

**BEFORE THE FEDERAL ENERGY REGULATORY COMMISSION
APPLICATION FOR LICENSE FOR MAJOR PROJECT –
EXISTING DAM**

Cannonsville Hydroelectric Development

FERC Project No. 13287



VOLUME 7

Appendix E-5: Phase IA Archeological Literature Review and Sensitivity Assessment



September 2011



HARTGEN

archeological associates inc

PHASE IA ARCHEOLOGICAL LITERATURE REVIEW AND SENSITIVITY ASSESSMENT

City of New York

**West of Hudson Hydroelectric Project: Cannonsville, Downsville, and Neversink
Dams**

FERC Project No. 13287

Towns of Deposit, Downsville, and Neversink
Delaware and Sullivan Counties, New York

HAA # 4277-11
OPRHP 09PR03088

Submitted to:

City of New York
New York City Department of Environmental Protection
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MANAGEMENT SUMMARY

SHPO Project Review Number: 09PR03088

Involved State and Federal Agencies: Federal Energy Regulatory Commission

Phase of Survey: IA

LOCATION INFORMATION

Location: Cannonsville Reservoir, Pepacton Reservoir, and Neversink Reservoir

Minor Civil Division: Town of Deposit (02506), Town of Colchester (02503), and Town of Neversink (10512)

Counties: Delaware and Sullivan

SURVEY AREA

Length: variable

Width: variable

Number of Acres Surveyed: Cannonsville approximately 4 acres, Pepacton/Downsville approximately 1 acre, Neversink approximately 1 acre

7.5 Minute Quadrangle Map: Cannonsville Reservoir, Downsville, and Liberty East (Neversink)

RECOMMENDATIONS

The project will be constructed in areas that have been previously disturbed by the construction of the previous dams and reservoirs. If the APE is restricted to these areas of previous disturbance no further archeological study is warranted.

Report Authors: Matthew Kirk and Walter R. Wheeler

Date of Report: June 2011

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1. The Neversink dam as viewed on the upstream portion towards the east. In the distance the intake structure can be seen, the Project proposes to replace one of the valves with a hydroelectric turbine.
2. View east of the downstream portion of the earthen dam at Neversink. The dam was constructed in 1953.
3. The waste weir or spillway at the Neversink dam as viewed from the northeast. The weir is composed of three large steps faced in granite to minimize the effects of scouring. The water is diverted to an inclined tunnel at the west end of the weir, just beyond view.
4. The intake structure at the Neversink dam and tunnel. The structure regulates water flow through the Neversink Tunnel and a minimum flow to the Neversink River through the former diversion tunnel. The Project proposes to replace one of the existing valves with a hydroelectric turbine.
5. The intake structure at Neversink as viewed west.
6. The Project proposes to replace an existing valve at the structure with a hydroelectric turbine. The valve releases water into an inclined tunnel located below the lawn in the foreground. The tunnel empties into the spillway channel and to an outlet into the Neversink River. A staging area will likely be located to the south (to the right) of the intake structure.
7. The current plans for the Project include a distribution line that will utilize an existing underground ductbank located along this steep bank to NY 55 (in the background).
8. View north of the downstream portion of the earthen dam at Downsville created for the Pepacton Reservoir. The proposed turbine will be installed in the valve control structure at the north end of the dam, seen at a distance in the photograph.
9. Upstream portion of the Downsville dam as viewed to the southwest. Stone rip-rap lines the interior section of the earthen dam. The proposed project area is just out of view to the right.
10. View east of the waste weir of the Downsville dam. The ogee crest of the weir is faced with granite. A waste channel to the left is excavated out of bedrock.
11. View west of the spillway channel of the Downsville dam. Below is the inclined tunnel lined in concrete that was once part of the diversion tunnel. The valve structure regulates a minimum flow of water from the reservoir and is located just out of view to the left. Water released from the valve structure enters the inclined tunnel below. Above the inclined tunnel is a secondary spillway channel for overflow at peak discharges. The Project proposes to replace the valve with a turbine.

12. The valve structure at the north abutment of the Downsville dam. The two-story brick and masonry building houses two valves that regulate minimum flow from the reservoir. The Project proposes to replace one of the valves with a turbine. A switch yard will be built in the immediate vicinity.
13. View west of the valve structure at Downsville dam, the rip-rap of the dam is to the left and to the right beyond the chain-link fence is the spillway channel.
14. A view of the downstream side of the Cannonsville dam. To the right is an access road at the top of the dam. To the lower left is the release chamber below the dam. The proposed powerhouse will be sited next to the existing release chamber. A small cluster of outbuildings are located in the distance, as indicated by the arrow.
15. The doubled-crested waste weir at Cannonsville dam and its associated spillway. The ogee-shaped weir is faced in granite. The spillway channel is cut through bedrock.
16. A small cluster of maintenance buildings remain along the top of the Cannonsville dam. Several other structures, including the Engineer's office and laboratory, were moved and/or demolished over the years, view west. The switchyard or substation will be sited behind the garage.
17. A small pole barn used in the maintenance of the facility currently holds salt and machinery. Another small building is likely a former office that is now largely abandoned. Both structures are located near the top center portion of the dam.
18. The intake structure along the reservoir at the Cannonsville dam, viewed to the southeast. The upstream portion of the dam is lined with stone rip-rap.
19. The release chamber is located at the western abutment of the Cannonsville dam. The proposed powerhouse will be located to the east of the chamber, as indicated by the arrow. The distribution lines extend up the dam face to the maintenance facility.
20. A view west of the proposed location of the powerhouse at Cannonsville dam. The powerhouse will be situated in area (see oval) previously disturbed by the construction of the dam and the deep stilling pool at the end of the release chamber.

Table List

1. Soils in the Cannonsville Project Area
2. Soils in the Downsville Project Area
3. Soils in the Neversink Project Area
4. OPRHP/NYSM Archeological Sites within Three Miles (4.8 km) of the Cannonsville Dam and within or Immediately Adjacent to the Reservoir.
5. OPRHP/NYSM Archeological Sites within Three Miles (4.8 km) of the Downsville Dam and within or Immediately Adjacent to the Reservoir.

PHASE IA LITERATURE REVIEW AND ARCHEOLOGICAL SENSITIVITY ASSESSMENT

INTRODUCTION

Hartgen Archeological Associates, Inc. (HAA, Inc.) was retained by The City of New York to conduct a Phase IA literature review for the proposed City of New York, West of Hudson Hydroelectric Project at the Cannonsville Dam, Downsville Dam, and Neversink Dam in the Towns of Deposit and Colchester in Delaware County, and the Town of Neversink in Sullivan County New York, respectively (Maps 1a and 1b, 2a-2c, and 3a-3c). The City of New York is currently exploring the possibility of licensing new hydroelectric facilities at these three sites (the Project) as part of the ongoing operation of their dams and reservoirs.

Acting through the New York City Department of Environmental Protection (DEP), the agency responsible for operating and managing the water supply system, the City has filed a Pre-Application Document (PAD) with the Federal Energy Regulatory Commission (FERC) to obtain a preliminary permit to conduct the necessary studies for the application process. The permit was granted in March 2009. The current archeological study is one of many studies being conducted in support of the DEP's efforts in the application process. The cultural resource study is a necessary step in the FERC permitting process, and is a requirement of federal law. Section 106 of the National Historic Preservation Act stipulates that federal agencies must consider the potential effects of the project on historic properties. FERC consults with the Advisory Council on Historic Preservation. The Advisory Council has delegated responsibility for reviewing the project to the New York State Historic Preservation Office (NYSHPO). Therefore, the NYSHPO will be the primary reviewing agency concerning the Project's impact on historic properties. The investigation was conducted according to the New York Archaeological Council's (NYAC) Standards for Cultural Resource Investigations and the Curation of Archaeological Collections in New York State (NYAC 1994).

PROJECT INFORMATION

The report is authored by Matthew Kirk, M.A., R.P.A., who also served as the Principal Investigator. Walter R. Wheeler is the architectural historian; he also contributed to the report. A site visit was conducted by Matthew Kirk and Walter R. Wheeler on Tuesday, April 13, 2010 to observe and photograph existing conditions within the project area. The site visit was led by Robert Principe, P.E., Hydro-Plant Engineer for the Bureau of Water Supply (BWS), Western Operations Division. Mr. Principe also provided information concerning the current operations of the facility, as well as insights into the proposed hydroelectric project. We were also assisted by Russell Betters who helped locate appropriate reports in the DEP library.

The site visit included the opportunity to visit the library at the DEP offices in Grahamsville to review pertinent maps, reports, and other material to aid in the cultural resource study. The library contained a wealth of information relative to the historical developments of the dams and associated reservoirs. Among the important materials reviewed were BWS annual reports and contract reports that detailed the construction history of each of the projects. Many of these reports contained maps and historical photographs. A small sample of the most relevant maps, photographs, and reports were copied at the library for inclusion in the current study. Much additional information is still available at the library. A sample of these materials, as well as information and current conditions along with photographs gathered during the site visit, are included in Appendix 1.

Project Location

The Project contemplates development of facilities at four separate reservoirs in the Catskills: Neversink, Pepacton, Cannonsville, and Schoharie (Maps 1a and 1b). In regard to the later Project location, the DEP has not yet come up with a viable project. As such, the Schoharie site is not considered further in this report. Should the DEP find a viable alternative for this location a separate Phase 1A Archeological Literature Review and Sensitivity Assessment will be conducted. The Project area at the Neversink dam includes the area in and immediately around the existing intake structure facility (Maps 2a, 3a, and 4a). The facility is located in the Town of Neversink, Sullivan County, New York. The Pepacton Reservoir is controlled by the

Downsville dam. Here, the Project area includes the existing release water chamber. The proposed hydroelectric turbines will replace an existing valve inside the structure and a small switch yard will be constructed in the immediate vicinity. The structure is located on the west abutment of the dam in the Town of Colchester, Delaware County, New York (Maps 2b, 3b, and 4b). Finally, the proposed development at the Cannonsville dam will entail the construction of a new powerhouse at the base of the dam immediately adjacent to and integral with the existing release water chamber. The release chamber is located near the south abutment of the dam in the Town of Deposit, Delaware County, New York (Maps 2c, 3c, and 4c).

Description of the Project Area

All three of the proposed developments of the Project are located within the existing reservoir systems for New York City (DEP 2009). Each is located within or immediately adjacent to the dams associated with each reservoir. At Neversink, the hydroelectric turbine will replace valves located between the intake structure for the East Delaware Tunnel and the inclined portal tunnel that provides a minimum flow for the Neversink River. Plans also include a small substation along the east elevation of the intake structure and a staging area just south of the intake structure (Map 4a). As will be discussed, the area proposed to be impacted by the Project at Neversink has been previously disturbed by the construction of the dam and its appurtenances.

The Project will also include a hydroelectric turbine at the Downsville dam of the Pepacton Reservoir. The turbine will be located within the existing release water chamber at the spillway (Map 4b). One turbine will replace one of the existing valves in the release water chamber, the other valve will remain to control water when the turbine is off-line and for a bypass system. The valves are located in two, 5.5-foot diameter supply tunnels, that are 90 feet in length and connect to the inclined portal tunnel where water is discharged (DEP 2009).

Finally, the Project will also include a new hydroelectric development at the Cannonsville dam. The Project will include the construction of a new powerhouse adjacent to and integral with the existing release water chamber at the south end of the dam (Map 4c). The powerhouse will include utilizing the existing tailrace composed of various sized pipes. Four turbines will be situated at the end of the pipes which will effectively serve as penstocks. A 78-inch diameter pipe will bifurcate into two 36-inch penstocks that will service one turbine. A second turbine will receive water from a 72-inch diameter penstock, and a 102-inch diameter penstock will bifurcate into two 72-inch pipes that will provide water to two separate turbines. The resulting powerhouse at the end of the penstock will house four new turbines with a capacity of 14.08 MW with a potential for annually generating 37.27 GWh (DEP 2009:2).

Description of the Area of Potential Effects (APE)

The Area of Potential Effects (APE) includes all portions of the property that will be directly or indirectly altered by the proposed undertaking. For the purposes of the current study, the APE for each of the developments within the Project is broadly defined and will be refined/narrowed as the Project designs advance. Based on current project plans the following observations can be made regarding the APE:

Neversink (Map 4a)

- The project will consist of a new turbine replacing an existing valve within the intake structure,
- a substation will be sited along the east elevation of the intake structure,
- a buried electrical line will utilize a ductbank along a steep slope to the east of the intake structure and tie into the existing grid along NY 55,
- a staging area will be utilized immediately south of the intake structure.

Pepacton/Downsville (Map 4b)

- The project will entail replacing the existing valve within the release structure,
- a new substation will be sited northwest of the release structure,
- a short underground electrical line will connect the substation to an existing utility pole to the south of the release structure,
- a staging area will be used immediately northeast of the release structure.

Cannonsville (Map 4c)

- A new powerhouse will be constructed immediately north of the existing release works building on the west face of the earthen dam,
- an existing leach field will be relocated to a site also along the west face of the dam,
- underground electric lines will be sited along the west face of the dam,
- overhead lines will also be used near the top of the dam,
- a new substation or switchyard will be built near the existing maintenance facility,
- existing overhead lines will be used to connect to the larger grid,
- three staging areas will be used downstream of the dam along an existing access road,
- a spoil disposal area will be sited downstream of the dam.

Environmental Background

The environment of an area is significant for determining the sensitivity of the project area for archeological resources. Precontact and historic groups often favored level, well-drained areas near wetlands and waterways. Therefore, topography, proximity to wetlands, and soils are examined to determine if there are landforms in the project area that are more likely to contain archeological resources. In addition, bedrock formations may contain chert or other resources that may have been quarried by precontact groups. Soil conditions can also provide a clue to past climatic conditions, as well as changes in local hydrology.

Present Land Use and Current Conditions

Each of the three components of the proposed Project is located within, and immediately adjacent to, an existing dam and reservoir. As such, these areas have witnessed extensive modifications and previous disturbance during their construction. These changes to the landscape are detailed below in the Historical Development section of the report. The soils, surficial bedrock, physiography and drainage of the areas immediately surrounding the proposed developments have been extensively modified from their original condition. A sense of those original conditions, however, can be gleaned from the historical maps and photographs that are presented as part of this report, as well as existing soil conditions and topography.

Soils

Soil surveys provide a general characterization of the types and depths of soils that are found in an area. This information is an important factor in determining the appropriate methodology if and when a field study is recommended. The soil type also informs the degree of artifact visibility and likely recovery rates. For example, artifacts are more visible and more easily recovered in sand than in stiff glacial clay, which will not pass through a screen easily. The United States Department of Agriculture, Natural Resources Conservation

Service (USDA NRCS) soil maps and units presented here are generated at such a scale as to be largely unreliable for the potential APE (Maps 5a-5c). Also, due to extensive land modification that occurred during the construction of the reservoir system, it is highly likely that virtually all of the soils in and around the proposed developments have been disturbed. These data therefore provide an indication of the types of soils that may have been present at these sites prior to construction of the dams and reservoirs.

Table 1. Soils in Cannonsville Project Area

	Name and Symbol	Soil Horizon Depth cm (in)	Texture, Inclusions	Slope	Drainage	Landform
LaC	Lackawanna flaggy silt loam (LaC)	0-46 cm (0-18 in)	Flaggy Si lo	8-15%	Well drained	drumlinoid ridges, hills, till plains
		46-117 cm (18-46 in)	Channery Si lo, flaggy Si lo, Si lo			
		117-180 cm (46-71 in)	Flaggy Si lo			
		180-310 cm (71-122 in)	Flaggy Si lo			
		310-465 cm (122-183 in)	Channery Si lo, very channery Sa lo, flaggy Lo			
LaD	Lackawanna flaggy silt loam (LaD)	0-46 cm (0-18 in)	Flaggy Si lo	15-25%	Well drained	drumlinoid ridges, hills, till plains
		46-117 cm (18-46 in)	Channery Si lo, flaggy Si lo, Si lo			
		117-180 cm (46-71 in)	Flaggy Si lo			
		180-310 cm (71-122 in)	Flaggy Si lo			
		310-465 cm (122-183 in)	Channery Si lo, Si lo, very channery Sa lo, flaggy Lo			
LaE	Lackawanna flaggy silt loam (LaE)	0-46 cm (0-18 in)	Flaggy Si lo	25-40%	Well drained	drumlinoid ridges, hills, till plains
		46-117 cm (18-46 in)	Channery Si lo, flaggy Si lo, Si lo			
		117-180 cm (46-71 in)	Flaggy Si lo			
		180-310 cm (71-122 in)	Flaggy Si lo			
		310-465 cm (122-183 in)	Channery Si lo, very channery Sa lo, flaggy Lo			
LdE	Lackawanna and Bath soils, very stony (LdE)	0-46 cm (0-18 in)	Flaggy Si lo	15-35%	Well drained	drumlinoid ridges, hills, till plains
		46-117 cm (18-46 in)	Channery Si lo, flaggy Si lo, Si lo			
		117-180 cm (46-71 in)	Flaggy Si lo			
		180-310 cm (71-122 in)	Flaggy Si lo			
		310-465 cm (122-183 in)	Channery Si lo, very channery Sa lo, flaggy Lo			
Ud	Udorthents, graded (Ud)	0-25 cm (0-10 in)	Gra sa lo	0-15%	Somewhat excessively	Man-modified

	Name and Symbol	Soil Horizon Depth cm (in)	Texture, Inclusions	Slope	Drainage	Landform
		25-452 cm (10-178 in)	Channery Lo, very Gra sa lo, Si cl lo		drained	
W	Water (W)	- cm (- in)		-%		

Key: Color: Br-Brown, Dk-Dark, Gr-Gray, Re-Red, Y-Yellow, Bk-Black, Ol-Olive
Texture: Co-Coarse, Fi-Fine, Gv-Gravel(ly), Lo-Loam, Sa-Sand, Si-Silt, Vy-Very, cl-clay

Table 2. Soils in Downsville Project Area

	Name and Symbol	Soil Horizon Depth cm (in)	Texture, Inclusions	Slope	Drainage	Landform
EIE	Elka-Vly channery silt loams, very stony (EIE)	Elka 0-8 cm (0-3 in)	Elka Moderately decomposed plant material	15-35%	Elka Well drained	Elka hills
		8-38 cm (3-15 in)	Channery Si lo			
		38-231 cm (15-91 in)	Channery Si lo, very channery Lo, Si lo, Sa lo			
		231-356 cm (91-140 in)	Very channery Si lo			
		356-465 cm (140-183 in)	Very channery Lo, Si lo, Sa lo			
OrF	Oquaga, Lordstown, and Arnot soils, very rocky (OrF)	0-38 cm (0-15 in)	Channery Si lo	35-70%	Well drained	benches, hills, ridges
		38-155 cm (15-61 in)	Very channery Si lo			
		155-218 cm (61-86 in)	Unweathered bedrock			
Ud	Udorthents, graded (Ud)	0-25 cm (0-10 in)	Gra sa lo	0-15%	Somewhat excessively drained	Man-modified
		25-452 cm (10-178 in)	Channery Lo, very Gra sa lo, Si cl lo			
W	Water (W)	- cm (- in)		-%		

Key: Color: Br-Brown, Dk-Dark, Gr-Gray, Re-Red, Y-Yellow, Bk-Black, Ol-Olive
Texture: Co-Coarse, Fi-Fine, Gv-Gravel(ly), Lo-Loam, Sa-Sand, Si-Silt, Vy-Very, cl-clay

Table 3. Soils in Neversink Project Area

Symbol	Name (Symbol)	Depth	Textures	Slope	Drainage	Landform
ArC	Arnot-Rock outcrop complex (ArC)	0-8 cm (0-3 in)	Moderately decomposed plant material	0-15%	Somewhat excessively drained	benches, hills, ridges
		8-20 cm (3-8 in)	Channery loam			
		20-109 cm (8-43 in)	Very channery loam, very channery silt loam			
		109-135 cm (43-53 in)	Unweathered bedrock			
ArE	Arnot-Rock outcrop complex (ArE)	0-8 cm (0-3 in)	Moderately decomposed plant material	15-35%	Somewhat excessively drained	benches, hills, ridges
		8-20 cm (3-8 in)	Channery loam			

Symbol	Name (Symbol)	Depth	Textures	Slope	Drainage	Landform
		20-109 cm (8-43 in)	Very channery loam, very channery silt loam			
		109-135 cm (43-53 in)	Unweathered bedrock			
Ud	Udorthents, smoothed (Ud)	- cm (- in)		0-15%	Moderately well drained	
WeC	Wellsboro gravelly loam (WeC)	0-46 cm (0-18 in)	Gravelly loam	8-15%	Moderately well drained	drumlinoid ridges, hills, till plains
		46-147 cm (18-58 in)	Channery silt loam, gravelly loam, loam			
		147-386 cm (58-152 in)	Channery sandy loam, gravelly loam, silt loam			
		13-25 cm (5-10 in)	Loam			
		25-180 cm (10-71 in)	Channery fine sandy loam, gravelly sandy loam, loam			
		180-386 cm (71-152 in)	Gravelly fine sandy loam, very gravelly sandy loam, loam			

Key: Color: Br-Brown, Dk-Dark, Gr-Gray, Re-Red, Y-Yellow, Bk-Black, Ol-Olive
Texture: Co-Coarse, Fi-Fine, Gv-Gravel(ly), Lo-Loam, Sa-Sand, Si-Silt, Vy-Very, cl-clay

Bedrock Geology

The bedrock geology of the three proposed sites in the Project and their surrounding environs are largely dominated by Devonian Period sedimentary rocks that were laid down in ancient sea beds over 380 million years ago. At Cannonsville and Neversink, the underlying bedrock is principally Walton Formation shale and sandstone, formed as part of the West Falls Group. The formation at Downsville is slightly older, consisting of Enfield and Kattel Formations of shale, siltstone, and sandstone formed as part of the Sonyea Group. These bedrock formations do not contain chert, quartz, or other types of lithic resources that were frequently exploited by Native American people. Nor are there other types of mineral resources exploited later in the historic period. As such, there is little likelihood of precontact or historic era quarries in the area, despite the fact that bedrock is frequently exposed at the surface.

Physiography

Steeply sloped areas are considered largely unsuitable for human occupation. As such, the standards for archeological fieldwork in New York State generally exclude areas with a slope in excess of 12% from archeological testing (NYAC 1994). Exceptions to this rule include steep areas with bedrock outcrops, overhangs, and large boulders that may have been used by precontact people as quarries or rock-shelters. Such areas may still warrant a systematic field examination, however none are expected in the APE of the Project.

Originally, the three reservoirs and their associated dams were set into narrow river valleys of the Catskill Mountains. In particular, the dams were often situated in the narrowest sections of the valley, thereby utilizing the existing landscape to help in the formation of the resulting reservoir. Virtually all of the proposed APE of the Project will be located in areas where the original landscape has been heavily modified during dam and reservoir construction.

DOCUMENTARY RESEARCH

A pre-screening report was generated by Hartgen Archeological Associates, Inc., in May 2009 to assist with the submission of the Pre-Application Document (PAD) to FERC (DEP 2009). The pre-screening involved systematically searching through the archeological site files kept by the Office of Parks, Recreation and Historic Preservation (OPRHP) and the New York State Museum (NYSM) located at the OPRHP archives on Peebles Island, in Waterford, New York. Information concerning all reported precontact and historic period archeological sites within a three-mile (4.8 km) radius of the dam at each reservoir was collected. In addition, data relating to those sites located within and immediately adjacent to each of the three reservoirs, but outside of the 3-mile (4.8 km) search radius was also collected. The OPRHP's electronic database was also searched for properties listed on or eligible for listing on both the State and National Registers of Historic Places that are located within or immediately adjacent to each of the dam sites.

The site files were reviewed again in April 2010 by Rebecca Glazer, Hartgen's senior researcher, to ensure that no new sites or properties were added to the OPRHP database. No new information was located at each of the three sites.

Cannonsville

Previously Reported Cultural Resources

OPRHP and NYSM Identified Archeological Sites

The NYSM and OPRHP files contain 33 reported sites within three miles (4.8 km) of the Cannonsville dam and 14 reported sites outside of the three-mile (4.8 km) search radius but within or immediately adjacent to the reservoir. These sites include 39 historic sites and eight precontact sites. The nearest site, a mid 19th-century sawmill, was identified during a 1979 historic industrial resources survey and is located immediately adjacent to the east side of the Cannonsville dam. Thirty-four of the historic sites located within three miles (4.8 km) of the Cannonsville dam or within and adjacent to the reservoir were identified over the course of the 1979 historic industrial resources survey by utilizing historic maps rather than subsurface archeological investigation. All of those sites identified during the 1979 survey represent 19th-century industrial complexes that were once located along the Delaware River or its contributing tributaries; many of which are now submerged within the Cannonsville Reservoir. The location, brief description, and National Register status of each site are provided below in Table 4. The National Register status of each resource is determined by the OPRHP. Typically, resources are determined to be eligible or ineligible for listing on the National Register based on criteria developed by the National Park Service (1990, revised 2002). In some circumstances, resources have not been evaluated and are listed as unevaluated, in several other instances there were no records to indicate whether resources were evaluated or unevaluated; and for the purposes of this table are listed as unknown.

Table 4: OPRHP/NYSM Archeological sites within three miles (4.8 km) of the Cannonsville dam and within or immediately adjacent to the reservoir.

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02506.00000 1		Cider mill (WBD-139)	Mid 19 th -century map documented industrial site	Unevaluated	1.5 miles (2.4 km) northeast (now within reservoir)
02506.00000 2		Sawmill (WBD-141)	Mid 19 th -century map documented industrial site	Unevaluated	Immediately adjacent to the east side of dam
02506.00000 3		Sawmill (WBD-142)	Mid 19 th -century map documented industrial site	Unevaluated	1.3 miles (2 km) northwest
02506.00000 9		H. Hess Sawmill (WBD-156)	Remains of stone foundation and dam associated with mid 19 th -century sawmill	Unevaluated	2.4 miles (3.8 km) northeast

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02506.000010		Sawmill, Wagon Shop (WBD-157)	Mid 19th-century map documented industrial site	Unevaluated	2.1 miles (3.3 km) north
02506.000011		Blind Manufacture (WBD-158)	Mid 19th-century map documented industrial site	Unevaluated	2.2 miles (3.5 km) northwest
02506.000012		Ira Snyder Carding Mill (WBD-159)	Mid 19th-century map documented industrial site	Unevaluated	1.4 miles (2.2 km) northwest
02506.000013		Ira Snyder Axe Factory (WBD-160)	Mid to late 19th-century map documented industrial site	Unevaluated	1.4 miles (2.2 km) northwest
02506.000014		Ira Snyder Sawmill (WBD 161)	Mid to late 19th-century map documented industrial site	Unevaluated	1.4 miles (2.2 km) northwest
02506.000015		Southern NY Power Co. (WBD-160A)	Foundation remains as well as smokestack, sills, and exterior waterwheel associated with early 19 th -century power plant	Unevaluated	1.4 miles (2.2 km) northwest
02506.000016	5851	Briggs Site (SUBi-1124)	Late Archaic and Woodland period camp site	Unevaluated	1.3 miles (2.0 km) northwest
02506.000017		Site 2	Late Archaic camp site	Not eligible	1.7 miles (2.7 km) west
02506.000018		DEL-186	Historic quarry	Unevaluated	1.5 miles (2.4 km) south
02506.000019		DEL-187	Historic quarry	Unevaluated	2.1 miles (3.3 km) southeast
02506.000020		DEL-189	Historic quarry	Unevaluated	2.5 miles (4.0 km) southeast
02506.000024		DEL-9932	Undated stone foundation; possibly a barn	Unevaluated	4,900 ft (1,493 m) southwest
02506.000026		Deposit Airport I Site (SUBi-2048)	Late Archaic, Middle Woodland, and Late Woodland components: chert flakes, fire-cracked rock, points, biface, pottery fragments	Unevaluated	2.5 miles (4.0 km) southwest
02506.000027		Deposit Airport II Site (SUBi-2049)	Archaic through Late Woodland: biface, points, pottery fragments, flakes, and an adze	Unevaluated	2.4 miles (3.8 km) southwest
02506.000028		Wheeler Historic Site (SUBi-2070)	Architectural and domestic deposits dating to the mid-19 th century	Unevaluated	2.4 miles (3.8 km) southwest
02518.000002		Sawmill (WBD-97)	Mid 19 th -century map documented industrial site	Unevaluated	9.5 miles (15.2 km) northeast
02518.000004		Sawmill (WBD-99)	Mid 19th-century map documented industrial site	Unevaluated	7 miles (11.2 km) northeast (now within reservoir)
02518.000009		N. Boyd Sawmill (WBD-103)	Mid 19th-century map documented industrial site	Unevaluated	6.9 miles (11.1 km) northeast (now within Dryden Brook inlet of reservoir)
02518.000010		Sawmill (WBD-104)	Mid 19th-century map documented industrial site	Unevaluated	6.4 miles (10.2 km) northeast (now within reservoir)

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02518.00001 1		Gregory Sawmill (WBD-105)	Early through mid 19th-century map documented industrial site	Unevaluated	6.1 miles (9.8 km) northeast (now within reservoir)
02518.00001 2		Sawmill (WBD-106)	Early 19th-century map documented industrial site	Unevaluated	5.5 miles (8.8 km) northeast (now within reservoir)
02518.00001 3		W.H. Sprague Lumber Manufacturing (WBD-107)	Mid 19th-century map documented industrial site	Unevaluated	3.6 miles (5.7 km) northeast (now within reservoir)
02518.00001 4		E.B. & M.W. Owens Wagon Shop, Blacksmith Shop (WBD-109)	Mid 19th-century map documented industrial site	Unevaluated	3.5 miles (5.6 km) northeast (now within reservoir)
02518.00002 5		J. Tillotson Sawmill (WBD-128)	Mid 19th-century map documented industrial site	Unevaluated	7.9 miles (12.7 km) northeast (now within reservoir)
02518.00002 6		W. Huggins/W.B. McGibbon Sawmill (WBD-130)	Early through mid 19th-century map documented industrial site	Unevaluated	5.5 miles (8.8 km) northeast (now within reservoir)
02518.00002 8		Sprague/Ogden & Leal/Jester/Deposit Milling Co./McLaughlin Gristmill (WBD-132)	Early through late 19th-century map documented industrial site	Unevaluated	3 miles (4.8 km) northeast (now within reservoir)
02518.00002 9		J.A. Kenyon Tannery (WBD-133)	Mid through late 19th-century map documented industrial site	Unevaluated	3 miles (4.8 km) northeast (now within reservoir)
02518.00003 0		Sawmill (WBD-134)	Early through mid 19th-century map documented industrial site	Unevaluated	3 miles (4.8 km) northeast (now within reservoir)
02518.00003 1		Huntington Sawmill (WBD-135)	Early through late 19th-century map documented industrial site	Unevaluated	2.1 miles (3.3 km) east (now within reservoir)
02518.00003 3		E. Boyd Sawmill (WBD-137)	Mid 19th-century map documented industrial site	Unevaluated	2.9 miles (4.6 km) northeast
02518.00003 4		Burr Map Sawmill (WBD-138)	Early 19th-century map documented industrial site	Unevaluated	1.5 miles (2.4 km) northeast (now within reservoir)
02519.00003 2		E. Beers/W. Beers/O. Hanford Sawmill (WBD-96)	Mid 19th-century map documented industrial site	Unevaluated	9.4 miles (15.1 km) northeast
02544.00000 3		Tannery (WBD-162)	Mid 19th-century map documented industrial site	Unevaluated	2 miles (3.2 km) west
02544.00000 4		Deposit Steam Mill (WBD-163)	Mid 19th-century map documented industrial site	Unevaluated	2 miles (3.2 km) west
02544.00000 5		R. H. Evans Cottage D Sawmill (WBD-164)	Mid 19th-century map documented industrial site	Unevaluated	1.9 miles (3.0 km) west
02544.00000 6		W. Evans/B.E. Hadley Sawmill (WBD-165)	Mid 19th-century map documented industrial site	Unevaluated	1.9 miles (3.0 km) west

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02544.000007		Hadley Steam Mill (WBD-167)	Late 19th-century map documented industrial site	Unevaluated	2.1 miles (3.3 km) west
02544.000008		N.K.W. Sash Factory (WBD-168)	Mid 19th-century map documented industrial site	Unevaluated	2.2 miles (3.5 km) west
02544.000009		Organ Factory and Wagon Shop (WBD-169)	Mid 19 th -century map documented industrial site	Unevaluated	2.3 miles (3.7 km) west
02544.000013		Deposit Airport III Site	Chert flakes, cortical chunk, chert shatter fragments	Unevaluated	2.4 miles (3.8 km) west
	761	No information	One fluted projectile point identified as a stray find	Unknown	3 miles (4.8 km) northeast (now within reservoir)
	3131	No information	Reported location of a precontact village burial site	Unknown	1.4 miles (2.2 km) west
	8407	No information	Reported traces of precontact occupation	Unknown	2 miles (3.2 km) west

State and National Register of Historic Places

A review of the OPRHP computer inventory identified no properties listed on the State or National Register of Historic Places or eligible for such a listing immediately adjacent to the Cannonsville dam.

Downsville/Pepacton

Previously Reported Cultural Resources

OPRHP and NYSM Identified Archeological Sites

The NYSM and OPRHP files contain 22 reported sites within three miles (4.8 km) of the Downsville dam and 29 reported sites outside of the three-mile (4.8 km) search radius but within or immediately adjacent to the associated Pepacton reservoir. These sites include 47 historic sites and four precontact sites. The nearest site is a mid 19th-century sawmill located approximately 3,200 feet east of the dam that was identified through a 1979 industrial resource survey which relied primarily upon historic maps to identify historic sites. Of the 47 documented historic sites located within three miles (4.8 km) of the Downsville dam or within and adjacent to the reservoir, 45 were identified during the 1979 historic industrial resources survey representing several 18th- and 19th-century industrial complexes that were once located along the Delaware River or its contributing tributaries. Many of these industrial sites are now submerged within the Pepacton Reservoir. The location, brief description, and National Register status of each site are provided below in Table 5.

Table 5: OPRHP/NYSM Archeological sites within three miles (4.8 km) of the Downsville dam and within or immediately adjacent to the reservoir.

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02501.000002		Sawmill (EBD-59)	Mid 19th-century map documented industrial site	Unevaluated	11.5 miles (18.5 km) northeast (now within reservoir)
02501.000003		L.D. Jackson Sawmill (EBD-61)	Mid 19th-century map documented industrial site	Unevaluated	11.2 miles (18.0 km) northeast (now within reservoir)

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02501.000004		L.D. Jackson Gristmill (EBD-62)	Mid 19th-century map documented industrial site	Unevaluated	11.2 miles (18.0 km) northeast (now within reservoir)
02501.000005		Sawmill (EBD-64)	Mid 19th-century map documented industrial site	Unevaluated	10.5 miles (16.8 km) northeast
02501.000006		T. Gregory Sawmill (EBD-65)	Mid 19th-century map documented industrial site	Unevaluated	9.5 miles (15.2 km) northeast (now within reservoir)
02501.000010		H. Hawver/Leander Barnhart & Anson Jenkins Sawmill (EBD-69)	Mid 19th-century map documented industrial site	Unevaluated	6.7 miles (10.7 km) east (now within reservoir)
02501.000011		J. Dickson Sawmill (EBD-71)	Mid 19th-century map documented industrial site	Unevaluated	7.5 miles (12.0 km) northeast (now within reservoir)
02501.000021		James and L.B. McCabe Sawmill (EBD-96)	Mid 19th-century map documented industrial site	Unevaluated	8 miles (12.8 km) northeast
02501.000022		Andrew Hawver Sawmill (EBD-97)	Mid 19th-century map documented industrial site	Unevaluated	7.8 miles (12.5 km) northeast (now within reservoir)
02501.000023		Samuel McCabe & Sons/ Andrew Hawver Tannery (EBD-99)	Early to mid 19th-century map documented industrial site	Unevaluated	7.8 miles (12.5 km) northeast (now within reservoir)
02501.000024		W.B. Shafer Sawmill (EBD-101)	Early to mid 19th-century map documented industrial site	Unevaluated	7.3 miles (11.7 km) northeast (now within reservoir)
02501.000025		George Wilson Sawmill (EBD-102)	Mid 19th-century map documented industrial site	Unevaluated	7.6 miles (12.2 km) northeast (now within reservoir)
02501.000026		James Wilson Sawmill (EBD-103)	Mid 19th-century map documented industrial site	Unevaluated	6.5 miles (10.4 km) northeast (now within reservoir)
02501.000027		Alfred Shaver Sawmill (EBD-105)	Mid 19th-century map documented industrial site	Unevaluated	6.5 miles (10.4 km) east (now within reservoir)
02501.000033		William Shaver Sawmill (EBD-111)	Mid 19th-century map documented industrial site	Unevaluated	6.7 miles (10.7 km) east (now within reservoir)
02503.000004		H.S. Shaver Sawmill (EBD-112)	Mid 19th-century map documented industrial site	Unevaluated	4.5 miles (7.2 km) northeast (now within reservoir)
02503.000005		Shaver Tannery (EBD-113)	Mid 19th-century map documented industrial site	Unevaluated	4.5 miles (7.2 km) northeast (now within reservoir)
02503.000008		Philip Allen Sawmill (EBD-116)	Mid 19th-century map documented industrial site	Unevaluated	4 miles (6.4 km) east (now within reservoir)
02503.000009		Sawmill (EBD-117)	Mid 19th-century map documented industrial site	Unevaluated	4 miles (6.4 km) east (now within reservoir)
02503.000011		A.C. Biggar Sawmill (EBD-121)	Mid 19th-century map documented industrial site	Unevaluated	4.8 miles (7.7 km) northeast

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02503.000012		Anthony Lloyd Gristmill (EBD-122A)	Late 18 th -century map documented industrial site	Unevaluated	4 miles (6.4 km) northeast (now within reservoir)
02503.000014		Cidermill (EBD-124)	Mid 19 th -century map documented industrial site	Unevaluated	4 miles (6.4 km) northeast (now within reservoir)
02503.000015		H. Hurlburt Sawmill (EBD-125)	Mid 19 th -century map documented industrial site	Unevaluated	4 miles (6.4 km) northeast (now within reservoir)
02503.000016		David Wilson Sawmill (EBD-127)	Mid 19 th -century map documented industrial site	Unevaluated	2.7 miles (4.3 km) east (now within reservoir)
02503.000017		John Merit Sawmill (EBD-128)	Mid 19 th -century map documented industrial site	Unevaluated	2.4 miles (3.8 km) northeast
02503.000018		Sawmill (EBD-129)	Remains of a masonry dam and foundation associated with a mid 19 th -century sawmill	Unevaluated	2.2 miles (3.5 km) northeast
02503.000019		John Holmes Sawmill (EBD-130)	Mid 19 th -century map documented industrial site	Unevaluated	1.6 miles (2.5 km) northeast (now within reservoir)
02503.000020		Hiram More Sawmill (EBD-131)	Mid 19 th -century map documented industrial site	Unevaluated	1.5 miles (2.4 km) northeast
02503.000021		Miller Sawmill (EBD-133)	Mid 19 th -century map documented industrial site	Unevaluated	1.7 miles (2.7 km) southeast
02503.000022		Sawmill (EBD-134)	Mid 19 th -century map documented industrial site	Unevaluated	3,200 ft (975 m) east
02503.000026		S. Hotchkiss Sawmill (EBD-140)	Stonework remains associated with a mid 19 th -century sawmill	Unevaluated	2.1 miles (3.3 km) north
02503.000027		N. Elwood Sawmill (EBD-141)	Remains of foundation and dam associated with a mid 19 th -century sawmill	Unevaluated	1.7 miles (2.7 km) north
02503.000029		J. S. William Sawmill (EBD-143)	Mid 19 th -century map documented industrial site	Unevaluated	2.5 miles (4.0 km) northwest
02503.000030		Robert Beates Sawmill (EBD-144)	Mid 19 th -century map documented industrial site	Unevaluated	1.3 miles (2.0 km) northwest
02503.000036		Sawmill (EBD-150)	Mid 19 th -century map documented industrial site	Unevaluated	2.6 miles (4.1 km) northwest
02503.000037		Sawmill (EBD-151)	Mid 19 th -century map documented industrial site	Unevaluated	2.4 miles (3.8 km) northwest
02503.000038		William Rose Gristmill (EBD-152)	Revolutionary War period map documented industrial site	Unevaluated	1.7 miles (2.7 km) northwest
02503.000039		George Downs/J.D. Downs Tannery (EBD-153)	Mid 19 th -century map documented industrial site	Unevaluated	1.4 miles (2.2 km) northwest
02503.000040		J.D. Downs & Elwood Gristmill (EBD-154)	Mid 19 th -century map documented industrial site	Unevaluated	1.3 miles (2.0 km) northwest
02503.000041		Steam Sawmill (EBD-154A)	Late 19 th -century map documented industrial site	Unevaluated	2.2 miles (3.5 km) southwest

OPRHP #	NYSM #	Identifier	Description	National Register Status	Location in Relation to Dam
02503.00004 2		Downs & Elwood Sawmill (EBD-155)	Remains of dam and laid stone foundation associated with a mid 19 th -century sawmill	Unevaluated	1.7 miles (2.7 km) southwest
02503.00004 3		J. & H. & P. Radeker Sawmill (EBD-156)	Remains of dam associated with a mid 19 th -century sawmill	Unevaluated	2.2 miles (3.5 km) southwest
02503.00004 4		A. Campbell Sawmill and Gristmill (EBD-157)	Remains of dam associated with a mid 19 th -century sawmill/gristmill	Unevaluated	2.4 miles (3.8 km) southwest
02503.00004 5		H. Radeker Sawmill (EBD-158)	Remains of a stone dam associated with a mid 19 th -century sawmill	Unevaluated	2.8 miles (4.5 km) southwest
02503.00006 7		14-81-4	Mid to late 19 th -century house foundation with cellar hole	Unevaluated	5,000 ft (1,524 m) southeast
02514.00004 1		N. Tompkins Sawmill (EBD-58)	Mid 19 th -century map documented industrial site	Unevaluated	12 miles (19.3 km) northeast
	3124	ACP DELA 6	Apple orchard associated with historic village	Unknown	3 miles (4.8 km) east (now within reservoir)
	3125	ACP DELA 7A	Precontact village site fortified with earthworks and "abundant in arrowheads"	Unknown	12.5 miles (20.11 km) northeast (now within reservoir)
	7316	ACP DELA 7B	Precontact village site fortified with earthworks and trees; trees date fort to approximately 1000 years old	Unknown	11.5 miles (18.5 km) northeast (now within reservoir)
	7317	ACP DELA 7C	Stone battle axe and "abundant arrowheads" uncovered in immediate locality of NYSM 3125 and 7316	Unknown	11.5 miles (18.5 km) northeast (now within reservoir)
	8014	No Information	Precontact village site	Unknown	3.4 miles (5.4 km) northeast (now within reservoir)

State and National Register of Historic Places

A review of the OPRHP computer inventory did not identify any properties listed on the State or National Register of Historic Places or eligible for such a listing immediately adjacent to the Downsville dam.

