 0.2-percent AEPs were determined for Flint Brook and the Third Branch White River. This report also describes the hydrologic and hydraulic analyses of several proposed alternatives to mitigate flooding along Flint Brook at the hatchery. Water-surface profiles and flood inundation boundaries were determined for the 10-, 2-, 1-, and 0.2-percent AEPs for the proposed mitigation alternatives (Stantec, Inc., written commun., 2013).

Study Area

The study area includes the hatchery in Roxbury and parts of the drainage basins of Flint Brook and the Third Branch White River that are upstream from or include the hatchery (fig. 1). The Town of Roxbury encompasses 40.6 square miles (mi^2) approximately 16 mi southwest of the capitol city of Montpelier, Vt. It is the southernmost town in Washington County. Elevations range from 880 feet (ft) along the river valleys to 3,060 ft at the peak of Rice Mountain (Town of Roxbury and Central Vermont Regional Planning Commission, 2011).

The southernmost area of the Town of Roxbury where the hatchery is located is within the Third Branch White River Basin drainage area. The Third Branch White River Basin at

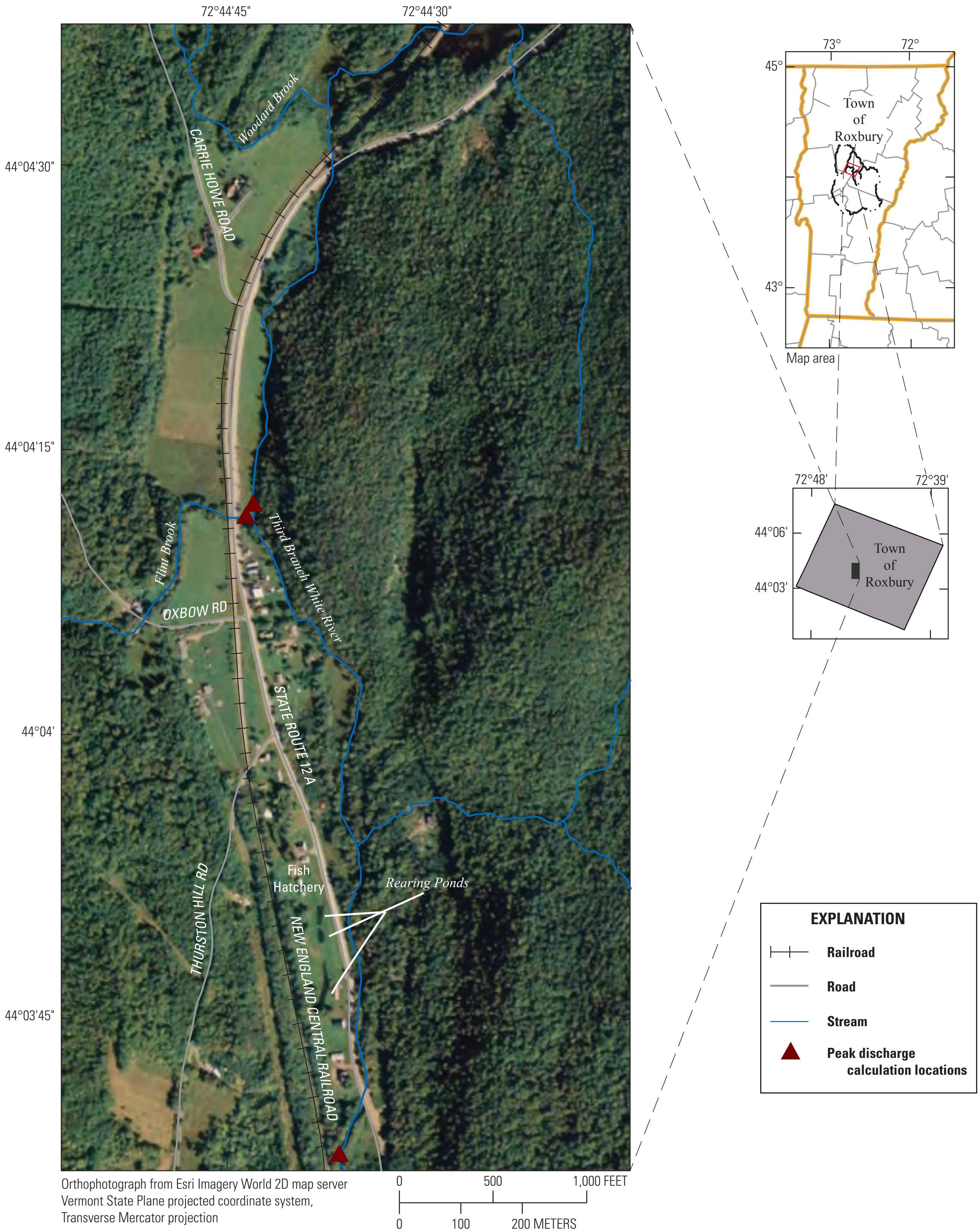

Figure 1. The location of the Roxbury Fish Culture Station and study reaches of the Flint Brook, and the Third Branch White River.

about 500 ft south of the hatchery drains an area of 10.3 mi^2. Flint Brook is a headwater tributary to the Third Branch White River north of the hatchery. The drainage area of Flint Brook is 4.35 mi^2. Hydraulic models were developed for a 1.17-mi reach of the Third Branch White River and a 0.25-mi reach of Flint Brook.

Estimates of Peak Stream Discharges

Flint Brook is a tributary of the Third Branch White River upstream from the hatchery. Flint Brook and the Third Branch White River originate in the mountains and have steep narrow channels characterized by dramatic fluctuations in flow during extreme rainfall events that can vary by several orders of magnitude.

Flint Brook and the Third Branch White River at their confluence are expected to have near coincident flood peaks because they have very similar basin characteristics—drainage area, channel length and slope, type of terrain and land cover. At their confluence, the drainage areas for Flint Brook and the Third Branch White River are 4.35 and 4.97 mi^2, respectively. The change in basin elevation from the headwaters of the stream to the boundary of the watershed is 1,590 ft for Flint Brook and 1,020 ft for the Third Branch White River, and the channel length to the basin divide is 19,400 ft for Flint Brook and 21,200 ft for the Third Branch White River. The basins are mostly forested land with low-density development along the valley floors. Basin characteristics were applied to a basin lag time equation to determine lag times of 4.1 hours for Flint Brook and 4.8 hours for the Third Branch White River (Sauer and others, 1983). Lag time is computed as the time from center-of-mass of rainfall excess to the center-of-mass of the corresponding runoff.

Peak Discharges for Selected Annual Exceedance Probabilities

Peak discharges for given AEPs are often calculated from annual peak data from streamgages. Regional regression equations can be used to estimate the peak discharges for the AEPs where streamgages are not available. Peak discharges for selected locations on Flint Brook and the Third Branch White River were calculated for the 10-, 2-, 1-, and 0.2-percent AEPs using regional regression equations (table 1; Olson, 2014). The explanatory variables in the regression equations include the basin characteristics of drainage area, mean annual precipitation, and percentage of wetland area (table 2).

Peak Discharges for August 2011 Flood

Peak discharge estimates for the August 2011 flood (tropical storm Irene) for select locations on Flint Brook and the Third Branch White River (table 3) were derived using a drainage-area discharge equation (Johnstone and Cross, 1949):

$$\frac{Q_1}{Q_2} = \left(\frac{A_1}{A_2}\right)^{exp} \tag{1}$$

where

Q_1 and Q_2 are the discharges at specific locations,
A_1 and A_2 are drainage areas at these locations, and
exp is an exponent derived from regional regression equations.

Table 1. Peak discharges for selected annual exceedance probabilities for Flint Brook and the Third Branch White River in Roxbury, Vermont.

[Prediction intervals calculated using regional regression equations, except for flows from tropical storm Irene on August 28–29, 2011, which were estimated using the drainage-area discharge equation from Johnstone and Cross (1949). mi^2, square miles; ft^3/s, cubic feet per second; %, percent; PI, prediction interval]

Location	Drainage area, in mi^2	Discharge for given annual exceedance probability, in ft^3/s											
		10%	90% PI		2%	90% PI		1%	90% PI		0.2%	90% PI	
			Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
Third Branch White River below the Roxbury Fish Culture Station	10.3	898	486	1,660	1,450	717	2,930	1,730	826	3,610	2,500	1,070	5,840
Third Branch White River above confluence with Flint Brook	4.97	431	233	797	699	345	1,420	836	399	1,750	1,210	520	2,840
Flint Brook at confluence with the Third Branch White River	4.35	478	257	887	785	386	1,600	944	448	1,990	1,390	590	3,260

Table 2. Characteristics of the drainage basins for Flint Brook and the Third Branch White River in Roxbury, Vermont.

[mi^2, square miles; %, percent; in., inches]

Location	Drainage area, in mi^2	Wetlands, in %	Mean annual precipitation, in in.
Third Branch White River below the Roxbury Fish Culture Station	10.3	0.653	47.78
Third Branch White River at confluence with Flint Brook	4.97	1.027	46.64
Flint Brook at confluence with the Third Branch White River	4.35	0.343	49.65

Table 3. Peak discharges for the area near the Roxbury Fish Culture Station in Roxbury, Vermont, during tropical storm Irene on August 28–29, 2011.

[Derived from the drainage-area discharge equation (DA–Q) from Johnstone and Cross (1949) using 0.816 for the exponent component of the equation. mi^2, square miles; ft^3/s, cubic feet per second]

Location	Drainage area, in mi^2	DA–Q relation—0.816 exponent, in ft^3/s
Third Branch White River below the Roxbury Fish Culture Station	10.3	4,320
Third Branch White River at confluence with Flint Brook	4.97	2,380
Flint Brook at confluence with the Third Branch White River	4.35	2,140

The drainage-area discharge equation can be used to estimate streamflow at a site where no streamflow data were collected by using known streamflow from a nearby location. This approach adjusts for the difference in drainage area as well as incorporating some regional characteristics by using the exponents from regional regression equations. The known peak discharges used in the drainage-area discharge equation are from the Dog River streamgage (04287000), which is the closest streamgage to the hatchery. The 0.02-percent AEP exponent (0.816) from regression equations derived for the Dog River streamgage by Olson (2014) was used for the exp term in the drainage-area discharge equation because the magnitude of the discharge for August 2011 flood at the nearby streamgage on Dog River at Northfield Falls was about equal to a 0.2-percent AEP event (fig. 1–1; table 1–1). Using the drainage-area discharge equation with the Dog River peak discharge for the August 2011 flood (22,200 cubic feet per second [ft^3/s]) and its drainage area of 76.6 mi^2 estimated using USGS data from the StreamStats Program, the peak discharges for Flint Brook and the Third Branch White River are 2,140 and 4,320 ft^3/s, respectively (table 3; U.S. Geological Survey, undated). The drainage area for Dog River was derived from a 32.81-ft (10-meter) digital elevation model that has been hydrologically corrected with the National Resources Conservation Service Watershed Boundary Dataset and the USGS National Hydrography Dataset. Although the differences in the drainage area are outside the limits generally used for this type of estimation, which are usually 0.5 to 1.5, the adjusted peak discharge from the Dog River watershed was the best alternative because of its close proximity to the hatchery (less than 10 mi) and the likelihood that the Dog River, Flint Brook, and Third Branch White River basins experienced very similar amount, duration, and intensity of rainfall during tropical storm Irene.