Neversink

Previously Reported Cultural Resources

OPRHP and NYSM Identified Archeological Sites

The NYSM and OPRHP files contain only one reported site, NYSM 8643, within three miles (4.8 km) of the Neversink dam. NYSM 8643 is described as an "Indian trail" that extends along the entire length of the eastern half of the Neversink Reservoir, including the area now occupied by the dam. No other sites were reported within or immediately adjacent to the reservoir.

State and National Register of Historic Places

A review of the OPRHP computer inventory did not identify any properties listed on the State and National Registers of Historic Places or eligible for such a listing immediately adjacent to the Neversink dam.

Summary

The site file search revealed that a number of archeological sites are located within a three-mile (4.8 km) radius of the dams at each of the proposed sites, as well as along the edges of the shorelines of the associated reservoirs or within the reservoir. In all, 99 sites were located in the vicinity of the three proposed developments of the Project. At Cannonsville 47 sites had been previously reported; 33 within three miles (4.8 km) of the dam and another 14 within or along the reservoir. Near the Downsville dam, there were 22 previously reported sites within a three-mile (4.8 km) radius. Another 29 sites were located within or along the reservoir. Only one site was previously reported at Neversink. The vast majority—85 of 99 sites—were historic. The remaining 14 sites were precontact in age. Of these, four were located during recent cultural resource surveys for the Deposit Airport by the Public Archaeology Facility; the others are reported sites with little additional information.

Many of the 85 historical sites are reported based on a 1979 industrial survey of the area that utilized historical maps of the area. No reconnaissance or fieldwork occurred at any of these sites, and much of the information concerning the sites including their location was gleaned from the maps. Many of the sites are now submerged under the reservoir and not within the immediate vicinity of the Project.

At Cannonsville, a sawmill site is reported immediately behind the dam. A review of the historical maps presented below suggests the site is now under the reservoir and will not be impacted by the Project. Similarly, a sawmill site was reported east of the Downsville dam, over 3,000 feet to the east. This site too is now submerged and will not be impacted by the Project.

There are no State or National Register listed or eligible properties within the immediate vicinity of the APE of the three proposed sites of the Project.

HISTORICAL DEVELOPMENT OF THE PROJECT

Overview

The Neversink, Pepacton, and Cannonsville Reservoirs are part of a large network of related systems that provide the City of New York with drinking water (Maps 1a and 1b). Together, the system consists of over 315 miles of aqueducts and tunnels, 22 dams and storage reservoirs, five distribution and balancing reservoirs, and numerous appurtenances (Bone 2006b:213). The system is broadly divided into the East of Hudson facilities, also known as the New Croton system, which is the earliest of the groups, and the West of Hudson facilities. The West of Hudson facilities can be further divided into the Catskill and Delaware systems. The Delaware system (including the Neversink, Pepacton, and Cannonsville reservoirs) comprises the latest and largest of the aqueducts, dams, and reservoirs and is the focus of the current study (Map 1b). A brief overview of the entire system is provided below, together with more detailed histories of the Neversink, Pepacton, and Cannonsville reservoirs.

The Old Croton system was initiated in the 1830s and represents the first organized attempt by the city government to provide clean and reliable water to its residents. The Old Croton system consisted of damming the Croton River in Westchester County. Water was fed through an aqueduct into two receiving reservoirs in the city itself. By 1911, the system was expanded to include 12 reservoirs which necessitated the construction of a second larger aqueduct started in 1885 (Bone 2006a:12-13).

Despite efforts to expand the water system, New York City grew at a rate that threatened to exceed its supply of water. State legislation created the Board of Water Supply (Board), as a result, and tasked the group with exploring new options for the water system. The Board immediately set out to construct a new Catskill system. The Catskill system eventually grew to include two new reservoirs and over 92 miles of aqueducts.

By 1922, the Catskill system virtually doubled the water supply for New York City. Shortly afterwards, the Board began planning for further expansion of the system and turned its attention to the Delaware River watershed. Over the next few decades, the Board built another four reservoirs and 159 miles of pressurized supply tunnels and an 84-mile long aqueduct. By 1965, the Delaware system added capacity for another 850 million gallons of water per day (although this is rarely if ever reached) from 1,015 square miles of watershed (Bone 2006a:13).

Appendix 1 presents a sample of historical maps, plans, drawings and photographs detailing the construction of the dams. These were found in the DEP Grahamsville office library and were culled from various annual reports of the Board, as well as issued contract specifications. The plans will assist the reader in understanding the various components of the dam and its relationship to the proposed APE of the Project. The photos also provide evidence for the scale and scope of the construction efforts and the impact on the surrounding landscape.

Neversink

The Neversink Reservoir was initially planned around 1927 as part of the New York City drinking water system and draws on the Neversink River watershed (Photos 1-6). The original plan contemplated a site upstream of its present location in the Village of Curry. These plans were changed, however, and the revised concept called for a dam near the Village of Neversink. The new design tripled the amount of water the reservoir could potentially hold (Bone 2006b:208). To make way for the dam and reservoir, farms and 1,500 residents in the hamlets of Neversink and Bittersweet had to be removed.

Site clearance began in 1941. Due to similarities in geophysical conditions, construction techniques mirrored those previously utilized at the Merriman dam (Rondout Reservoir), which was nearly complete by this time. Construction of the reservoir and aqueduct was delayed by World War II, and extended over the next 14 years. The project was completed on October 23, 1955 (Neversink 2010).

At Neversink, the underlying bedrock lay fairly deep. This necessitated a large trench at the site of the core-wall, excavated about 50 feet deep from the original ground surface. Additional excavation was needed to reach the bedrock, which was over 100 feet deep in some places. As a result, individual caissons were sunk down to the bedrock from the bottom of the cut-off trench. Concrete subsequently filled the caissons. Over the caissons, a poured concrete wall completed the cut-off wall. Atop the cut-off wall, construction crews laid an impervious mixture of clay soils. Various grades of material were packed overtop of the impervious core to create the earthen embankment. On the reservoir side stone rip-rap was installed; workers placed topsoil on the downstream side of the dam surface and sowed grass. The resulting lawn is carefully maintained to prevent the growth of trees and brush (Photo 2).

Construction of the spillway was undertaken once the embankment was completed. A portion of the original diversion channel was subsequently incorporated into the waste weir and outlet channel (Photo 3). A new inclined tunnel connected the intake chamber and the outlet channel. Once the dam was completed, flow through the outlet channel and aqueduct was controlled by a series of valves inside the intake structure located at the northeast corner of the dam.

The diversion channel was eventually plugged with concrete and the reservoir began to fill. Work on the reservoir was intermittent due to the war. By 1953, the reservoir was completely filled and water over topped the spillway (Bone 2006b:209). A year later the system was brought on-line. The impoundment at the

spillway elevation of 1440 feet above msl covers 93 square miles and consists of a storage capacity of 35 billion gallons of water.

A portion of the water leaving the reservoir is redirected into the inclined tunnel to the outlet channel to provide a minimum flow for the downstream reaches of the Neversink River. The minimum flow is based on a release regime agreed to by the Decree Parties¹ that assists in mitigating flood events, and provides flow in the mainstream and Delaware Bay to help protect ecological health (DEP 2009). As a result, each of the City of New York dams on the Delaware River is equipped with mechanisms for releasing water. At Neversink, the release chamber is situated within the intake structure that regulates flow to the Neversink tunnel. At Cannonsville and Downsville, the intake structures are located at a distance from the dam, therefore separate release water chambers were incorporated into the construction of those dams.

According to the construction documents and related photographs, this area has been heavily disturbed from the construction of the dam and nearby Neversink Tunnel. Early construction documents indicate that grading occurred at least to the 1,500 foot elevation level, or about half of the distance from the intake structure to NY 55. During the site visit, a lack of trees older than 50 years in age along the slope was noted, indicating that the entire hill side was cleared of vegetation and perhaps graded as part of the dam building efforts in the early 1950s (Photo 7).

Downsville/Pepacton

Construction of the Downsville dam and Pepacton Reservoir began in 1947 and was completed around 1954 (Photos 8-13). At the time, the reservoir and dam were the largest in the New York City Water system, holding 140 billion gallons collected from a watershed over 372 square miles in area (Bone 2006b:209). The resulting reservoir stretches over 18.5 miles. To accommodate the new dam and reservoir, nearly 200 buildings and their appurtenant structures and facilities were removed, along with large trees and other vegetation. The communities of Arena, Shavertown, Pepacton, and Union Grove were impacted by the work, resulting in the displacement of over 900 people.

The dam was situated along a narrow of the river valley between the Village of Downsville and the hamlet of Pepacton. John Burroughs, a resident of the area who wrote about his experiences in the valley, identified the word “Pepacton” as an Indian name for the East Branch, meaning “marriage of the waters” (Burroughs 1900:v). According to historical maps, there was sparse development in this area. At least two buildings appear to have been present in the immediate vicinity of the dam, including one in the proximity of the project area at the north abutment of the dam near the spillway. In addition to the buildings, a road along the north shore had to be relocated further up the hill away from the dam, and a section of the Delaware and Hudson Railroad was also moved to higher ground near the south end of the dam.

Cannonsville

The Cannonsville Reservoir is located along the West Branch of the Delaware River in Delaware County in the Towns of Tompkins and Deposit, just east of the Village of Deposit. Constructed between 1960 and 1965, the reservoir has a normal storage capacity of 300,000 acre-feet or 95.7 billion gallons of water (Bone 2006b:213). The reservoir consists of an earth-fill embankment dam, stone masonry sided channel spillway,

¹ The Decree Parties include the State of New York, the State of New Jersey, the State of Delaware, the Commonwealth of Pennsylvania, and the City of New York and are parties to a 1954 Supreme Court Decree that stipulates the City of New York's right to 850 MGD of water from the Delaware watershed and associated conditions thereof.

overflow weir and its associated stilling basin, concrete intake tower, an intake structure, concrete water release chamber and its associated stilling basin, the West Delaware tunnel aqueduct and its associated intake structure, and the impoundment.

The construction of the dam and reservoir resulted in the displacement of 94 farms and the relocation of all or parts of five settlements with over 900 people along the river. The dam is situated between the modern day Village of Deposit and the former hamlet of Cannonsville. The dam is located in a narrow segment of the valley just downstream from a former mill with its extensive headrace, mill pond, and tailrace. The former mill complex is located behind the current dam and all archeological evidence was likely erased during the construction of the dam and preparation of the land for the subsequent reservoir. The mill complex formed a long, thin island along the main channel of the river.

HISTORICAL MAP REVIEW

In general, the project areas have been heavily modified by the construction of the associated dams and subsequent clearing and filling of the reservoirs. During the course of construction for each of the water supply systems, numerous homes, farms, local industries and businesses, and social institutions were removed and/or relocated. In most instances, the dams were placed at narrows within their respective valleys. As such, there is often relatively sparse development in the immediate vicinities of the dams.

Neversink

According to the 1910 USGS map that was photo-revised in 1932, there are two structures in the vicinity of the Project APE (the current valve house) (Map 6). Later Board maps from 1948 (see Appendix 1) indicate the engineer's house and water tanks approximately in the location of the two structures on the USGS map. Both structures are located well to the northeast. It is unclear if these are the same structures (perhaps the engineer's house was a former residence that was repurposed) or if these structures were removed and the water tanks and engineer's house were built specifically for the project. These structures are no longer extant, nor is there any surface indication of them. The location of the structures is outside of the APE.

Downsville/Pepacton

At Downsville, the historical maps indicate a number of farms in the vicinity of dam and spillway. Early maps such as the Burr 1829 and Gould 1856 maps (not reproduced here) provide a general sense of the vicinity of the project area as intermittently settled with small family farmsteads. According to Beers 1869 map, there are three farms on the north side of the river including those belonging to "I. Teed," "H. Fuller," and "L. Hawley" (Map 7). On the east side, is one farm that was owned by "J. Brorle." Also of note, is a label along the flats of the river, below the current location of the dam, indicating the location of the "Old Indian Camp." The next detailed map of the area was not produced until 1924 by the USGS (Map 8). It appears that the three farms along the north side of the river are still extant, as well as one along the south side. Also by this time, the Delaware and Hudson Railroad had constructed its line along the south side of the river. In 1947, the Board survey map (see Appendix 1) indicates at least five farmsteads on the north side of the river in the vicinity of the dam and outlet channel, each with their own constellation of barns and outbuildings. Also indicated is a single farm along the south side. Several other buildings are also indicated in the general vicinity on both sides of the river. None of the structures are labeled. This map is particularly important since it overlays the proposed construction of the dam, outlet channel, inclined tunnel portal and other important features on former landscape of the area. According to this map, there are no structures in the immediate vicinity of the proposed APE. Further, the map indicates how extensively modified this area is following the construction of the dam and reservoir.

Cannonsville

The early historical maps of the area surrounding Cannonsville including the 1829 Burr map provide only a general sense of the development of the area. The Gould map of 1856 (not reproduced here) and the Beers maps of 1869 are very similar, however the Beers map provides more detail. According to the Beers map,

there are five structures in the vicinity of the Cannonsville dam; four houses and a sawmill (Map 9). On the north side of the river area structures owned by “Widow W. Commings,” “P.L. Burrows”, and another by “Mrs. Burrows.” The sawmill and “Palmer” house are located on the south side near the vicinity of the proposed powerhouse. Based on the map information, an archeological site—the former location of a sawmill to the east of the dam—has been reported to the OPRHP. The next detailed map of the area was not produced until 1926 by the USGS (Map 10). This map indicates a structure very near the north abutment of the dam, but no structures along the south side. What appears to be the remnants of the mills’ headrace, pond, and tailrace are indicated as a narrow side branch of the river on this map, but there is no indication of the Palmer sawmill or house (suggesting that it was no longer extant by this time). The “Burrow” houses on the north side of the river are still extant at this time. Based on comparison with modern topographic maps, it appears that the former “Mrs. Burrows” house is north of the spillway. The “P.L. Burrows” house is located west of the spoil disposal and Staging Area 1, outside of the APE. A series of maps printed for the Board annual report did not indicate any structures that were present around 1960 during the construction of the dam (see Appendix 1). Based on the former topography of the area it is likely that the sawmill and its appurtenant facilities were located to the east of the dam (as indicated on the OPRHP site form). The circa 1960 construction maps also indicate that the land around the current APE has been extensively modified to accommodate the new dam and release chamber, especially those areas along the former river bank and downstream of the dam on the north side of what is now effectively a man-made island. This appears to be confirmed by both the soils maps (Map 5c) and orthoimages (Map 3c) of the areas.

ARCHITECTURAL DISCUSSION

Neversink

The Neversink reservoir consists of an earthen embankment dam, intake chamber, tunneled aqueduct, spillway, waste weir, outlet channel and stilling basin composed of concrete and cut stone, and the impoundment itself (Photos 1-6). The impoundment at the spillway elevation of 1440 feet above msl covers 93 square miles and consists of a storage capacity of 35 billion gallons of water. The dam is 2,830 feet long with a maximum height above the original ground surface of about 190 feet. The Neversink tunnel is approximately 5 miles long and connects to the Rondout Reservoir and eventually the Delaware aqueduct.

Like the dams at Downsville and Cannonsville, Neversink is a large earthen dam (Photos 1 and 2). Dams of this scale had not been previously attempted. Yet with new material, technologies, and machinery, massive projects such as this were suddenly feasible by the second quarter of the 20th century. The dams were all constructed in similar fashion, beginning with the construction of a diversion channel that steers water from the construction of the dam. The cores of the dams at Neversink and Pepacton consist of concrete cut-off walls keyed to the underlying bedrock. At Cannonsville the core-wall was composed entirely of compacted soils (Bone 2006b:212). These cut-off walls are critical in preventing water from seeping under the earthen fill and threatening the integrity of the dam. The core-wall construction differed slightly at each location. The Neversink dam was designed by engineer Medwin Matthews. Contract documents for this structure are dated January 2, 1948 and bear the name of Roger W. Armstrong, chief engineer, along with those of consulting engineers Karl R. Kermison, Thomas H. Wiggin and Silas H. Woodard. The contract for its construction was signed with S. A. Healy Company of White Plains, NY on April 22 of that same year (Contract 365 1948).

The intake structure is a two-story brick and concrete building completed in 1954, and its primary function is to regulate the flow of water through the Neversink tunnel (Photo 4 and 5). A portion of the water, however, is redirected into the inclined tunnel to the outlet channel to provide a minimum flow for the downstream reaches of the Neversink River. At Neversink, the release chamber is situated within the intake structure that regulates flow to the Neversink tunnel.

The proposed turbine will be installed in the release water tunnel between the intake chamber and the waste weir and outlet channel (Photo 6). The turbine will replace the existing valve that regulates the water through the release tunnel. Since the turbine will be installed in an existing facility, ground disturbing activities

associated with the new hydroelectric facility will be minimal. A substation will be constructed along the east elevation of the existing intake structure. The switch yard will be approximately 1,000 square feet in size; its final location has yet to be determined. Power will be supplied to the existing grid by tying into an electrical ductbank immediately to the east of the intake structure along a steeply sloped hill below NY 55 (Photo 7).

Downsville/Pepacton

The contract drawings for the Downsville/Pepacton dam and appurtenant structures are dated December 1, 1949. They are signed by Medwin Matthews “designing engineer” (Contract 401 1950). The dam is an earthen embankment approximately 2,400 feet in length with a height of approximately 200 feet above the original ground surface (Photos 8-13). At the core of the dam is a concrete cut-off wall that was buried in a trench and joined to the underlying bedrock, at some locations over 110 feet deep. Above the cut-off wall, a layer of impervious clay fill was placed, over which heavy machinery rolled sorted grades of soil. The crest of the dam is about 45 feet wide and carries a small, paved access road for maintenance of the facility (Photo 8). The interior wall of the dam is protected with stone rip-rap (Photo 9), the downstream wall is grass covered and exposed.

Water is released from the reservoir through three separate facilities. The first is a waste-weir and spillway located at the west abutment of the dam (Photos 10-13). The curvilinear waste weir is a composite of concrete and granite masonry (Photo 10). The S-shape of the waste weir is designed to minimize the impacts of scouring (Bone 2006b:210). The ogee-shaped weir allows excess water in the reservoir into the spillway which was carved out of the surrounding bedrock.

The crest of the spillway is 1,280 feet and it extends 800 feet in length from northeast to southwest. The spillway is lined with a mortared granite facing and is about 950 feet long. The spillway empties water into a 40-foot diameter tunnel (originally the diversion tunnel during dam construction) (Bone 2006b:210) (Photo 11). In the event water flow exceeds the tunnel, there is a waste channel above the tunnel. Both the tunnel and upper waste channel discharge into a stilling pool with 10-foot high concrete steps to slow the force of the water before entering an open waste channel that flows into the East Delaware River downstream. The water is further calmed by a small, concrete weir in the river approximately 2000 feet from the spillway (Bone 2006b:210).

An intake structure is located immediately to the south of the spillway to regulate a minimum flow of water back into the East Delaware when water is below the crest of the waste weir (Photos 12 and 13). It was designed by Chester W. Allen, architect, and drawings of it were included in the original contract documents dated December 1, 1949 (Contract 401 1950). The intake is an 8-foot diameter tunnel that transitions to two 5-foot diameter pipes that enter the release chamber. A series of valves regulate the flow. The valves are controlled in the two-story brick and concrete superstructure above the release water chamber. The structure was completed in 1954 as evidenced by a date-stone incorporated into a large frieze just below the second floor windows. Water exits through a stilling chamber and into the 40-foot diversion tunnel that is part of the spillway.

The East Delaware tunnel intake is located approximately 3.5 miles upstream of the dam. The intake chamber has two inlets separated by a concrete pier. The inlets are further divided vertically providing four different levels of flow that can be regulated via sluice gates. The pressure tunnel is bored through bedrock and has a diameter of about 11 feet. The tunnel walls are supported by gunite (a sprayable concrete mixture), concrete arches, and/or steel frames. Its capacity is 700 million gallons of water per day. The East Delaware tunnel or aqueduct extends 25 miles to the southeast and, like the West Delaware aqueduct, empties into the Rondout Reservoir for settling (Bone 2006b:210). A maintenance shop and garage were constructed in 1969.

Cannonsville

The Cannonsville reservoir is located along the West Branch of the Delaware River in Delaware County in the Towns of Tompkins and Deposit, just east of the Village of Deposit. Constructed between 1960 and 1965, the reservoir has a normal storage capacity of 300,000 acre-feet or 95.7 billion gallons of water (Bone

2006b:213). The contract drawings are dated July 2, 1956, and are signed by Stanley M. Dore, chief engineer and by consulting engineers Thomas H. Wiggin, Malcolm Pirnie, and Karl R. Kennison. Medwin Matthews was Acting Executive Design Engineer and George E. Hugh was Acting Division Engineer (Contract 462 1956).

The reservoir consists of an earth-filled embankment dam, stone masonry sided channel spillway, overflow weir and its associated stilling basin, concrete intake tower, an intake structure, concrete water release chamber and its associated stilling basin, the West Delaware tunnel aqueduct and its associated intake structure, and the impoundment.

The dam at Cannonsville is slightly different from those at Neversink and Downsville, instead of a concrete core-wall keyed to the underlying bedrock, the core of the dam consists of impervious soils tightly packed together (Bone 2006b:213). A cut-off trench was still constructed to ensure that water did not seep under the dam. And although made of compacted soil, the core-wall was much smaller than the ones utilized at Neversink and Downsville. The dam is situated in a narrow of the steeply-sided valley of the West Branch and stands 204 feet above the original ground surface. The dam is faced on the impoundment side with stone rip-rap. On the downstream side, the earthen fill was capped with topsoil and grass planted over top (Bone 2006b:213) (Photo 14).

The overflow weir was excavated through bedrock and is largely faced with granite masonry (Photo 15). Its total length is 800 feet. Two separate crests at the north and south end of the weir regulate water into the overflow weir. The lower crest is an ogee weir about 240 feet long at an elevation of 1,150 feet. The upper crest is 560 feet long and with an elevation of 1,158 feet. Water exits the weir into an impressive side channel that was excavated through bedrock that extends approximately 1,760 feet downstream to a stilling pool.

The earthen dam is topped with a small, paved road that extends from the waste weir to the release chamber at the east end of the dam (Photo 14). A small complex of maintenance structures was once located toward the west end of the dam, near the waste weir. The structures included the engineer's office and soils laboratory, a large garage, several smaller barns/outbuildings, and several sheds and a small pump house that provides water to the buildings. According to the current maintenance supervisor, Kim Scanlon, the engineer's office and soils laboratory were demolished by the DEP approximately 15 years ago. Other garages, sheds and outbuildings are still extant, including one structure constructed as a soils laboratory or as a field office for project engineers (Photos 16 and 17). Other structures associated with the construction of the facility, including housing, were razed some time after completion of the project.

Water enters the water supply system through the West Delaware tunnel located well upstream of the dam near the Cannonsville Bridge in the Town of Andes. The intake structure, a two-story brick and masonry building, houses the valves that regulate the flow of water into the aqueduct. The aqueduct itself consists of an 11.3-foot diameter, concrete-lined pressure tunnel that was bored through the bedrock. The tunnel has a capacity of over 500 million gallons of water per day. It stretches over 44 miles to the southeast eventually carrying water into the Rondout Reservoir (Bone 2006b:212). From the Rondout, water is collected into the Delaware aqueduct which extends 85 miles to the southeast under the Hudson River and into the West Branch Reservoir in Putnam County where the water is settled.

The intake tower on the left abutment of the dam controls the minimum flow discharged into the river (Photo 18). The water is released through an 11 foot 11-inch concrete conduit controlled by a gatehouse above the release water chamber. The gates are attached to eight steel pipes of varying size which release water into the stilling basin and eventually into the river (Photo 19).

Access to the facility is provided by a small access road. A recently constructed bridge carries the access road over the West Branch just below the release chamber. Just north of the bridge the road forks; to the southeast access is provided to the release water chamber and stilling pool and to the northwest access is provided to the top of the dam and maintenance structures.

The proposed powerhouse will be situated at the bottom of dam immediately adjacent to the release chamber (Photo 20). A short tailrace will return water into the existing stilling pool. A switch yard will be located near

the maintenance facilities near the top of the dam. A new transmission line will carry power from the powerhouse to the switchyard and from the switchyard to a set of existing transmission lines nearby.

ARCHEOLOGICAL SENSITIVITY ASSESSMENT

The archeological sensitivity of a project area is based on a combination of factors that include the current environmental conditions, past environmental conditions, soils, topography, and the like, as well as a project area's proximity to other known archeological sites and map-documented structures. The first portion of this report provides information regarding these pertinent environmental conditions in addition to the known resources of the area as documented in existing literature.

In general, the Project proposes to construct hydroelectric turbines in the Delaware and Neversink River drainages along existing reservoir systems within the Catskill Mountains. These drainages are known to contain archeological sites associated with precontact people who lived, hunted, and gathered resources in the area for millennia. European settlers first arrived in the area following the American Revolution, when the last substantial groups of Native Americans left the area. Settlement started slowly at first, driven by New England farmers searching for new agricultural lands to exploit. Later the large supply of timber fostered sawmills and related industries that relied on harvesting wood. Despite the rich agriculture and woodlands, the population of the area remained relatively small. Historical maps of the area suggest the proposed APEs of the Project were often in marginal areas away from large farms or dense areas of settlement. The topography of the APEs of the Project is typically along the valley walls, at the abutments of the dam. The natural soils in these areas are largely glacially derived, suggesting that archeological sites, if they were present, would not be deeply buried. The former topography of these areas, prior to dam building, was such that the areas were sloped. It is unlikely that large, substantial precontact archeological sites would be located on such landforms.

According to the OPRHP site files, at Cannonsville, a 19th-century sawmill was formerly located in the vicinity of the APE. Analyses of the maps, however, indicate the site was located to the south of the existing dam. Aside from buildings utilized in the construction of the dam, the historical maps do not indicate any other map-documented structures within or immediately adjacent to the proposed APEs.

Overall, the archeological sensitivity of the Project area is moderate for precontact archeological sites and moderate for historic archeological sites.

ARCHEOLOGICAL POTENTIAL

Although the APEs of the Project have moderate sensitivity for both precontact and historical archeological sites, the potential for locating intact archeological sites that may be eligible for the National Register has been greatly diminished by the later construction of the reservoir systems. Land clearing, moving, and building associated with each of the massive dams at Neversink, Downsville, and Cannonsville has thoroughly disturbed the APEs of the Project. There is no likelihood of locating archeological sites at the proposed location of the turbines and powerhouse, nor at the proposed switchyards. The associated distribution lines will also be located in disturbed areas. Staging areas will also be located in areas of previous disturbance. At Cannonsville, three staging areas will be located along the river just downstream from the dam outfall. Soil maps and project plans suggest this area was disturbed during dam construction to create a stable river bank. Also at Cannonsville, a spoil disposal area is planned for an area downstream of the dam. Similarly, soil maps and the site visit suggest this area was previously disturbed by the dam development and may have been used previously as a spoil area. Overall, there is no potential for locating archeological sites in, or immediately around the proposed APEs of the Project.

RECOMMENDATIONS

Both of the proposed turbines at Neversink and Pepacton will involve replacing existing valves in the release structures. As a result, there is no proposed disturbance in areas that have not been previously disturbed. Similarly, the powerhouse, switchyard, and distribution lines at Cannonsville will be located within the

footprint of the existing dam which has been previously disturbed. The distribution lines at Pepacton and Neversink will utilize existing power lines and poles and ductbanks. As a result, no further archeological work is recommended for the Project based on the current APE and design plans.

BIBLIOGRAPHY

Beers, F.W.

1869 *Atlas of Delaware County, New York*. F.W. Beers, A.D. Ellis & G.G. Soule, New York.

1875 *County Atlas of Sullivan, New York*. Walker & Jewett, New York.

Bone, Kevin

2006a Preface. In *Water-Works: The Architecture and Engineering of the New York City Water Supply*. Edited by Kevin Bone. Pp 10-16. The Monacelli Press, Inc., New York.

2006b The Delaware System. In *Water-Works: The Architecture and Engineering of the New York City Water Supply*. Edited by Kevin Bone. Pp 180-213. The Monacelli Press, Inc., New York.

Burr, David

1829 Map of the County of Delaware. *An Atlas of the State of New York Containing a Map of the State and Several of the Counties*. David H. Burr, New York.

Contract 365

1948 *Contract 365, Board of Water Supply of the City of New York. Information for Bidders, Forms of Bid, Contract, Bond and Certificates, Specifications and Drawings for the Construction of the Neversink Dam and Appurtenant Works in the Town of Neversink, Sullivan County, New York*. Copy on file at the offices of the Bureau of Water Supply and Wastewater Collection, Grahamsville, New York.

Contract 401

1950 *Contract 401, Board of Water Supply of the City of New York. Information for Bidders...for the Construction of the Downsville Dam and Appurtenant Works in the Town of Colchester, Delaware County, New York*. Copy on file at the offices of the Bureau of Water Supply and Wastewater Collection, Grahamsville, New York.

Contract 462

1956 *Contract 462, Board of Water Supply of the City of New York. Information for Bidders, Forms of Bid...for the Construction of Access Roads, Bridges and Appurtenant Structures for the Cannonsville Dam in the Town of Deposit, Delaware County, New York*. Copy on file at the offices of the Bureau of Water Supply and Wastewater Collection, Grahamsville, New York.

Department of Environmental Protection (DEP)

2009 *City of New York, West of Hudson Hydroelectric Project: Schoharie, Cannonsville, Pepacton, and Neversink Developments, Project No. 13287-000. Pre-application Document*. Available online, http://www.nyc.gov/html/dep/pdf/hydroelectric/pad_filing_final.pdf.

Gates, C. G.

1856 *Map of Sullivan County, New York*. Gillette & Huntington, Philadelphia.

Gould, Jay

1856 *Map of Delaware County, New York*. Collins G. Keeney, Philadelphia.

National Park Service (NPS)

1990 (revised 2002) How to Apply the National Register Criteria for Evaluation. *National Register Bulletin*. United States Department of the Interior, National Park Service, Cultural Resources. <http://www.nps.gov/nr/publications/bulletins/pdfs/nrb15.pdf> (Accessed May 2011).

Neversink

2010 <http://www.neversinkfd.org/townhistory.htm> accessed on 30 June 2010.

New York Archaeological Council (NYAC)

- 1994 *Standards for Cultural Resource Investigations and the Curation of Archaeological Collections in New York State*. NYAC, n.p.

Office of Parks, Recreation and Historic Preservation (OPRHP)

- 2005 *New York State Historic Preservation Office (SHPO) Phase I Archaeological Report Requirements*. OPRHP, Waterford, New York.

United States Department of Agriculture (USDA NRCS)

- 1980 *Soil Survey of Rensselaer County, New York*. United States Department of Agriculture Soil Conservation Service in cooperation with Cornell University Agricultural Experiment Station. Soil Conservation Service, Washington, D.C.

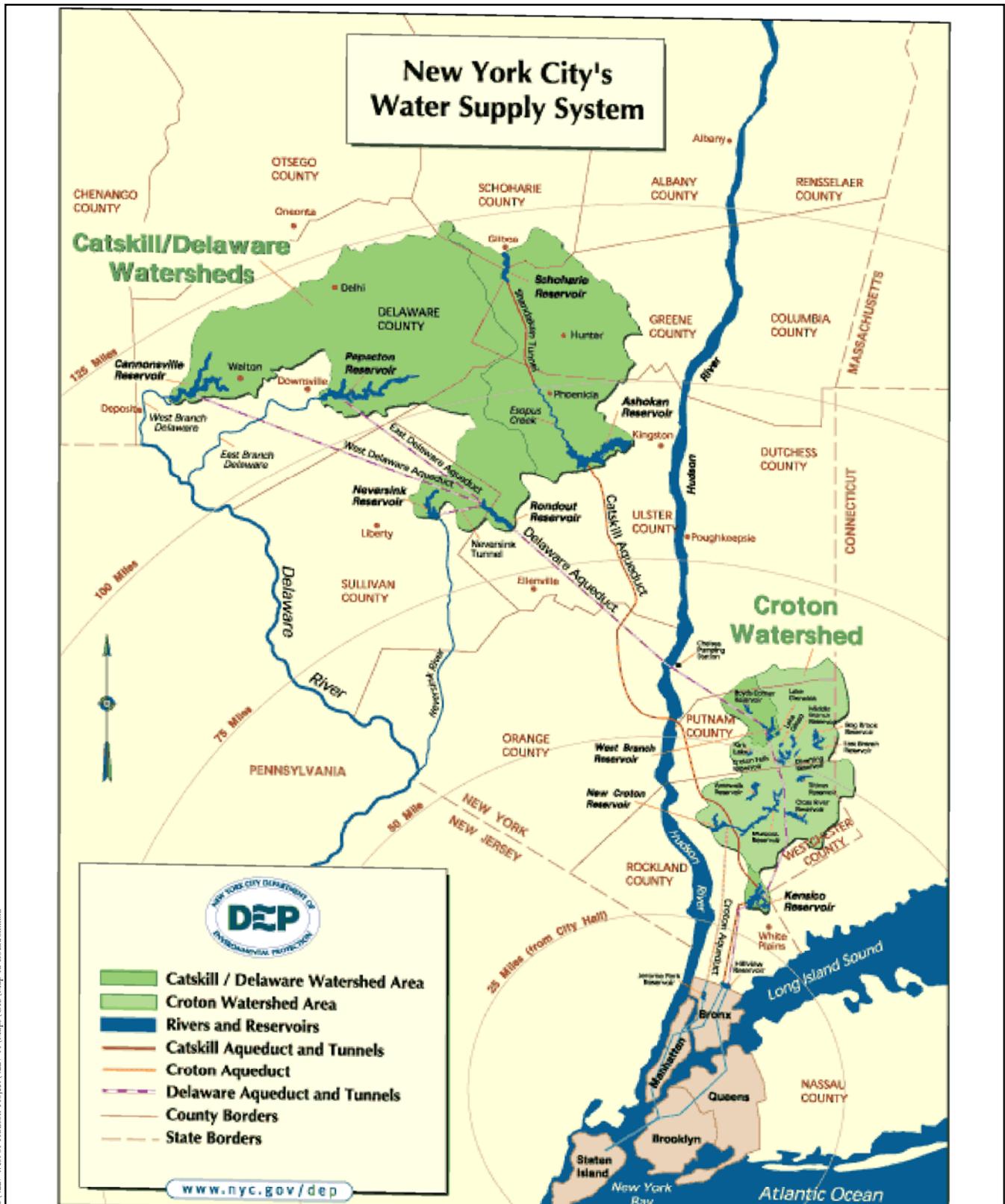
United States Geological Survey

- 1926 *Deposit 15' Topographic Quadrangle, New York*. U.S. Government Printing Office, Washington, D.C.
- 1924 *Andes 15' Topographic Quadrangle, New York*. U.S. Government Printing Office, Washington, D.C.
- 1932 *Neversink 15' Topographic Quadrangle, New York*. U.S. Government Printing Office, Washington, D.C. Originally printed in 1910.
- 1965 *Deposit 7.5' Topographic Quadrangle, New York*. Reston, Virginia.
- 1981 *Cannonsville Reservoir 7.5' Topographic Quadrangle, New York*. Reston, Virginia. Originally printed in 1965.
- 1982 *Liberty East 7.5' Topographic Quadrangle, New York*. Reston, Virginia. Originally printed in 1966.
- 1995 *Downsville 7.5' Topographic Quadrangle, New York*. Reston, Virginia.

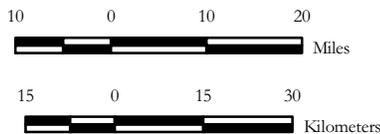
United States Department of Transportation

- 1994 *Liberty East 7.5' Planimetric Quadrangle, New York*.
- 1994 *Deposit 7.5' Planimetric Quadrangle, New York*.
- 1985 *Cannonsville 7.5' Planimetric Quadrangle, New York*.
- 1985 *Downsville 7.5' Planimetric Quadrangle, New York*.

MAPS



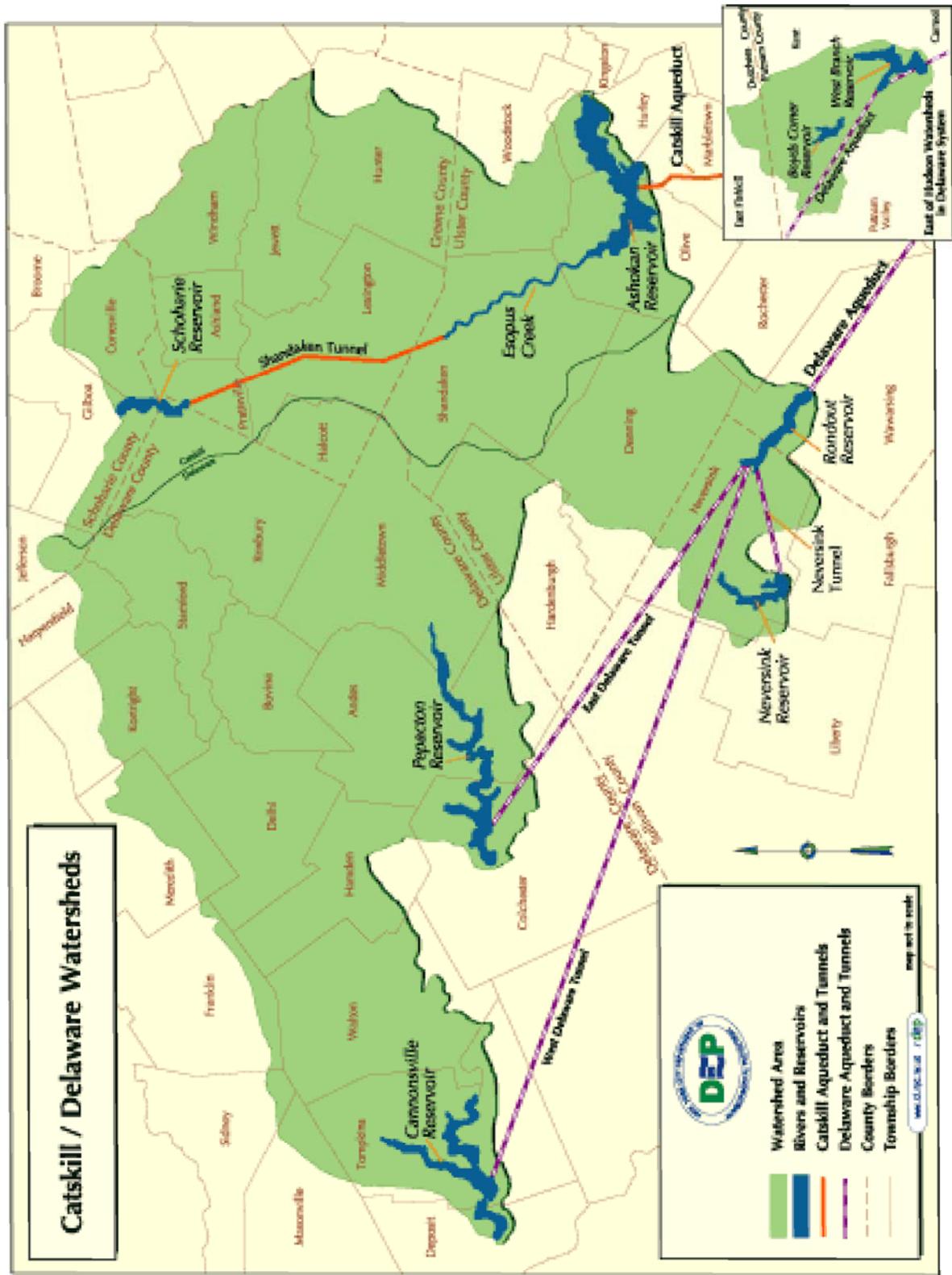
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Project Location (DEP 2009)



Map 1a



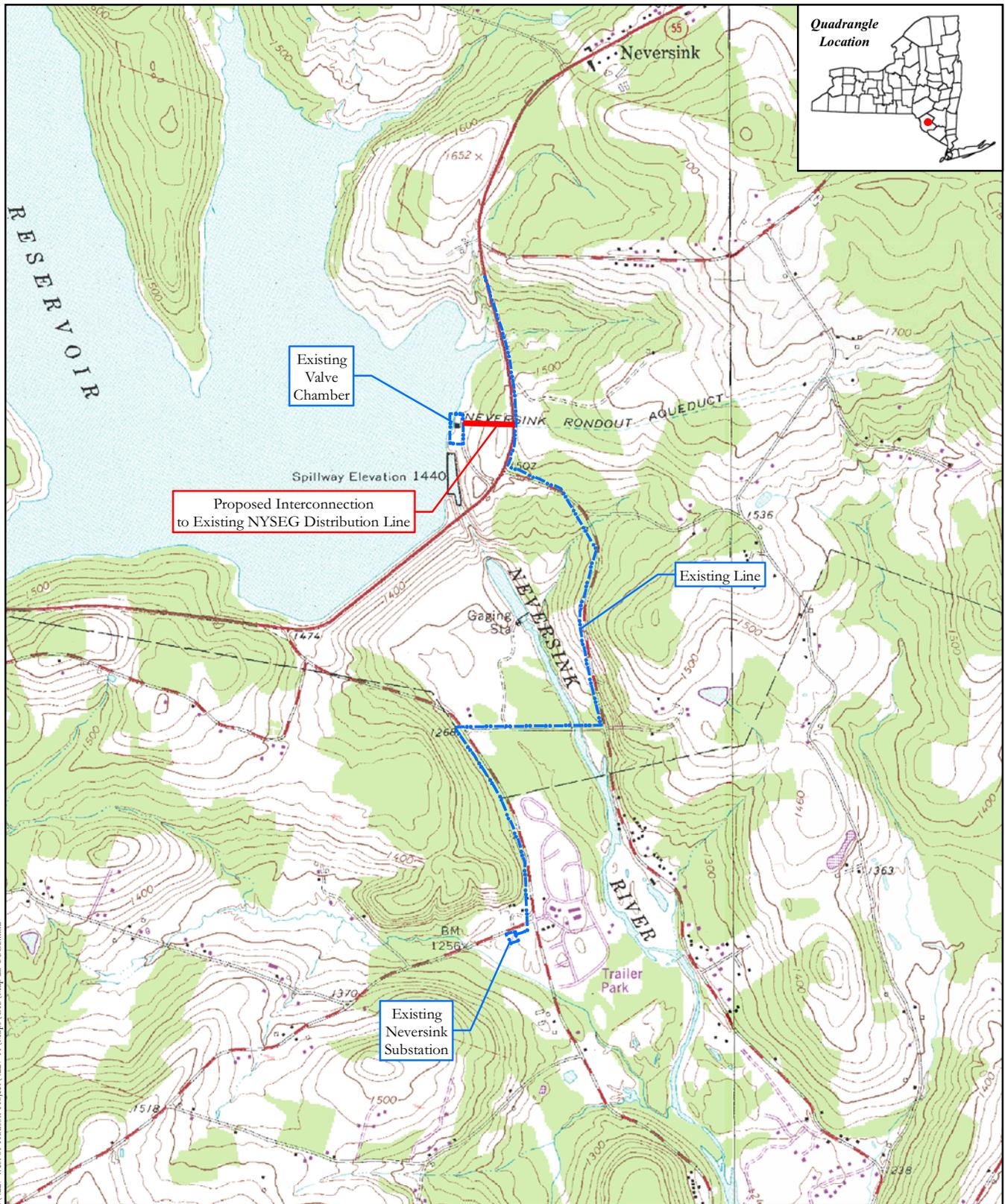
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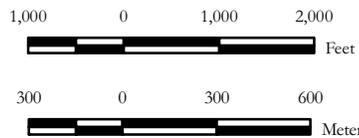
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Map 1b



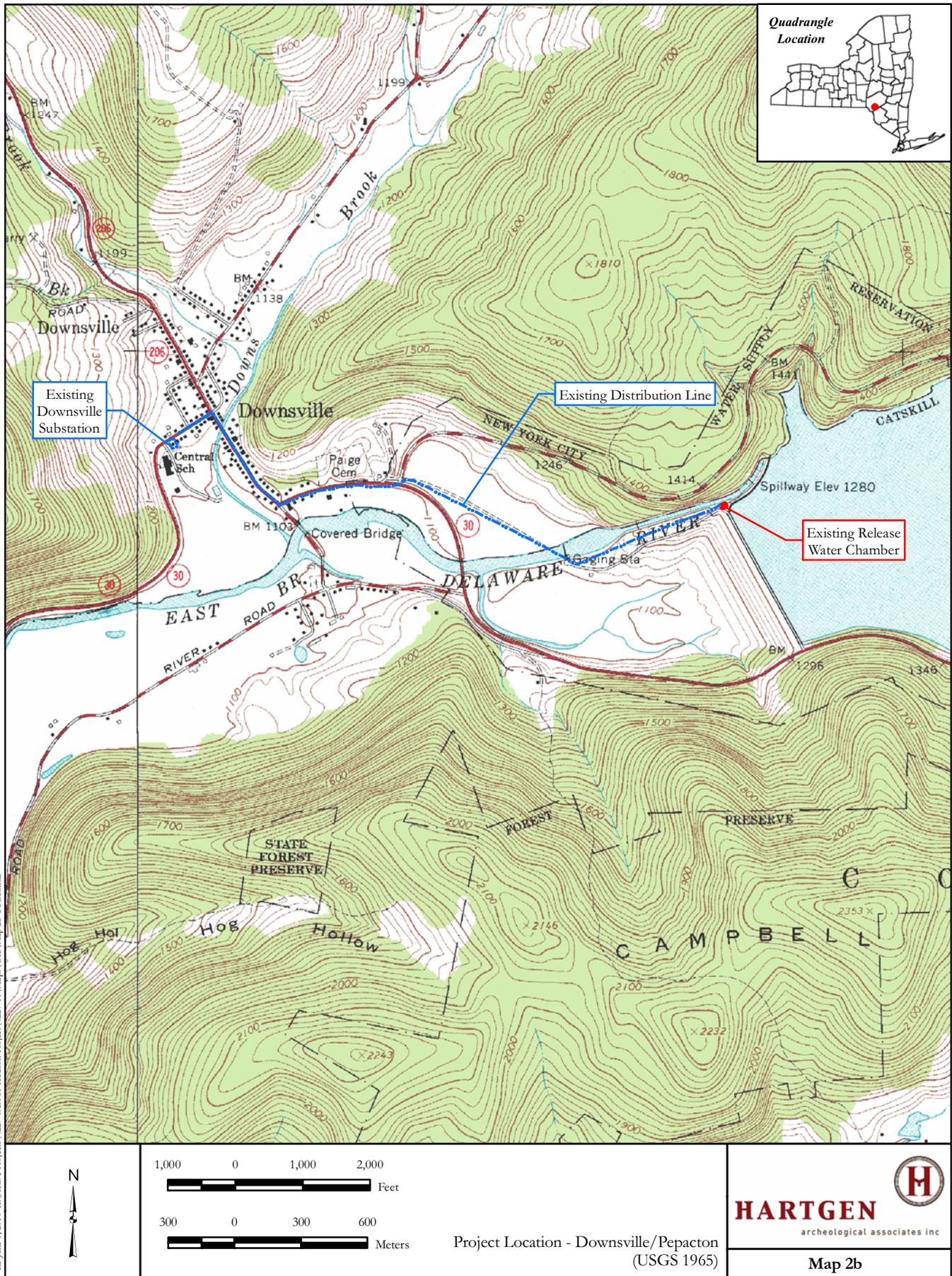
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Project Location - Neversink Dam
 (USGS 1982)

HARTGEN
 archeological associates inc

Map 2a

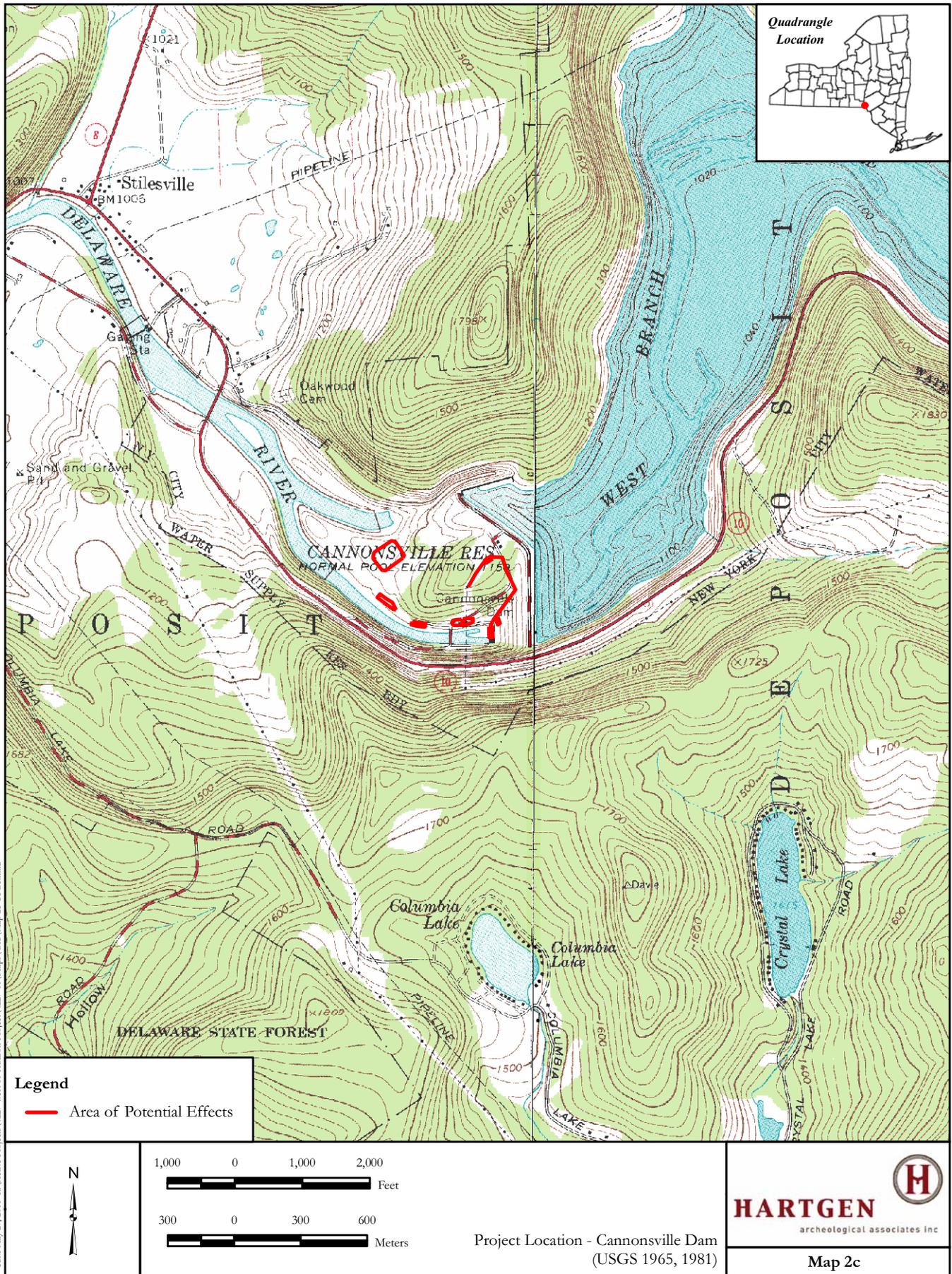


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Project Location - Downsville/Pepacton
 (USGS 1965)

HARTGEN
 archeological associates inc

Map 2b



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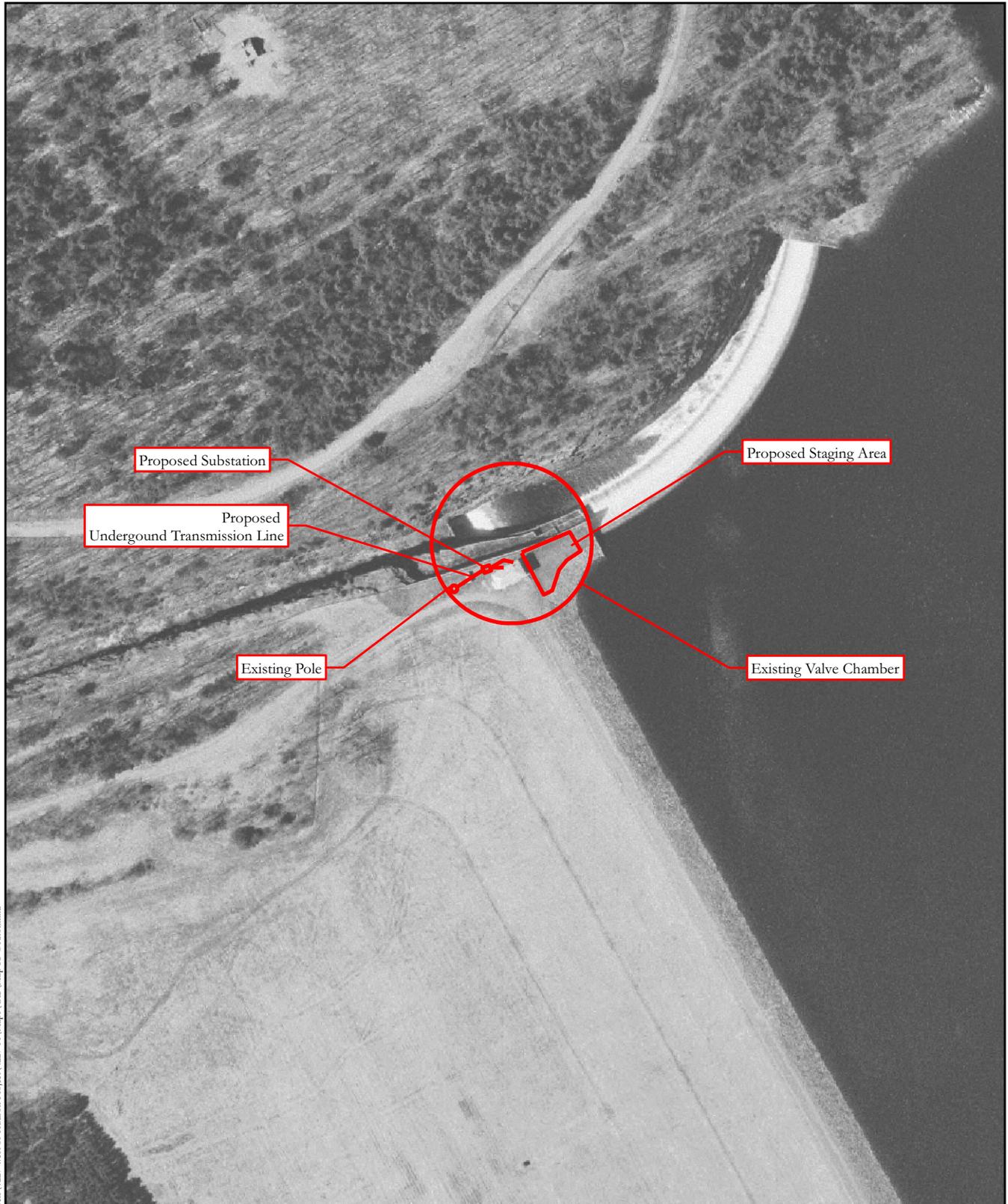
250 0 250 500
Feet

80 0 80 160
Meters

Project Location - Neversink Dam
(NYSOCSCI 2004)



Map 3a



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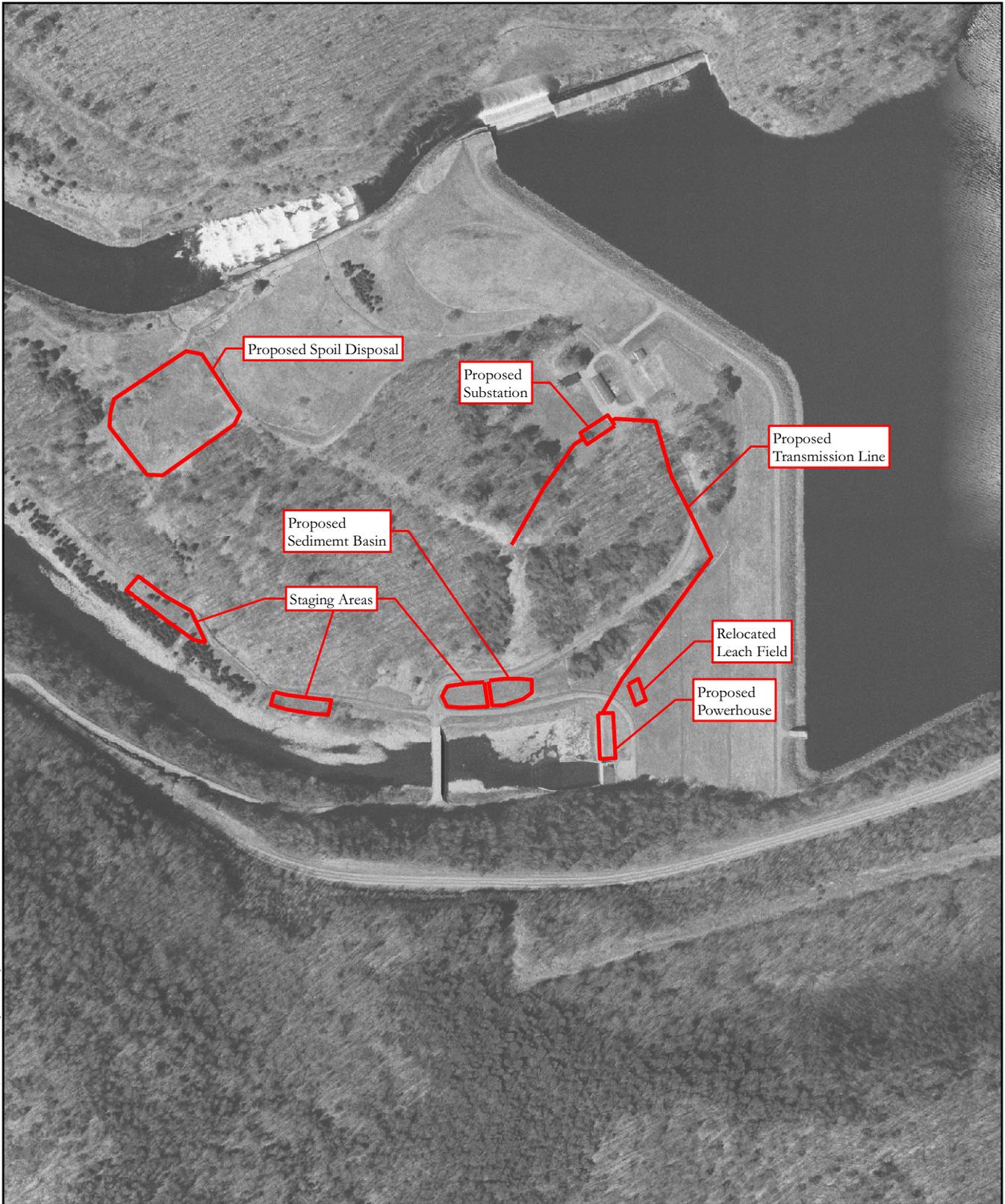
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Feet

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Meters

Project Location - Downsville/Pepacton
(NYSOCSCI 2004)



Map 3b



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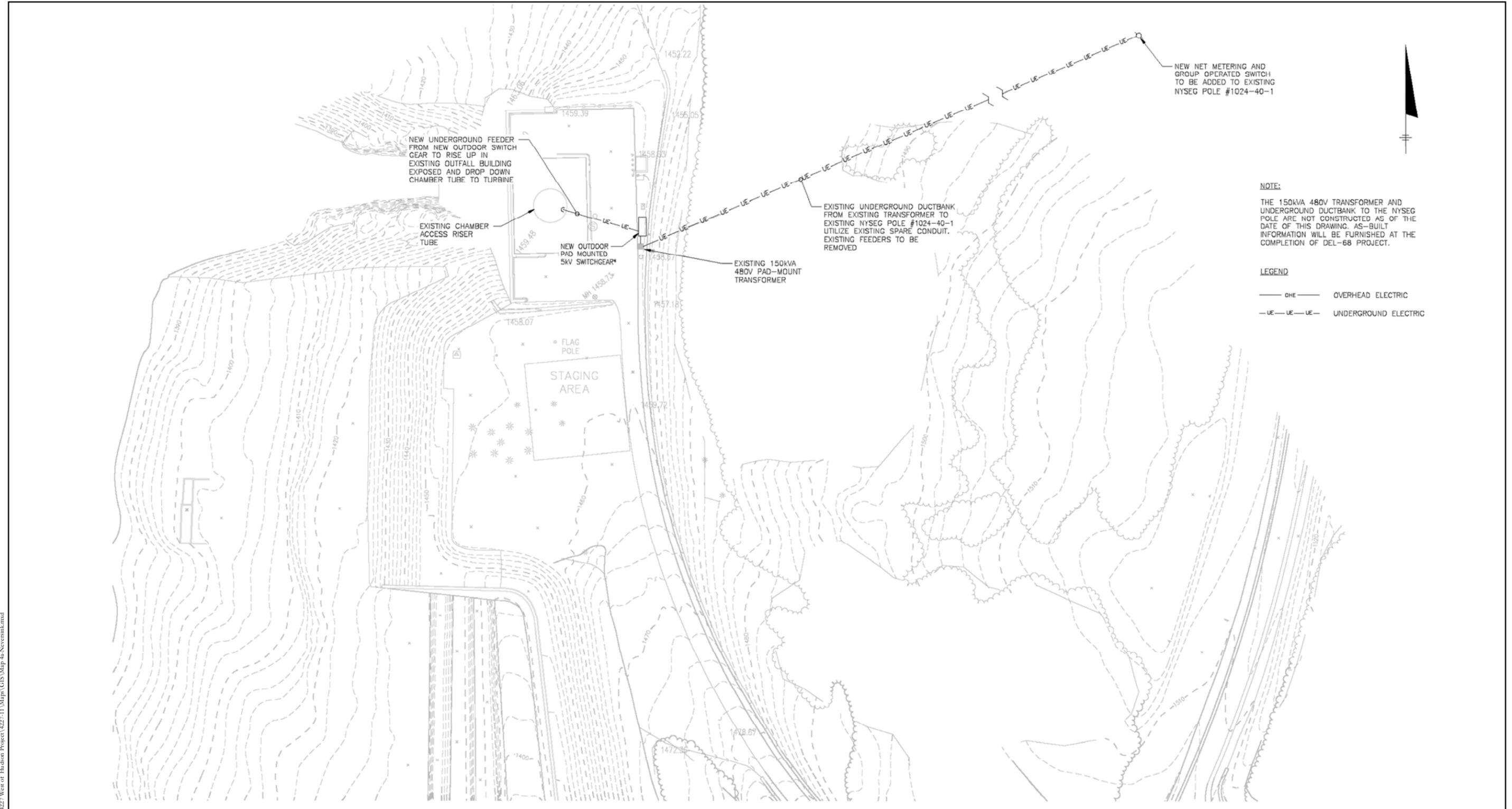
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Feet

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Meters

Project Location - Cannonsville Dam
(NYSOCSCI 2004)

HARTGEN
archeological associates inc

Map 3c



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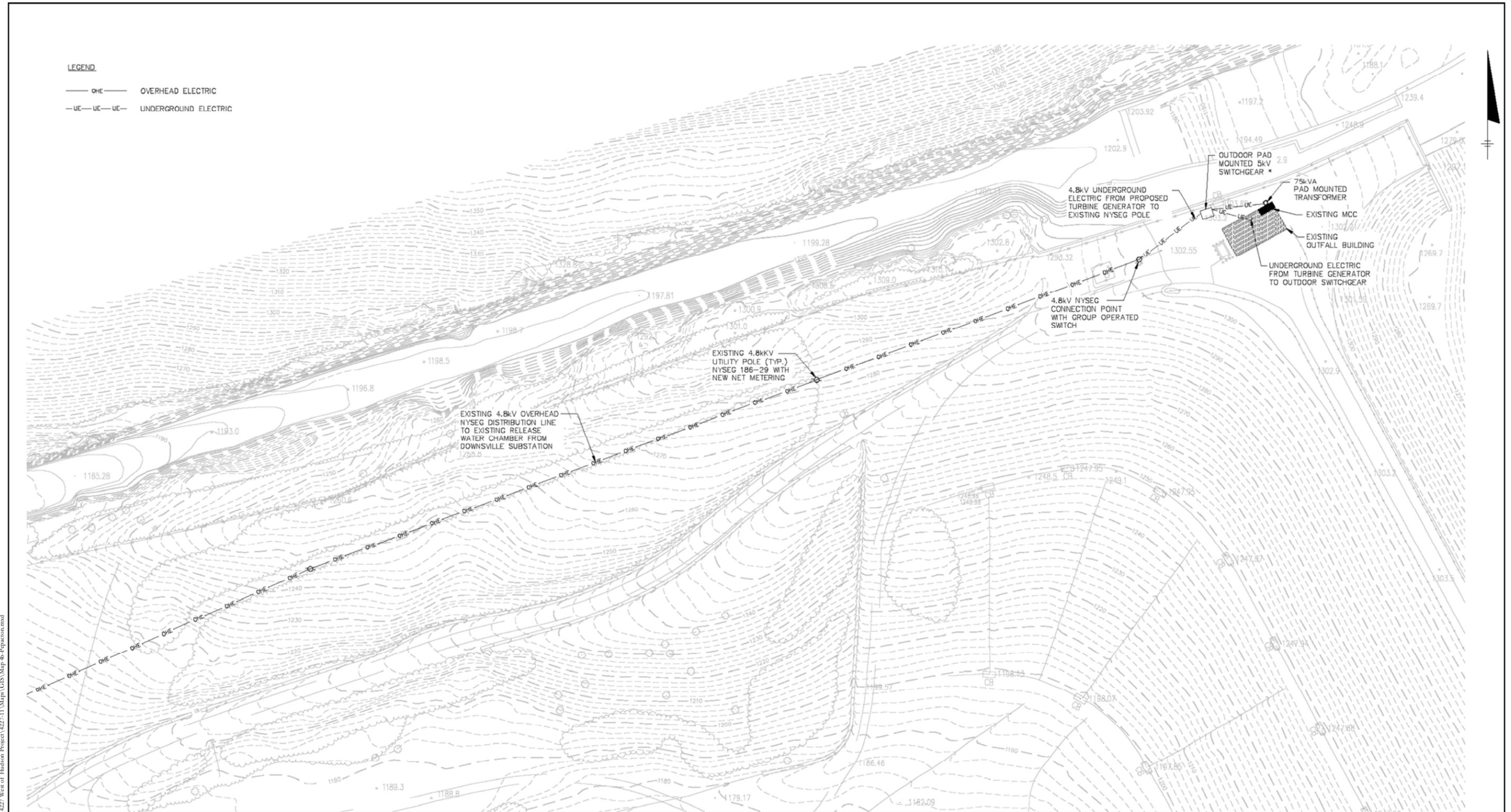


Note: Contour interval is 2 feet.



Conceptual Plan of Neversink
 (DEP and O'Brien & Gere)

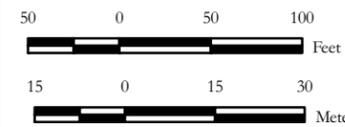
Map 4a



LEGEND

- OHE — OVERHEAD ELECTRIC
- UE — UE — UE — UNDERGROUND ELECTRIC

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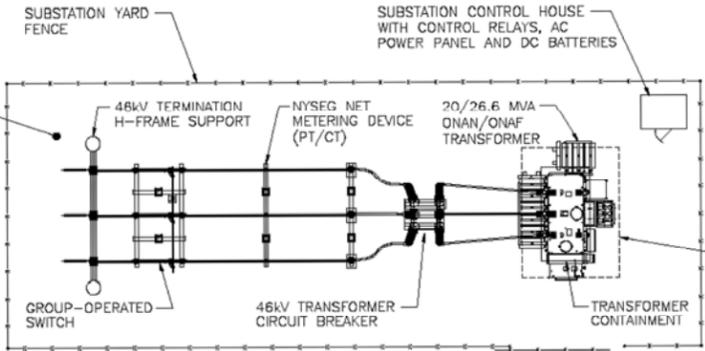
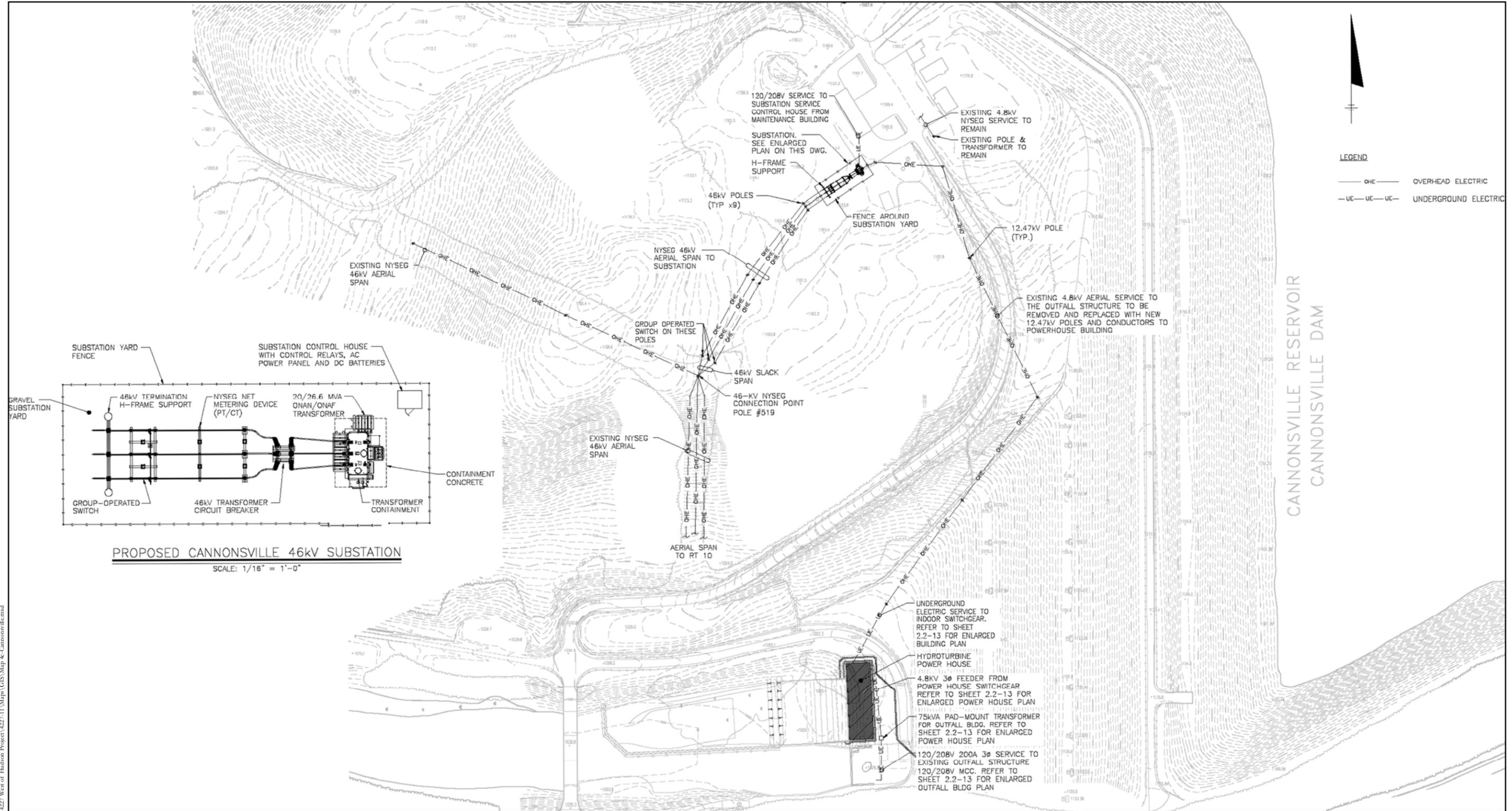


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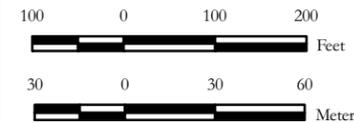
Conceptual Plan of Pepacton
 (DEP and O'Brien & Gere)

Map 4b



PROPOSED CANNONSVILLE 46kV SUBSTATION

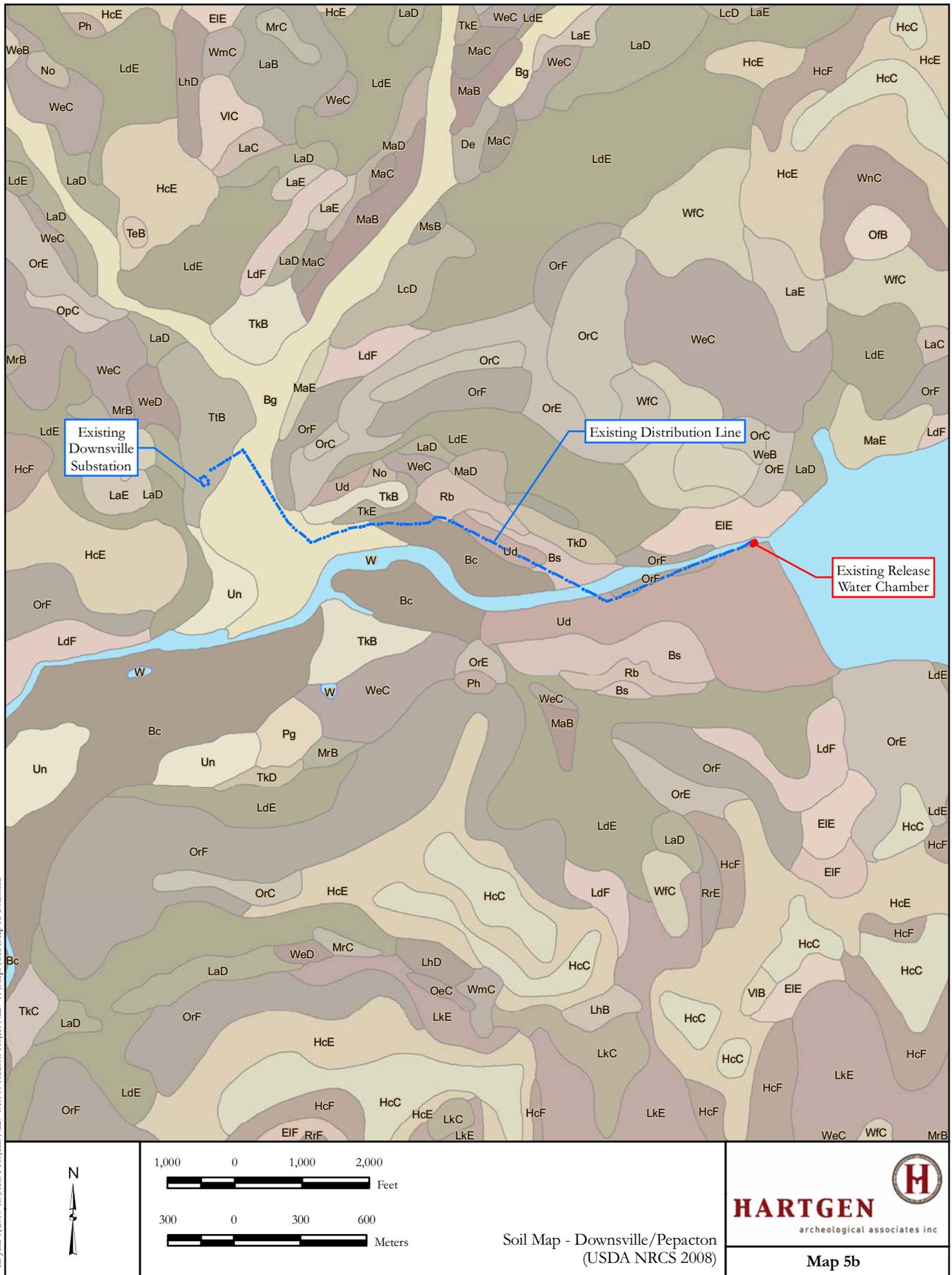
SCALE: 1/16" = 1'-0"

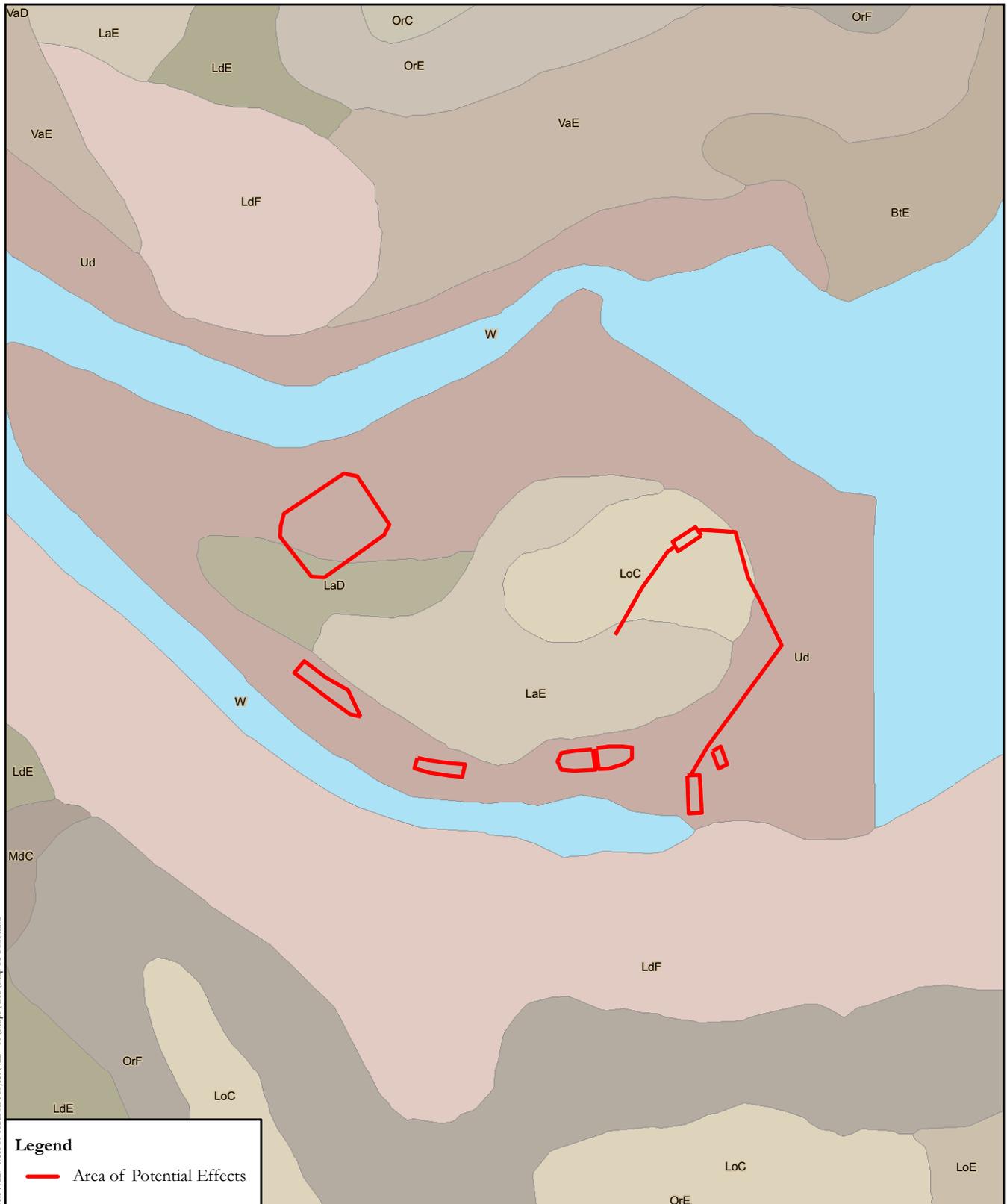


Note: Contour interval is 2 feet.