Peak discharge for Flint Brook determined from the drainage-area discharge equation (equation 1) is within the uncertainty limits of the 0.2-percent AEP flood estimate (the 90-percent predication interval is 590 to 3,260 ft^3/s). The peak discharges from the drainage-area discharge equation were confirmed using hydraulic modeling. Peak discharges are an input parameter for hydraulic modeling. The hydraulic modeling methods compute water-surface elevation (WSE) on the basis of step-backwater calculations and are calibrated to match flood high-water marks (HWMs). Hydraulic modeling indicated that the derived peak discharges satisfactorily simulated WSEs that matched the flood HWMs at the hatchery (table 3–1).

Peak discharge for Flint Brook for the August 2011 flood estimated from the drainage-area discharge equation (2,140 ft^3/s) exceeds the peak discharge estimated from the regression equations (1,390 ft^3/s) at the 0.2-percent AEP. Peak discharge for the Third Branch White River estimated from the drainage-area discharge equation (4,320 ft^3/s) also exceeds the peak discharge estimated from the regression equations (2,500 ft^3/s) for the 0.2-percent AEP. The peak discharge estimates from the drainage-area discharge equation for the two streams are within the 90-percent prediction interval of the regional regression equations.

Divergent Flows Affecting the Magnitudes of Peak Discharge at Flint Brook

During the August 2011 flood, Flint Brook and another tributary of the Third Branch White River (Woodard Brook) were observed to have substantial overbank flows that did not follow their respective channels to their confluence with the Third Branch White River (fig. 1). Woodard Brook is about 3,600 ft north of the hatchery. Typically, overbank streamflow spills over a floodplain adjacent to a stream; however, this was not the case for Flint Brook and Woodard Brook.

When Flint Brook overtops its channel banks during flood events, a portion of the overbank flow diverges from the main channel and drains east and then south through the hatchery. During the August 2011 flood, Flint Brook breached its banks where a retaining wall failed. The divergent overbank flow from Flint Brook was evaluated to be the primary source of flooding to the hatchery. Peak discharges from the August 2011 flood through the hatchery were estimated to be 2,072 ft^3/s, which is 97 percent of Flint Brook peak discharges; 65 ft^3/s remained within the channel banks, draining under Oxbow Road.

During the August 2011 flood, a portion of overbank flow from Woodard Brook also diverged from its main channel. From visual inspection of high-definition imagery and light and detection ranging (lidar) elevation data obtained shortly after the August 2011 flood, there is evidence to suggest that the divergent flow possibly affected the lower reach of Flint Brook near its confluence with the Third Branch White River, but it did not affect the flooding at the hatchery. The divergent flow from Woodard Brook drained south towards Carrie Howe Road and then paralleled the NECR until it flowed into Flint Brook upstream of the NECR and State Route 12A bridges near the confluence with the Third Branch White River. A detailed hydrologic and hydraulic analysis of Woodard Brook was outside the scope of the study.

Hydraulic Analyses of the 2011 Flood and the 10-, 2-, 1-, and 0.2-Percent AEP Floods as Applied to Flood Mitigation Alternatives

Hydraulic analyses were done for a 0.25-mi reach of Flint Brook from its confluence with the Third Branch White River to 300 ft upstream from the Oxbow Road crossing and a 1.17-mi reach of the Third Branch White River from 350 ft below the State Route 12A crossing south of the hatchery (upstream) to its confluence with the Woodard Brook. In addition, hydraulic analyses were done for the Flint Brook diversion channel, which is parallel to Oxbow Road and the divergent overland flow path that Flint Brook follows through the hatchery during extreme high-flow events.

The hydraulic models incorporate new field-survey data at structures, high-resolution land-surface elevation data, peak discharge estimates of the August 2011 flood from a drainage-area discharge equation, and peak discharges for the 10-, 2-, 1-, and 0.2-percent AEPs from regional regression equations (Olson, 2014).

Methods.—Water-surface profiles were computed for the study reaches using the computer program Hydrologic Engineering Center-River Analysis System (HEC–RAS; version 4.1; U.S. Army Corps of Engineers, 2010a,b). HEC–RAS is a one-dimensional modeling system that computes water-surface profiles for gradually varied flow by solving the one-dimensional energy equation and for rapidly varied flow (such as flow at hydraulic structures) by solving the momentum equation. Input parameters for steady-flow analyses in HEC–RAS include cross-section geometry, which includes station and elevation data; geometric and elevation data for the culverts, bridges, and roads; roughness coefficients for the channel, overbank areas, and culverts; and flood discharge.

The starting WSEs in the Flint Brook model at the downstream end of the study reach are the peak flood elevations of the Third Branch White River at the confluence with Flint Brook for the same events. Backwater from the Third Branch White River was used as a starting WSE due to the fact that the peaks were assumed to have occurred within close temporal proximity to each other. The starting water-surface conditions in the model for the Third Branch White River at the downstream end of the study reach is normal depth.

Field surveys of the stream channel and surveys of structure geometry, including the bridges on Flint Brook and the Third Branch White River and the retaining wall on Flint Brook, were obtained for the modeled reaches. Lidar-derived elevation data were used to supplement the field survey data of the stream channels. The overbank portions of the cross sections (fig. 2–1) were derived from high-resolution land-surface elevation data derived from lidar surveys. Lidar-derived data were collected and processed by Fugro EarthData, Inc. from surveys flown during March and April 2012 for seven sections of highway corridors for the Vermont Agency of Transportation in response to damage during tropical storm Irene on August 28–29, 2011. The lidar-derived data were collected to a vertical accuracy of ±0.3 ft (9.25 centimeters [cm]) root-mean square error (RMSE) and ±0.6 ft (18.2 cm) at the 95-percent confidence level according to the National Standard for Spatial Data Accuracy standard methodology (Fugro EarthData, Inc., 2012). The station and elevation data in the channel part of a cross section were merged with lidar-derived data to form complete cross sections (appendix 2). The geometry of a diversion channel, proposed as one of the possible flood mitigation measures, was obtained from a model produced by Stantec, Inc. (written commun., 2013). The geometry of the divergent flow path through the hatchery was obtained solely from lidar-derived data. Manning's roughness coefficients (n-values) for the channel and overbanks for the hydraulic models were determined from field observations (table 4) and by application of methods described in Arcement and Schneider (1989) and Coon (1998).

HWMs were used to calibrate the hydraulic models. The USGS identified and flagged three HWMs in the vicinity of the hatchery within days of the August 2011 flood (Medalie and Olson, 2013). These accuracy of the data from these HWMs were rated excellent (±0.02 ft) to fair (±0.10 ft). In 2014, an additional 11 HWMs were identified and surveyed in March and April 2014 (appendix 3). The accuracy of the data from these 11 HWMs from 2014 were considered to be very poor quality (±0.2 ft) due to the length of time between the storm and the documentation of the HWMs and were not used to rigorously calibrate the model to predicted flows.

Table 4. Manning's roughness coefficient for Flint Brook and Third Branch White River in Roxbury, Vermont.

Stream reach	Roughness coefficient	
	Channel areas	Overbank areas
Flint Brook	0.05–0.065	0.08
Third Branch White River	0.055–0.06	0.07–0.12

Water-Surface Profiles and Flood Inundation Mapping for the August 2011 and 10-, 2-, 1-, and 0.2-Percent AEP Floods

The results of the hydrologic and hydraulic analyses were used to create water-surface profiles (appendix 4) and flood inundation maps that characterize the extent of flooding at the hatchery for the selected AEP peak discharge conditions for the proposed mitigation alternatives. A flood inundation map to show a generalized depiction of the flood inundation area of the August 2011 flood (tropical storm Irene) in the vicinity of the hatchery (appendix 5) also was created.

The 10-, 2-, 1-, and 0.2-percent AEP (100- and 500-year) flood boundaries were drafted with a geographic information system (GIS) using lidar-derived data processed with 2-ft contour intervals. The flood boundaries were determined by the HEC–RAS simulated water elevations at each stream cross section and interpolated between cross sections. The flood inundation maps outline the hatchery's flood risk under the mitigation alternatives described in the hydraulic analyses section of this report (appendix 6). Under alternative A (existing [2014] infrastructure), the hatchery is subject to flooding at the 0.2-percent AEP (fig. 6–1A). Alternatives B (enlarging existing bridge openings and raising the height of the retaining wall; fig. 6–1B), C (realigning Flint Brook to south side of Oxbow Road and construct two new bridges), and D (creating a diversion channel for overflow and construct two new bridges) indicate no flood risk to the hatchery at the 10-, 2-, 1-, or 0.2-percent AEPs. Flood inundation maps were generated for alternative B, but not alternatives C and D, which are based on altered, presumed channel geometry. The maps of inundated areas are for planning purposes only and are not intended for regulatory, permitting, or other legal purposes.

Water-Surface Profiles for Flint Brook During the August 2011 Flood

Water-surface profiles were developed for a 0.25 mi reach of Flint Brook upstream from its confluence with the Third Branch White River (appendix 4). A major factor in the magnitude of flooding through the hatchery is the structural failure of a retaining wall along Flint Brook immediately upstream from the brook's crossing under the bridge at Oxbow Road. To simulate the observed WSEs for the August 2011 flood, the hydraulic model for Flint Brook was based on a failed (collapsed) retaining wall. Because data were not collected during the storm, it is unknown when the channel banks were breached and the retaining wall failed. Consequently, it was assumed that the retaining wall failed at the elevation of the channel banks (993 ft) without the wall in place. The three bridges (Oxbow Road, NECR, and State Route 12A) along the 0.25-mi reach were modeled as they are currently [2014]. The flow was split between the main channel and the divergent overbank flow (about 0.5-mi reach) through the hatchery based on the presumed elevation of the failed retaining wall. To simulate the observed WSEs through the hatchery for the August 2011 flood, a divergent flow path model was developed. The simulated WSEs in the hatchery compared well (within 0.2 ft) with the HWM identified and surveyed in 2011.

The portion of overbank flow from Woodard Brook that diverged from the main channel during the August 2011 flood possibly affected the lowest reach of Flint Brook, but did not appear to have affected the flooding at the hatchery. The divergent flow from Woodard Brook drained south towards Carrie Howe Road and entered Flint Brook upstream of the NECR and State Route 12A bridges near the confluence with the Third Branch White River. During the August 2011 flood, both bridges were overtopped. The divergent flow from Woodard Brook most likely entered Flint Brook near the time the retaining wall failed on Flint Brook (near its peak stage), causing the two bridges to be overtopped. No HWMs were available to confirm the simulated WSEs in the lower reach of Flint Brook where the divergent flow from Woodard Brook combined with Flint Brook.

Water-Surface Profiles for Third Branch White River During the August 2011 Flood and for Selected AEPs

Water-surface profiles were developed for a 1.17-mi reach of the Third Branch White River (appendix 4). The Third Branch White River runs parallel to the hatchery on the eastern side of State Route 12A. The river crosses State Route 12A about 0.4 mi north of the hatchery and again at the southernmost section of the hatchery. The hydraulic model includes 2 bridges and 27 channel cross sections. The peak discharges used as input for the model were those estimated for selected AEP flood discharges and for the August 2011 flood. The HWMs found along the Third Branch White River were rated fair to very poor and subject to uncertainty (Benson and Dalrymple, 1967). Consequently, the HWMs were used only as a general guide in calibrating the model. The simulated WSEs for the August 2011 flood ranged between 0.2 and 0.5 ft of the HWMs obtained in 2011.

The simulated WSEs at the 10-, 2-, 1-, and 0.2-percent AEPs are lower than the road elevations along State Route 12A, indicating that the Third Branch White River does not overtop State Route 12A for the selected AEPs and become a contributing flooding source to the hatchery. The simulated WSEs for the August 2011 flood (peak discharges less than the 0.2-percent AEP) are appreciably lower than the State Route 12A road elevations for the majority of the river reach studied, except for a small section in the lowest reach (1,800 ft downstream from Thurston Hill Road) where the simulated WSE for one stream cross section is equal to the road elevation. It is possible that a minor amount of flow (less than 5 ft^3/s) from the Third Branch White River flowed along State Route 12A and into the hatchery during the August 2011 flood. At this cross section, the simulated WSE for the August 2011 flood is 2 ft higher than the simulated WSE for the 0.2-percent AEP discharge. The elevation difference between the channel bed and State Route 12A is about 8 ft.

Water-Surface Profiles for Flint Brook for 10-, 2-, 1-, and 0.2-Percent AEP Floods and Analysis of Mitigation Alternatives

To improve flood-related hydraulic performance at Flint Brook and reduce flood inundation of the surrounding areas, four mitigation alternatives were proposed by Stantec, Inc., to the Vermont Agency of Transportation for the reconstruction efforts at the hatchery (Stantec, Inc., written commun., 2013). These four mitigation alternatives were evaluated as part this study. In order to evaluate the mitigation alternatives, hydraulic models of Flint Brook with the existing conditions [2014] and proposed infrastructure changes were developed and used in conjunction with peak discharges from the hydrologic analyses described in the earlier sections of this report. Water-surface profiles were developed for each mitigation alternative (appendix 4). The models for mitigation alternatives at Flint Brook do not include potential divergent flows from Woodard Brook, which was not within the scope of this report.

The four mitigation alternatives for Flint Brook that are being considered by the Vermont Agency of Transportation included the following:

- Alternative A—no changes to the existing infrastructure;
- Alternative B—improvement of existing infrastructure (enlarging the bridge openings and raising the height of the retaining wall along Flint Brook);
- Alternative C—realignment of Flint Brook (realigning the bed of Flint Brook to the southern side of Oxbow Road to accommodate larger stream discharges than currently flow through the channel); and
- Alternative D—diversion of Flint Brook (constructing an overflow channel for excess flood water while keeping the existing Flint Brook channel intact).

For all alternatives, the NECR and State Route 12A bridges are modeled as a single structure based on the proximity of the two bridges to one another and the fact that the upstream NECR bridge has a narrower bridge opening than the State Route 12A bridge. Even under alternative B in which the NECR bridge is widened to 20 ft, the NECR bridge is still the more constricting structure of the two bridges.

Alternative A—Existing Infrastructure

Under existing infrastructure (alternative A), the retaining wall immediately upstream from Oxbow Road is modeled at its current [2014] repaired geometry. The existing infrastructure model is a baseline for comparison of the three mitigation alternatives with changes to the bridges, retaining wall, and channel. The bridges—on Oxbow Road, at the NECR, and on State Route 12A—were modeled using their current [2014] geometry (field surveyed in March 2014). The hydraulic model assumes the retaining wall would remain intact for all modeled flows. The lowest surveyed elevation of the retaining wall is 999.8 ft; water-surface profiles in excess of this elevation in the vicinity of the retaining wall were modeled as flow through the hatchery. The hydraulic analysis indicated that Flint Brook would overtop the retaining wall and inundate the hatchery at the 0.2-percent AEP, but not at the 10-, 2-, and 1-percent AEPs. After flow diverges (about 140 ft^3/s) from the main channel and floods the hatchery at the 0.2-percent AEP flow, the Oxbow Road bridge would have the capacity to convey the remaining flow without overtopping but the NECR and State Route 12A structures would be overtopped.

Alternative B—Improvement of Existing Infrastructure Along Flint Brook

For the model evaluating improvement of existing infrastructure (alternative B), the hydraulic carrying capacity of two of the bridges (Oxbow Road and NECR) would be increased. No hydraulic improvements were identified for the existing Route 12A bridge. The Oxbow Road bridge would be widened from 21 to 30 ft, and the NECR bridge would be widened from 12 to 20 ft. An additional improvement to the existing infrastructure would include changes to the retaining wall upstream from the Oxbow Road bridge. The elevations of the low chords and bridge decks would remain the same for both bridges. The retaining wall would be improved by "the placement of additional material on the crest of the wall or installing a new structure in place of the existing wall, such as a vertical concrete wall" (Stantec, Inc., written commun., 2013). The improved wall would be approximately 120 to 150 ft long and 2 ft higher than the existing wall. No analyses were performed on to the stability of the proposed wall or whether it would be built as a certified levee or a retaining wall as it currently [2014] exists. An assumption made as a part of this hydraulic analysis is that the retaining wall would not fail (breach) for the selected AEP that were analyzed. The elevation of the improved retaining wall in the hydraulic analysis for this study was assumed to be 1,001.8 ft, 2 ft higher than the existing wall. The hydraulic analysis showed that raising the height of the retaining wall by 2 ft from 999.8 to 1,001.8 ft would contain the 10-, 2-, 1-, and 0.2-percent AEP flows. The downstream bridges with expanded openings (Oxbow Road, NECR, and State Route 12A) would have the capacity to convey flow up to and including the 0.2-percent AEP without overtopping.

Alternative C—Realignment of Flint Brook

For the model evaluating the realignment of Flint Brook (alternative C), Flint Brook would be realigned to run along the southern side of Oxbow Road. The new channel would be approximately 800 ft in length and flow in an eastward orientation. This alternative also includes constructing two new bridges over Flint Brook at the NECR and on State Route 12A south of Oxbow Road. The existing Oxbow Road bridge would be decommissioned. The NECR and State Route 12A bridges north of Oxbow Road would remain in place to accommodate drainage from a small tributary between the Oxbow Road bridge and the Third Branch White River. The hydraulic analysis indicated that the NECR and State Route 12A bridges over the realigned channel and the new channel on the southern side of Oxbow Road would contain the flows up to and including the 0.2 percent AEP.

Alternative D—Diversion of Flow from Flint Brook

For the model evaluating diversion of extreme discharges from Flint Brook (alternative D), Flint Brook would maintain its existing channel alignment as the main water course, but a diversion channel would be constructed to accommodate any flows in excess of the 1-percent AEP. The overflow channel would require construction of an overflow section of the retaining wall upstream of Oxbow Road bridge and the installation of three new 12 ft by 7 ft box culverts under a driveway, the NECR, and State Route 12A. These culverts would have effective openings of 12 ft by 5 ft, with 2 ft taken into account for embedment. The hydraulic analysis indicated that the combination of the diversion channel and the existing Flint Brook channel would provide sufficient conveyance to carry up to and including the 0.2-percent AEP flow from Flint Brook.

Summary and Conclusions

The flood of August 28–29, 2011, from tropical storm Irene caused extensive damages to the hatchery and the transportation infrastructure in the Town of Roxbury, Vermont. Several bridges along and near State Route 12A and the New England Central Railroad (NECR) in Roxbury were heavily damaged. Flood damages resulted in a presidential disaster declaration on September 1, 2011, for the 12 counties in Vermont affected by the August 2011 flood, including Washington County where the State-owned Roxbury Fish Culture Station (the hatchery) is located. Historic and recent flooding at the hatchery could have been caused by Flint Brook and the Third Branch White River. The destruction of the hatchery during the August 2011 flood demonstrates the importance of understanding the magnitude of peak discharges and overland flows for the purposes of developing effective future flood mitigation measures. Hydrologic and hydraulic analyses of Flint Brook and the Third Branch White River were done to better understand the flooding risk at the hatchery in Roxbury and support efforts by the Federal Emergency Management Agency to assist State and local mitigation and reconstruction efforts.

The hydrologic and hydraulic analyses indicate that divergent flow from Flint Brook where it breached its channel banks at a collapsed retaining wall is the cause of flooding at the hatchery. Peak discharges through the hatchery and the Third Branch White River were estimated to be 2,070 cubic feet per second (ft^3/s; 97 percent of peak discharge from Flint Brook) and 4,320 ft^3/s, respectively. The peak discharges for the August 2011 flood for Flint Brook and the Third Branch White River have less than a 0.2-percent probability of being equaled or exceeded any given year. The Third Branch White River flows adjacent to the hatchery and does not flood the hatchery for annual exceedance probabilities (AEP) of 0.2-percent or greater. Evidence from a visual inspection of high-definition imagery and lidar-derived elevation data obtained after the August 2011 flood suggests that divergent overbank flow from Woodard Brook possibly affected the NECR and State Route 12A bridges at the lowest reach of Flint Brook.

The four flood mitigation alternatives being considered by the Vermont Agency of Transportation include making no changes to the existing [2014] infrastructure (alternative A), making structural improvements to existing bridges and retaining wall along Flint Brook (alternative B), realignment of Flint Brook to flow along the southern side of Oxbow Road (alternative C), and creating a diversion channel for flows from Flint Brook greater than the 1-percent AEP (alternative D). Peak discharges for the 10-, 2-, 1-, and 0.2-percent AEPs do not flood the hatchery for any of the mitigation alternatives with the exception of the 0.2-percent AEP flood under alternative A.

Water-surface profiles and an flood inundation map of the August 2011 flood were developed for Flint Brook and the Third Branch White River in the vicinity of the hatchery. Water-surface profiles and flood boundaries for 10-, 2-, 1-, and 0.2-percent AEP floods also were developed for the existing [2014] conditions for Flint Brook and the Third Branch White River and for several mitigation alternatives for Flint Brook. Because Flint Brook has been determined to be the source of flooding at the hatchery, mitigation alternatives apply to the stream channel of Flint Brook, its vicinity, and associated infrastructure.

This report documents (1) the magnitude and extent of flooding in the vicinity of the hatchery following the August 2011 flood and (2) the hydrologic and hydraulic modeling used to evaluate existing conditions and proposed mitigation alternatives in the vicinity of the hatchery. The hydraulic models incorporate new field-survey data at structures, high-resolution land-surface elevation data, and peak discharges estimates of the August 2011 flood from a drainage-area discharge equation and peak discharges for the 10-, 2-, 1-, and 0.2-percent AEPs from regional regression equations (Olson, 2014). WSEs were determined using a standard step-backwater method (HEC–RAS, version 4.1) calibrated by high-water marks collected by U.S. Geological Survey. The water-surface profiles for the 10-, 2-, 1-, and 0.2-percent AEP floods and the flood inundation maps can be used by Federal, State, and local agencies for flood recovery efforts.