LEGEND

- OHE — OVERHEAD ELECTRIC
- UE — UE — UNDERGROUND ELECTRIC





TSM May 25, 2011 R:\Aetive Projects\4227 West of Hudson Project\4227-11\Maps\GIS\Map 5c-Soil.mxd

Legend

— Area of Potential Effects



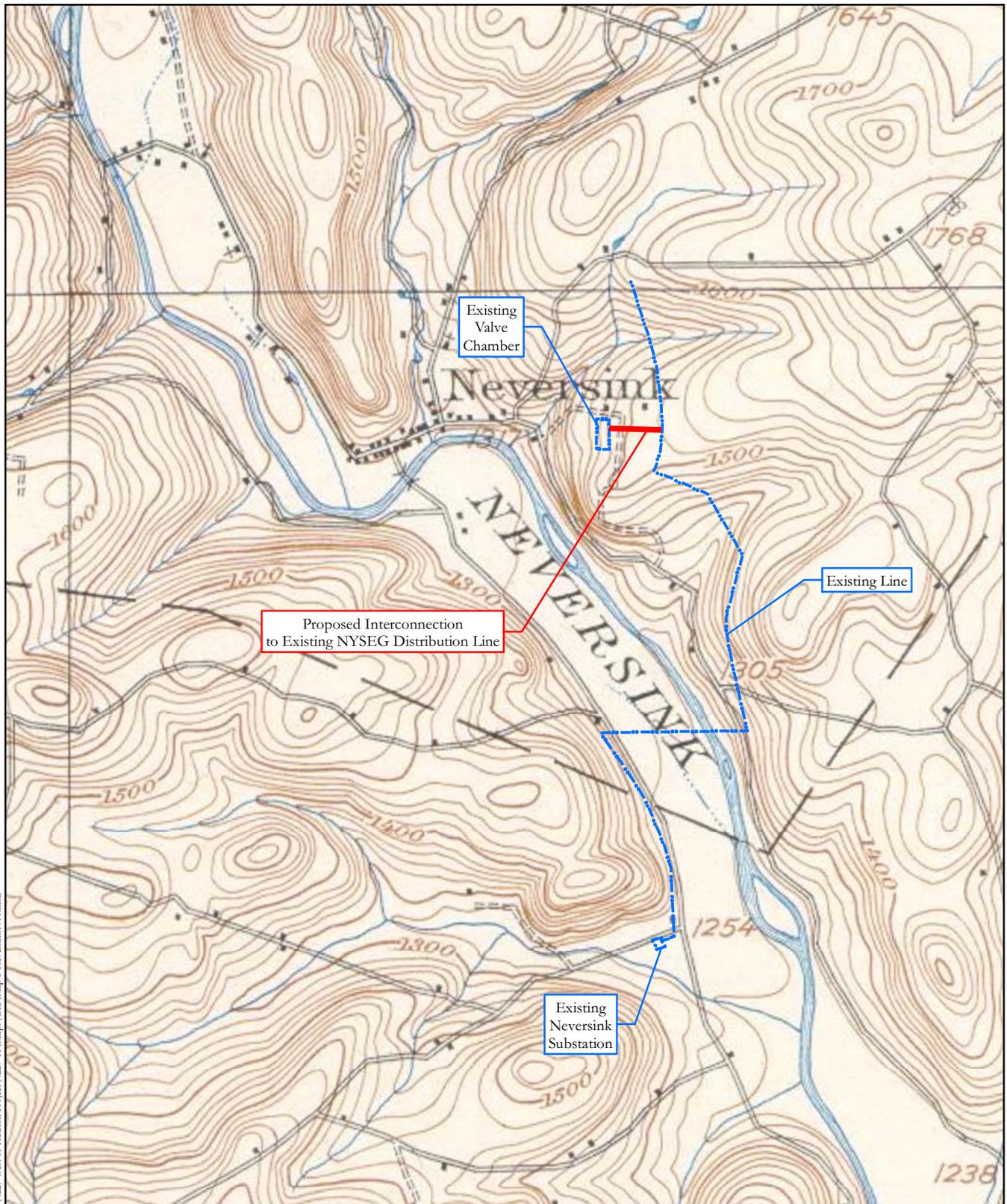
300 0 300 600
 Feet

90 0 90 180
 Meters

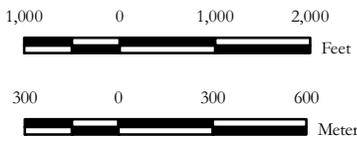
Soil Map - Cannonsville Dam
 (USDA NRCS 2008)



Map 5c



ES June 2, 2010 R:\Aetree Projects\4227 West of Hudson Project\4227-11\Maps\GIS\Map 6-Neversink 0910.mxd



Neversink Dam
(USGS 1910)



Map 6

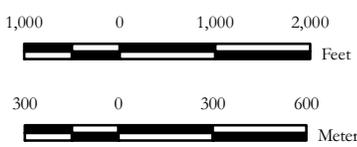


Existing Downsville Substation

Existing Distribution Line

Existing Release Water Chamber

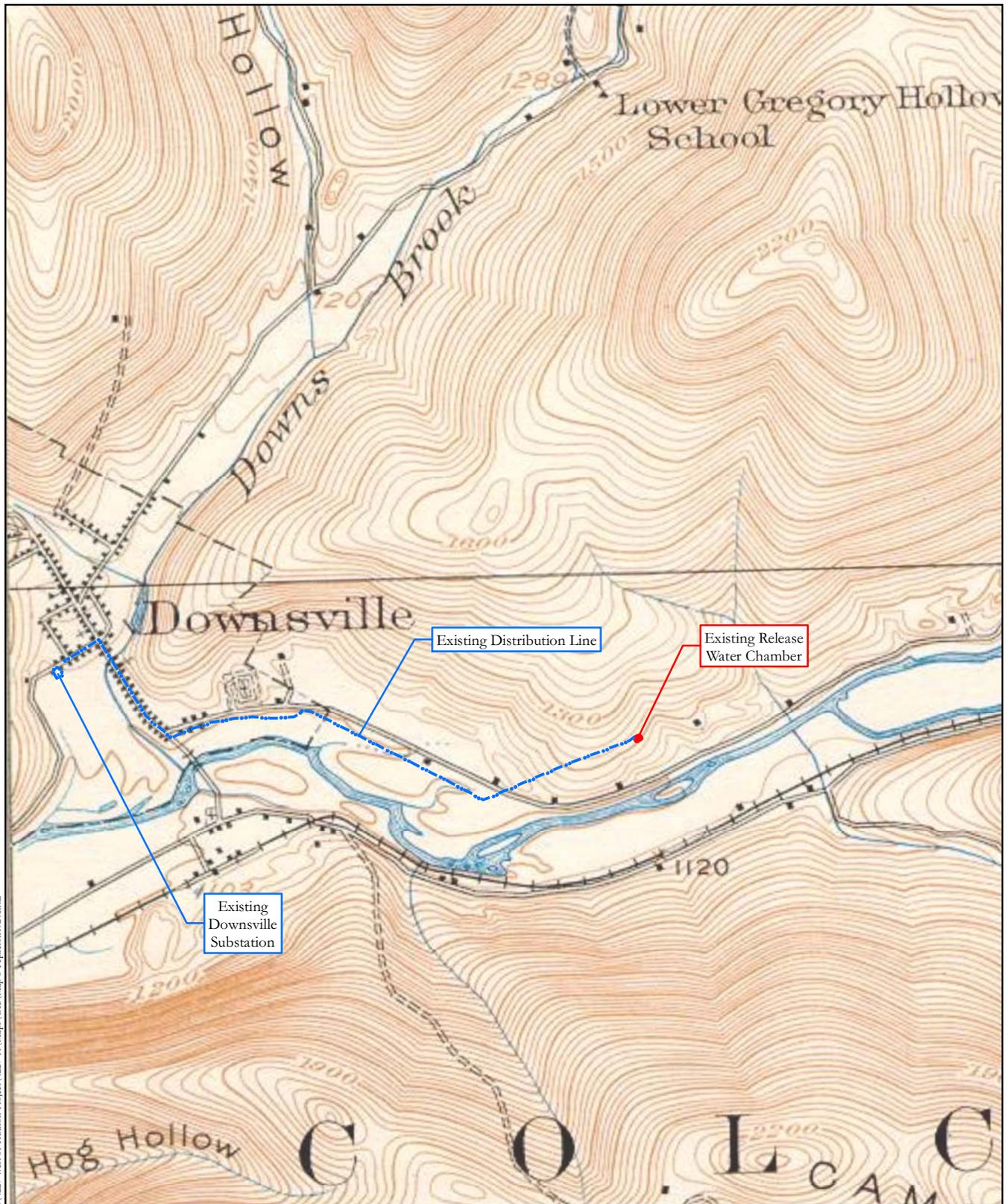
ES June 2, 2010 R:\Aetree Projects\4227 West of Hudson Project\4227-11\Maps\GIS\Map 7 - Pepacton 1869.mxd



Downsville/Pepacton
 (Beers 1869)



Map 7



ES June 2, 2010 R:\Aetree Projeers\4227 West of Hudson Project\4227-11\Maps\GIS\Map 8-Pepacton1924.mxd



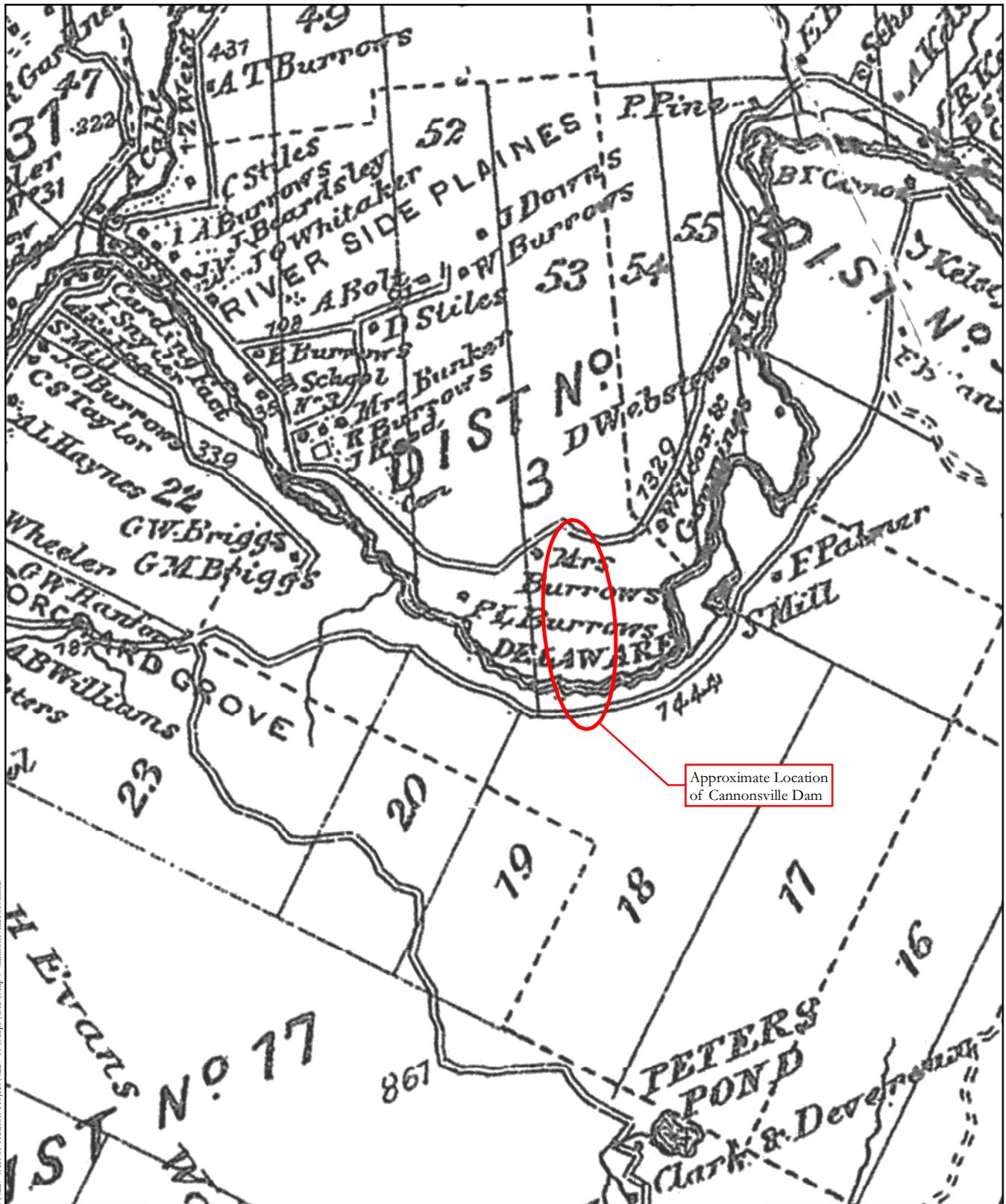
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Feet

300 0 300 600
Meters

Downsville/Pepacton
(USGS 1924)

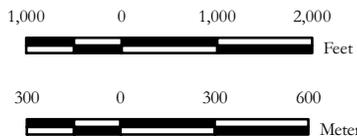


Map 8



Approximate Location
of Cannonsville Dam

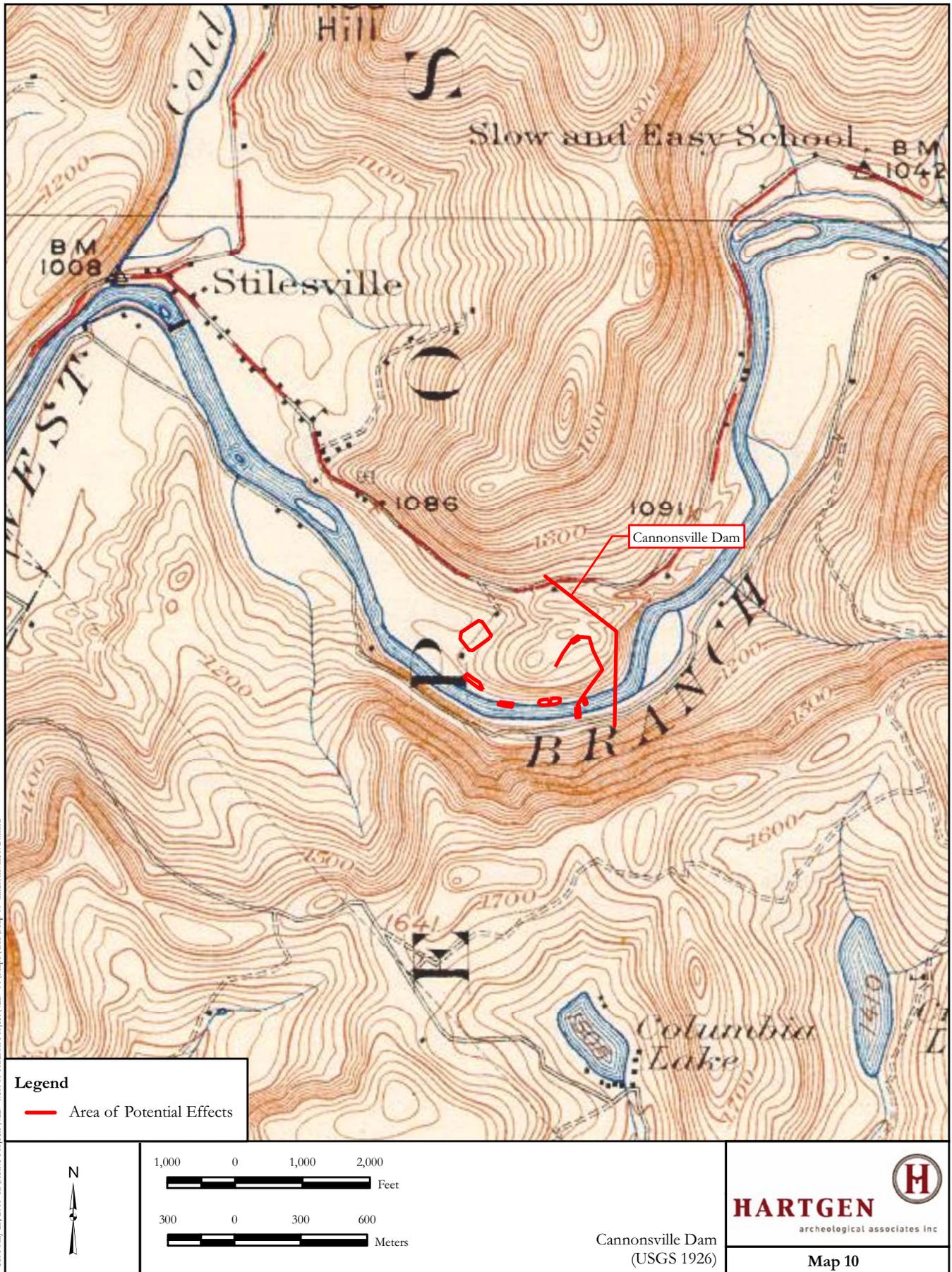
ES June 2, 2010 R:\Aetree Projects\4227 West of Hudson Project\4227-11\Maps\GIS\Map 9\Cannonsville1869.mxd



Cannonsville Dam
(Beers 1869)



Map 9



TSM May 25, 2011. R:\Aetere Projects\4227 West of Hudson Project\4227-11\Maps\GIS Map 10\Cannonsville 0924.mxd

Legend

— Area of Potential Effects



1,000 0 1,000 2,000
Feet

300 0 300 600
Meters

Cannonsville Dam
(USGS 1926)



Map 10

PHOTOGRAPHS



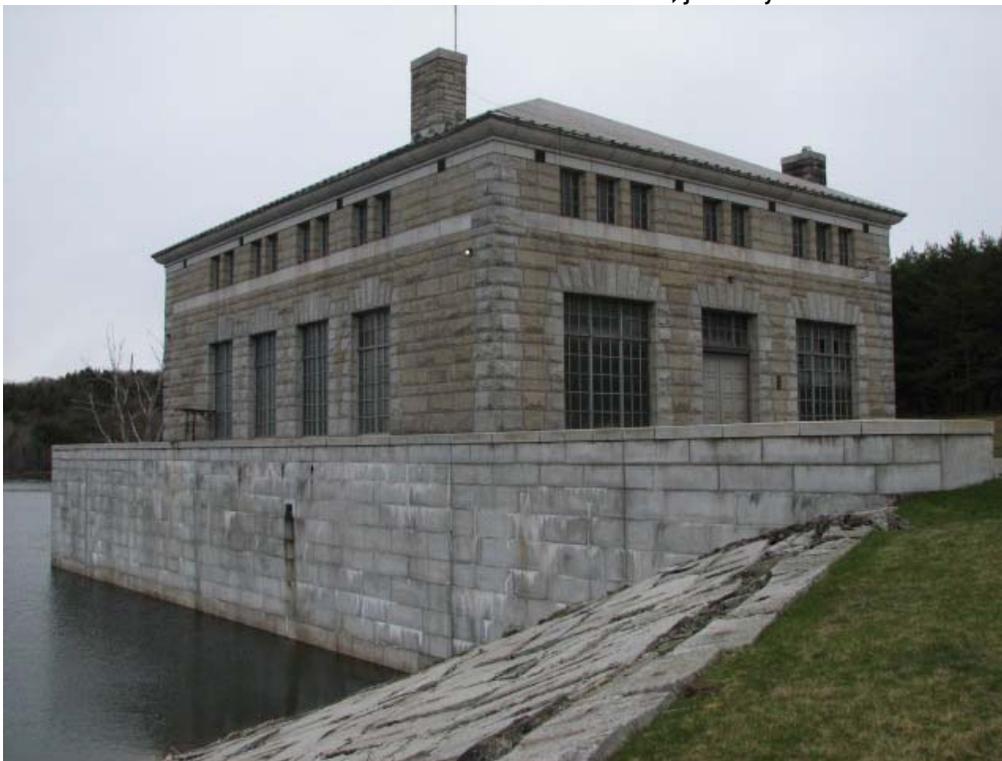
Photograph 1. The Neversink dam as viewed on the upstream portion towards the east. In the distance the intake structure can be seen, the Project proposes to replace one of the valves with a hydroelectric turbine.



Photograph 2. View east of the downstream portion of the earthen dam at Neversink. The dam was constructed in 1953.



Photograph 3. The waste weir or spillway at the Neversink dam as viewed from the northeast. The weir is composed of three large steps faced in granite to minimize the effects of scouring. The water is diverted to an inclined tunnel at the west end of the weir, just beyond view.



Photograph 4. The intake structure at the Neversink dam and tunnel. The structure regulates water flow through the Neversink Tunnel and a minimum flow to the Neversink River through the former diversion tunnel. The Project proposes to replace one of the existing valves with a hydroelectric turbine.



Photograph 5. The intake structure at Neversink as viewed west.



Photograph 6. The Project proposes to replace an existing valve at the structure with a hydroelectric turbine. The valve releases water into an inclined tunnel located below the lawn in the foreground. The tunnel empties into the spillway channel and to an outlet into the Neversink River. A staging area is likely to be located south (to the right) of the intake structure.



Photograph 7. The current plans for the Project include a distribution line that will utilize an existing underground ductbank located along this steep bank to NY 55 (in the background).



Photograph 8. View north of the downstream portion of the earthen dam at Downsville created for the Pepacton Reservoir. The proposed turbine will be installed in the valve control structure at the north end of the dam, seen at a distance in the photograph.



Photograph 9. Upstream portion of the Downsville dam as viewed to the southwest. Stone rip-rap lines the interior section of the earthen dam. The proposed project area is just out of view to the right.



Photograph 10. View east of the waste weir of the Downsville dam. The ogee crest of the weir is faced with granite. A waste channel to the left is excavated out of bedrock.



Photograph 11. View west of the spillway channel of the Downsville dam. Below is the inclined tunnel lined in concrete that was once part of the diversion tunnel. The valve structure regulates a minimum flow of water from the reservoir and is located just out of view to the left. Water released from the valve structure enters the inclined tunnel below. Above the inclined tunnel is a secondary spillway channel for overflow at peak discharges. The Project proposes to replace the valve with a turbine.



Photograph 12. The valve structure at the north abutment of the Downsville dam. The two-story brick and masonry building houses two valves that regulate minimum flow from the reservoir. The Project proposes to replace one of the valves with a turbine. A switchyard will be built in the immediate vicinity.



Photograph 13. View west of the valve structure at Downsville dam, the rip-rap of the dam is to the left and to the right beyond the chain-link fence is the spillway channel.



Photograph 14. A view of the downstream side of the Cannonsville dam. To the right is an access road at the top of the dam. To the lower left is the release chamber below the dam. The proposed powerhouse will be sited next to the existing release chamber. A small cluster of outbuildings are located in the distance, as indicated by the arrow.



Photograph 15. The doubled-crested waste weir at Cannonsville dam and its associated spillway. The ogee-shaped weir is faced in granite. The spillway channel is cut through bedrock.



Photograph 16. A small cluster of maintenance buildings remain along the top of the Cannonsville dam. Several other structures, including the Engineer's office and laboratory, were moved and/or demolished over the years, view west. A switchyard or substation will be sited just behind the garage.



Photograph 17. A small pole barn used in the maintenance of the facility currently holds salt and machinery. Another small building is likely a former office that is now largely abandoned. Both structures are located near the top center portion of the dam.



Photograph 18. The intake structure along the reservoir at the Cannonsville dam, viewed to the southeast. The upstream portion of the dam is lined with stone rip-rap.



Photograph 19. The release chamber is located at the western abutment of the Cannonsville dam. The proposed powerhouse will be located to the east of the chamber, as indicated by the arrow. The distribution lines will extend up the dam face to the maintenance facility.

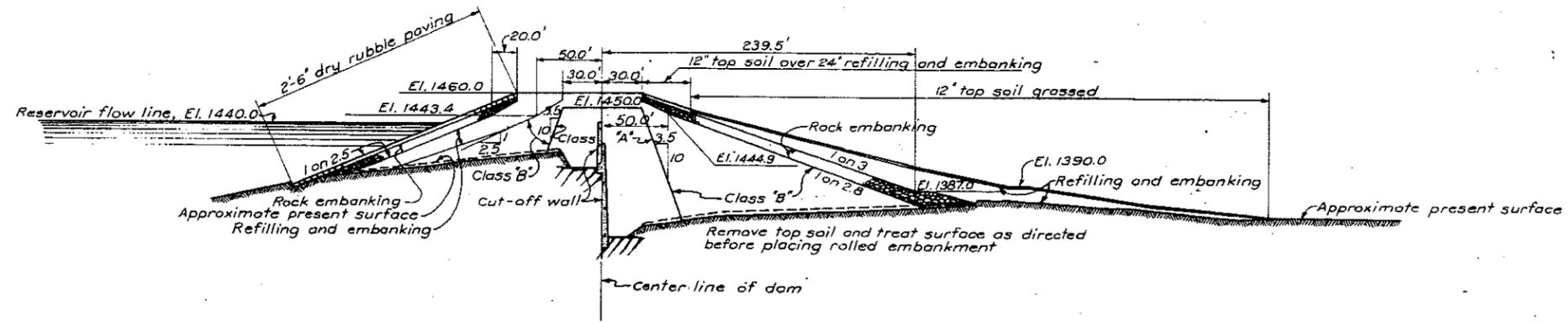
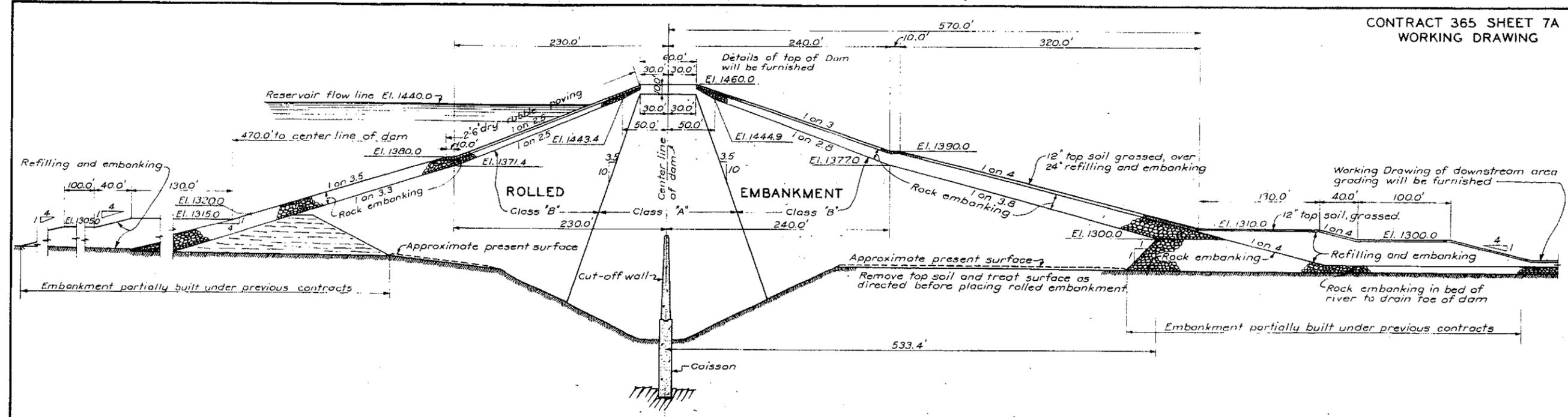


Photograph 20. A view west of the proposed location of the powerhouse at Cannonsville dam. The powerhouse will be situated in the area (see oval) previously disturbed by the construction of the dam and the deep stilling pool at the end of the release chamber.

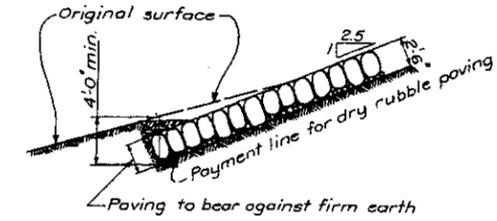
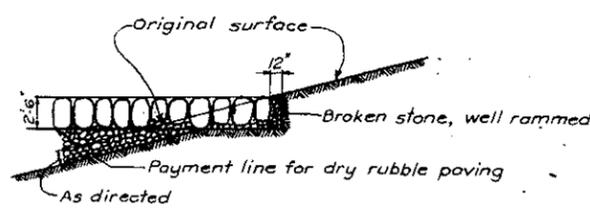
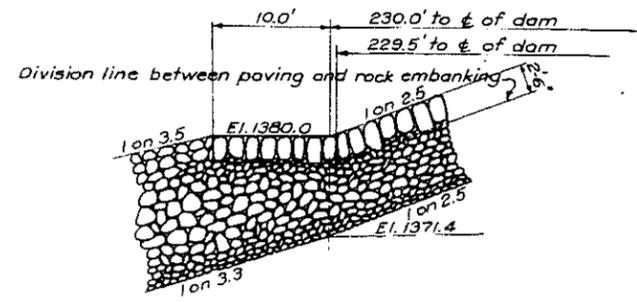
APPENDIX 1: Historic Plans, Maps and Photos (Board)

Historic Photos, Plans, and Maps of the Neversink Dam

**As taken from the Board of Water Supply of the City of New York, Annual
Reports Dated 1936 to 1950**



Dimensions given for finished surface do not apply at ends of dam.
 For plan showing surface grading at ends of dam and location of Sections A-A, B-B and C-C, see Sheet 5A, Acc. 641B7.
 For downstream slope drainage, see Sheet 7B, Acc. 641B8.



Drawn A.C.
 Traced H.W.W.
 Checked K.W.A.V. B.B.
 Madrin Mathews
 Designing Eng

10 2 6 10 14 18 22 Ft.

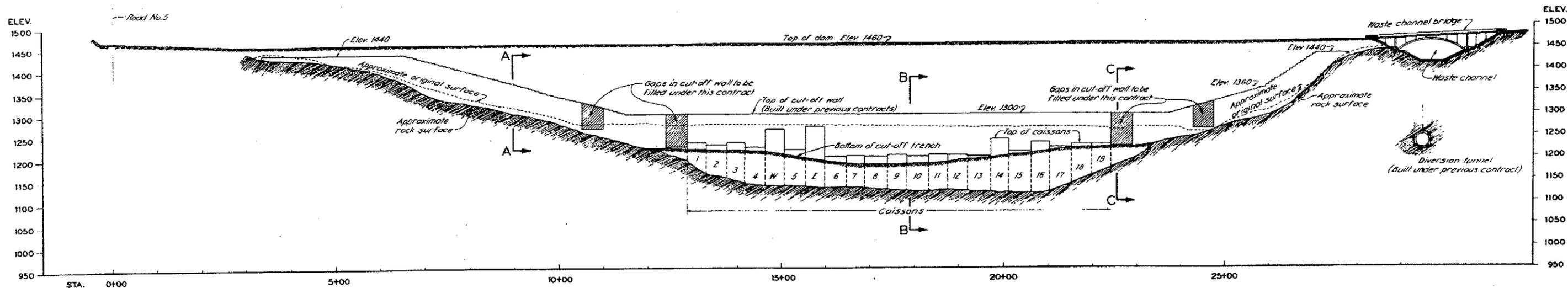
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10 2 6 10 14 18 22 Ft.

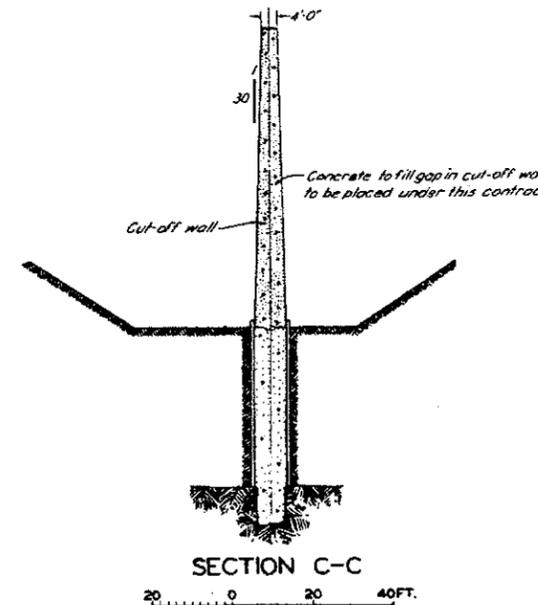
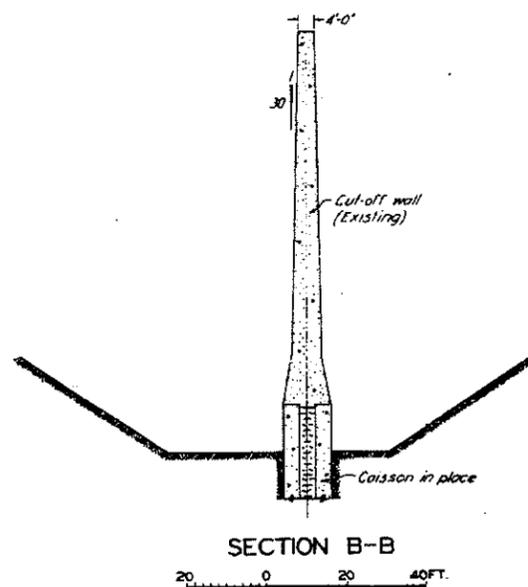
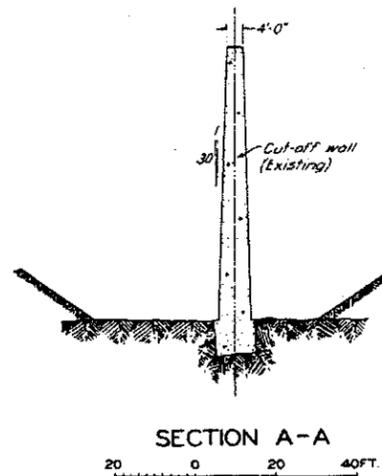
John M. Fitzgerald
 Dept Eng Hdqrs
 Chief Eng

City of New York
 BOARD OF WATER SUPPLY
NEVERSINK DAM
 SECTIONS
 MARCH 18, 1949
 File Cont. 365-3.4N
 Acc 64155

60 0 60 120 Ft.



PROFILE OF DAM ON CENTER LINE
(Looking upstream)



For plan of dam see Sheet 5, Acc 63365
For sections of dam see Sheet 7, Acc 63368
For highways see Sheet 23, Acc 63326

City of New York
BOARD OF WATER SUPPLY
NEVERSINK DAM
PROFILE
100 0 100 200 FT.
JANUARY 2, 1948

Drawn H.F.F.
Traced G.F.
Checked R.W.A. & G.C.
Machinist Matthews
Designing Eng.

Leon J. Curtis
Dept. Eng. Hdqrs.

File - Cont. 3C5-3.4 N

Acc. 63384

APE is in the foreground out of view

ACCESSION HEADQUARTERS D-7220, 7221, 7222

Neversink Reservoir - Neversink Dam

Contract 384 - S.A.Heely Company, Contractor

Dam Area.

Camera located on center line of dam at Station 28+00 looking west. In the center of the picture can be seen the cut-off trench excavation in which the following equipment is at work: A P & H shovel with 3 cubic yard bucket, a Northwest rigged as a dragline with a 3-1/2 cubic yard bucket, and a Lima crane and several rear dump Euclid trucks of 10 yard capacity. On both slopes of the cut-off trench can be seen the wellpoint rings and the small buildings over the pumps and the discharge lines running up the slope. The line of buildings along the road on the left are, starting in the foreground, the compressor house (with a new building being constructed over a boiler), a locker house, contractor's office and B.W.S. office. In back of these buildings there is a boiler house and concrete aggregate batching plant. Beyond the batching plant are the aggregate stock piles. To the left of the stock piles is the rock embankment placed under Contract 360 and to the left of that is the downstream embankment placed under Contract 384. The mound in the left background is the storage pile of the topsoil placed under Contract 360. Just in front of that is the roof of the Contractor's garage and machine shop. Near the left of the picture, just above the top of the trees is the center penter shop. To the right of the trench is the upstream cofferdam constructed under Contract 360 and beyond it is the upstream embankment area. In the center background the trees have been cut and the brush cleared preparatory to excavating the cut-off trench on the west abutment.

February 20, 1947.



Part A

Part B



Part C



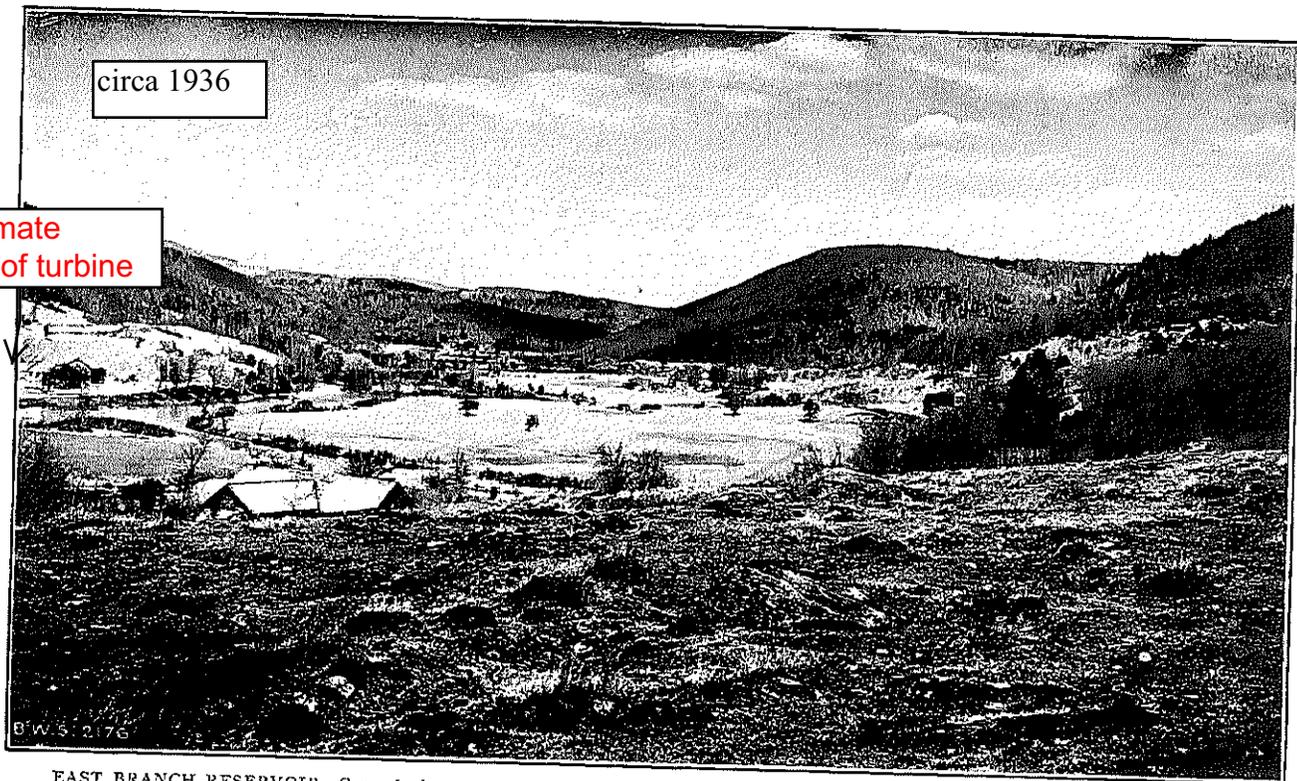
substituted highway Road 2. The batching plant and aggregate stock pile may be seen at left center. Note terraced construction of downstream class "B" embankment at center left. Rolled embankment operations of both class "A" and class "B" were in progress when photo was taken. The elevation of fill adjacent to cut-off wall on downstream side is about 1082, with upstream side about 2.5 feet higher. On the right may be seen the upstream coffer-dam and the temporary reinforced concrete spillway and the upstream rock embanking. In the background across the center of the panorama may be seen the excavation for waste and weir channels. At extreme right is a portion of substituted highway Road 2 as constructed under Contract 402.
October 21, 1950.

Approximate location of APE



Historic Photos, Plans, and Maps of the Downsville Dam

**As taken from the Board of Water Supply of the City of New York, Annual
Reports and Contract Specifications Dated 1947 to 1951**



EAST BRANCH RESERVOIR—General view of the valley at the proposed Downsville dam site on the East Branch of the Delaware river.

PEFACTON RESERVOIR - DOWNSVILLE DAM

CONTRACT 401 - BIANCHI, CENTRAL, MUNROE-LANGSTROTH, RUGO, CONTRACTOR

Plate No. 16

Acc. Hdq. D. 10449

View of excavation for weir cut-off trench which has been carried down 2 feet more or less below red shale bed. Note close drill marks in lower right foreground. Close drilling was ordered to minimize overbreakage in cut-off trench. At upper right center may be noted the badly jointed and fractured condition of the overlying sandstone bed. In center background is the head frame over the release water control shaft and at the left a portion of the concrete cut-off wall of the dam.

10244

July 13, 1951

Approximate
location of turbine



PEPACTON RESERVOIR -- DOWNSVILLE DAM

CONTRACT 401 - BIANCHI, CENTRAL, MUNROE-LANGSTROTH, RUGO, CONTRACTOR

Plate No. 29

Acc. Hdq. D. 10392

View shows inlet channel and diversion tunnel portal, both constructed under Contract 400. In center background is rock cut for overflow spillway weir and at left is a portion of the concrete cut-off wall. To the right of the wall is the steel headframe used during the construction of the release water control shaft and tunnel.

62801

May 25, 1951



Approximate location of turbine

D 10392

PLATE NO. 1

PEPACTON RESERVOIR - DOWNSVILLE DAM

CONTRACT 401 - BIANCHI, CENTRAL, MUNROE-LANGSTROTH, RUGO, CONTRACTOR

Plate No. 1

Acc. Hdq. D. 10266

View shows cut-off wall and upstream dam embankment during unwatering of trench. Water surface at elevation 1090+. Temporary overflow spillway on left. At right of spillway, upstream coffer-dam built under Contract 400. Downstream embankment on right. View shows stockpiling on upstream rock embanking section of rock excavated for overflow weir channel.

April 10, 1951

FEB 9 1952

View taken from near the location of the proposed turbine



Part A

CONTRACT 400 SHEET 2
SHEETS IN SET, 19



Approximate
location of APE

Property line of the City of New York
Right of way of substituted new highway to be built under Contract 402

Inclined
tunnel portal

Center line of
diversion tunnel

To Shave-town

CAT HOLLOW
STREAM

APPROXIMATE LIMIT
CONTRACT 400

Center line of outlet channel

The Contractor may be required
to place earth refilling and em-
banking and rock embanking in
portions of the river channel as
ordered.

EAST BRANCH
DELAWARE RIVER

Soil storage area

Dike

Settling basin

Sewage disposal plant

Engineer's office

Brook relocation

Center line of former railroad
Right of way of substituted
new highway to be built under
Contract 402

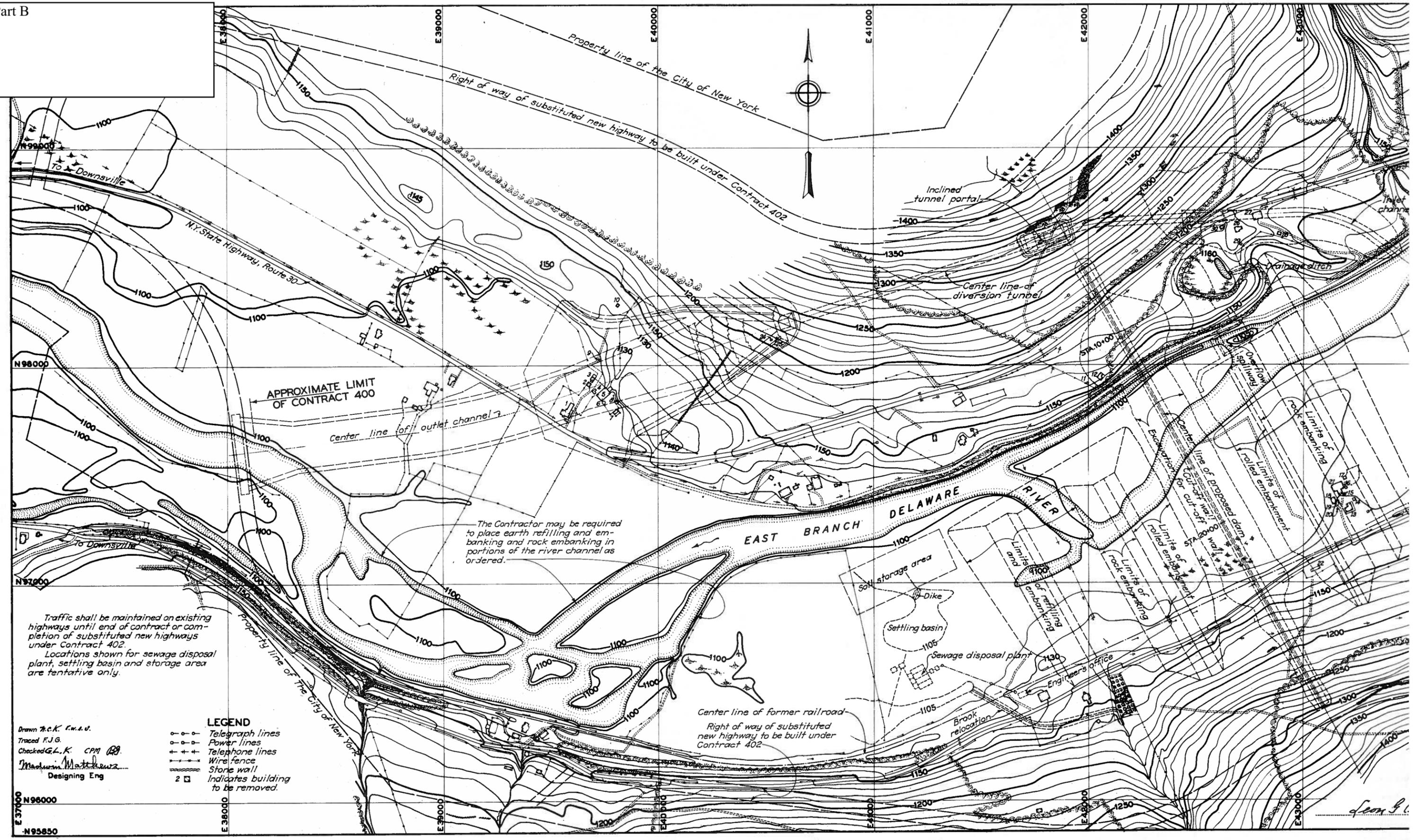
City of New York
BOARD OF WATER SUPPLY
DOWNSVILLE DAM
STREAM CONTROL
AND CUT-OFF WALL
LOCATION PLAN

200 0 200 400 Ft
JULY 1, 1947

Leon G. Cantler
Dept Eng Hdqrs

File Cont. 400-3.42 ED Acc 62765





APPROXIMATE LIMIT OF CONTRACT 400

The Contractor may be required to place earth refilling and embanking and rock embanking in portions of the river channel as ordered.

Center line of former railroad
Right of way of substituted new highway to be built under Contract 402

Traffic shall be maintained on existing highways until end of contract or completion of substituted new highways under Contract 402.
Locations shown for sewage disposal plant, settling basin and storage area are tentative only.

Drawn T.C.K. E.W.A.V.
Traced F.J.G.
Checked G.L.K. CPM
M. Matt
Designing Eng

- LEGEND**
- Telegraph lines
 - Power lines
 - +—+— Telephone lines
 - x—x— Wire fence
 - x—x— Stone wall
 - 2 □ Indicates building to be removed.

N96000
N95850

E38000

E39000

E40000

E41000

E42000

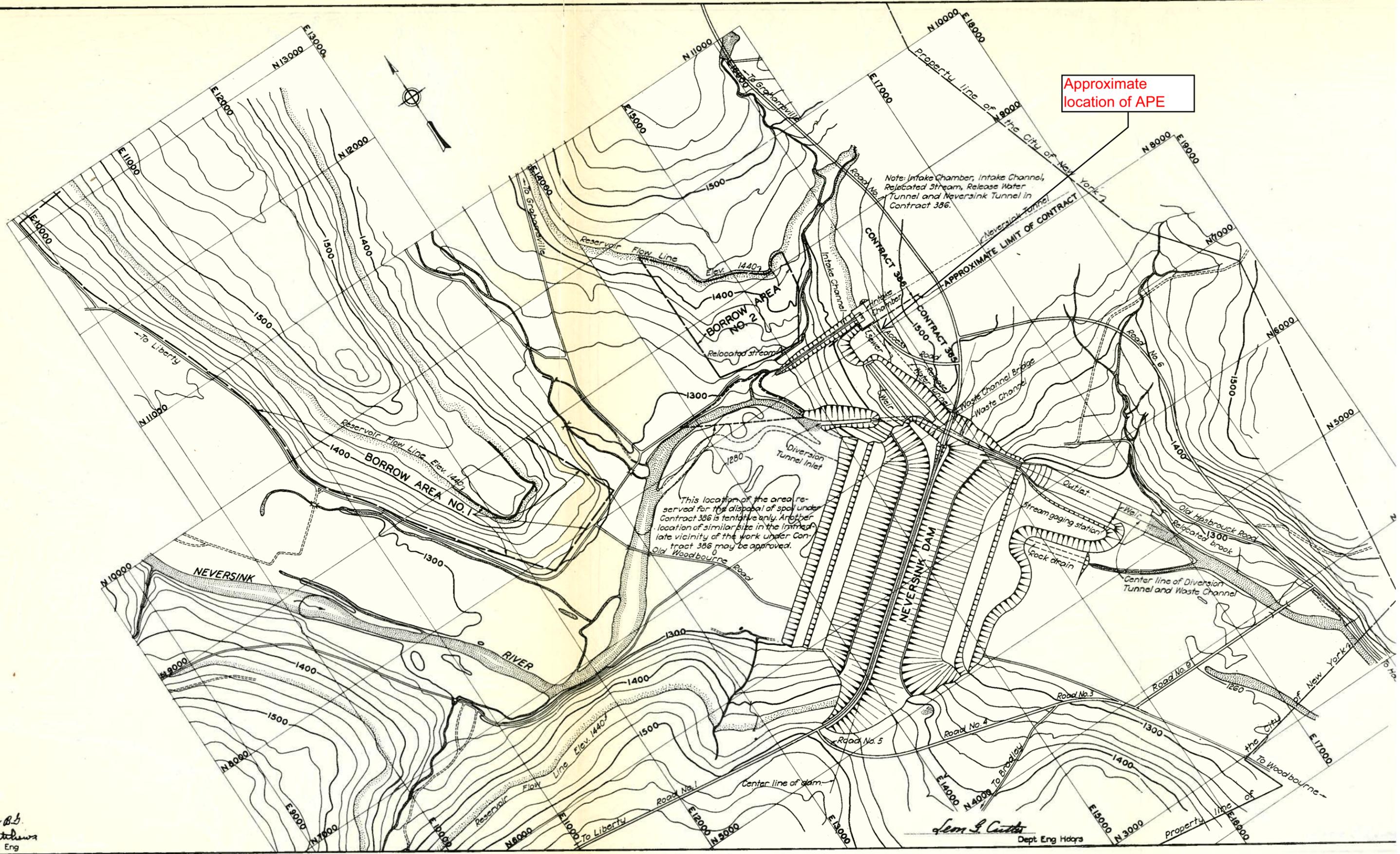
E43000

Leon G.

Approximate location of APE

Note: Intake Chamber, Intake Channel, Relocated Stream, Release Water Tunnel and Neversink Tunnel in Contract 386.

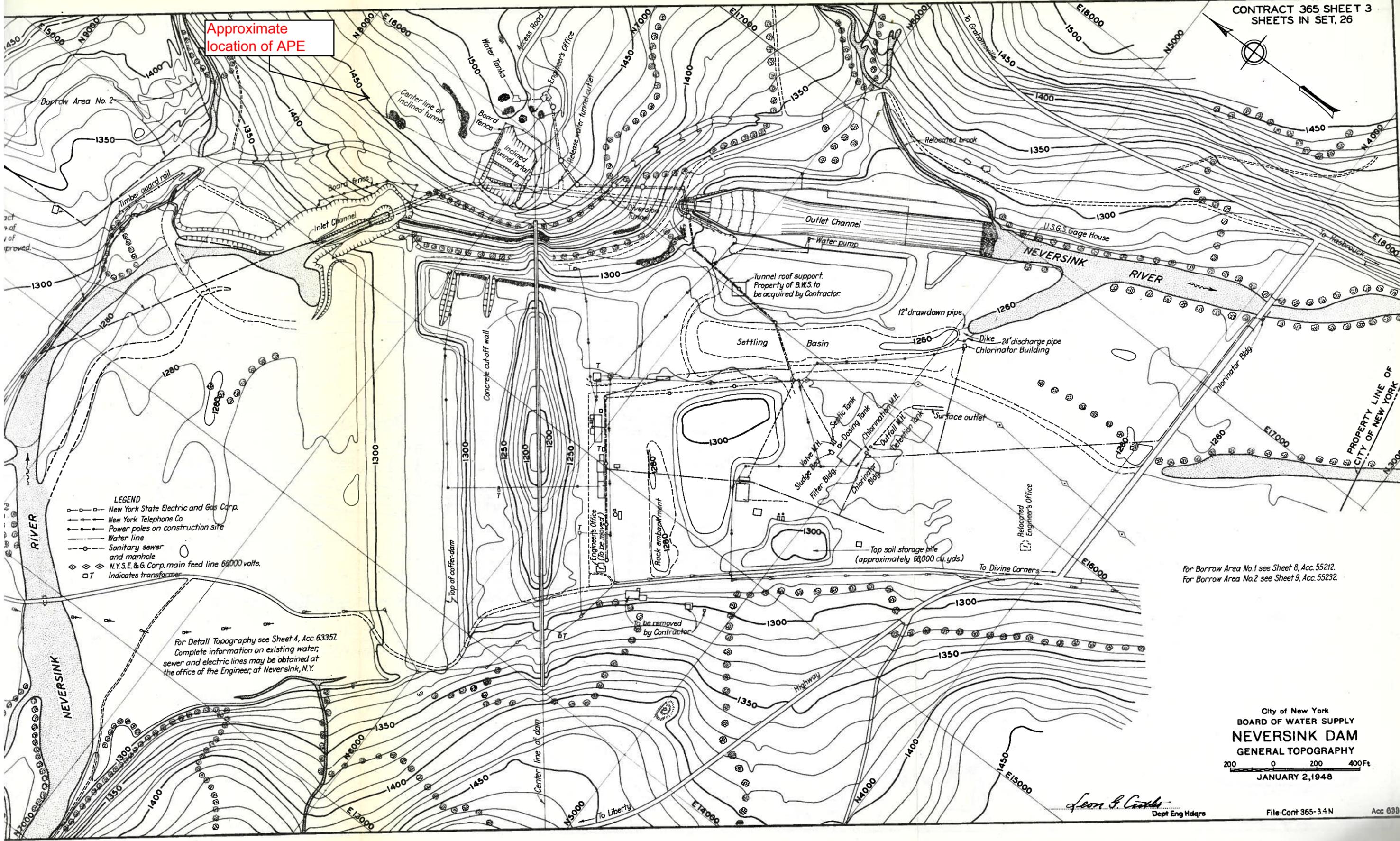
This location of the area reserved for the disposal of spoil under Contract 386 is tentative only. Another location of similar size in the immediate vicinity of the work under Contract 386 may be approved.



Drawn E.N.W.
Traced RPD
Checked K.W.A.S. & B.S.
Madwin Matthews
Designing Eng

Sam L. Curtis
Dept Eng Hdqrs

Approximate
location of APE



- LEGEND**
- New York State Electric and Gas Corp.
 - +— New York Telephone Co.
 - Power poles on construction site
 - |— Water line
 - Sanitary sewer and manhole
 - ◇— N.Y.S.E. & G. Corp. main feed line 68,000 volts.
 - T Indicates transformer

For Detail Topography see Sheet 4, Acc. 63357.
Complete information on existing water, sewer and electric lines may be obtained at the office of the Engineer, at Neversink, N.Y.

For Borrow Area No. 1 see Sheet 8, Acc. 55212.
For Borrow Area No. 2 see Sheet 9, Acc. 55232.

City of New York
BOARD OF WATER SUPPLY
NEVERSINK DAM
GENERAL TOPOGRAPHY

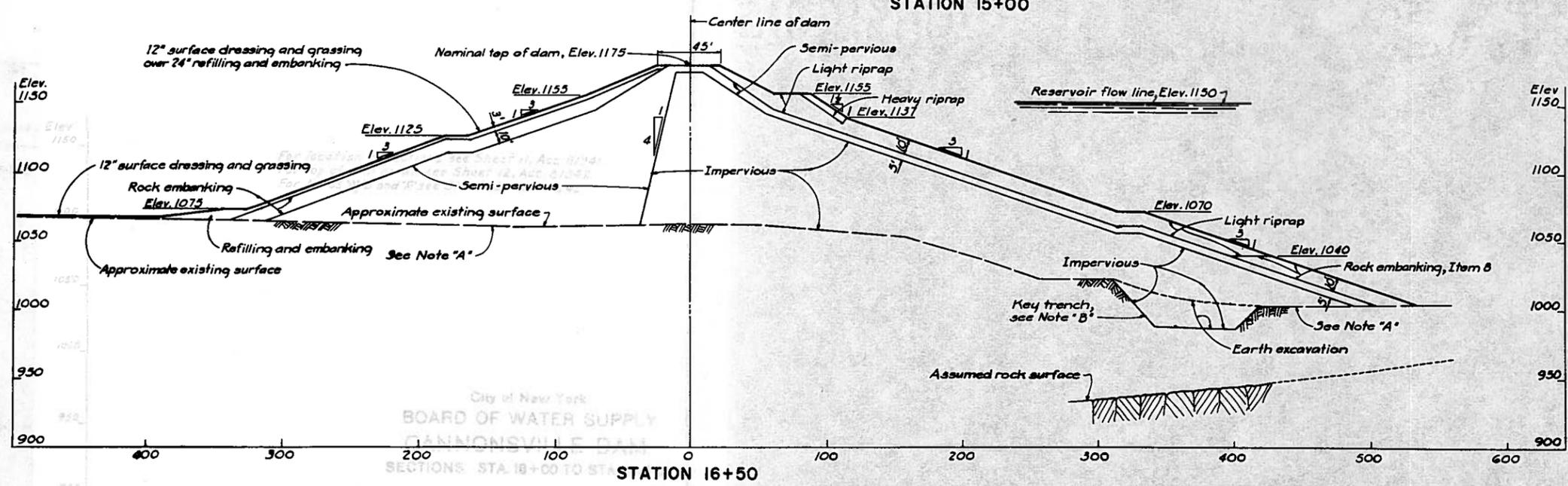
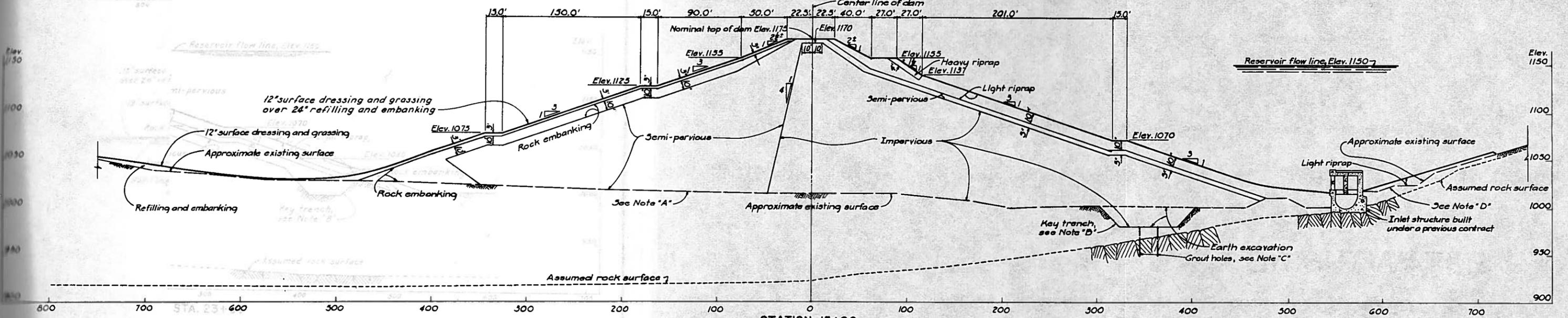
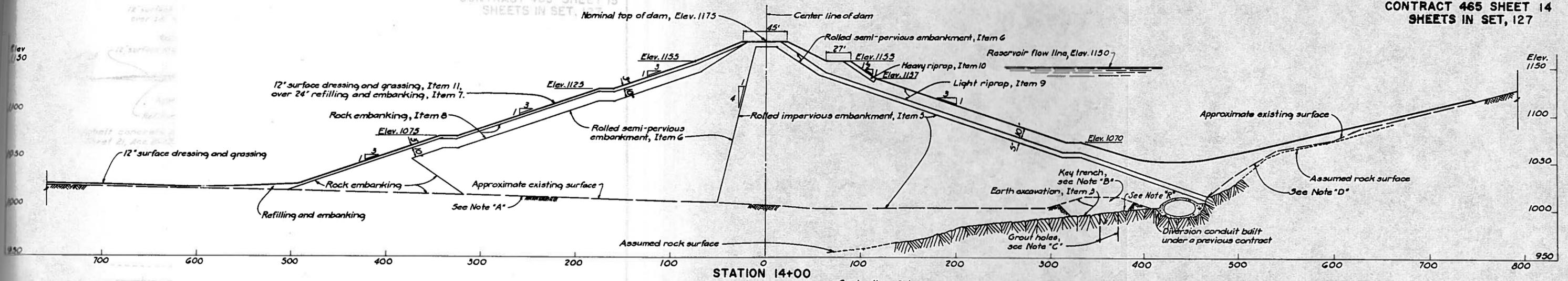
JANUARY 2, 1948

Leon B. Curtis
Dept. Eng. Hdqrs.

File Cont 365-34N Acc 63376

Historic Photos, Plans, and Maps of the Cannonsville Dam

**As taken from the Board of Water Supply of the City of New York, Annual
Reports and Contract Specifications Dated 1960 to 1972**



For location of sections see Sheet 11, Acc. 81341.
For top of dam detail see Sheet 12, Acc. 81342.
For Notes "A", "B", "C", "D" and "R" see Sheet 13, Acc. 81343.

City of New York
BOARD OF WATER SUPPLY
CANNONVILLE DAM
SECTIONS STA. 14+00 TO STA. 16+50

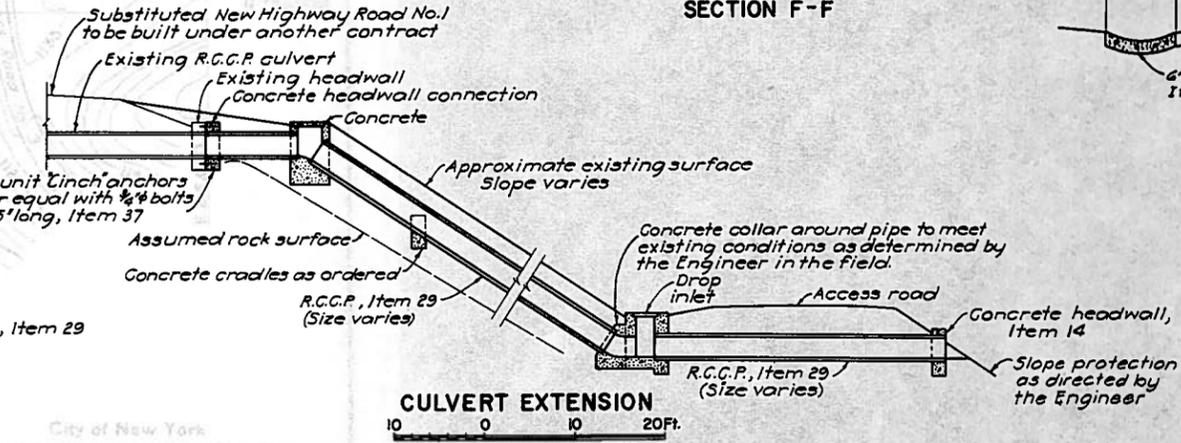
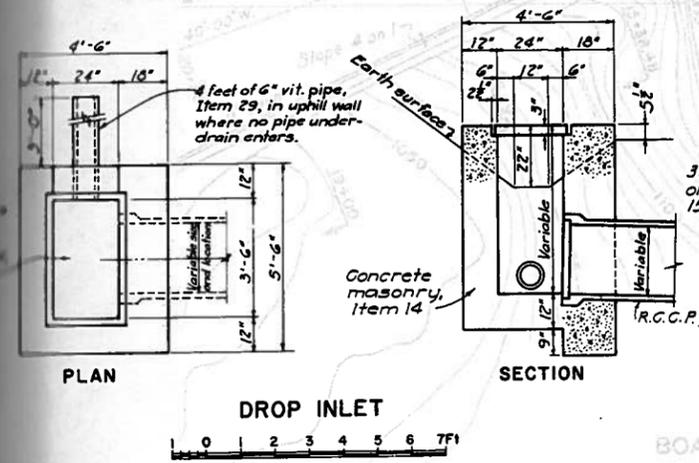
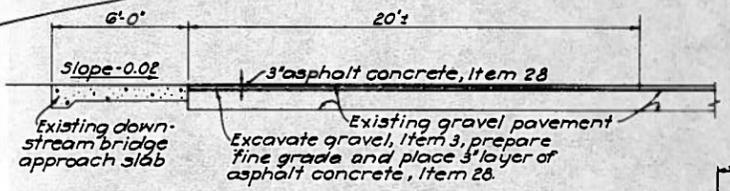
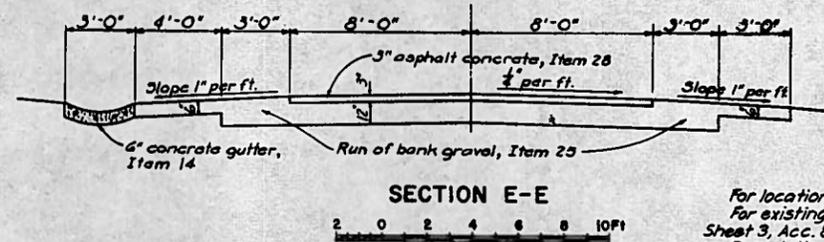
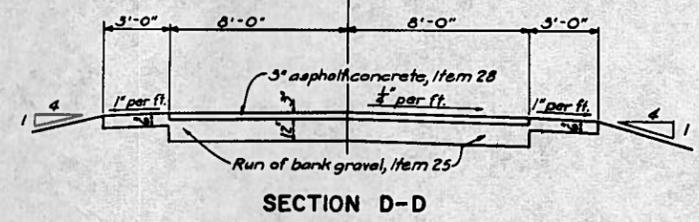
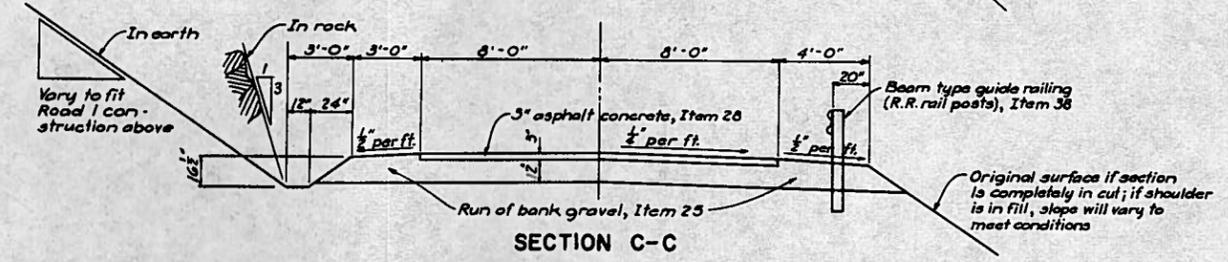
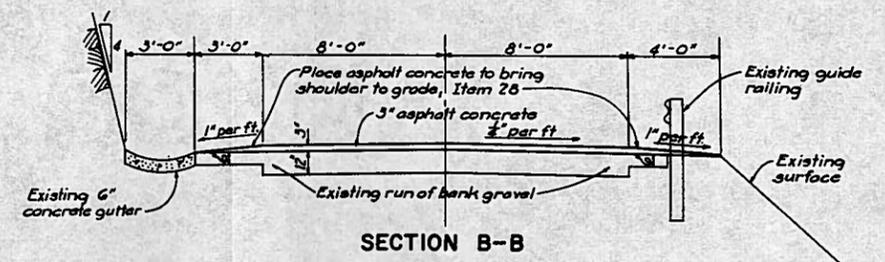
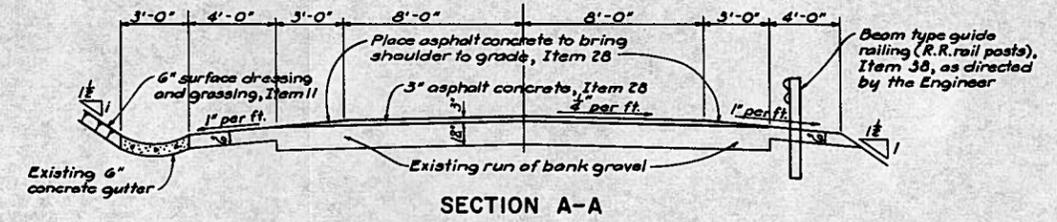
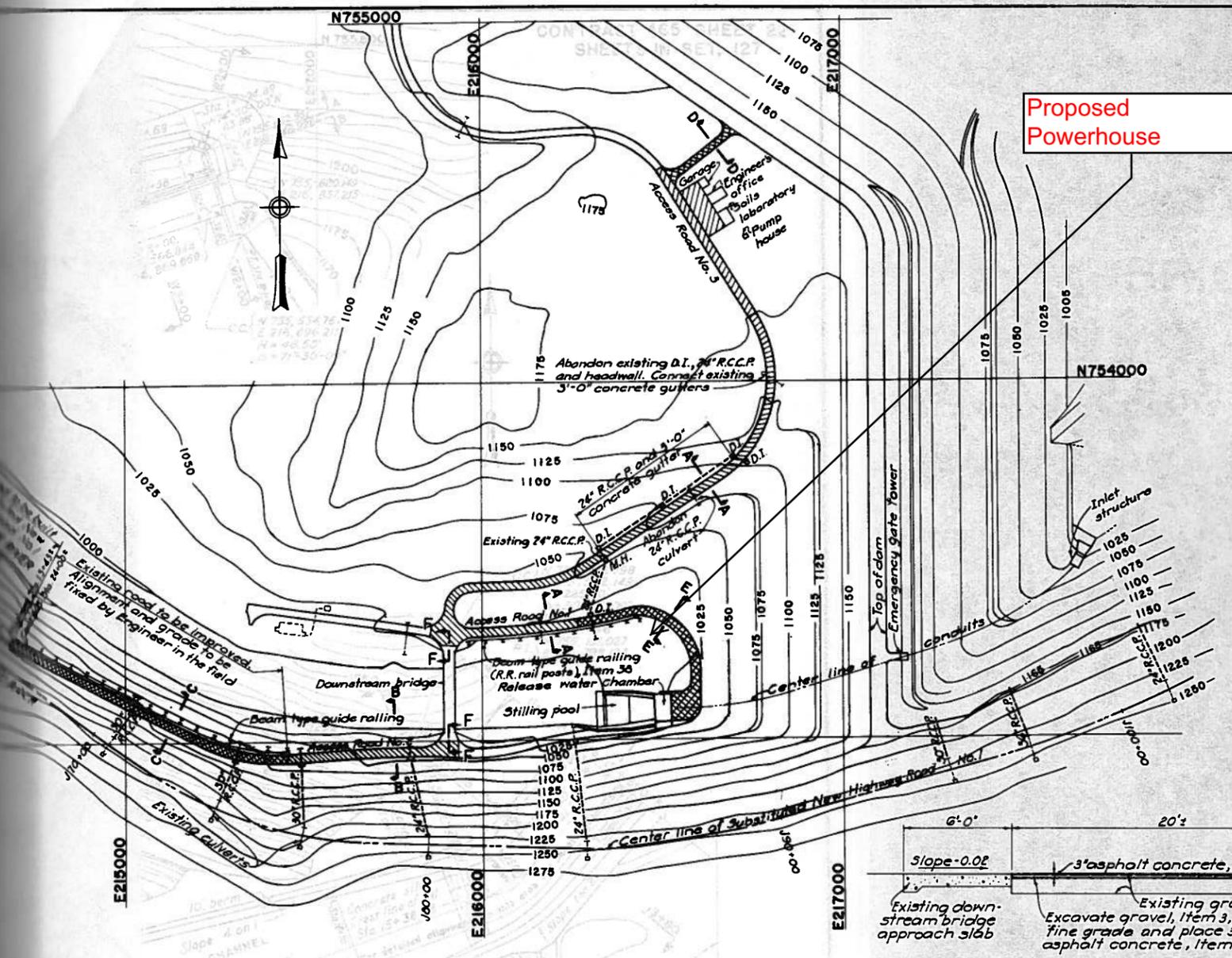
City of New York
BOARD OF WATER SUPPLY
CANNONVILLE DAM
SECTIONS STA. 14+00 TO STA. 16+50

Medwin Matthews
Executive Design Eng.

George Spann
Deputy Chief Eng. Design Dept.

50 0 50 100 Ft.
FEBRUARY 15, 1960
File: Cont. 465-3.4 Cv. Acc. 81344

Proposed
Powerhouse



- LEGEND**
- Indicates roadways or areas to be surfaced with asphalt concrete.
 - Indicates roadways or areas to be regraded, realigned and surfaced with 3\"/>

For location plan see Sheet 2, Acc. 81332.
For existing general topography see Sheet 3, Acc. 81333.
For existing detail topography see Sheets 7 to 10 inclusive, Accs. 81334 to 81337 inclusive, respectively.
For plan of dam see Sheet 11, Acc. 81341.

The access roads, culverts, culvert extensions and drop inlets shown on this sheet are illustrative of the type of construction required. The alignment, grades of the access roads and drainage pipes with appurtenant structures will be determined by the Engineer in the field.

The location, alignment, grades and type of structures required for the extension of the existing R.C.C.P. culverts are to be determined by the Engineer in the field to meet the existing conditions. The culverts shown existing will be built under the contract for the Substituted New Highway Road No. 1.

Medwin Matthews
Executive Design Eng.

George Spann
Deputy Chief Eng. Design Dept.

City of New York
BOARD OF WATER SUPPLY
CANNONVILLE DAM
ACCESS ROADS

200 0 200 400 Ft.

FEBRUARY 15, 1960

File: Cont. 465-3.4 Cv. Acc. 81351

**BEFORE THE FEDERAL ENERGY REGULATORY COMMISSION
APPLICATION FOR LICENSE FOR MAJOR PROJECT –
EXISTING DAM**

Cannonsville Hydroelectric Development

FERC Project No. 13287



VOLUME 8

**Appendix E-6: Impact of Construction Related Activities and New Construction on
Aesthetics**



September 2011

**City of New York
West of Hudson Hydroelectric Project**

Project No. 13287

Aesthetics Report

**Impact of Construction-Related Activities and New
Construction on Aesthetics**

Cannonsville, Pepacton, and Neversink Developments



June 2011

EXECUTIVE SUMMARY

The City of New York (“City”), acting through the New York City Department of Environmental Protection (“DEP”) has filed with the Federal Energy Regulatory Commission (“FERC”) a Notice of Intent to develop hydroelectric generation at the West of Hudson Hydroelectric Project (“Project”). As part of the licensing process for the Project, the DEP conducted a study to evaluate the impact of construction-related activities and permanent structures on aesthetics at the Cannonsville, Pepacton, and Neversink Reservoirs.

A field survey was conducted in June 2010 to evaluate the aesthetic impact of construction activities and construction of permanent structures on the character of the area. In addition, public viewsheds were identified and the views from those locations evaluated to determine the visual impacts, if any, of the Project.

At the Cannonsville development, the new powerhouse will be slightly larger than the adjacent existing low-level outlet works, but it will be constructed in a manner that will cause it to be visually compatible with the existing structure. The new overhead power lines will be constructed along the same path as the existing power lines, thereby minimizing their impact. The new substation will be constructed adjacent to existing structures, which will minimize its aesthetic impact. Although some trees will be removed for the substation and interconnection facilities, sufficient screening around the structures and facilities will remain, thereby minimally disrupting the character of the area. The construction activities will be concentrated in a few locations. While such activities may impact the character of the area, any such impacts will be temporary and should not be considered significant.