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Appendixes 1–6

Appendix 1. Peak Discharges at Streamgages in the Vicinity of the Roxbury Fish Culture Station in Roxbury, Vermont, From Tropical Storm Irene, August 28–29, 2011

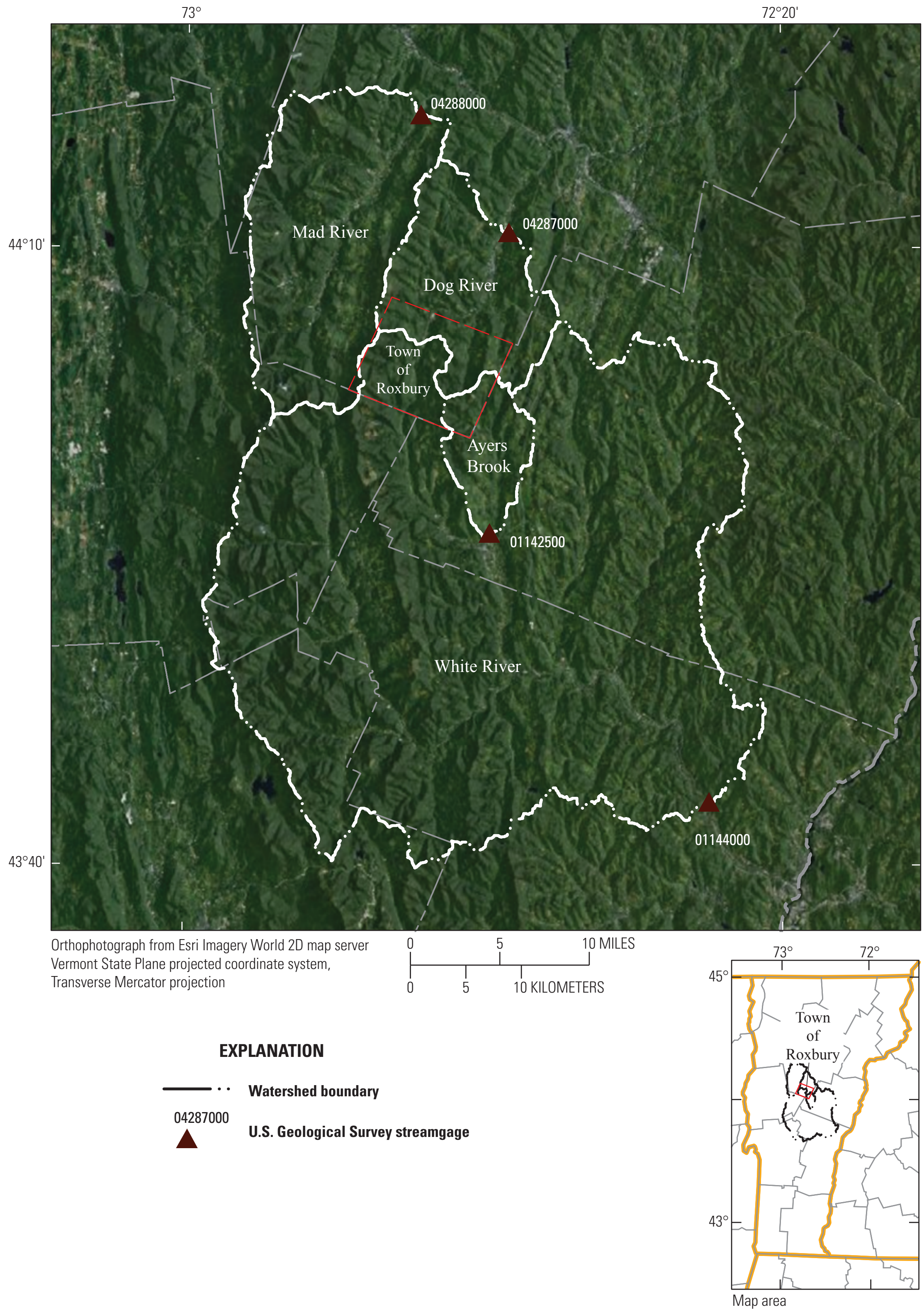

Figure 1–1. Locations of U.S. Geological Survey streamgages that have peak discharge data for the August 2011 flood caused by tropical storm Irene near Roxbury, Vermont.

Table 1–1. Peak discharges at streamgages in the vicinity of the Roxbury Fish Culture Station in Roxbury, Vermont, from tropical storm Irene, August 28–29, 2011.

[USGS, U.S. Geological Survey; mi^2, square miles; ft^3/s, cubic feet per second; ft, feet; Vt., Vermont; lat, latitude; long, longitude; mi, miles; <, less than]

USGS streamgage number	Streamgage name	Drainage area,[1] in mi	Streamgage location	2011 peak streamflow						Previously known maximum		Period of record, water years[3]
				Date	Local time	Discharge, in ft^3/s	Stage, in ft	Rank/years	Annual exceedance probability, in percent[2]	Date	Discharge, in ft^3/s	
01142500	Ayers Brook at Randolph, Vt.	30.5	Lat 43°56’04”, long 72°39’30”, Orange County, on right bank, 135 ft upstream from bridge on State Highway 12, 0.4 mi upstream from Adams Brook, 0.7 mi upstream from mouth, and 0.9 mi northeast of Town Hall in Randolph.	8/28/2011	07:30 PM	3,920	15.04	1/72	0.2–1	6/27/1998	3,480	1940–2011
01144000	White River at West Hartford, Vt.	690	Lat 43°42’51”, long 72°25’07”, Windsor County, Hydrologic Unit 01080105, on left bank, 700 ft upstream from highway bridge at West Hartford, and 7.4 mi upstream from mouth.	8/29/2011	1:30 AM	90,100	28.36	2/96	0.2–1	11/4/1927	120,000	1916–2011
04287000	Dog River at Northfield Falls, Vt.	76.6	Lat 44°10’58”, long 72°38’27”, Washington County, on right bank just downstream of New England Central Railroad bridge, 0.9 mi northeast of Cox Brook Road and State Highway 12 intersection in Northfield Falls, 1.1 mi downstream from Cox Branch, and 4.2 mi downstream of Station 04286500, Dog River at Northfield.	8/28/2011	07:45 PM	22,200	17.26	1/77	<0.2	6/30/1973	10,600	1935–2011
04288000	Mad River near Moretown, Vt.	139	Lat 44°16’38”, long 72°44’35”, Washington County, on left bank, at downstream side of Munns Road bridge, 0.4 mi downstream of Welder Brook, 2.0 mi northeast of Moretown Mountain Road and State Highway 100B intersection in Moretown, 3.2 mi west of State Highway 100B bridge across Winooski River in Middlesex, and 3.8 mi upstream from mouth.	8/28/2011	08:15 PM	24,200	19.26	1/84	0.2–1	11/3/1927	23,000	1928–2011

[1]Drainage area is determined from a geographic information system and digital datasets and may not match previously published drainage area.

[2]Exceedance probability is reported as a single value if peak discharge in 2011 is within 5 percent of discharge computed for the reported exceedance probability; otherwise, it is reported as a range.

[3]Period of record is all years with peak discharge.

Appendix 2. Cross Sections for Flood Inundation Maps and Water-Surface Profiles in the Vicinity of the Roxbury Fish Culture Station in Roxbury, Vermont

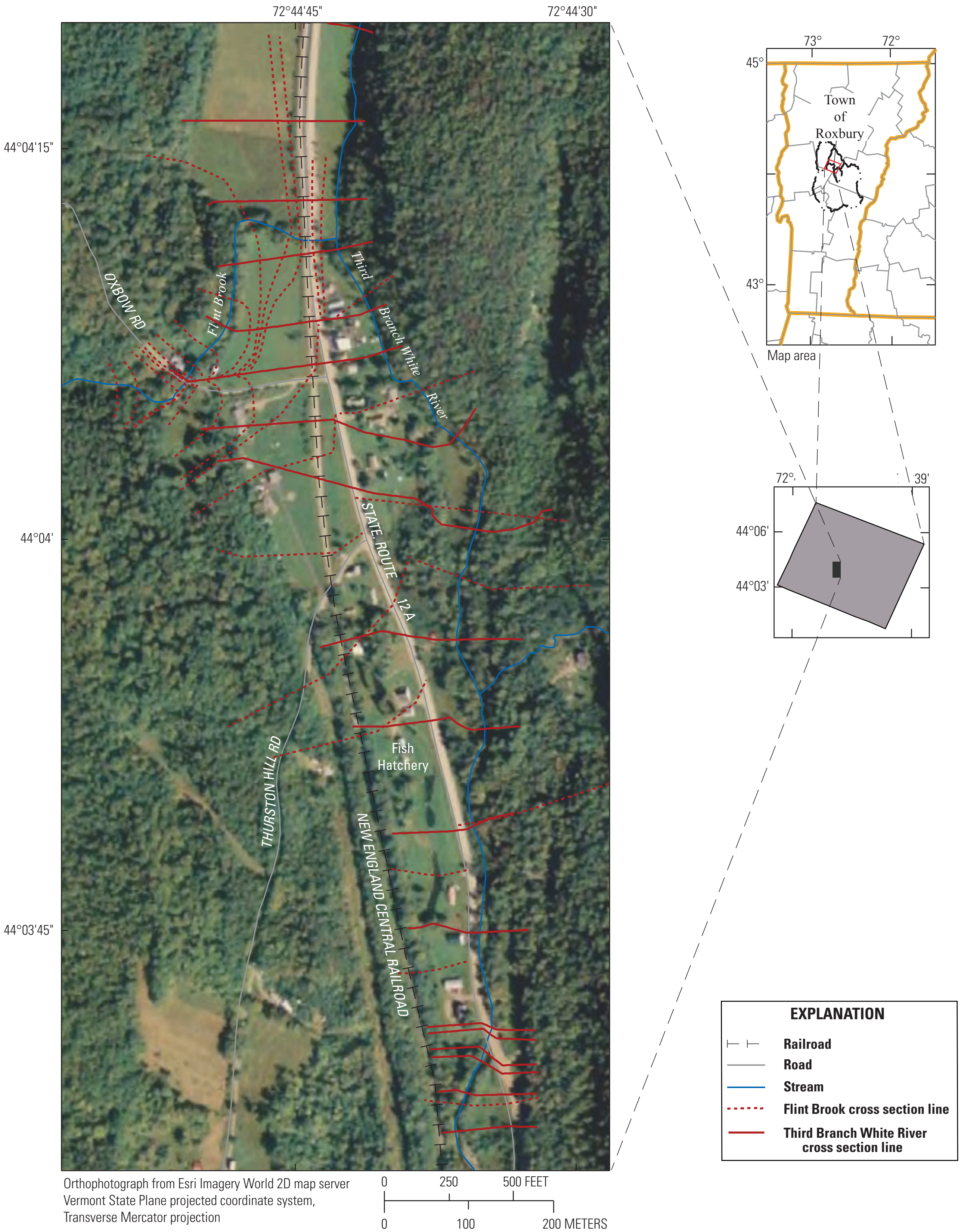

Figure 2–1. Locations of 27 cross sections used for flood inundation maps and water-surface profiles in the area near and around the Roxbury Fish Culture Station in Roxbury, Vermont. Fish hatchery, Roxbury Fish Culture Station; Rd, Road; RT12A, Vermont State Route 12A.

Appendix 3. High-Water Marks in the Vicinity of the Roxbury Fish Culture Station in Roxbury, Vermont, Resulting from Flooding from Tropical Storm Irene, August 28–29, 2011

Table 3–1. High-water marks from flooding in the vicinity of the Roxbury Fish Culture Station in Roxbury, Vermont, from tropical storm Irene, August 28–29, 2011.