Public viewing of the low-level outlet works, construction sites, and staging areas at the Cannonsville development (generally, “Project areas”) is possible only from State Route 10 and the Cannonsville Reservoir. Parking and stopping areas along State Route 10 offer obstructed views of the Project areas, and there is no public location at which the entirety of the Project areas may be seen. Access to Cannonsville Dam is controlled by a DEP gate adjacent to State Route 10, and none of the Project areas are accessible by, or open to, the public. Although the Cannonsville Reservoir is open to the public, subject to certain requirements set forth in the DEP’s regulations, the elevation of the earthen dam prevents boaters from seeing any of the Project areas. For the foregoing reasons, neither the construction of the Project, nor the presence of the new structure and appurtenances, will have any material adverse impact on aesthetics or the general character of the area.

At the Pepacton development, the turbine and generator set will be located within the existing release water chamber, so they will not affect aesthetics or the character of the area. The appurtenances to be constructed and the construction activities will be limited in scope and scale. They will be located adjacent to the release water chamber with a short run (approximately 80 feet) of subsurface electrical lines to tie into an existing distribution pole. The appurtenances will be visible from some parts of the Pepacton Reservoir, but, to a large extent, they will be screened by the release water chamber. They will be barely visible from State Route 30 due to their small size and the distance between their location and the road. They will not be visible from the Village of Downsville due to their size and the screening provided by the surrounding natural vegetation. The temporary staging area will be visible from both the reservoir and roadway, but the visual impact of the construction activities is expected to be minimal. For the foregoing reasons, neither the construction of the Project, nor the presence of the new facilities, will have any material adverse impact on aesthetics or the general character of the area.

At the Neversink development, as at the Pepacton development, the turbine and generator set will be located within the existing structure. Also, the appurtenances to be constructed and the construction

activities will be limited in scope and scale. They will be located near the intake structure, with the electrical lines between the structure and the substation, and between the substation and New York State Electric & Gas Corporation's ("NYSEG") distribution system being located underground in existing conduits. The appurtenances will be visible from certain vantage points along State Route 55 and the lands surrounding the reservoir, but barely so because of their small size and the distances between them and the identified viewsheds. The appurtenances will be almost entirely screened from the reservoir by the existing structure. Further, the location of the appurtenances adjacent to the forested area will further shield their appearance. While the temporary staging area will be more visible due to its location next to the intake structure, the limited scale of the construction activities will minimize the visual impacts of the construction activities. For the foregoing reasons, neither the construction of the Project, nor the presence of the new facilities, will have any material adverse impact on aesthetics or the general character of the area.

At all three developments, the staging areas and new structures and appurtenances will be located predominantly in areas that are paved or mowed lawns, and therefore have little to no aesthetic significance. Upon completion of construction, all staging areas will be restored to their previous conditions, thereby eliminating all construction-related impacts. As a result, neither the Project nor its associated construction activities will change the character of the area or cause any measureable impact to these sites over either the short- or long-term.

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1.0 INTRODUCTION

The City, acting through DEP, has filed with the FERC a Notice of Intent to develop the Project, FERC Project No. 13287. The four sites are owned by the City and operated by the DEP as part of the City's water supply system. The DEP seeks to develop hydroelectric facilities at those sites while simultaneously maintaining its primary water supply function and adhering to the statutory and regulatory requirements governing its water supply operations, conservation releases, directed releases, water quality standards, and other related activities.

In accordance with the Preliminary Permit issued to the City by the FERC, the DEP is evaluating the technical and economic merit and feasibility for each proposed hydroelectric development. Based on the feasibility analysis completed to date, the DEP has suspended the completion of environmental studies at the Schoharie development while it continues to evaluate the economic feasibility of any hydroelectric facility at that site. The DEP will proceed with appropriate studies for that development in the event such an alternative is identified. Accordingly, this study is limited to the following three proposed developments:

Development	Dam	River
Cannonsville	Cannonsville Dam	West Branch Delaware River
Pepacton	Downsville Dam	East Branch Delaware River
Neversink	Neversink Dam	Neversink River

During the study plan development process, the DEP proposed to conduct a study to evaluate the impact of construction-related activities and permanent structures and facilities at the Cannonsville, Pepacton, and Neversink developments on aesthetics and the general character of the three areas.

The goals of this study, as outlined in the study plan, are to determine the potential impacts of construction-related activities and new structures on the aesthetics and general character of the Project areas. The objectives of this report are to:

- Document the existing visual character of the Project areas.
- Evaluate how newly constructed features and construction-related activities will impact the short-term and long-term aesthetics of the Project areas.
- Identify publicly accessible viewsheds and create photo renderings indicating the effect of new structures on the vistas.
- Discuss the need for, and potential types of, mitigation measures to address any short-term or long-term material adverse impacts caused by the Project.

2.0 SUMMARY OF PROPOSED CONSTRUCTION ACTIVITIES

This section summarizes the proposed construction-related activities and locations of new permanent structures and facilities based on the current designs for the Project. These designs, and the corresponding structure locations and analysis of potential impacts on aesthetics and the character of the areas, are subject to change as the DEP's proposal is refined and the licensing process advances.

2.1 Cannonsville Development

The Cannonsville development includes the construction of a separate powerhouse adjacent to the existing low-level outlet works. The existing penstock would be extended into the powerhouse, with the turbine discharges flowing through steel draft tubes into concrete chambers beneath the powerhouse floor. Water from these chambers will be discharged into a widened common tailrace channel and into the West Branch of the Delaware River. The powerhouse will be longer and slightly taller than the existing low-level outlet works. The approximate powerhouse dimensions are 168 feet long, 54 feet high and 52 feet high. The outside walls of the powerhouse will be constructed in a manner that creates the same granite look as the existing release works building.

[Figure 2.1-1](#) presents an overview of the proposed Cannonsville development, showing the location of the powerhouse, tailrace, the spoils area where excavated material from the powerhouse and tailrace construction will be disposed, and the temporary staging areas for equipment and material storage during construction. Additional work involves relocating the sewer pump station and leach field, installing a temporary cofferdam in the river, installing a temporary siphon over the spillway to maintain conservation flows during the tie-in to the existing conduit, constructing a generator lead from the powerhouse to an indoor switchgear, and installing the interconnection facilities from the substation to NYSEG's transmission system. The route for the generator lead is not yet finalized, but it is likely to run underground from the powerhouse indoor switchgear to a pole, then overhead approximately 1200 feet to the substation (approximately 43 feet wide by 115 feet long). There are existing poles in this area which will be replaced with 50-foot poles, of which approximately 10 feet will be below ground. The interconnection facilities between the new substation and the transmission line, approximately 460 feet, will consist of new overhead poles approximately 40 feet above ground. Access to the new structure and appurtenances will be from existing roadways at the site.

2.2 Pepacton Development

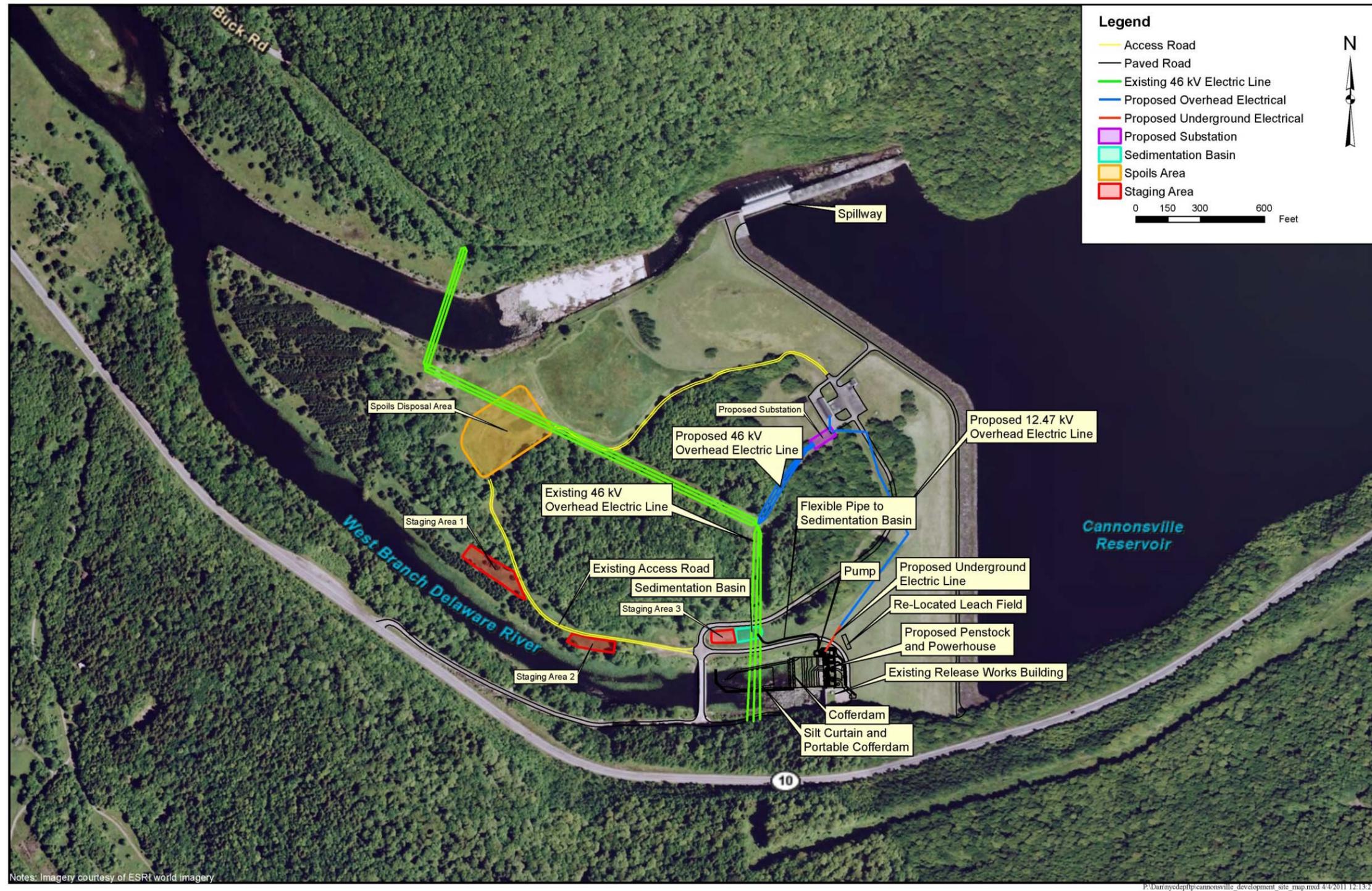
The Pepacton development consists of installing a turbine in one of the two pipe and valve assemblies in the existing release water chamber. [Figure 2.2-2](#) is the site plan showing the release water chamber, the proposed location of the associated electrical equipment (which will occupy an area approximately 9 feet wide by 12 feet long and include a small building), construction staging area, and interconnection with the NYSEG distribution system. Access to the electrical equipment will be from the existing roadway leading to the release water chamber and spillway crest. The interconnection lines connecting the facility to NYSEG's distribution system will be approximately 80 feet long and will be buried, if practical.

2.3 Neversink Development

The Neversink development consists of installing a turbine in one of the two pipe and valve assemblies in the valve chamber of the existing intake structure. [Figure 2.3-1](#) presents an overview of the proposed construction area showing the staging area, the location of the associated electrical equipment (which will occupy an area approximately 8 feet wide by 20 feet long and include a small building), and the interconnection with the NYSEG distribution system. Access to the electrical equipment will be from the

existing parking area adjacent to the intake chamber. Separate from the Project, the DEP is installing three three-inch conduits in an underground duct bank from State Route 55 to the intake chamber. One of those conduits will be used for the interconnection of the facility with NYSEG's distribution system.

Figure 2.1-1: Cannonsville Development Study Area



Notes: Imagery courtesy of ESRI world imagery

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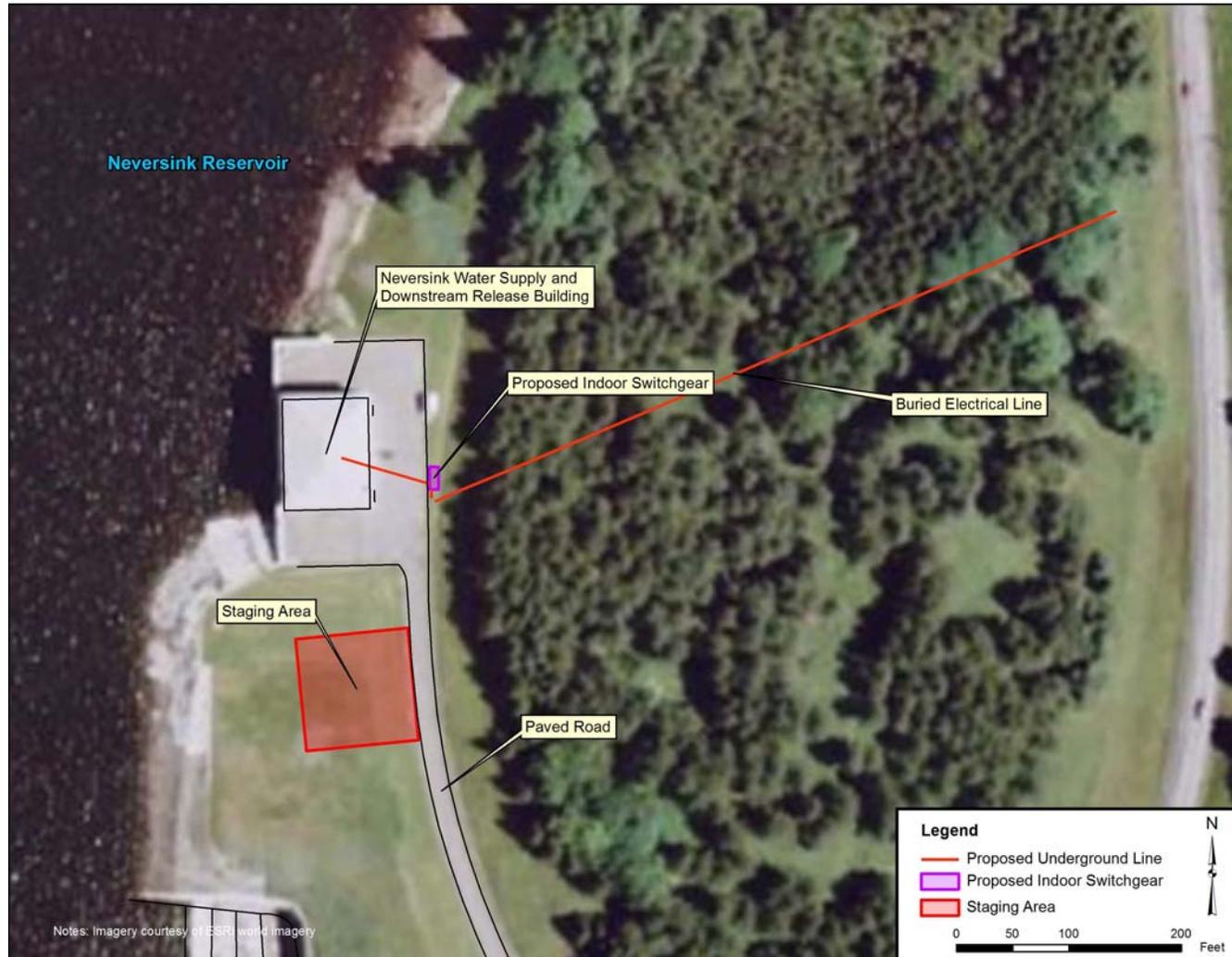
Notes: Imagery source: ESRI world imagery. All other data layers created by Gomez and Sullivan Engineers, P.C.

Figure 2.2-1: Pepacton Development Study Area.



Notes: Imagery source: ESRI world imagery. All other data layers created by Gomez and Sullivan Engineers. P.C.

Figure 2.3-1: Neversink Study Area.



Notes: Imagery source: ESRI world imagery. All other data layers created by Gomez and Sullivan Engineers, P.C.

3.0 METHODS

3.1 Base Map Preparation

Base maps were created prior to the field survey showing the Project areas and identifying potential public viewsheds of the Project areas. The identification of the potential viewsheds was accomplished using a combination of orthoimagery (ArcGIS software) and sightlines from the roadways and other areas to the Project areas.

3.2 Field Survey

On June 28, 29, and 30, 2010, the field survey was conducted and photographs were taken documenting the character of each development. In addition, photographs were taken from the identified public viewsheds and City-owned lands, referred to as “restricted areas”.¹

The field survey evaluated the potential viewsheds shown on the base maps. At Cannonsville, viewsheds of the location of the Cannonsville release works and proposed powerhouse, work/staging areas, substation, and the routes for the interconnection facilities were assessed. At Pepacton, the viewsheds were all directed to the release water chamber and surrounding area. At Neversink, the viewsheds were directed to the intake structure and surrounding area, as well as the route of the interconnection facilities. The survey examined the potential for impacts to aesthetics and the general character of the Project areas over the long-term arising from the new construction at the developments and temporarily associated with the construction activities.

[Figure 3.2-1](#) shows the photo locations taken at the Cannonsville development, which are labeled C1-C6. Photos locations are color-coded and reflect publicly accessible viewsheds (C1-C2) and restricted area viewsheds (C3-C6). The only sightlines from readily-accessible public viewsheds are from State Route 10, as shown on C1 and C2, and from Buck Road.² However, the views of the Project areas from those locations are highly obstructed by the surrounding vegetation.

[Figure 3.2-2](#) shows the photo locations taken at the Pepacton development, which are labeled as P1-P3 (P1-P2 are from publicly accessible viewsheds and P3 is from the restricted area). As a boater approaches the Project areas, the view would become obstructed by the earthen dam and the release water chamber. The distance between the public viewshed from State Route 30 and the electrical equipment, as well as the location of the release water chamber, as shown on P1 and P2, make the new facilities barely visible. Similarly, the distances involved will make the staging areas minimally visible from the reservoir and other public viewsheds.³

[Figure 3.2-3](#) shows the photo locations taken at the Neversink development, which are labeled as N1-N5 (N1-N4 are from publicly accessible viewsheds and N5 is from the restricted area). While the elevation differences between the reservoir surface and the Project areas will not present the same screening as at the other developments, the intake structure will shield the new facilities from view from many areas of

¹ While the reservoirs at all three developments are generally accessible to the public, boaters must stay at least 500 feet away from the dams and spillways.

² It may possible to see some or all of the Project areas from the surrounding hillsides, but such areas are not generally used by the public and are not included in the analysis.

³ As at Cannonsville, it may possible to see the Project areas from the surrounding hillsides, but such areas are not generally used by the public and are not included in the analysis.

the reservoir. As shown on NI-N3, there are public viewsheds of the new facilities and staging area from State Route 55. However, from all such viewsheds, the small size of the new facilities, their location relative to the intake structure and forest, and the distance between the roadway and the facilities will make them difficult to see or distinguish.⁴ The staging area will be more visible from the reservoir and roadway.

3.3 Photo Renderings

Using Adobe Photoshop, photo renderings were developed to depict the visual effect permanent structures and appurtenances will have on the character of the areas and, to the extent the new facilities are visible, to depict their aesthetic effect. These renderings are included in Section 4.0. At each development, vantage points were selected to highlight the relationship of the new facilities to their surroundings. In many cases, because the facilities are not visible from public viewsheds, the vantage points are from within the restricted areas. As applicable, such as at Neversink, both public and restricted vantage points were used.

⁴ The elevations of the lands around the Neversink Project areas are not as high as at Cannonsville and Pepacton. Therefore, the potential viewsheds from the surrounding lands are far more limited, and more likely to be obstructed by the vegetation. In any event, such areas are not generally used by the public and are not included in the analysis.

Figure 3.2-1: Cannonsville Photo Locations

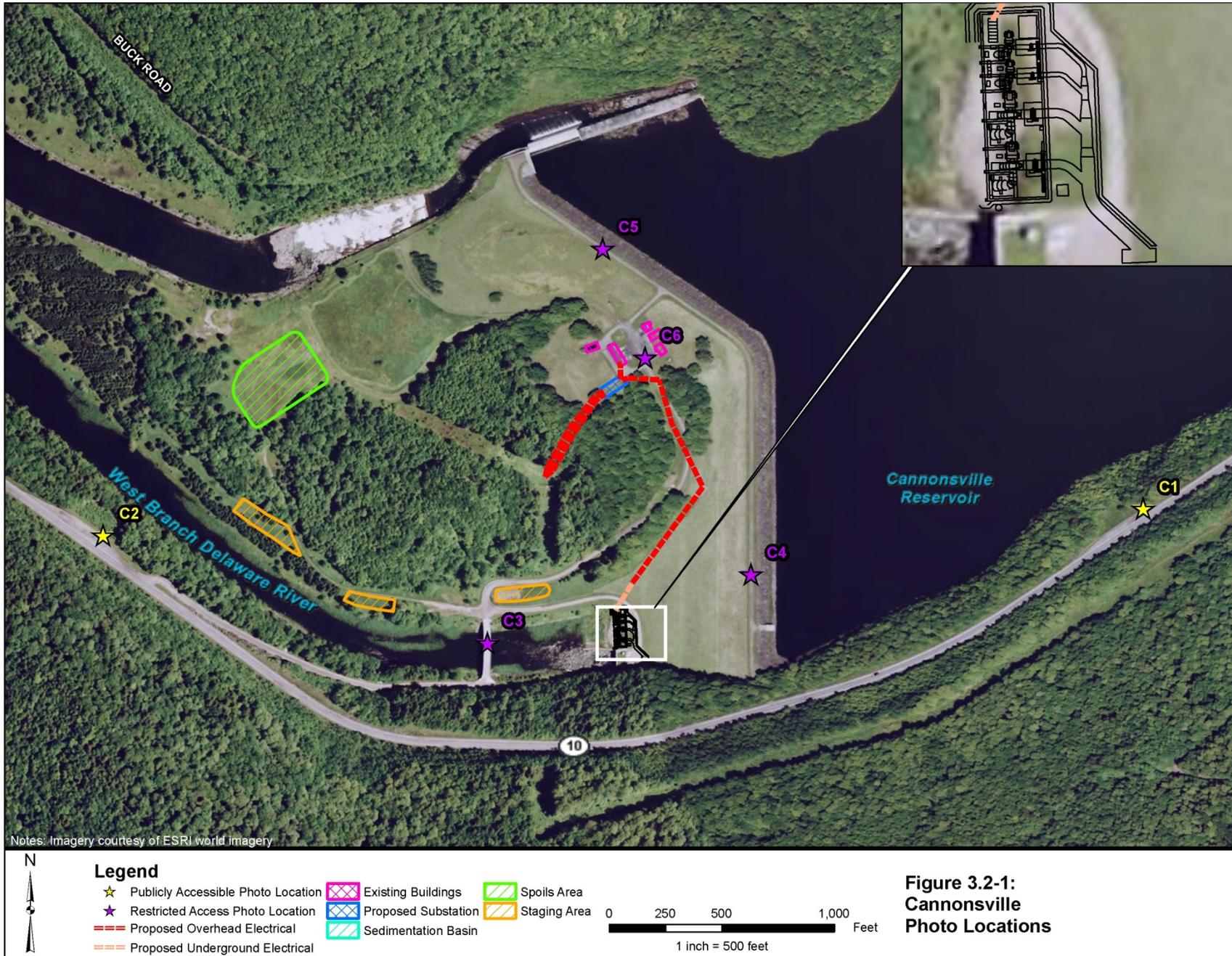
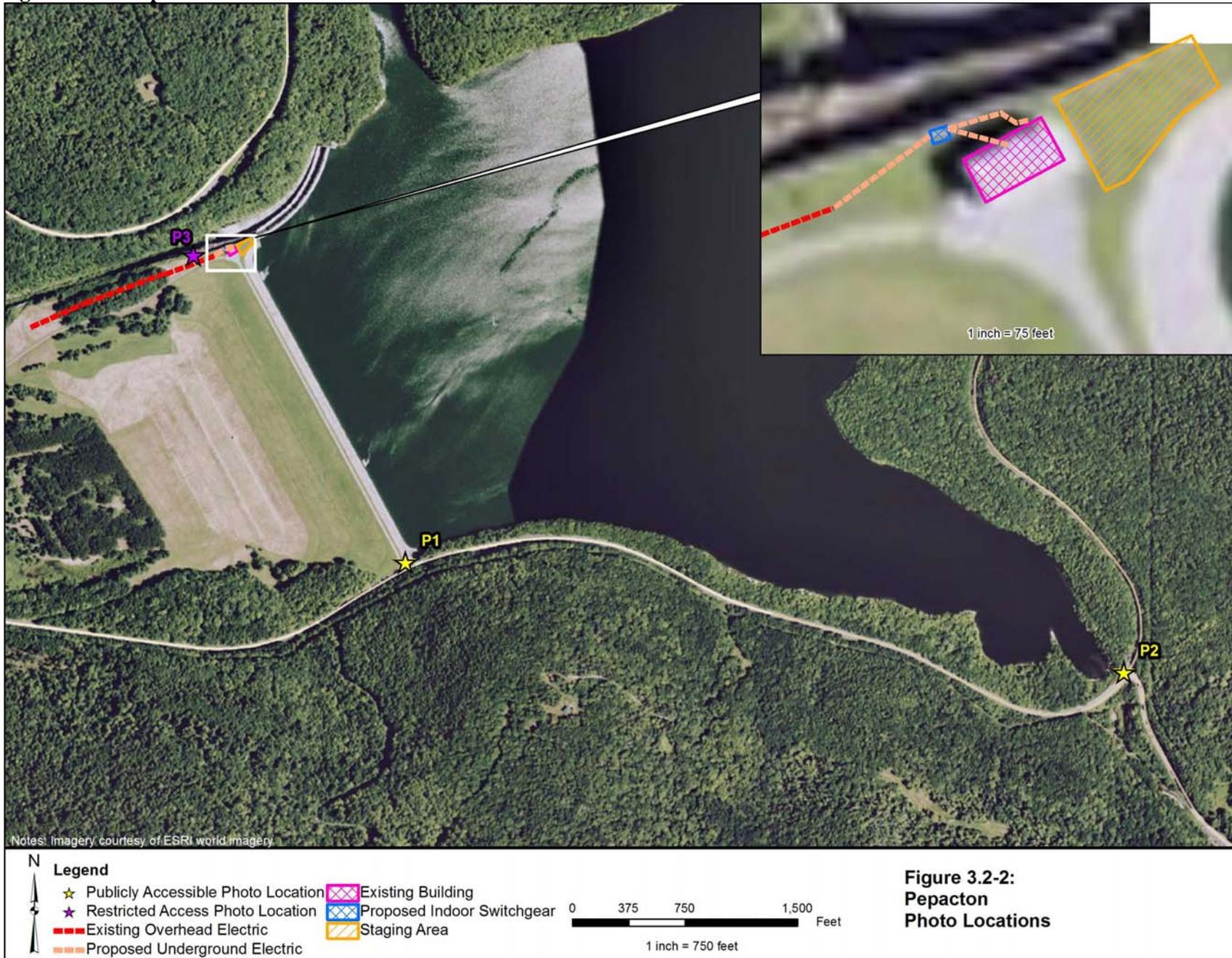


Figure 3.2-2: Pepacton Photo Locations



**Figure 3.2-2:
Pepacton
Photo Locations**

Figure 3.2-3: Neversink Photo Locations

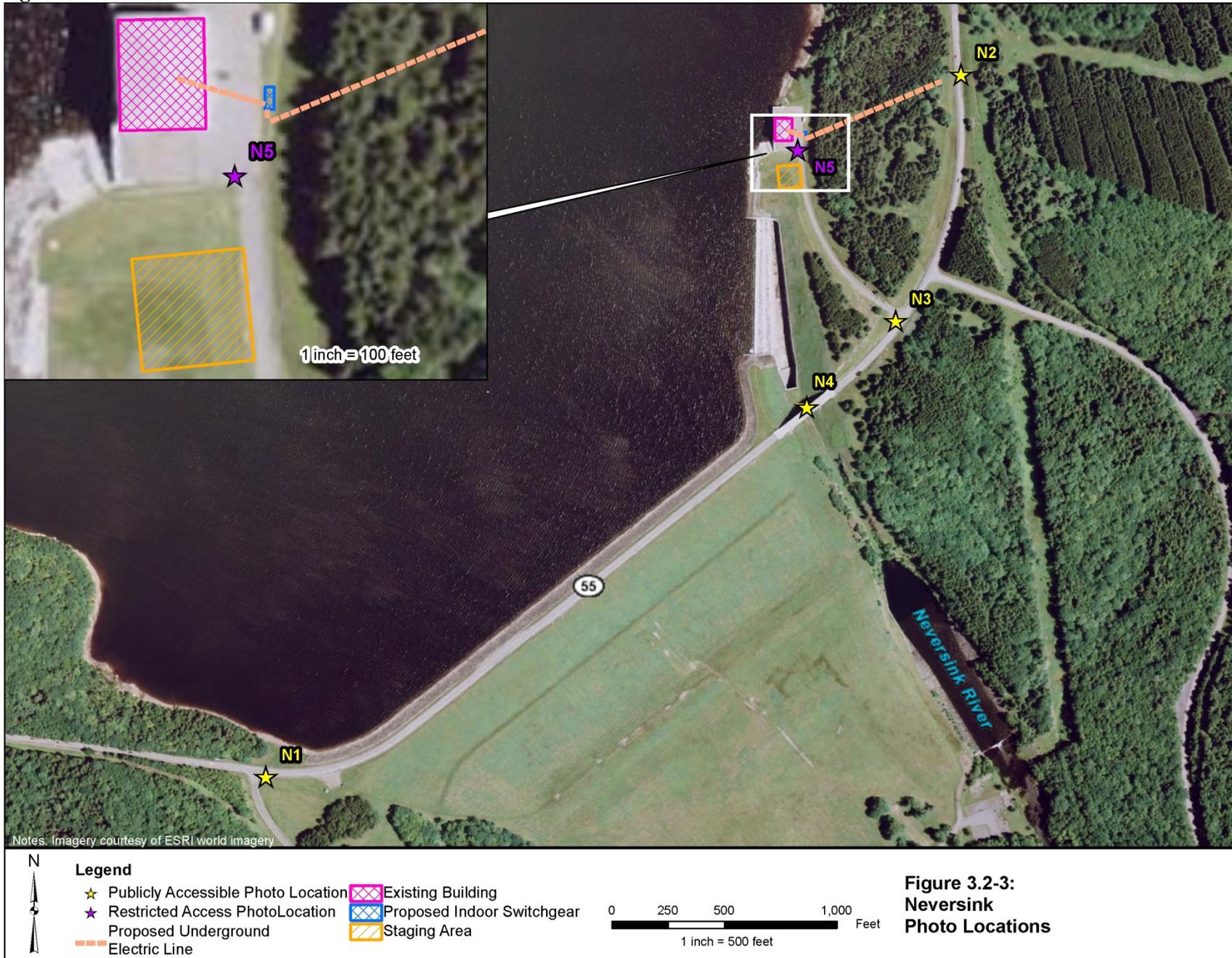


Figure 3.2-3:
Neversink
Photo Locations

4.0 RESULTS

4.1 Cannonsville Development

Public access for fishing on the Cannonsville Reservoir is allowed. Such access provides opportunities for the public to view the Project areas from the reservoir during this time. The land surrounding the Project areas is dense forest, with one major road traversing its southern edge and a minor road to the northwest. The Project areas maintain a natural feel, despite the existing structures, some of which (*e.g.*, the overhead power lines) blend in with the surrounding trees. Because the new structures and facilities will be constructed in the same locations as the existing structures, the general character of the development will remain the same.

4.1.1 Cannonsville Viewsheds

[Figure 4.1-1](#) shows the sightlines from the potential viewsheds discussed in Section 3.0. Based on the field survey and the ArcGIS analysis (which included a digital elevation model and 3D analyst extension), DEP concluded that the Project areas are not visible along any of the sightlines from the public viewsheds east of the Cannonsville Dam. The height of the earthen dam exceeds the height of the new structures and appurtenances. Therefore, and as shown on the figure, the dam fully screens the Project areas from the eastern viewsheds. As noted in Section 3.2 and above, the dense vegetation around the Project areas similarly screens the Project areas from the northern, western, and southern public viewsheds.

[Figure 4.1-2](#) shows the public viewshed located on State Route 10, about one-half mile east of the Project areas. This photograph demonstrates the above conclusion that the dam, as well as the vegetation in the area of the viewshed and behind the dam, fully screens the Project areas. Indeed, the existing service building that is next to the planned location of the substation is not visible at all from this location, indicating that the substation and other appurtenances also will not be visible.

To the west of the project location there is a pull-off on State Route 10, just before the access road, shown on [Figure 4.1-3](#). This viewshed is about 1,700 feet from the Project areas. Due to the dense vegetation around this public viewshed, the bulk of the Project areas are fully screened. Although construction vehicles entering and leaving the development site would be visible from this location, the relatively compact nature of the construction activities and the plan to dispose of spoils on-site, the number of vehicles trips is expected to be relatively limited and primarily involve mobilization, deliveries, demobilization, and the arrival and departure of the construction workers.

Buck Road is north of the Project areas, as shown on [Figure 4.1-1](#), but does not extend along the entire northern boundary. The point at which this road ends, approximately 3,000 feet northwest of the Project, does not provide any public viewshed of the Project areas.

4.1.2 Cannonsville Aesthetic and Area Character Analysis

The Project will not have any material adverse impact on aesthetics or the character of the area because none of the Project areas are visible from the identified public viewsheds.⁵ Moreover, most of the new structures and appurtenances will be constructed adjacent or near to existing structures, thereby

⁵ As noted in Section 3.2, it may possible to see some or all of the Project areas from the surrounding hillsides. For the same reasons explained in this Section 4.1.2, the visibility of the Project areas from such locations would not lead to any material adverse impacts on aesthetics or the general character of the area.

minimizing the magnitude of the disruption to the natural environment. To the extent possible, the new structures will be constructed using materials and techniques that will harmonize them with the existing structures. Further, while the distances from the public viewsheds to the Project areas and the dam are sufficient to screen the Project areas from most vantage points, a majority of the trees comprising the vegetative screening are coniferous, obstructing views even during winter months.

Within the restricted area, there could be some minimal impacts on aesthetics and the character of the area, but such impacts would not rise to level of being materially adverse. The powerhouse will be constructed next to the low-level outlet works and will be visible from the access road bridge ([Figure 4.1-4](#)) and the road atop the reservoir ([Figure 4.1-5](#)). The substation will be visible from the road atop the reservoir ([Figure 4.1-8](#)) and some of the lands near the spillway ([Figure 4.1-10](#)). [Figure 4.1-6](#) and [Figure 4.1-7](#) depict the powerhouse from the access road bridge and atop the dam, and [Figure 4.1-9](#) and [Figure 4.1-11](#) depict the substation from different vantage points along the road atop the dam. As noted above, the manner of location of these new structures and appurtenances will minimize their effect on the natural character of the Project areas.

The generator lead from the powerhouse to the substation will traverse the same path as an existing overhead electric line. For this reason, it will not have any incremental impact on aesthetics or the character of the area. The construction of the interconnection facilities will involve new poles and overhead electric lines, but they will be virtually unseen from most of the restricted area due to the shielding provided by surrounding trees and the topography of the land. For this reason, the area will maintain its current character.

Figure 4.1-1: Cannonsville Viewsheds and Sightlines

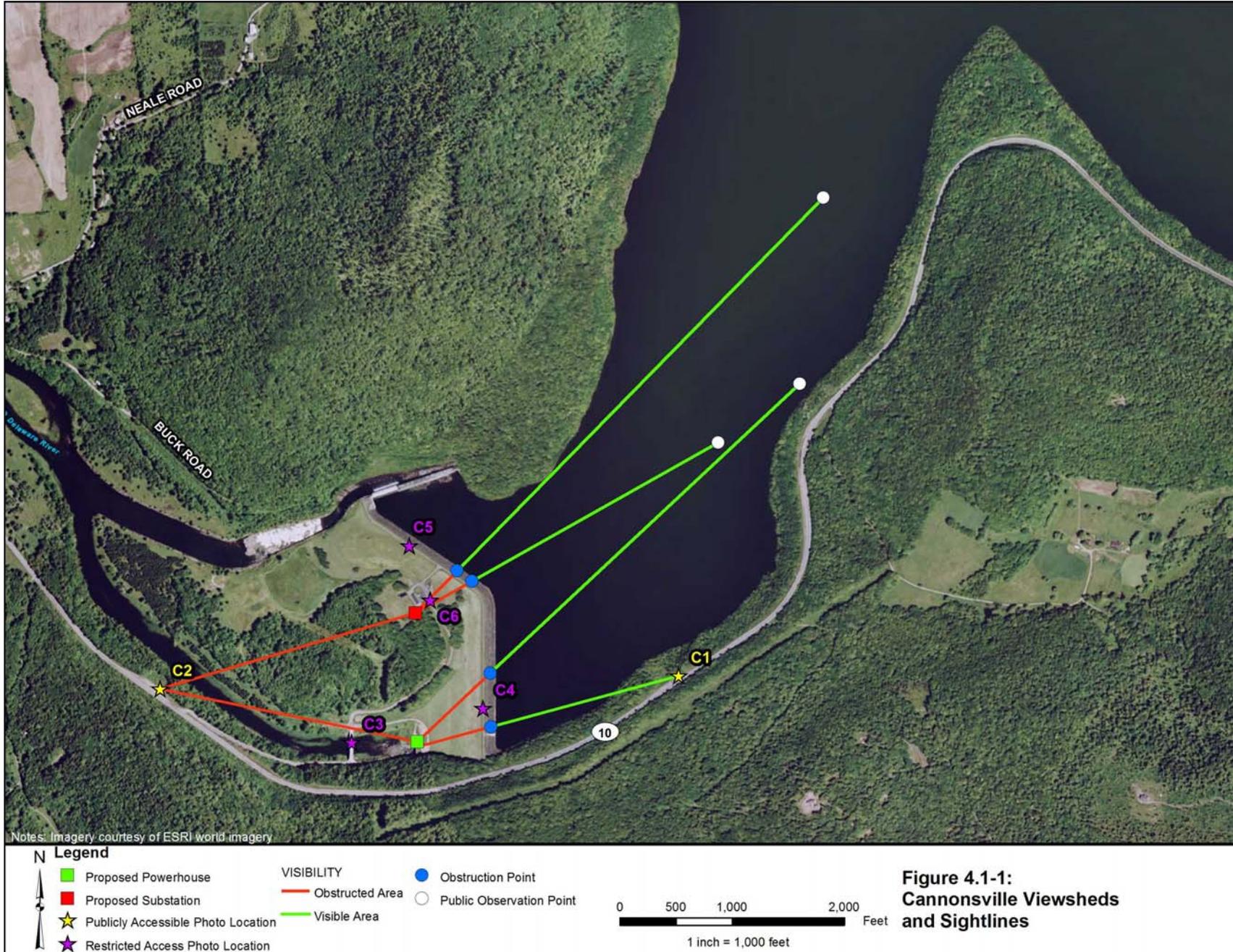


Figure 4.1-1:
Cannonsville Viewsheds
and Sightlines

Figure 4.1-2: C1 – View of Cannonsville from pulloff on State Route 10



Figure 4.1-3: C2 – View of Cannonsville from State Route 10



Figure 4.1-4: C3 – View of proposed powerhouse area from the bridge within the restricted area

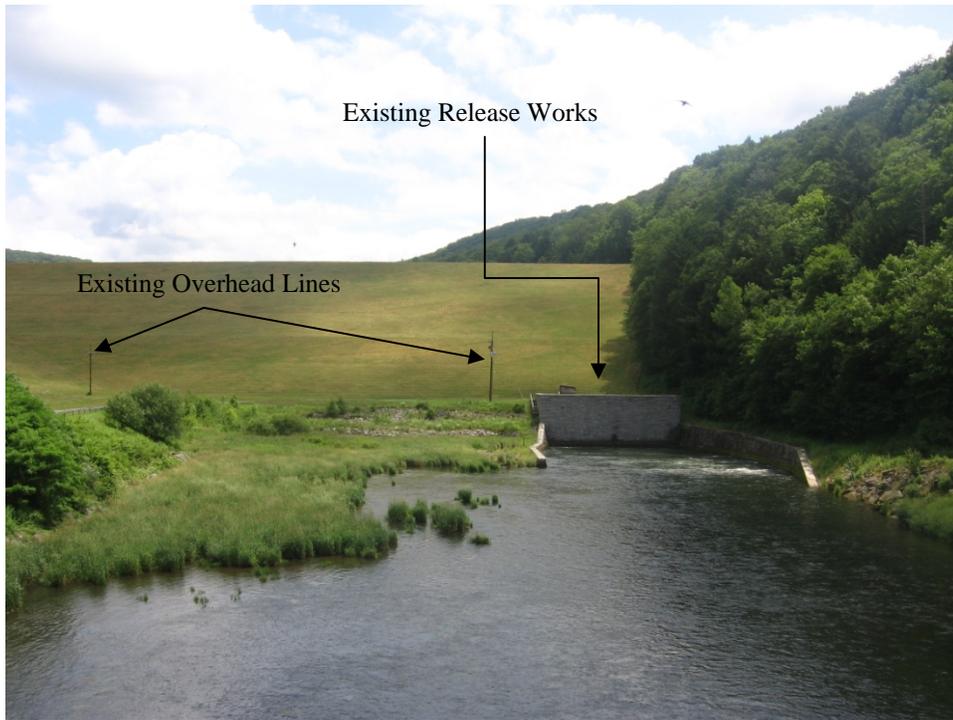


Figure 4.1-5: C4 – View of proposed powerhouse area from the road atop the Cannonsville Dam within the restricted area

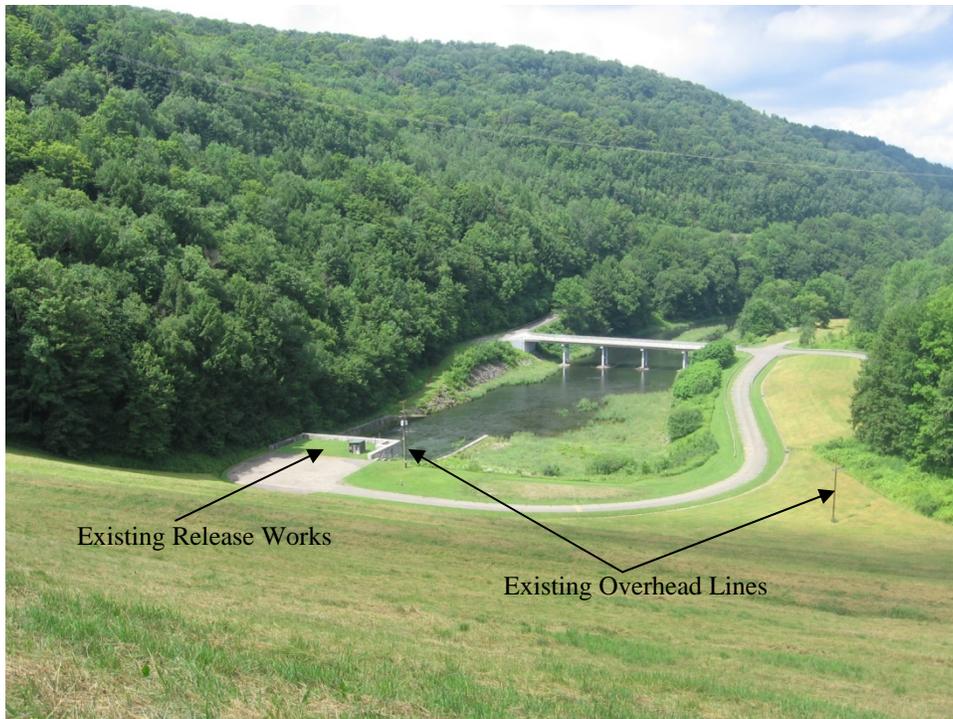


Figure 4.1-6: Photo rendering from the bridge within the restricted area



Figure 4.1-7: Photo rendering from the road atop the Cannonsville Dam within the restricted area



Figure 4.1-8: C5 – View of proposed substation location from atop dam within restricted area



Figure 4.1-9: Photo rendering of substation from atop dam within restricted area



Figure 4.1-10: C6 – View from near existing building within restricted area of substation location



Figure 4.1-11: Photo rendering from the road atop the Cannonsville Dam within the restricted area



4.2 Pepacton Development

Public access for fishing on the Pepacton Reservoir is allowed. This access provides opportunities for the public to view the Project areas from the reservoir. The land surrounding the Project areas is dominated by dense forest, with one major road along the southern edge of the reservoir and a minor road along the northern edge. The Project areas are comprised of mowed lawn and pavement, with an existing release water chamber and adjacent distribution line. Because the generating equipment will be constructed within the existing structure, and the new appurtenances are small and will be constructed either underground or very near the existing structure, the general character of the development will not be changed by the Project.

4.2.1 Pepacton Viewsheds

[Figure 4.2-1](#) shows the sightlines from the potential viewsheds discussed in Section 3.0. Based on the field survey and the ArcGIS analysis, DEP concluded that public viewsheds of the Project areas will be limited and the new appurtenances will be barely visible, if visible at all. There are direct sightlines to the appurtenances from the entrance to the Project areas on State Route 30 and from a small area on the reservoir, but the distances from those public viewsheds would be approximately 2,500 feet and at least 1,300 feet (the elevation difference between the surface of the reservoir and the top of the dam will obstruct the view of the Project areas from 1,300 feet to the 500-foot boundary of the restricted area), respectively. From the north and east, dense vegetation will fully screen the Project areas.

The public viewshed from State Route 30 at the entrance to the Project areas is shown on [Figure 4.2-2](#). The staging area would be visible from this location but the new electrical equipment that comprises the appurtenances to the generating facility would be partially shielded by the release water chamber. Additionally, construction vehicles entering and leaving the development site would be visible from this location. However, given the nature and extent of the construction activities, the number of vehicles trips is expected to be relatively limited and primarily involve mobilization, deliveries, demobilization, and the arrival and departure of the construction workers.

[Figure 4.2-3](#) shows a second public viewshed from State Route 30 to the southeast of the Project areas. While the staging area is potentially visible from this location, it is barely visible. The appurtenances would be fully screened by the release water chamber.

A third possible public viewshed was identified from State Highway Route 30A, which is directly north of the site. However, due to the topography of the area and the dense vegetation, the Project areas are not visible from this location.

4.2.2 Pepacton Aesthetic and Area Character Analysis

The Project will not have any material adverse impact on aesthetics or the character of the area because the visibility of the appurtenances and staging area from the public viewsheds is very limited to non-existent.⁶ To the extent the Project areas are visible, they are at substantial distances from the public viewsheds. As a result, the relative size of the appurtenances is greatly reduced, and the ability to distinguish the construction activities taking place on the staging area is similarly restricted. Moreover, due to their size and scale relative to the release water chamber, the appurtenances will essentially blend

⁶ As noted in Section 3.2, it may possible to see some or all of the Project areas from the surrounding hillsides. For the same reasons explained in this Section 4.2.2, the visibility of the Project areas from such locations would not lead to any material adverse impacts on aesthetics or the general character of the area.

in with the existing structure from most of the public viewsheds, further minimizing their impact on aesthetics and the character of the area. Because all new electric lines will be constructed underground, they will not have any impacts on aesthetics or the area character.

Temporary impacts may arise from the construction activities and vehicle trips described above. However, due to the size of the Project, the amount of visible construction activity and traffic will be limited. Therefore, the construction activities will not cause any material adverse impacts on aesthetics or the character of the area.

[Figure 4.2-4](#) shows a view of the location of the appurtenances from a grassy area to the west of the release water chamber, within the restricted area. [Figure 4.3-5](#) depicts the appurtenances that would be constructed at this location. Because they will occupy an already disturbed area, and as shown by the rendering, the addition of these facilities will not change the character of the area.

Figure 4.2-1: Pepacton Viewsheds and Sightlines

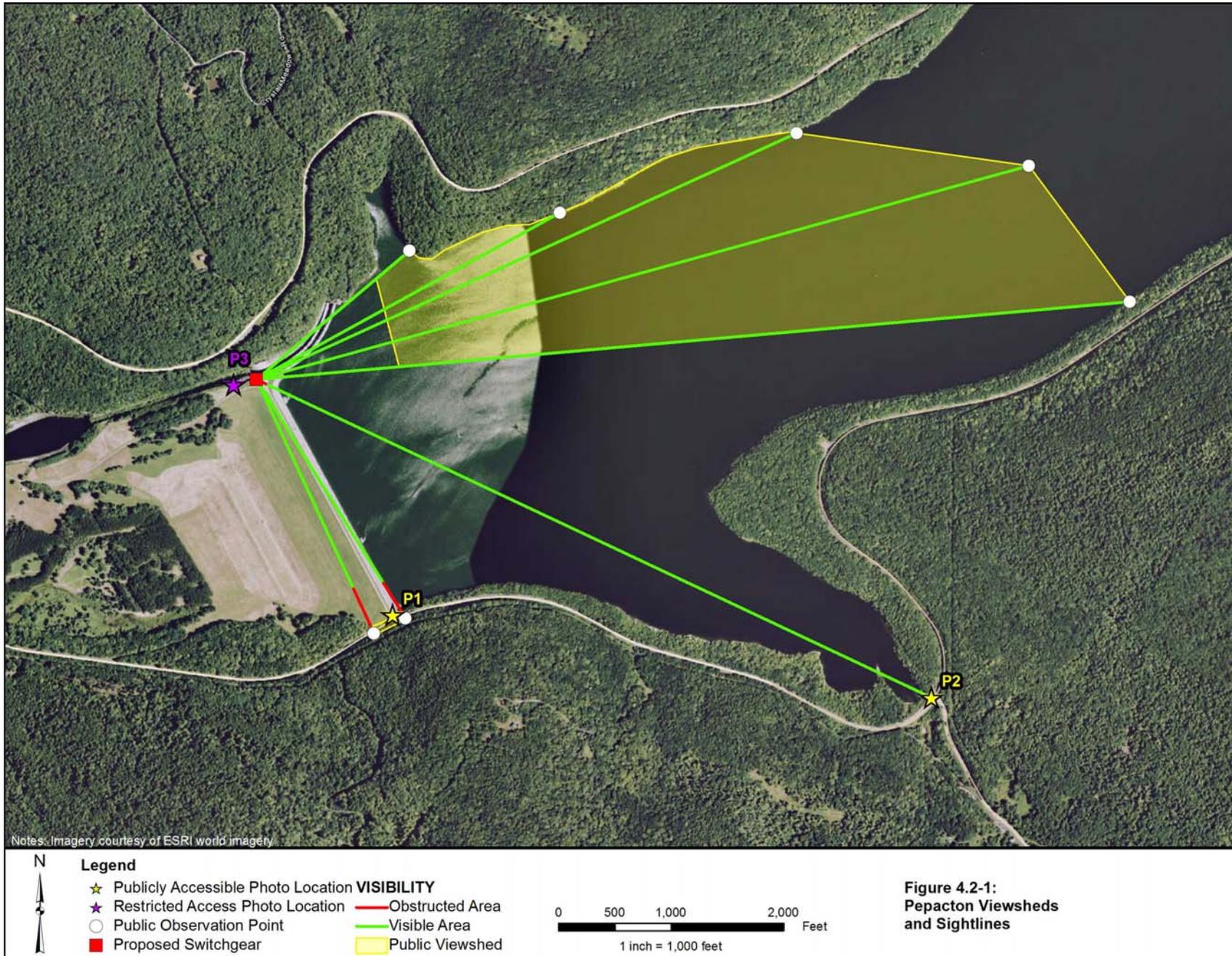


Figure 4.2-1:
Pepacton Viewsheds
and Sightlines

Figure 4.2-2: P1 – View of Pepacton development from DEP owned Access Road

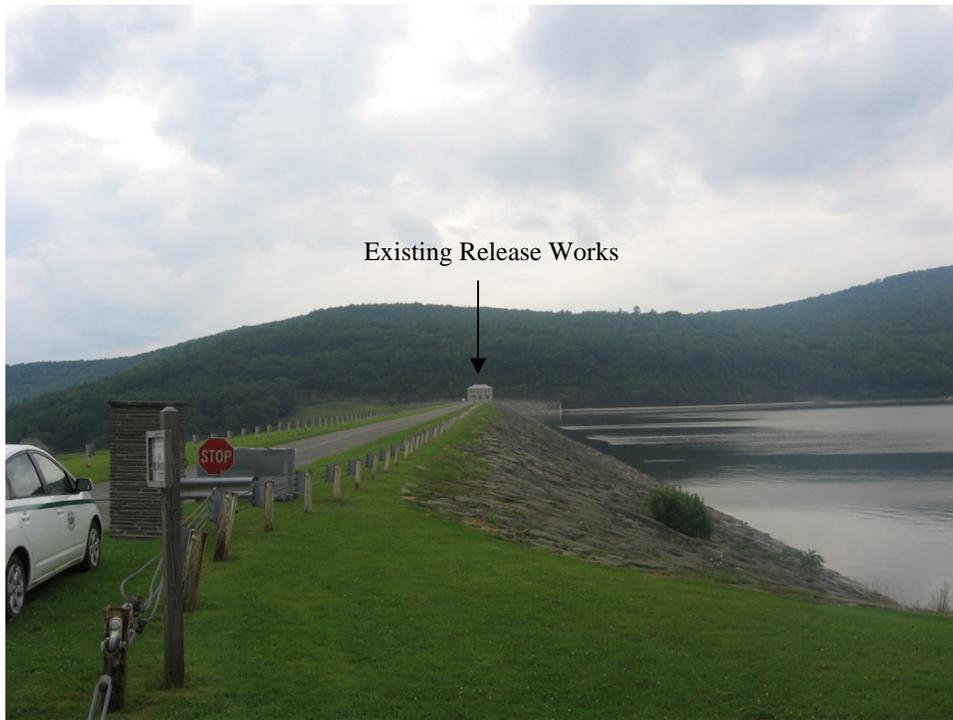


Figure 4.2-3: P2 – View of Pepacton development from State Route 30

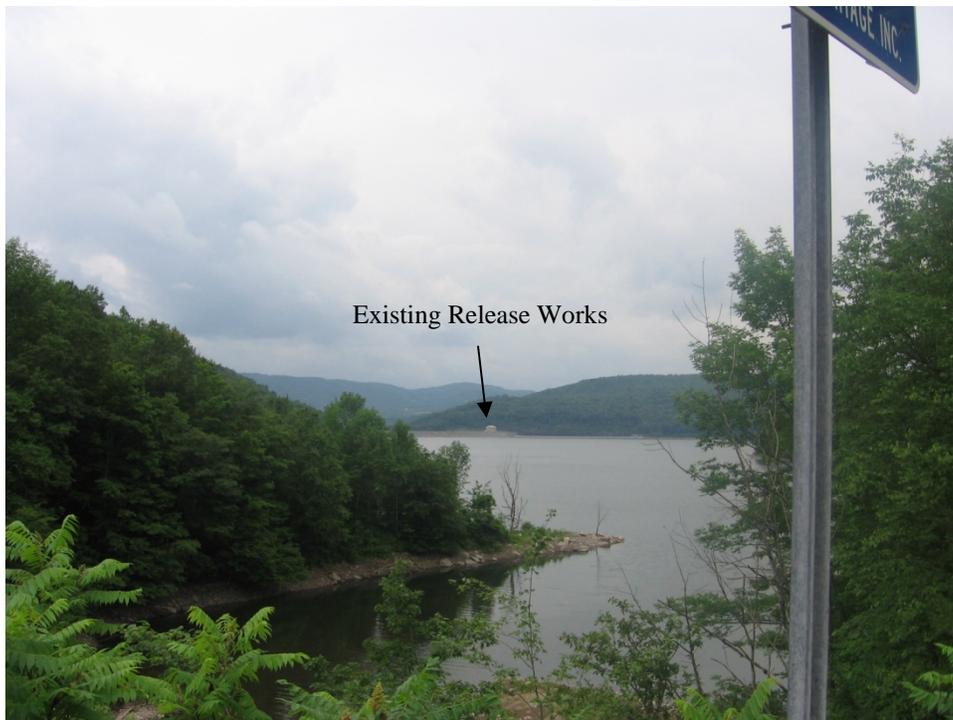
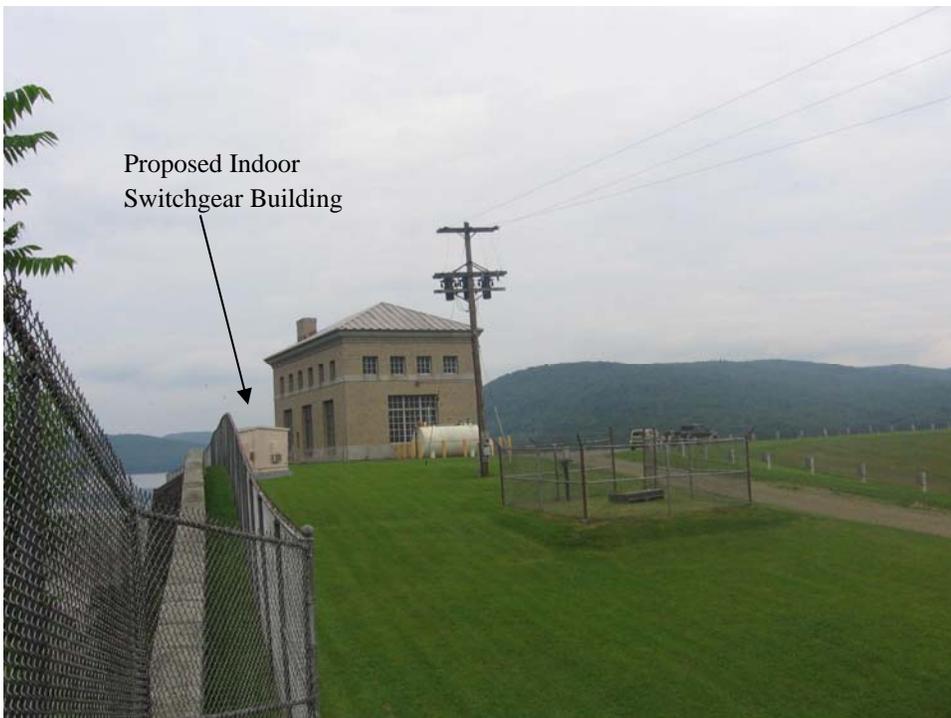


Figure 4.2-4: P3 – View of proposed switchgear building location from within restricted area



Figure 4.2-5: Photo rendering of switchgear building from within restricted area



4.3 Neversink Development

Public access for fishing on the Neversink Reservoir is allowed. This access provides opportunities for the public to view the Project areas from the reservoir. The land surrounding most of the Project areas is comprised of dense forest, with a major road along the top of the dam to the west, south, and east of the development site. The Project areas consist of mowed lawn, pavement, the existing intake structure, and a forested area. Because the generating equipment will be constructed within the existing structure, and the new appurtenances are small and will be constructed either underground or very near the existing structure, the general character of the development will not be changed by the Project.

4.3.1 Neversink Viewsheds

[Figure 4.3-1](#) shows the sightlines from the potential viewsheds discussed in Section 3.0. Based on the field survey and the ArcGIS analysis, DEP concluded that public viewsheds of the Project areas will be limited and the new appurtenances will be barely visible, if visible at all. There are direct sightlines to the appurtenances from certain parts of the reservoir and from State Route 55. However, the distances from those public viewsheds range from 500 feet to more than a half-mile.

[Figure 4.3-2](#) shows the public viewshed from the southwest, near the intersection of State Route 55 and Divine Corners Road. From this viewshed, there is a clear view of the intake structure. However, because this viewshed is nearly a half-mile from the structure, and the electrical equipment that comprises the appurtenances to the generating facility is screened by existing structure, the addition of such facilities will not change the view of the Project areas. While the temporary staging area will be visible from this location, it will comprise a very small portion of the view.

[Figure 4.3-3](#) shows the public viewshed directly to the east of the powerhouse on State Route 55. The dense vegetation obstructs all views of the Project areas except the point of interconnection with NYSEG's distribution facilities. Because the interconnection facilities will be placed underground, they will not be seen.

[Figure 4.3-4](#) shows the access road leading from State Route 55 to the intake building. Although construction vehicles will be seen entering and leaving the Project areas, the elevation drop will prevent the public from seeing the construction activity or the appurtenances from this location. Given the nature and extent of the construction activities, the number of vehicles trips is expected to be relatively limited and primarily involve mobilization, deliveries, demobilization, and the arrival and departure of the construction workers.

[Figure 4.3-5](#) shows the public viewshed from State Route 55 as it traverses the spillway adjacent to the Neversink Dam. From this vantage point, the Project areas would be visible. Because there is no pull-off at this location, the public would not routinely stop in this area and would have no more than fleeting glances of the Project areas.

4.3.2 *Neversink Aesthetic and Area Character Analysis*

The Project will not have any material adverse impact on aesthetics or the character of the area because the visibility of the appurtenances and staging area from the public viewsheds is limited.⁷ To a large extent, the Project areas are at substantial distances from the public viewsheds. As a result, the relative size of the appurtenances is greatly reduced. Further, due to their size and scale relative to the intake structure, and their location near a forested area, the appurtenances will essentially blend in with that structure and forest from most of the public viewsheds, further minimizing their impact on aesthetics and the character of the area. Because all new electric lines will be constructed underground, they will not have any impacts on aesthetics or the area character.

While the construction activities taking place on the staging area may be more noticeable, the nature of the Project will limit the amount of visible construction activity and traffic, and the staging area itself is relatively small. Therefore, the construction activities will not cause any material adverse impacts on aesthetics or the character of the area.

[Figure 4.3-6](#) depicts the appurtenances that would be constructed as seen from State Route 55. As shown by the photograph, they are essentially invisible from this vantage point. [Figure 4.3-7](#) shows the location appurtenances from within the restricted area, and [Figure 4.3-8](#) depicts the appurtenances from the same vantage point. Because the appurtenances will occupy an already disturbed area, and as shown by the rendering, the addition of these facilities will not change the character of the area.

⁷ As noted in Section 3.2, it may possible to see some or all of the Project areas from the surrounding lands. For the same reasons explained in this Section 4.3.2, the visibility of the Project areas from such locations would not lead to any material adverse impacts on aesthetics or the general character of the area.

Figure 4.3-1: Neversink Viewsheds and Sightlines

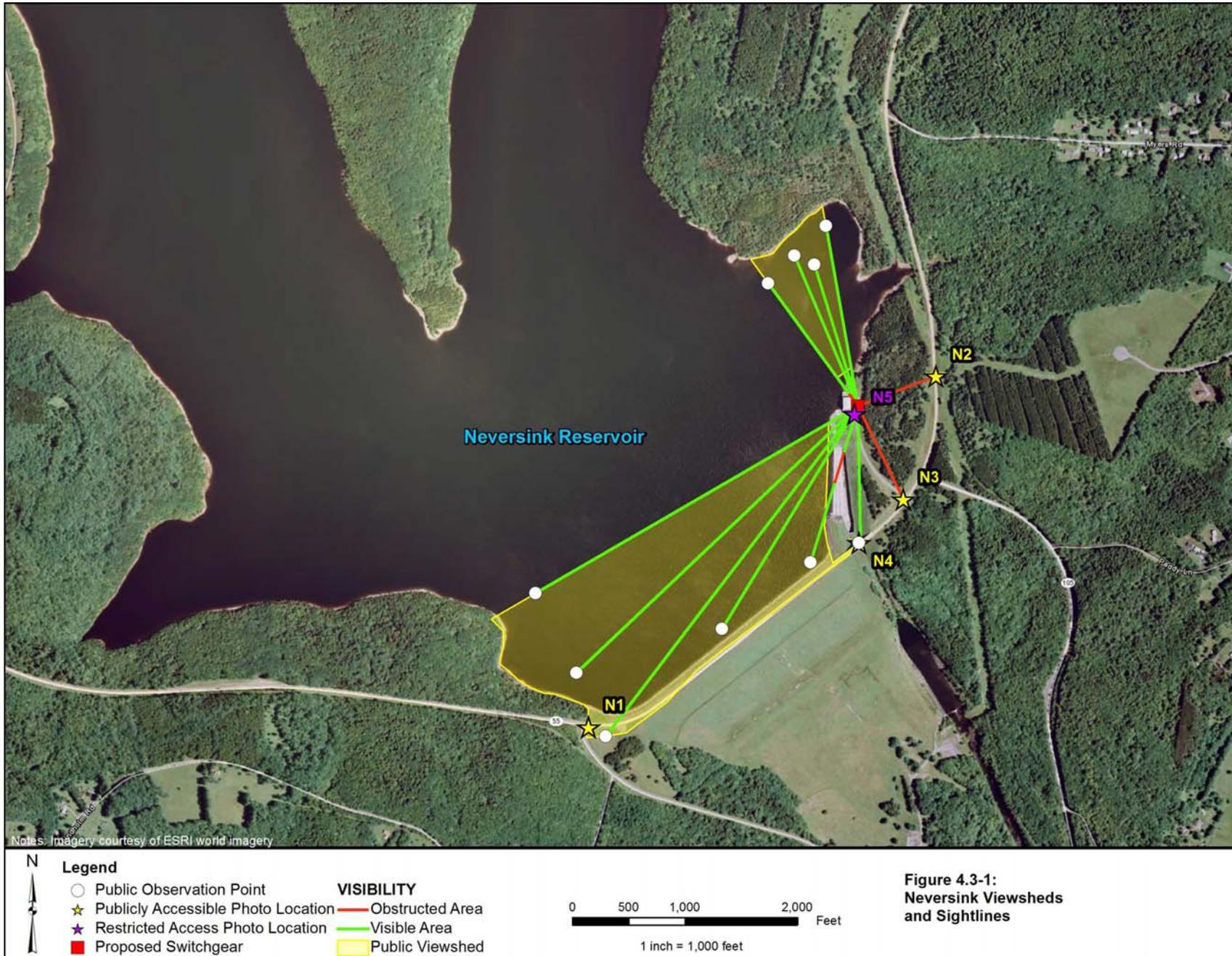


Figure 4.3-1:
Neversink Viewsheds
and Sightlines

Figure 4.3-2: N1 – View to Neversink development from State Route 55



Figure 4.3-3: N2 – View along State Route 55 of the existing distribution line serving the Neversink intake structure



Figure 4.3-4: N3 – View of the restricted access road to the Neversink development from State Route 55



Figure 4.3-5: N4 – View of the Neversink development from State Route 55 (note: this is not a stopping area)



Figure 4.3-6: Rendering of indoor switchgear building from photo location N4



Figure 4.3-7: N5 – Photo of indoor switchgear building location from restricted area



Figure 4.3-8: Rendering of indoor switchgear building from restricted area



5.0 MITIGATION

Because no material adverse impacts have been identified related to the construction activities or permanent structures to be added at the three developments, no mitigation strategies need to be developed or assessed.

**BEFORE THE FEDERAL ENERGY REGULATORY COMMISSION
APPLICATION FOR LICENSE FOR MAJOR PROJECT –
EXISTING DAM**

Cannonsville Hydroelectric Development

FERC Project No. 13287



VOLUME 9

Appendix E-7: Socioeconomic Study Report

City of New York



**Environmental
Protection**

September 2011

**City of New York
West of Hudson Hydroelectric Project**

Project No. 13287

Socioeconomic Study Report

Cannonsville, Pepacton, and Neversink Developments

Study Conducted By:

Hugh O'Neill Ltd d/b/a Appleseed

and

Bates White, LLC



August 2011

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EXECUTIVE SUMMARY

The City of New York (“City”), acting through the New York City Department of Environmental Protection (“DEP”) has filed with the Federal Energy Regulatory Commission (“FERC”) a Notice of Intent (“NOI”) to develop hydroelectric generation at the West of Hudson Hydroelectric Project, FERC Project No. 13287 (“Project”). As part of the licensing process for the Project, the City commissioned the conduct of a socioeconomic study with respect to the three developments (*i.e.*, Cannonsville, Neversink and Pepacton) associated the Project. This report presents the results of such study and is being submitted to FERC in support of the license application for the proposed Project.

The objective of the socioeconomic study was to identify and quantify the impacts of constructing and operating the three Project developments on factors such as employment, local government services, local tax revenues, and other relevant factors with respect to the municipalities and counties in the vicinity of the Project (“Impact Area”). In addition, other factors such as Project-related impacts on wholesale electricity prices and pollutant emissions were analyzed.

The City engaged the services of Hugh O’Neill Ltd d/b/a Appleseed (“Appleseed”) and Bates White, LLC (“Bates White”) to conduct the socioeconomic study of the Project. Appleseed conducted an analysis of Project impacts of traditional socioeconomic factors considered by FERC (*e.g.*, employment, population, local tax revenues and local government services). The analysis conducted by Bates White primarily focused on the potential Project-related impacts on wholesale electricity prices and pollutant emissions associated with electricity production in New York.

Economic Impact of Project Construction and Operation

Using the IMPLAN input-output modeling system – an econometric modeling system commonly used in the analyses of economic impacts – the direct, indirect and induced (or “multiplier”) effects of Project construction and ongoing operation were estimated.

Cannonsville Development

Of a total estimated construction cost of approximately \$42.5 million, it is projected that nearly \$3.1 million would be paid either to Delaware County subcontractors or to Delaware County residents employed by non-local contractors and subcontractors, generating 49 person-years of employment for Delaware County residents in construction and related industries during the anticipated 36 month construction period associated with the Cannonsville development. Through the multiplier effect, construction of the Cannonsville development is estimated to generate approximately \$1.2 million in additional economic output in Delaware County and ten person-years of employment.

Once fully operational, ongoing operation of the Cannonsville development is estimated to increase Delaware County’s annual economic by more than \$2.7 million.

Pepacton Development

Of a total estimated construction cost of approximately \$8.1 million, it is projected that approximately \$491,000 would be paid either to Delaware County subcontractors or to Delaware County residents employed by non-local contractors and subcontractors, generating 8 person-years of employment for Delaware County residents in construction and related industries during the anticipated 21 month construction period associated with the Pepacton development. Through the multiplier effect, construction of the Pepacton development is estimated to generate approximately \$192,000 in additional economic output in Delaware County and two person-years of employment.

Once fully operational, ongoing operation of the Pepacton development is estimated to increase Delaware County's annual economic by approximately \$454,000.

Neversink Development

Of a total estimated construction cost of approximately \$4.4 million, it is projected that approximately \$274,000 would be paid either to Sullivan County subcontractors or to Sullivan County residents employed by non-local contractors and subcontractors, generating 5 person-years of employment for Sullivan County residents in construction and related industries during the anticipated 21 month construction period associated with the Neversink development. Through the multiplier effect, construction of the Neversink development is estimated to generate approximately \$120,000 in additional economic output in Sullivan County and one person-years of employment.

Once fully operational, ongoing operation of the Neversink development is estimated to increase Delaware County's annual economic by slightly less than \$273,000.

Impact on Local Tax Revenues and Local Governmental Services

Assuming that: (a) the market value of each Project development is roughly equal to the respective construction costs of each development; and (b) equalization rates and tax rates for each of the three respective towns in which each development is located are the same as they were in 2010, an estimate of the applicable town, county and school property taxes to be paid with respect to each development was calculated. Utilizing these assumptions, the estimated town, county and school property taxes to be paid with respect to each development during its respective first year of operation are as follows: (a) approximately \$1.7 million for the Cannonsville development; (b) approximately \$158,000 for the Pepacton development; and (c) approximately \$112,000 for the Neversink development.

Due primarily to the relatively small number of new jobs associated with ongoing operations at each Project development, the respective impact of each development on local government services is expected to be minimal.

Impact on Recreation and the Character of the Affected Communities

Because: (a) the City is merely seeking to generate power from the discharges it is already obligated to provide and will continue to provide such discharges in accordance with the requirements of the operating protocol applicable to the operation of the reservoirs associated with each Project development; and (b) the Project developments are being constructed at existing facilities, the Project developments are expected to neither create new recreational opportunities nor impair existing recreational activities undertaken on the reservoir or downstream environs associated with each Project development.

Furthermore, the impact of each Project development on the character of the affected communities is expected to be minimal for several reasons, including: (a) the small increase in labor demands associated with the developments is unlikely to affect wages in either the directly affected industries or the labor force more broadly; (b) because the resident labor force in the two affected counties (*i.e.*, Delaware and Sullivan counties) and surrounding areas would easily absorb the small increase in labor demands generated by the Project developments, the developments are not anticipated to affect demand for housing or housing costs in such areas; and (c) due to their small impact on labor demands, the developments are not expected to affect other aspects of community character such as the predominantly low-density, rural character of the affected communities, existing patterns of land use and development, or the overall mix of local economic activity.

Impacts on Wholesale Energy Prices, Pollutant Emissions and System Reliability

In addition to the traditional socioeconomic impact assessment, three additional analyses were performed to assess the effects of the Project developments on reducing wholesale energy prices, reducing pollutant emissions and supporting reliability of the electric system.

Wholesale Energy Market Impacts

Electricity generated from the Project developments would lower wholesale market energy prices by displacing higher cost marginal generation in some hours. The estimated annual dollar benefit of such price reductions for the western region of the control area administered by the New York Independent System Operator, Inc. (“NYISO”) is approximately \$13.6 million annually.

Environmental Externality Benefits

Generation from the Project developments, estimated to be approximately 57,000 megawatt-hours (“MWh”) per year of emissions-free electricity, would provide environmental benefits by displacing generation of electricity from fossil fuels. Electricity generated from the Project developments will result in reductions in emissions by fossil-fueled generation sources by as much as 64,000 tons of carbon dioxide (“CO₂”), 170 tons of nitrogen oxides (“NO_x”), and 370 tons of sulfur dioxide (“SO₂”) annually, depending on the type of fossil-fuel generation displaced by the electricity produced from the Project developments. The estimated CO₂ emissions reductions are equivalent to removing between 5,600 and 11,100 vehicles from the road, depending on the type of fossil-fuel generation displaced.

Electric System Reliability Benefits

Interconnection of the Project developments may provide additional reliability and power quality benefits at both the local and the Statewide level, including the provision of certain ancillary services. These ancillary services are typically used by the transmission system operator to balance supply and demand and maintain the reliability and security of the system within acceptable standards. The ancillary services that the Project developments may be suited to provide include regulation service and frequency control, and reactive power supply and voltage support. Additionally, the proposed Project developments may have the effect of delaying the need for New York State Electric & Gas Corporation (“NYSEG”) to invest in upstream capacity needed to meet future load growth along the feeders to which they are connected.

1.0 INTRODUCTION

On September 15, 2008, the City, acting through DEP, filed an application for a preliminary permit with FERC to develop hydroelectric generation at four sites (*i.e.*, Project developments) that together comprise the Project.¹ Through the Project, the City is considering developing hydroelectric facilities at the Project developments, while simultaneously maintaining its crucial water supply operations in accordance with long-term sustainable drinking water needs, conservation releases, directed releases, water quality standards, and various other conditions affecting the City's water supply system, including determinations by and/or agreements with the U.S. Environmental Protection Agency, the New York State Department of Health, the New York State Department of Environmental Conservation, and the Delaware River Basin Commission. The delivery of high quality drinking water to approximately one-half of New York State's total population will remain the primary purpose and function of DEP's operations at the reservoirs and dams associated with the Project. All of the existing dams and reservoirs associated with the Project are owned by the City and operated by DEP to provide water for New York City and four nearby counties. The water supply system provides approximately 1.1 billion gallons of unfiltered high quality drinking water daily to approximately nine million New York State residents (approximately half of the State's total population), as well as the millions of tourists and commuters who visit New York City each year.²

By order issued March 20, 2009, FERC issued a Preliminary Permit to the City, facilitating its ability to proceed with its data collection, studies, and evaluation of the Project. On August 13, 2009, the City commenced the pre-filing process for the Project with the filing of its Notification of Intent and Pre-Application Document ("PAD"). In accordance with the Preliminary Permit, DEP is evaluating the technical and economic merit and feasibility for each proposed hydroelectric development. Based on the analysis completed to date, the City has not yet identified an economically viable project for the Schoharie Development. Accordingly, there are no additional studies proposed for the Schoharie Development at this time. However, the City will continue to investigate whether there is a technically and economically feasible option for this Project development, and will proceed with appropriate FERC licensing studies in the event such an alternative is identified.

Based on the foregoing, this socioeconomic study analyzes only the following three proposed Project developments: (1) Cannonsville Development; (2) Neversink Development; and (3) Pepacton Development.³

¹ The Project, as initially proposed by the City, consisted of the following four developments: (1) the Cannonsville Dam and Reservoir in Delaware County, New York ("Cannonsville Development"); (2) the Neversink Dam and Reservoir in Sullivan County, New York ("Neversink Development"); (3) the Downsville Dam and Pepacton Reservoir in Delaware County, New York ("Pepacton Development"); and (4) the Gilboa Dam and Schoharie Reservoir in Schoharie and Greene Counties, New York ("Schoharie Development").

² The City's water supply is comprised of three watersheds – Catskill, Croton, and Delaware – which are operated as an integrated system. The Cannonsville, Neversink and Pepacton Developments are part of the Delaware system. The Schoharie Development is part of the Catskill system.

³ For the purposes of this socioeconomic study, references to the "Project" herein are references to the Project inclusive of the three proposed Project developments assessed as part of this study.

2.0 SOCIOECONOMIC IMPACTS

In connection with the licensing process, the City elected to conduct a socioeconomic study regarding the Project. The overall objective of the socioeconomic study was to identify and quantify the impacts of constructing and operating the Project developments on employment, population, housing, personal income, local government services, local tax revenues and other relevant factors with respect to the Impact Area.

In order to accomplish this objective, the following activities were included in the socioeconomic study of the Project:

- Identify the appropriate Impact Area for conducting the socio-economic study, based on the Project location, existing demographic and economic linkages;
- Identify demographic and economic trends for the Impact Area, including:
 - Population;
 - Employment;
 - Personal income;
 - General economic condition;
 - Real estate characteristics;
 - Government Services and Facilities (e.g., police, fire, health, roads, education);
- Identify the economic impacts (direct, indirect, and induced) of Project construction and on-going Project operation on the demographic and economic trends for the Impact Area, including:
 - Evaluating whether the existing supply of housing (temporary and permanent) is sufficient to meet the needs of any additional population resulting from Project construction and operation;
 - Identifying any additional revenues (e.g., taxes) provided to the Impact Area resulting from Project construction and operation;
- Evaluate the incremental local government expenditures in the Impact Area (including school operating costs, road maintenance and repair, public safety costs and public utility costs) compared to the local government revenues in the Impact Area that would result from Project construction and operation;
- Evaluate the impact of the Project on recreational activities and character of the communities within the Impact Area;
- Identify and quantify, to the extent practicable, environmental externality benefits to the public, generally, associated with Project construction and operation (e.g., air pollution reduction resulting from the offset of fossil-fuel generation by the power generated by the Project); and

- Evaluate the potential impacts of the Project on wholesale electricity prices and system reliability in the Impact Area.

To conduct the socioeconomic study of the Project, the City engaged the services of two consultants: (1) Appleseed; and (2) Bates White. Appleseed conducted an assessment of the traditional socioeconomic impacts required by FERC regulations,⁴ while Bates White conducted an assessment relating to potential environmental externality benefits, reliability benefits and wholesale electricity price impacts associated with the Project. Accordingly, Appleseed is responsible for the content of Section 3.0 of this report, and Bates White is responsible for the content of Section 4.0.