[Elevation is in feet above the North American Vertical Datum of 1988. Latitude and longitude are shown in decimal degrees. The quantitative scale for rating accuracy of data from high-water marks is as follows: excellent, ±0.02 ft; good, ±0.05 ft; fair, ±0.10 ft; poor, ±0.20 ft; very poor, ±0.20 ft. ft, feet; Rd, Road; RT12A, State Route 12A; XS TBW_0120, Third Branch White River cross-section identifier]

Name	Survey date	Surveyed elevation, in ft	Latitude	Longitude	High-water mark type or description	Quality of high-water mark
435	10/13/2011	933.15	44.06086	-72.74284	Debris line 80 ft; downstream of bridge, 5 ft; landward from edge of water mark is on the landward side of 14-in. tree, other 3 ft above ground	Good
436	10/13/2011	934.75	44.06127	-72.74260	Debris line 25 ft; upstream of bridge, 50 ft; landward from edge of water mark is on the landward side of 3 in.-tree, other 6 ft above ground	Good
437	10/13/2011	953.99	44.06520	-72.74420	Debris line 750 ft; upstream of bridge, 75 ft; landward from edge of water mark is on the landward side of 3-in. fence 3 ft above ground	Excellent
HWM-VT-ROXBURY-001	4/2/2014	979.0	44.06798	-72.74529	On the mailbox at 3453 and 3459 Roxbury Rd (RT12A); does not represent peak elevation	Very poor
HWM-VT-ROXBURY-002	4/2/2014	942.2	44.06311	-72.74367	Mud line in the small green shed used for storing compressed gas cylinders, on hatchery property	Very poor
HWM-VT-ROXBURY-003	4/2/2014	949.6	44.06454	-72.74439	Debris line from hatchery personnel photo, on front porch post at northwest corner, main hatchery building	Very poor
HWM-VT-ROXBURY-004	4/2/2014	980.8	44.06834	-72.74568	On railroad crossing sign at south side Oxbow Rd; does not represent peak elevation	Very poor
HWM-VT-ROXBURY-005	4/2/2014	971.6	44.06667	-72.74499	Debris line from observer's photo, on fruit tree in front of abandoned house at 9 Thurston Hill Rd	Very poor
HWM-VT-ROXBURY-006	4/2/2014	970.0	44.06639	-72.74501	Mud line inside front porch of abandoned house, at 9 Thurston Hill Rd	Very poor
HWM-VT-ROXBURY-007	3/31/2014	952.1	44.06497	-72.74429	Mud and grass line inside garage building, on hatchery property	Very poor
HWM-VT-ROXBURY-008	3/31/2014	951.1	44.06495	-72.74427	Exterior of garage building, on hatchery property, identified by hatchery personnel from memory	Very poor
HWM-VT-ROXBURY-009	3/31/2014	950.1	44.06480	-72.74425	Mud and seed line, along interior walls and lockers, inside hatchery workshop	Very poor
HWM-VT-ROXBURY-010	4/1/2014	943.4	44.06369	-72.74314	Debris, on 3-in.-diameter limb of yellow birch tree, above XS TBW_0120	Very poor
HWM-VT-ROXBURY-011	4/1/2014	975.4	44.06894	-72.74498	Observer recollection of highest river stage, at corner of his garage, at rear of 3375 Roxbury Rd (RT12A)	Very poor

Appendix 4. Water-Surface Profiles for the 10–, 2–, 1–, and 0.2–Percent Annual Exceedance Probabilities and Floods Resulting From Tropical Storm Irene, August 28–29, 2011, for Flint Brook and the Third Branch White River in Roxbury, Vermont

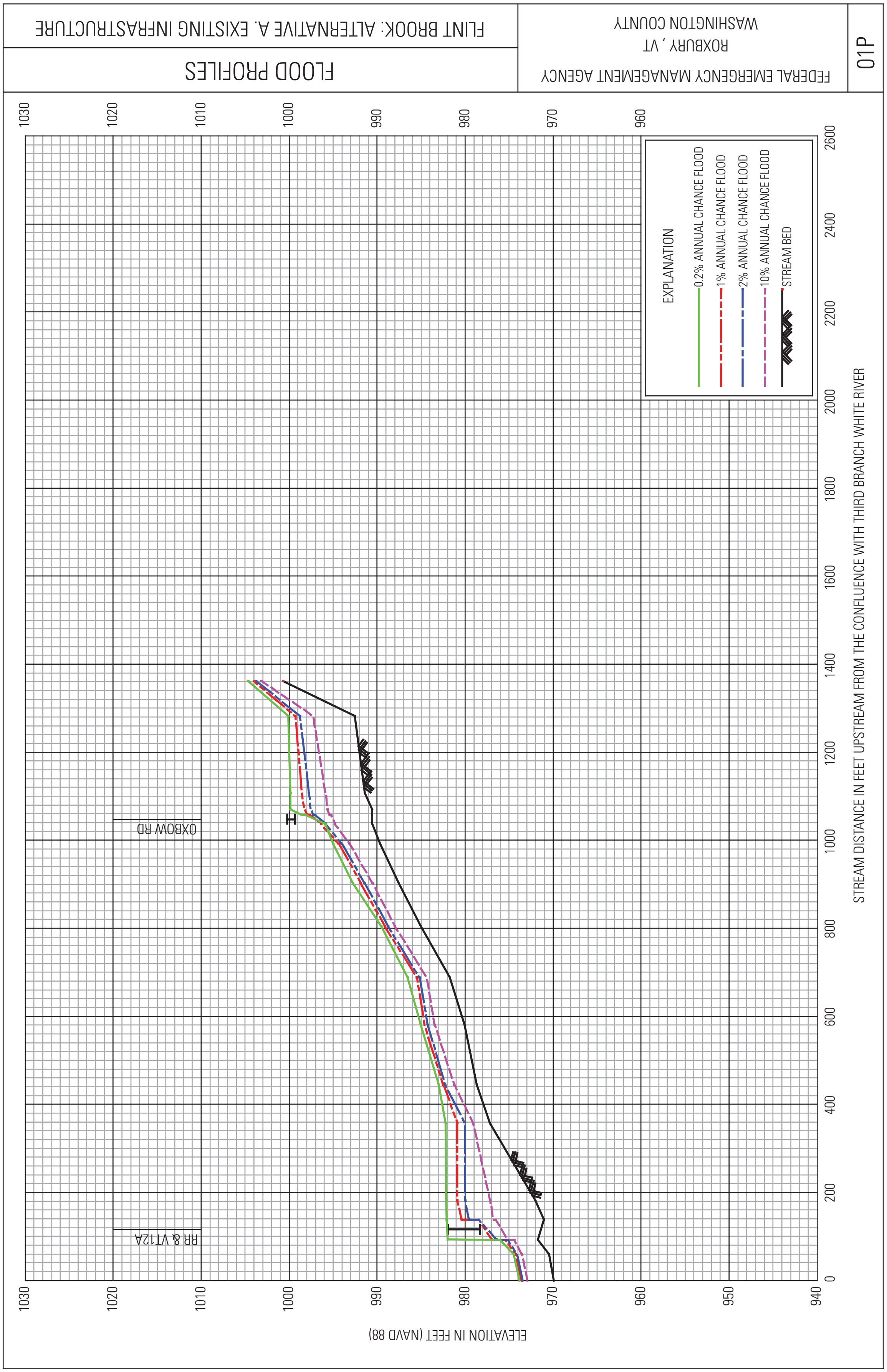

Figure 4–1. Flood profile of Flint Brook in Roxbury, Vermont, under existing conditions [2014]. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.

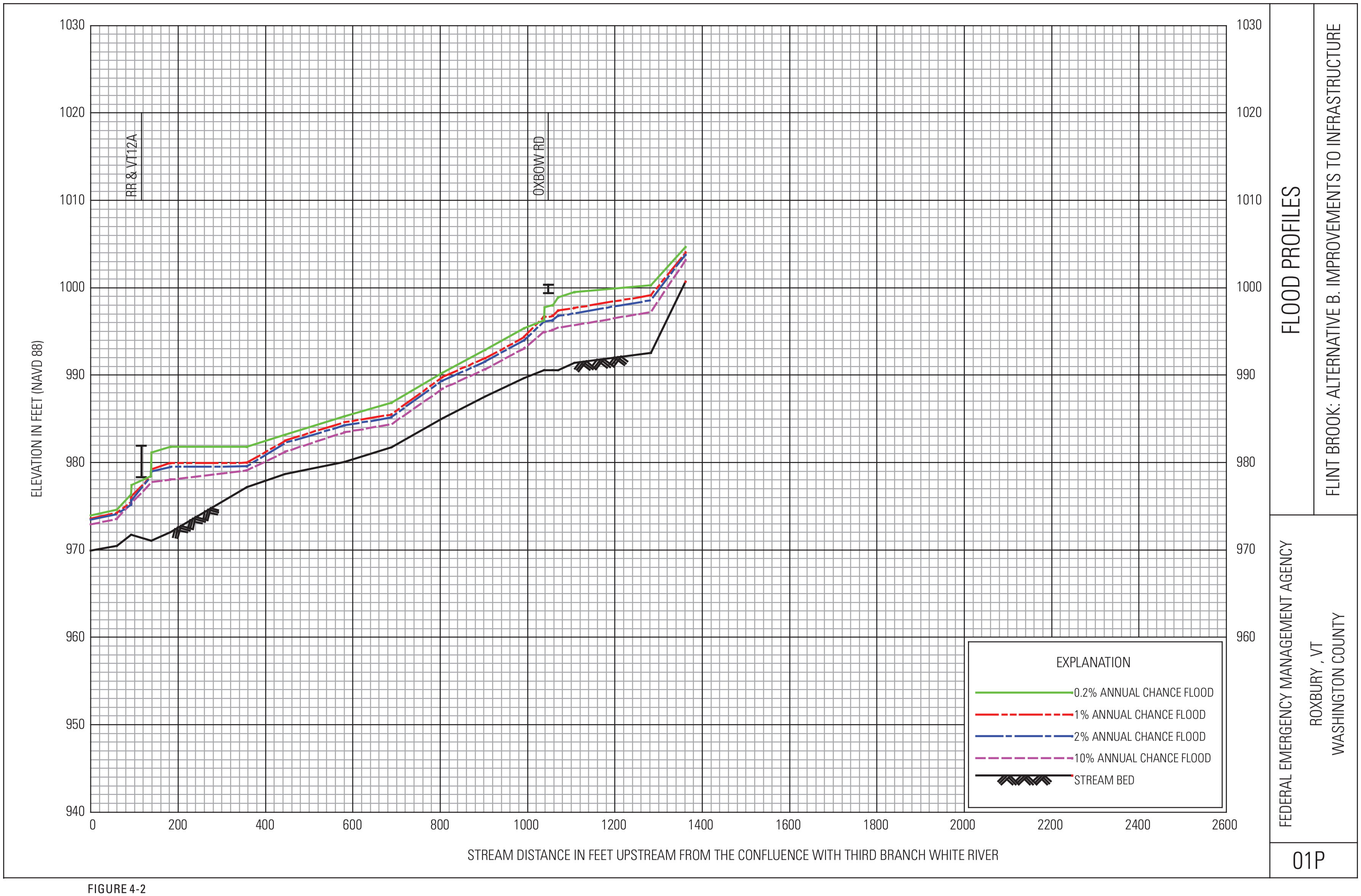

Figure 4–2. Flood profile of Flint Brook in Roxbury, Vermont, evaluating a mitigation alternative with infrastructure improvements. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.

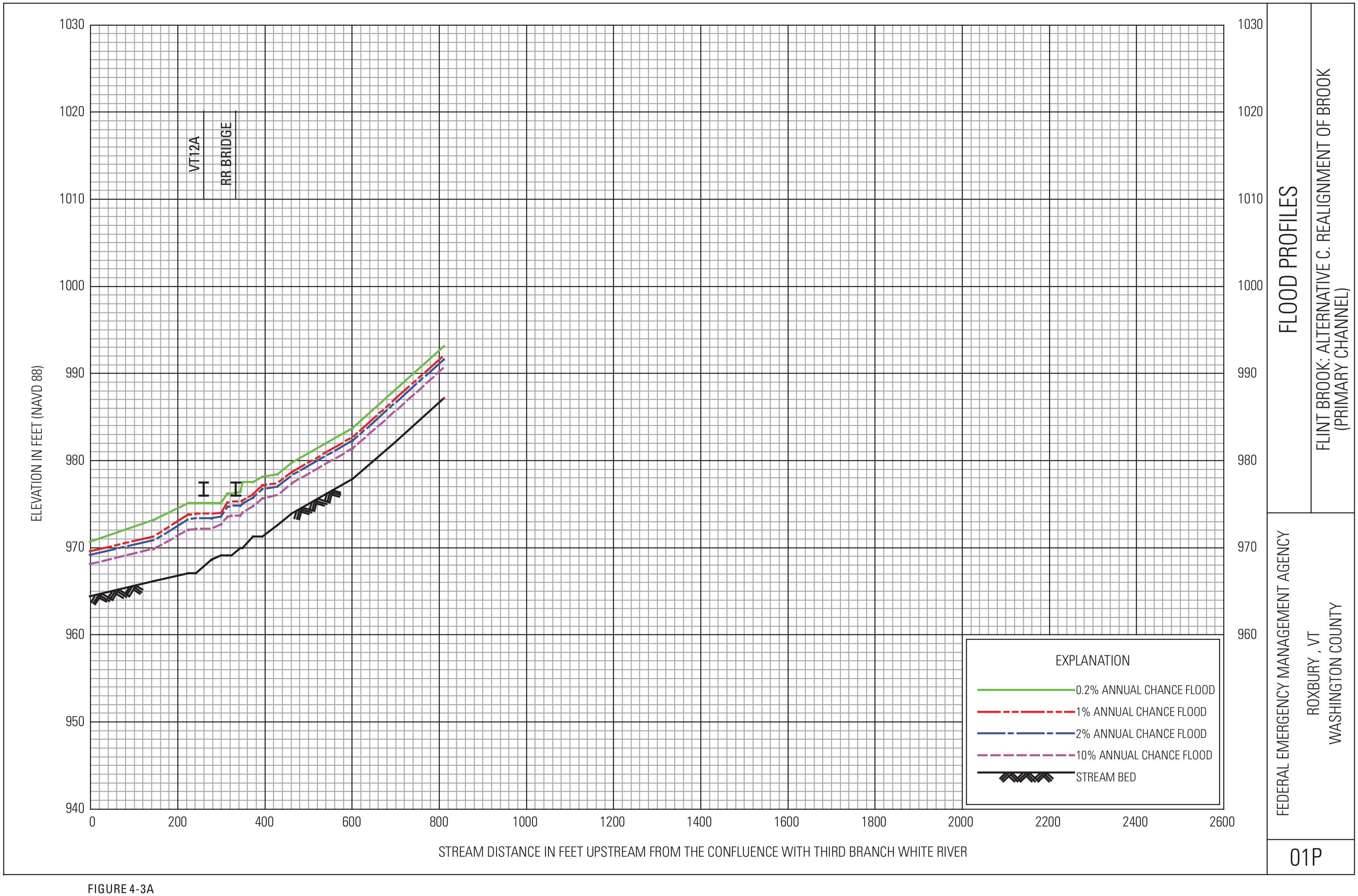

Figure 4–3. Flood profile of *A*, the main channel and *B*, the secondary channel of Flint Brook under a mitigation alternative where Flint Brook in Roxbury, Vermont, is realigned to a new channel with the current [2014] channel serving as a secondary (overflow) channel. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.

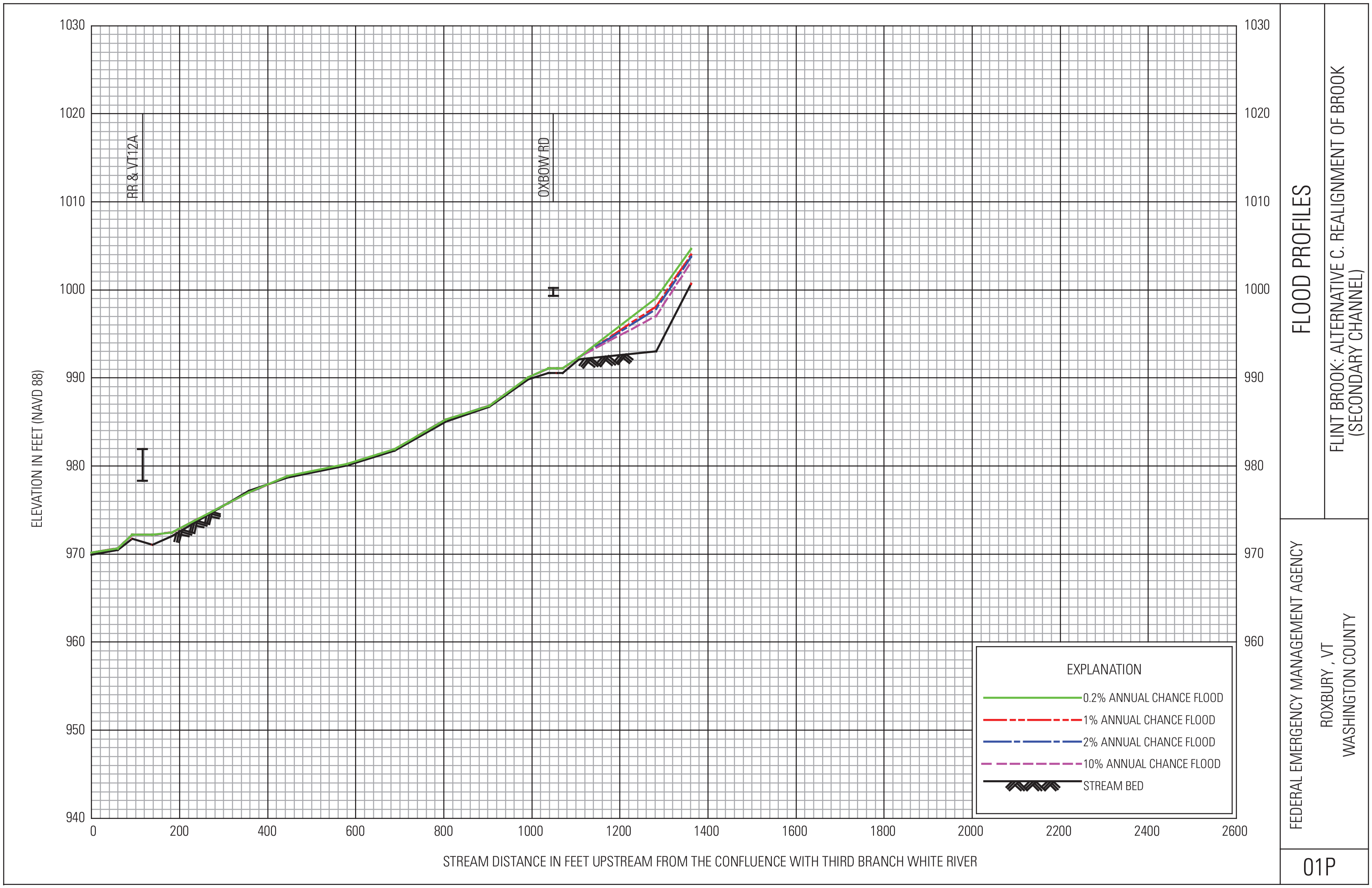

FIGURE 4-3B

Figure 4–3. Flood profile of *A*, the main channel and *B*, the secondary channel of Flint Brook under a mitigation alternative where Flint Brook in Roxbury, Vermont, is realigned to a new channel with the current [2014] channel serving as a secondary (overflow) channel. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.—Continued

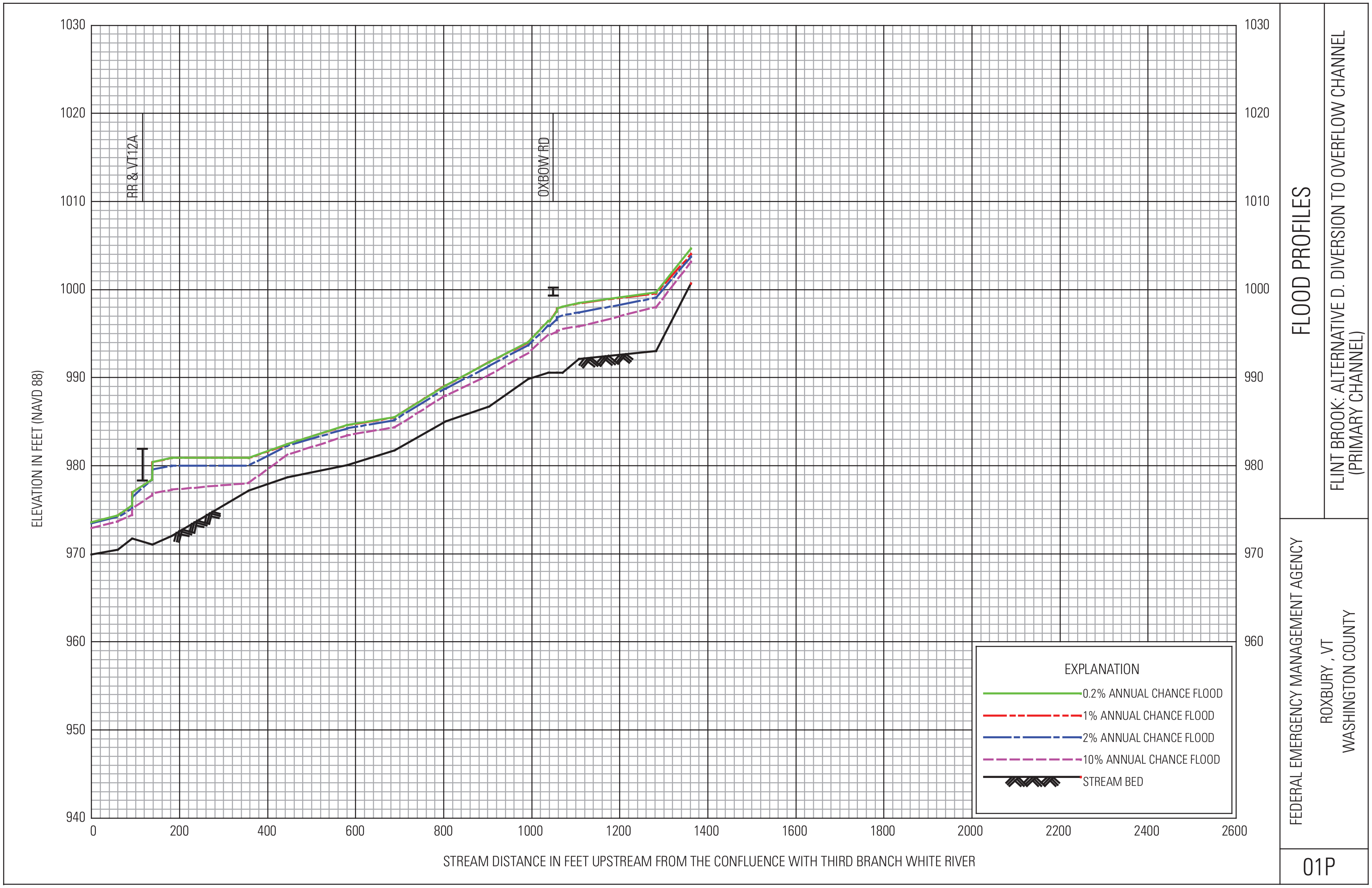

FIGURE 4-4A

Figure 4–4. Flood profile of *A*, Flint Brook and *B*, a diversion channel evaluating a mitigation alternative with realignment of Flint Brook in Roxbury, Vermont, to a diversion channel. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.

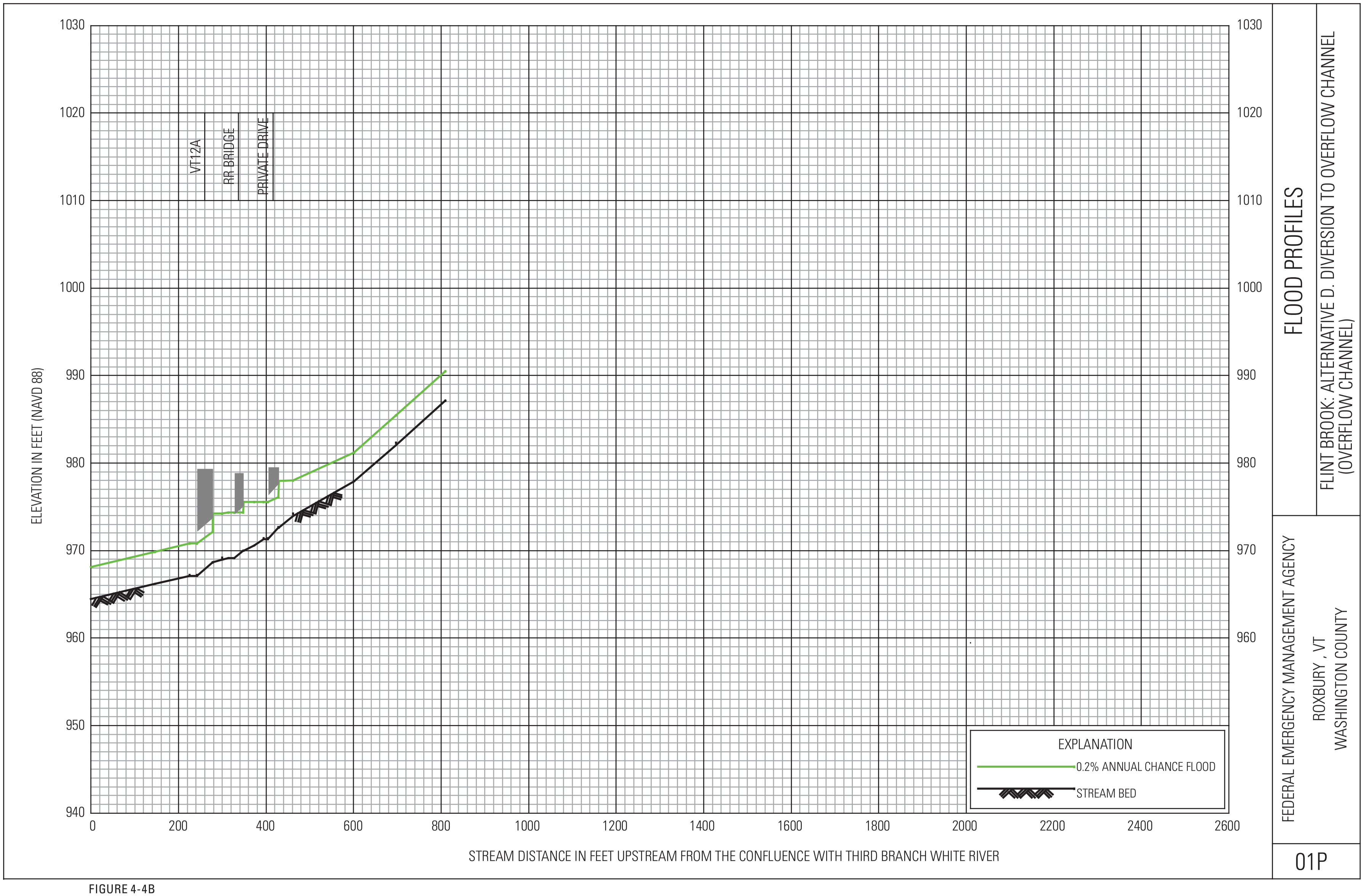

Figure 4–4. Flood profile of *A*, Flint Brook and *B*, a diversion channel evaluating a mitigation alternative with realignment of Flint Brook in Roxbury, Vermont, to a diversion channel. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.—Continued

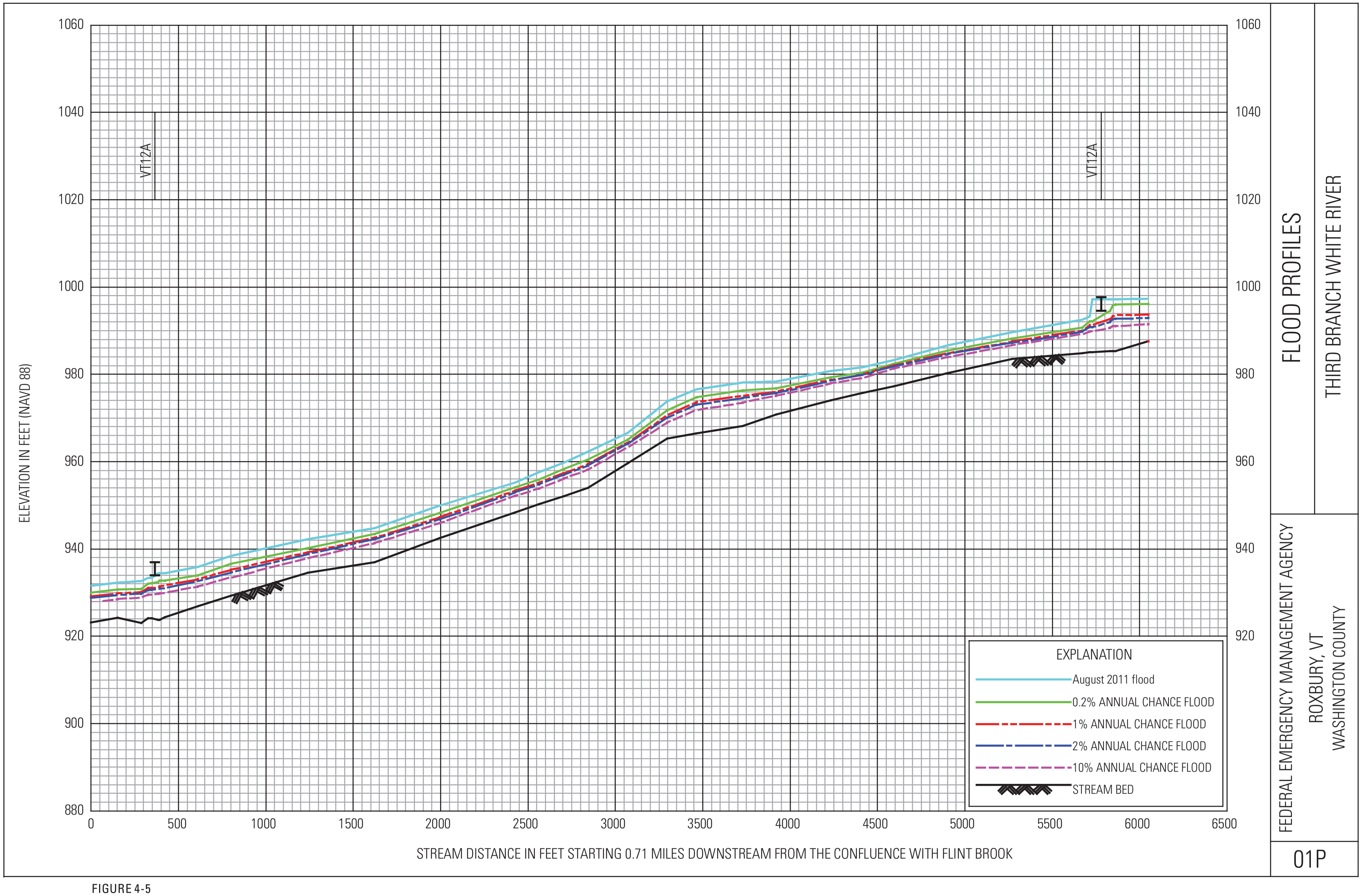

Figure 4–5. Flood profile of the Third Branch White River in Roxbury, Vermont. Fish hatchery, Roxbury Fish Culture Station; NAVD 88, North American Vertical Datum of 1988; Rd, Road; RT12A, Vermont State Route 12A.

Appendix 5. Flood-Peak Inundation Map of Tropical Storm Irene, August 28–29, 2011, in the Vicinity of the Roxbury Fish Culture Station for Flint Brook and the Third Branch White River, Roxbury, Vermont

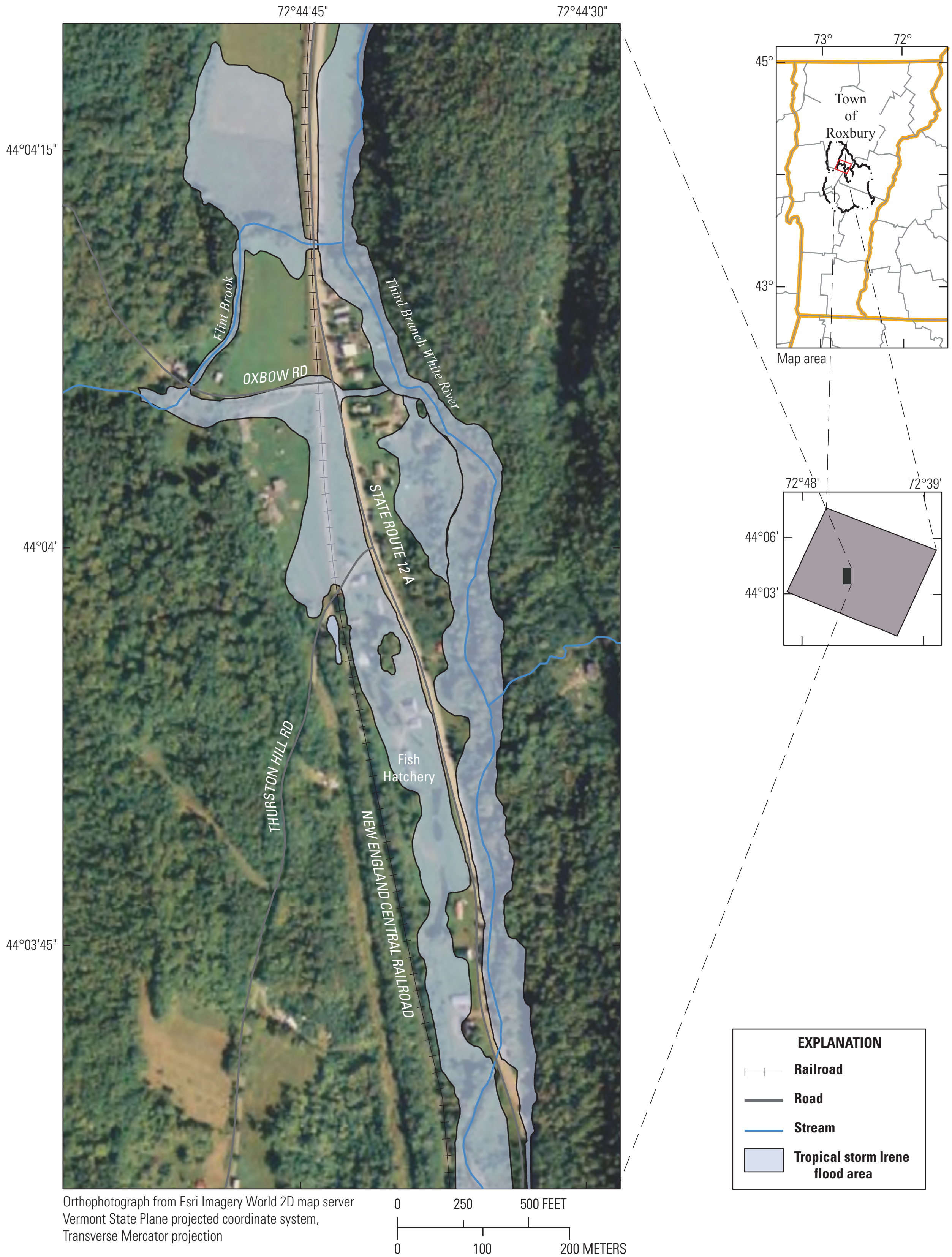

Figure 5–1. Flood inundation map for the area near and around the Roxbury Fish Culture Station in Roxbury, Vermont, from flooding caused by tropical storm Irene, August 28–29, 2011. Fish hatchery, Roxbury Fish Culture Station; Rd, Road; RT12A, Vermont State Route 12A.

Appendix 6. Flood-Peak Inundation Maps for the 10–, 2–, 1–, and 0.2–Percent Annual Exceedance Probabilities for Two Mitigation Alternatives at the Roxbury Fish Culture Station for Flint Brook, Roxbury, Vermont

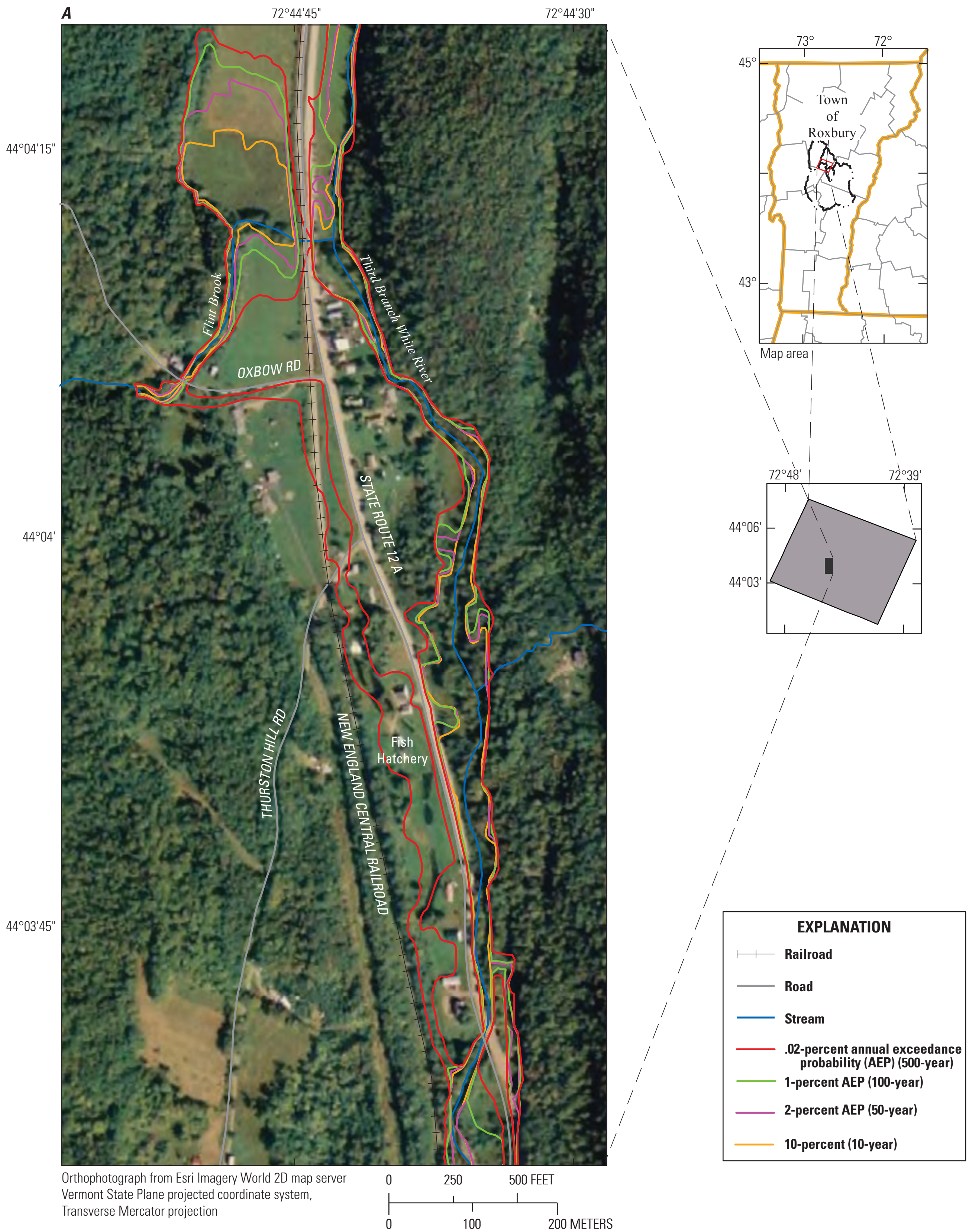

Figure 6–1. Annual exceedance probabilities for the area near and around the Roxbury Fish Culture Station in Roxbury, Vermont, under *A*, existing conditions [2014] and *B*, a mitigation alternative where existing bridge openings are enlarged and the height of the retaining wall is increased. Fish hatchery, Roxbury Fish Culture Station; Rd, Road; RT12A, Vermont State Route 12A.

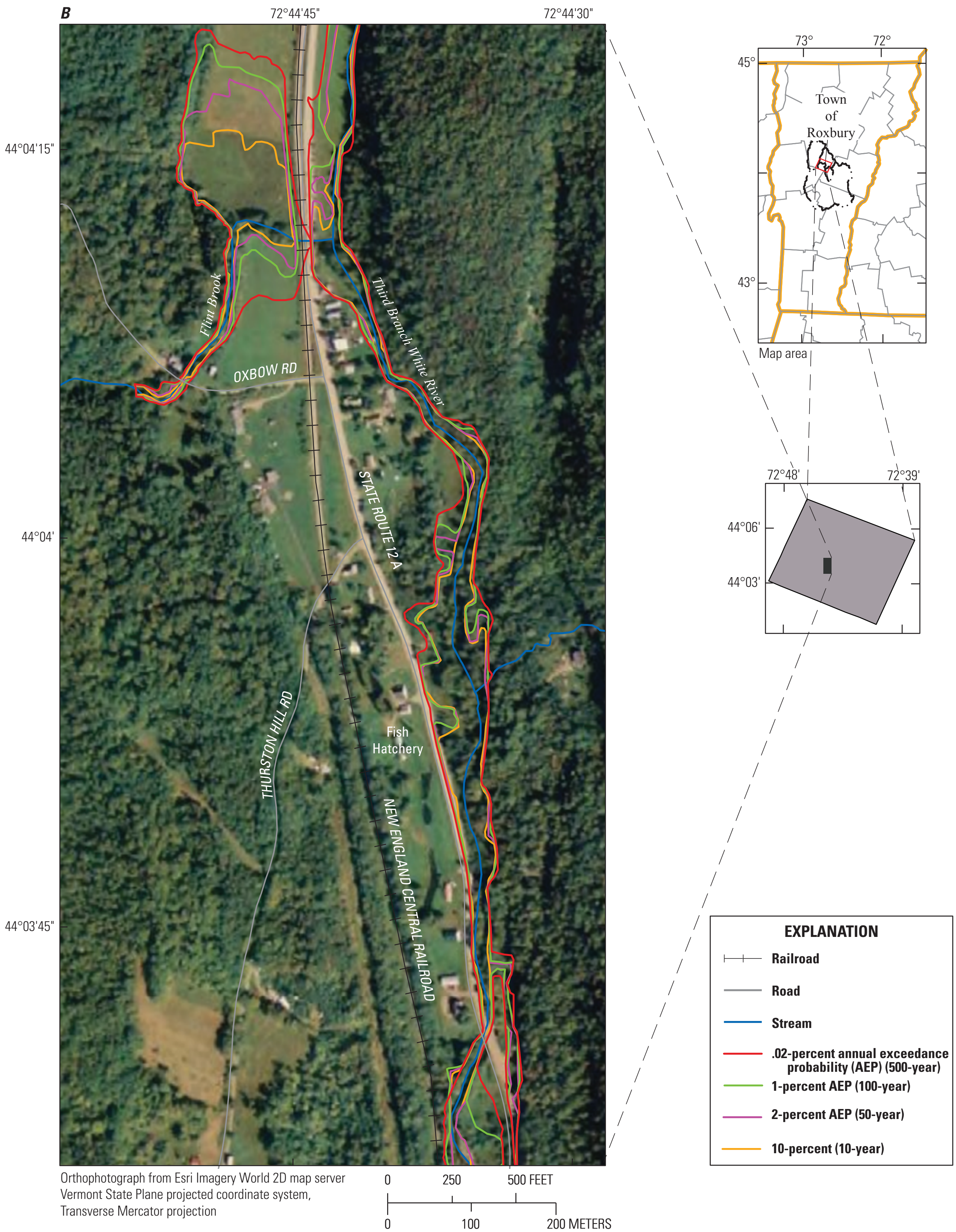

Figure 6–1. Annual exceedance probabilities for the area near and around the Roxbury Fish Culture Station in Roxbury, Vermont, under *A*, existing conditions [2014] and *B*, a mitigation alternative where existing bridge openings are enlarged and the height of the retaining wall is increased. Fish hatchery, Roxbury Fish Culture Station; Rd, Road; RT12A, Vermont State Route 12A.—Continued

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