3.0 ASSESSMENT OF TRADITIONAL SOCIOECONOMIC FACTORS

3.1 Introduction

Section 3 of this report assesses the economic impact of the proposed Cannonsville, Pepacton and Neversink Developments. In order to understand the socioeconomic context within which the Project developments would be constructed, an analysis of current demographic and economic conditions and recent trends in the towns most likely to be affected by the Projects are presented below.

3.2 Areas of Analysis and Sources of Data

Two of the proposed Project developments – Cannonsville and Pepacton – would be located in Delaware County. The Neversink Development would be located in Sullivan County. For purposes of this analysis, the towns in which socioeconomic conditions are most likely to be affected by the developments are as follows:

- The towns in which the proposed facilities would be located (i.e., Deposit, Colchester and Neversink);
- Other towns that, when added to the three cited above, account for more than half of all of the workforce of the towns in which the proposed facilities would be located. For example, about 54 percent of all those whose place of work is in the Town of Deposit live either in the town itself or in the Towns of Walton or Sanford; and
- Any other towns that directly border Deposit, Colchester or Neversink.

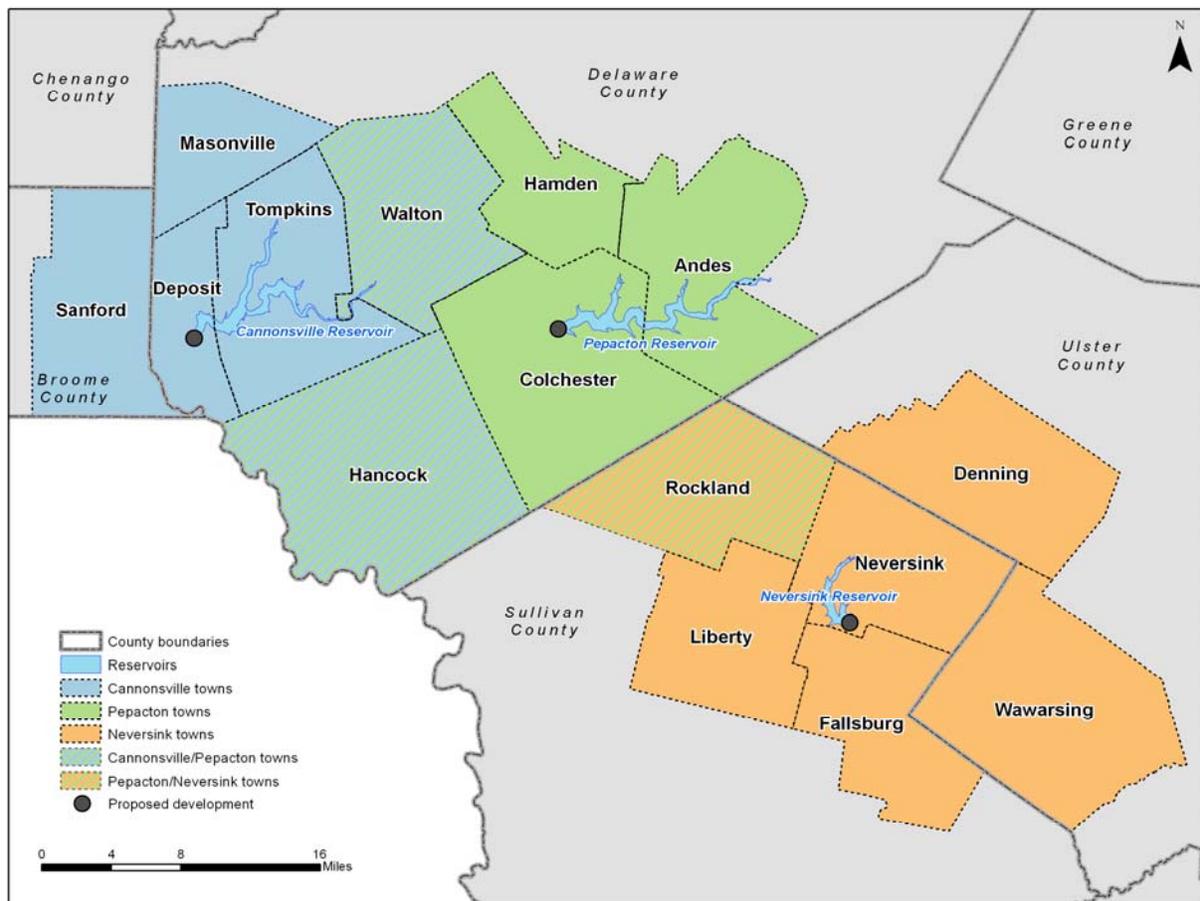
Figure 3.1 shows the fifteen towns that are included in the review of demographic and economic conditions and trends.

Data used in preparing profiles of each of these fifteen towns were taken primarily from several sources:

⁴ See 18 C.F.R. § 4.41(f)(5).

- U.S. Census data for 2000 and 2010 was used to show population, median age, and housing trends.
- The Census Bureau’s American Community Survey for 2005-2009 provides the most recent available data on educational attainment, employment and unemployment, industry employment characteristics, and educational attainment rates.
- The Census Bureau’s journey-to-work data for 2000 provides the most recent available data showing on a small-area basis where people live and work.

Figure 3.1: Map of Reservoirs Project Developments in Relation to Towns and Counties Assessed



3.3 Socioeconomic Conditions and Trends

This section describes the town-level socioeconomic conditions and trends during the past decade, organized by Project development.

3.3.1 Cannonsville Development

The following sections describe socioeconomic conditions and trends in six towns (five in Delaware County and one in Broome County that could potentially be affected by the Cannonsville facility: (1) Deposit, (2) Hancock, (3) Masonville, (4) Tompkins, and (5) Walton in Delaware County; and (6) Sanford in Broome County.

3.3.1.1 Town of Deposit

According to the 2010 Census, the population of the Town of Deposit was 1,712 – an increase of 1.5 percent since 2000. This represents a slightly slower rate of growth than for New York State as a whole, but is more positive than the overall trend in Delaware County, which experienced a slight decline in population during the same period (Table 3.1). The Town had a population density of 39.8 persons per square mile, which reflects the Town’s rural character.

Table 3.1: Town of Deposit Population, 2000 and 2010

Geography	2000	2010	% Change
Deposit	1,687	1,712	1.5%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

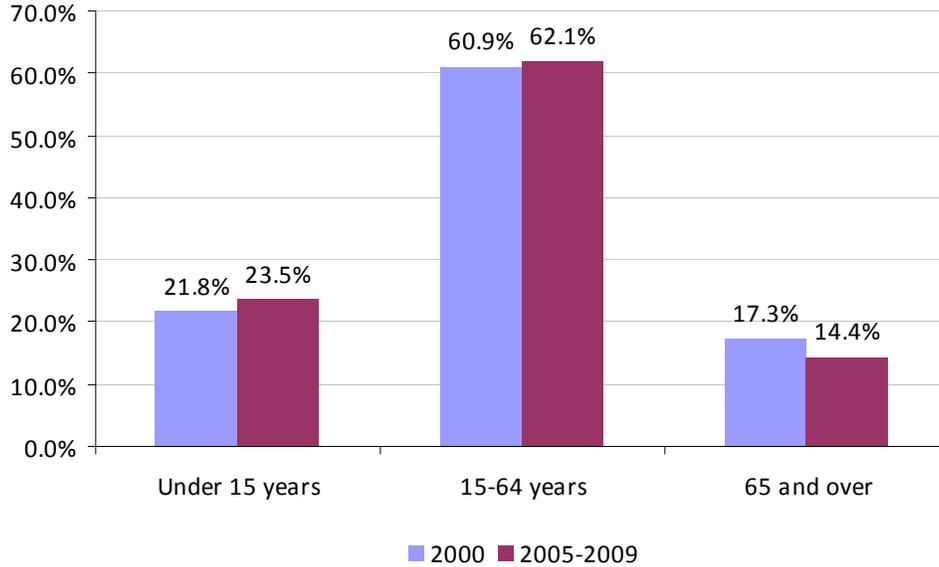
As shown by Table 3.2, the number of housing units in the Town of Deposit increased by 11.8 percent between 2000 and 2010 – an increase of 119 units. Housing for seasonal or recreational use accounted for 31.2 percent of all housing units in 2010; and such units accounted for almost all housing growth in the Town between 2000 and 2010.

Table 3.2: Town of Deposit Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Deposit	1,048	1,131	7.9%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

According to the Census Bureau’s American Community Survey (“ACS”), the median age in Deposit during the years 2005-2009 was 37.6 – a slight decrease from the 38.3 reported in the 2000 Census. As depicted by Figure 3.2, the age distribution of the Town of Deposit changed significantly between 2000 and 2009. The population age 15-and-under and aged 15-64 increased by about 10 percent and 15 percent, respectively. More dramatically, the population 65-and-over decreased by about 30 percent.

Figure 3.2: Town of Deposit Age Distribution, 2000 and 2005-2009



Resident employment, as shown in Table 3.3, decreased by slightly more than 13 percent in the Town of Deposit between 2000 and 2005-2009. The reduction in employment is significant considering that employment in the State actually increased during the same time period by 8.6 percent.

Table 3.3: Town of Deposit Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Deposit	709	615	-13.3%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.3 shows, the largest number of employed residents of the Town of Deposit – about 29 percent – worked in education, health care and social assistance. The manufacturing sector accounted for 15 percent of all resident employment, reflecting a strong concentration of manufacturing firms in western Delaware County. Another 12 percent of the Town’s employed residents worked in construction; 11 percent in retail trade; and 61 percent in the arts, entertainment and hospitality sector.

Figure 3.3: Town of Deposit Resident Employment - Top Employment Sectors, 2005-2009

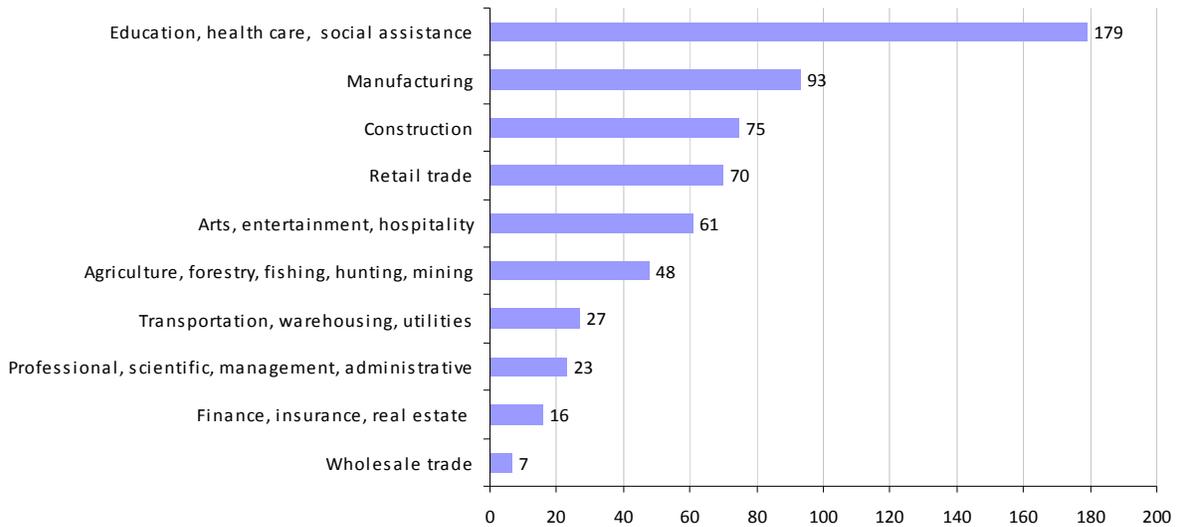


Table 3.4 shows that the unemployment rate for the Town of Deposit during the years 2005-2009 averaged 8.1 percent – higher than the overall rate for Delaware County or for New York State.⁵

Table 3.4: Town of Deposit Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Deposit	7.2%	8.1%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

As shown in Table 3.5, the median household income (“MHI”) for the Town of Deposit for the years 2005-2009 was \$34,621 – 83 percent of the median household income for Delaware County, and just 63 percent of the statewide median household income for the same period. Moreover, after adjusting for inflation, the Town’s MHI fell by 6.5 percent between 2000 and 2005-2009, indicating that the Town fell further behind the rest of the County and the State during this period.

Table 3.5: Town of Deposit Median Household Income (2009 dollars), 2000 and 2005-2009

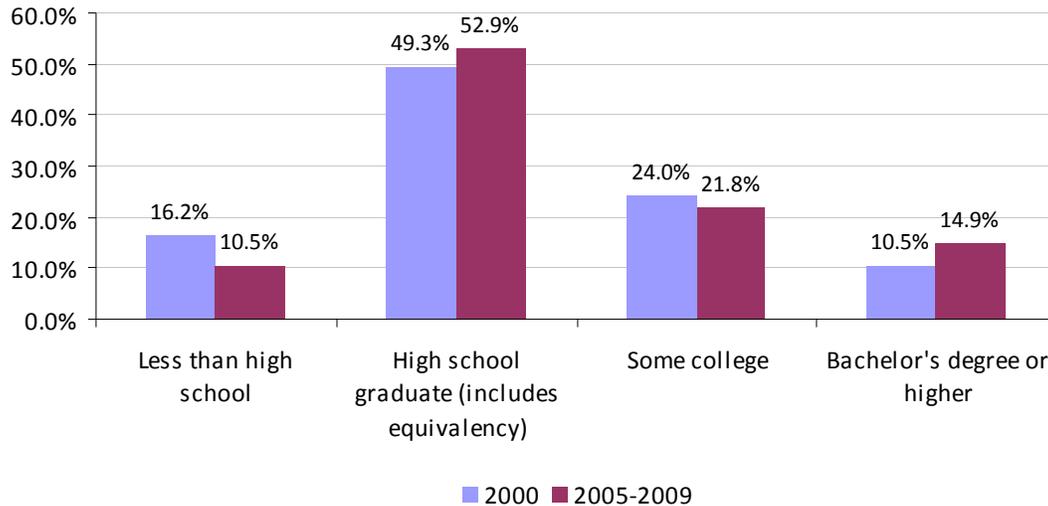
Geography	2000	2005-2009	% Change
Deposit	\$37,022	\$34,621	-6.5%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As Figure 3.4 shows, the Town of Deposit has experienced some positive changes in the areas of secondary and post-secondary educational attainment. The percentage of residents age 25 and over who lack a high school diploma fell between 2000 and 2005-2009, while the percentage of

⁵ It should be noted that with respect to all of the unemployment data presented in this report, the percentage unemployment rate for 2005-2009 does not fully reflect the impact of the economic recession that commenced in 2008 and the continuing economic downturn that has followed thereafter.

residents who held at least a bachelor’s degree rose. Nevertheless, in the area of college and advanced degree attainment, the Town still trails both Delaware County (18.2 percent) and New York State (31.8 percent).

Figure 3.4: Town of Deposit Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.1.2 Town of Hancock

As shown in Table 3.6, in 2010 the population of the Town of Hancock was 3,224 (with a population density of 20.3 persons per square mile), a decline of 6.5 percent since 2000. The Town’s population loss was, thus, significantly larger in percentage terms than the 0.1 percent decline in Delaware County’s population.

Table 3.6: Town of Hancock Population, 2000 and 2010

Geography	2000	2010	% Change
Hancock	3,449	3,224	-6.5%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

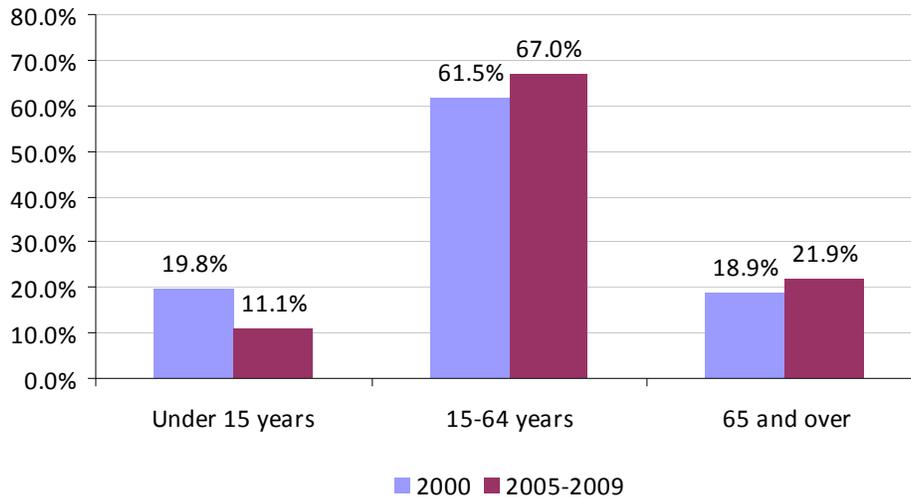
While its resident population declined between 2000 and 2010, Hancock’s housing stock grew by 9.2 percent, as shown in Table 3.7. As of 2010, seasonal and recreational housing accounted for 45 percent of all units in Hancock, an increase of about 23 percent since 2000.

Table 3.7: Town of Hancock Housing Units, 2000 and 2010

Geography	2,000	2010	% Change
Hancock	2,512	2,743	9.2%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	7,950,035	3.5%

As demonstrated by Figure 3.5, the population of the Town of Hancock aged between 2000 and 2005-2009. During this period, the median age increased to 48.2 years. The share of the population under the age of 15 fell by 8.7 percentage points, while the share of the population between 15 and 64 rose by 5.5 percentage points, and the population older than 65 increased by 3 percentage points.

Figure 3.5: Town of Hancock Age Distribution



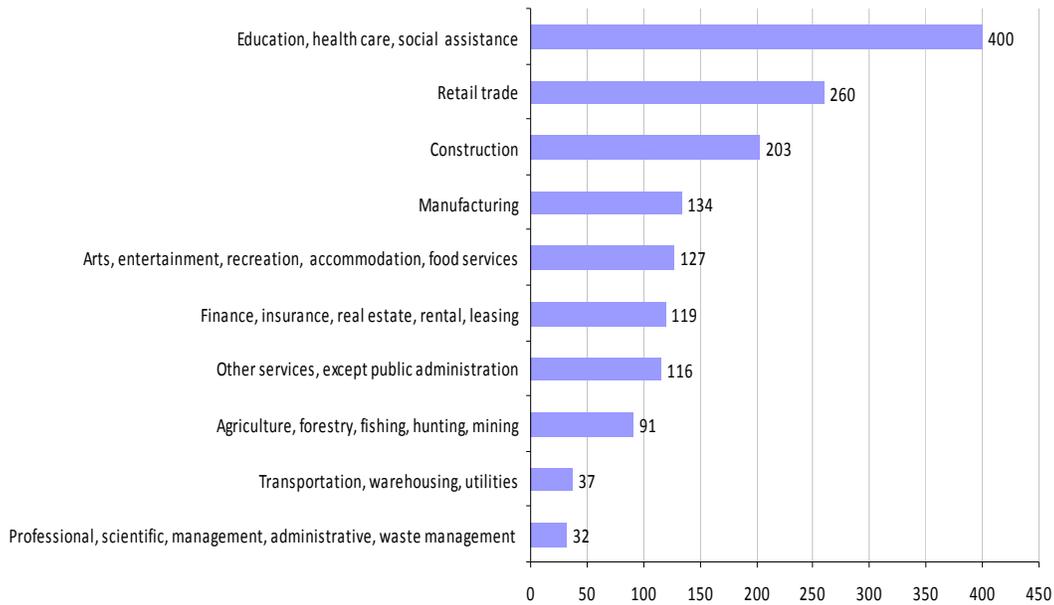
Resident employment in the Town of Hancock increased by nearly 19 percent between 2000 and 2005-2009. This growth rate was more than double the growth in the State during this period, as depicted in Table 3.8.

Table 3.8: Town of Hancock Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Hancock	1,338	1,593	19.1%
Delaware County	208	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As depicted by Figure 3.6, approximately 25 percent of employed residents of the Town of Hancock worked in education, health care and social assistance in 2005-2009, 16 percent in retail trade; nearly 13 percent in construction; and 8 percent in manufacturing.

Figure 3.6: Town of Hancock Resident Employment - Top Employment Sectors, 2005-2009



As Table 3.9 shows, the Town of Hancock’s unemployment rate declined by 3 percentage points between 2000 and 2005-2009, and was below the unemployment rates of both Delaware County and the State for 2005-2009.

Table 3.9: Town of Hancock Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Hancock	8.9	5.9%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

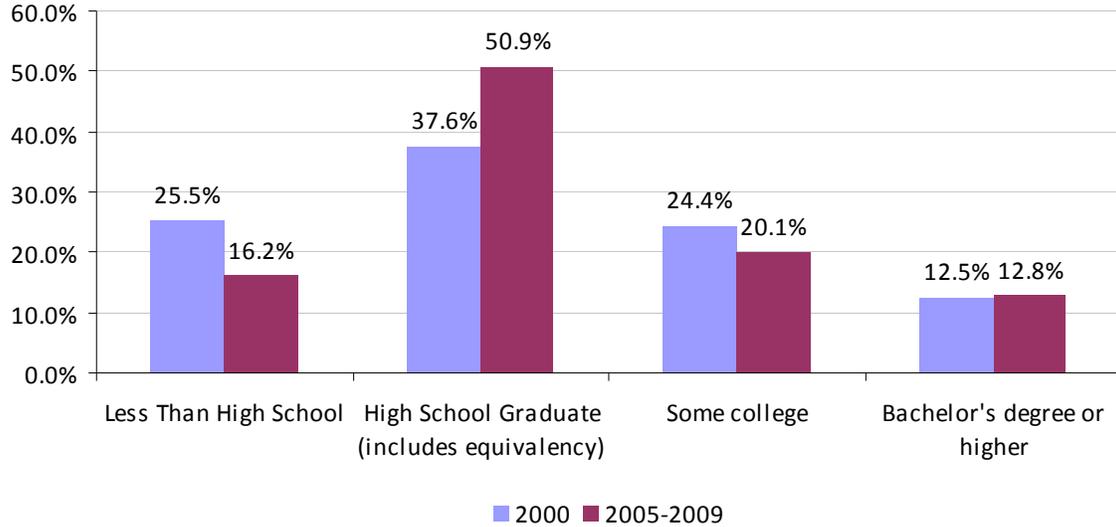
The MHI in the Town of Hancock decreased by slightly less than one percent between 2000 and 2005-2009, as shown in Table 3.10. While a decrease in MHI during this period is consistent with trend in Delaware County and the State, the Town’s MHI remained slightly below the level in Delaware County and well below the level in the State.

Table 3.10: Town of Hancock Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Hancock	\$39,853	\$39,583	-0.7%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As depicted in Figure 3.7, educational attainment increased in the Town of Hancock between 2000 and 2005-2009 as the number of high school graduates increased, while the number with less than a high school degree or some college experience decreased considerably. The percentage of people age 25-and-older who held a bachelor’s degree or higher remained flat (and relatively low) between 2000 and 2005-2009.

Figure 3.7: Town of Hancock Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.1.3 Town of Masonville

As shown by Table 3.11, the population of the Town of Masonville declined by 6 percent between 2000 and 2010 – a sharper decline than the nominal change that Delaware County experienced during the same period. The town had a primarily rural character with a population density of 24.3 persons per square mile.

Table 3.11: Town of Masonville Population, 2000 and 2010

Geography	2000	2010	% Change
Masonville	1,407	1,320	-6.2%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

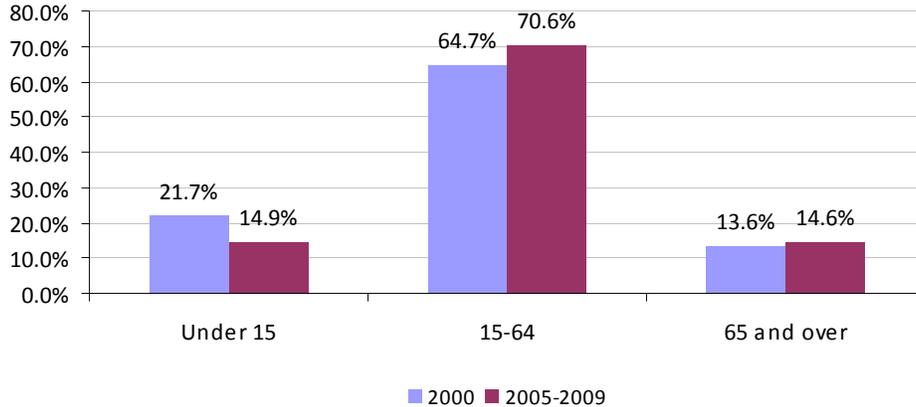
While the population of the Town of Masonville decreased between 2000 and 2010, the town experienced strong growth (15.5 percent) in its housing stock. Seasonal and recreational housing accounted for more than half the growth in the Town’s housing stock during this period; and as of 2010, such units made up 28.9 percent of all housing in Masonville (Table 3.12)

Table 3.12: Town of Masonville Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Masonville	716	850	18.8%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

As demonstrated by Figure 3.8, between 2000 and 2005-2009 Masonville’s population aged 15-64 increased slightly (by about 3 percent), while the population aged 15 and under decreased more significantly (by about 35 percent). The share of the population 65 and over remained virtually unchanged during the same time period

Figure 3.8: Town of Masonville Age Distribution, 2000 and 2005-2009



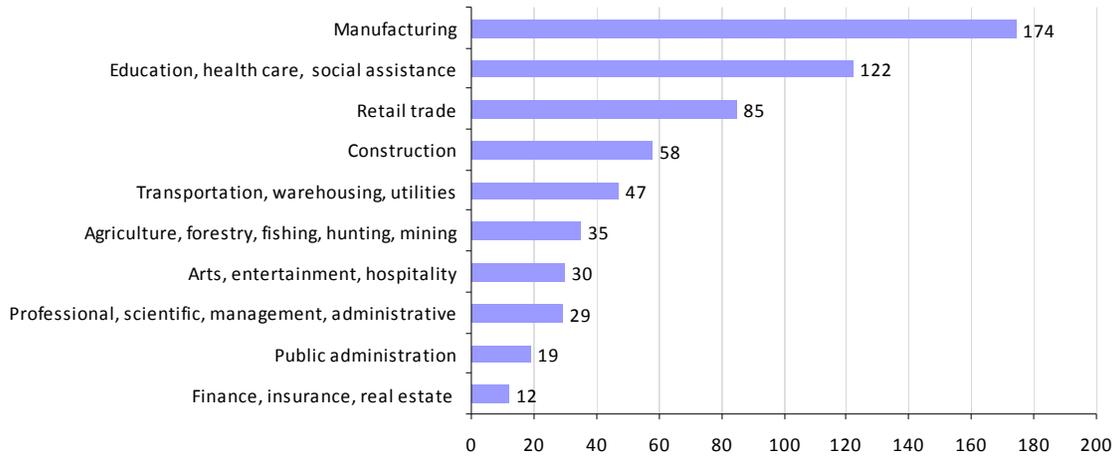
Resident employment in Masonville by nearly 1.5 percent between 2000 and 2005-2009, which was in contrast to the slight growth that Delaware County and the more significant growth that the State experienced in 2005-2009, as demonstrated by Table 3.13.

Table 3.13: Town of Masonville Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Masonville	633	624	-1.4%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.9 shows, the Census Bureau’s ACS data indicate that between 2005 and 2009, an average of 174 Masonville residents worked in manufacturing – about 28 percent of the town’s employed residents. The relatively high percentage of all employees working in manufacturing reflects this sector’s continued importance in the economy of Delaware County. Other major employers of Masonville residents include the education, health and social assistance sector (nearly 20 percent of the town’s employed residents), retail trade (14 percent) and construction (more than 9 percent).

Figure 3.9: Town of Masonville Resident Employment - Top Employment Sectors, 2005-2009



As Table 3.14 shows, between 2005 and 2009 the Town’s unemployment rate averaged 8.5 percent – significantly higher than the rates for Delaware County as a whole, or for New York State. Moreover, the average rate for 2005-2009 (as reported by ACS) does not reflect the full impact of the recession.

Table 3.14: Town of Masonville Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Masonville	5.1%	8.5%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

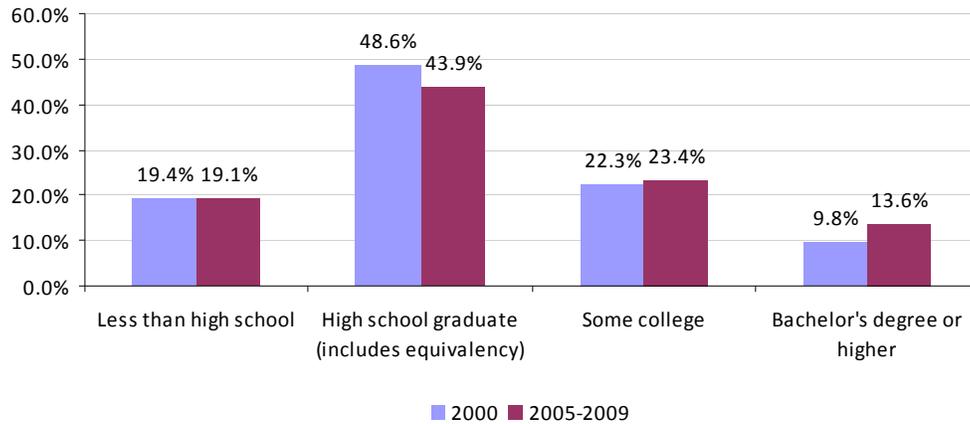
As depicted in Table 3.15, the Town of Masonville’s MHI grew by 17 percent between 2000 and 2005-2009, while MHI declined at both County and State levels during the same period. As a result of this growth, the Town’s MHI is 19 percent higher than the County’s – and lags the statewide MHI by 10 percent.

Table 3.15: Town of Masonville Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Masonville	\$42,495	\$49,702	17.0%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

The percentage of all Masonville residents age 25-and-older who have at least a bachelor’s degree rose between 2000 and 2005-2009, but at 13.6 percent is still relatively low. At the same time, the percentage of those 25-and-older who have not completed high school is still relatively high (Table 3.10).

Figure 3.10: Town of Masonville Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.1.4 Town of Tompkins

In 2010, the population of the Town of Tompkins was 1,247 – as shown in Table 3.16, an increase of 12.9 percent since 2000. The Town’s population density (12.7 persons per square mile) had increased from its 2000 level, at a rate that mirrors the rate of population growth that the Town of Tompkins experienced.

Table 3.16: Town of Tompkins Population, 2000 and 2010

Geography	2000	2010	% Change
Tompkins	1,105	1,247	12.9%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

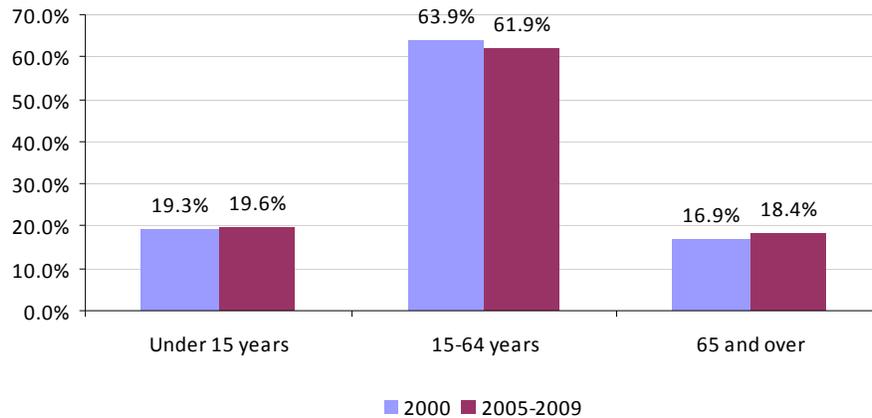
As shown in Table 3.17, the number of housing units in the Town of Tompkins grew by 13 percent between 2000 and 2010. Seasonal and recreational housing accounted for about 38 percent of all units in 2010.

Table 3.17: Town of Tompkins Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Tompkins	768	884	15.1%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

For 2005-2009, the median age in Tompkins was 37.2. As shown in Figure 3.11, the overall age distribution in the Town was relatively unchanged between 2000 and 2005-2009.

Figure 3.11: Town of Tompkins Age Distribution, 2000 and 2005-2009



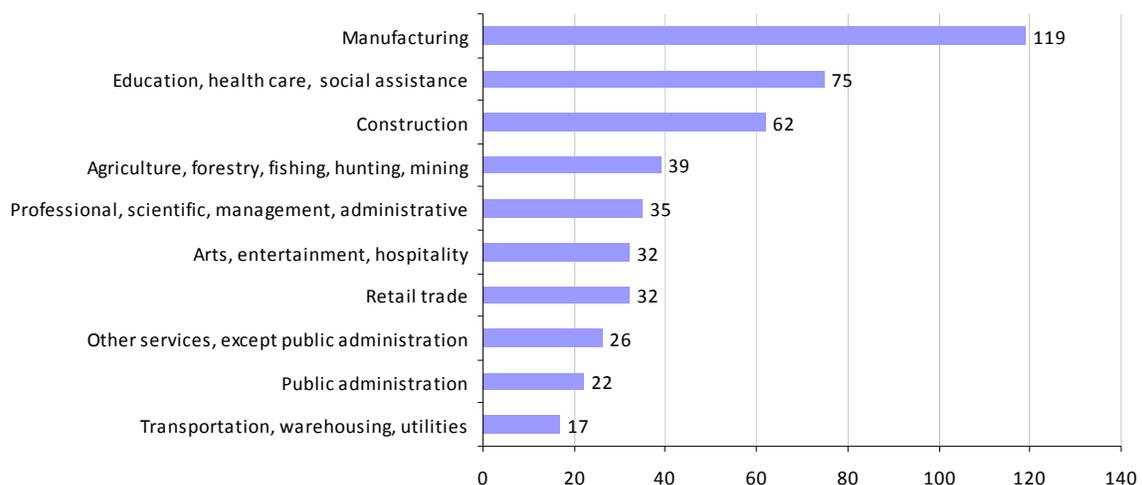
As shown by Table 3.18, resident employment in the Town of Tompkins decreased by more than 3 percent between 2000 and 2005-2009, whereas resident employment increased in both Delaware County and the State during the same period.

Table 3.18: Town of Tompkins Resident Employment, 2000 and 2005-2009

Geography	2,000	2005-2009	% Change
Tompkins	506	489	-3.4%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.12 shows, the manufacturing sector was the leading employer of Tompkins residents during 2005-2009, accounting for 24 percent of the Town’s employed residents. Other leading sectors include education, health and social assistance (15 percent), construction (13 percent), and agriculture and natural resources (8 percent).

Figure 3.12: Town of Tompkins Resident Employment - Top Employment Sectors, 2005-2009



As Table 3.19 shows, the Town of Tompkins’s unemployment rate for 2005-2009 was 5.2 percent – considerably lower than the County-wide and State-wide rates for the same period.

Table 3.19: Town of Tompkins Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Tompkins	6.8%	5.2%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

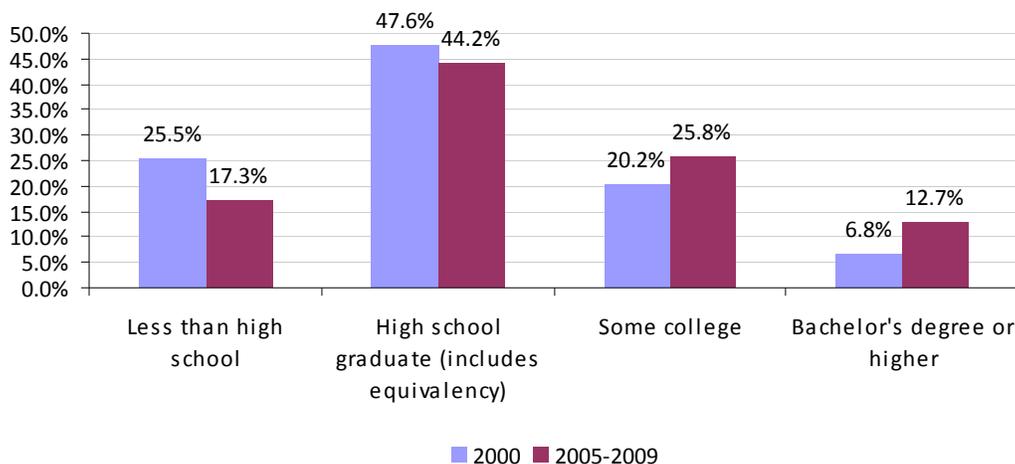
The Census Bureau’s ACS data indicates that in real terms, the Town’s median household income declined by 11 percent between 2000 and 2005-2009, as depicted in Table 3.20. In 2000 the Town’s MHI had been 8.5 percent higher than that for Delaware County; for 2005-2009, it was 3 percent lower.

Table 3.20: Town of Tompkins Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Tompkins	\$45,363	\$40,378	-11.0%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As in other towns in the region, the level of educational attainment in Tompkins rose between 2000 and 2005-2009, with 38.5 percent of all residents age 25-and-older having had at least some college experience. Nevertheless, even with this increase the percentage of all 25-and-older residents who have earned at least a bachelor’s degree (12.7 percent) is still relatively low (Figure 3.13)

Figure 3.13: Town of Tompkins Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.1.5 Town of Sanford

As shown in Table 3.21, the Town of Sanford’s population declined slightly between 2000 and 2010, while the population in Broome County and the State increased slightly during that same period. In 2010, the Town’s population density was 26.7 persons per square mile reflecting the

Town's primarily rural nature, which was much lower than the County's population density (284.2 persons per square mile).

Table 3.21: Town of Sanford Population, 2000 and 2010

Geography	2000	2010	% Change
Sanford	2,477	2,407	-2.8%
Broome County	200,534	200,600	0.03%
New York	18,976,457	19,378,102	2.1%

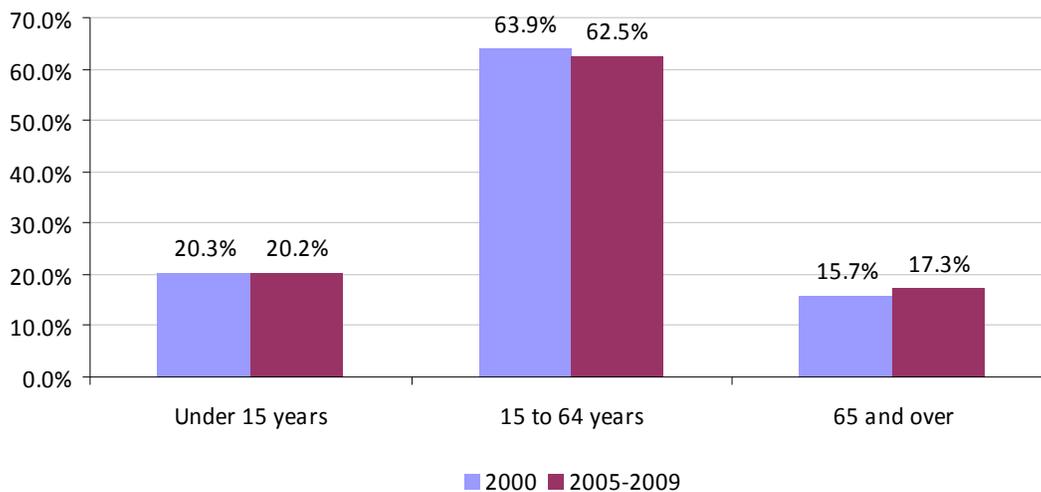
Despite the decline in its resident population, Sanford experienced growth in the number of housing units. This growth rate exceeded the rate that Broome County and the State experienced, as shown in Table 3.22. Seasonal and recreational housing accounted for 44 percent of housing units.

Table 3.22: Town of Sanford Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Sanford	1,545	1,739	12.6%
Broome County	88,816	90,563	2.0%
New York	7,679,307	8,108,103	5.6%

The median age was 40.9 in 2005-2009. As depicted in Figure 3.14, the Town of Sanford is aging slightly. Between 2000 and 2005-2009, the share of the Town's population over age 64 increased, while the percentage age 15 through 64 decreased.

Figure 3.14: Town of Sanford Age Distribution, 2000 and 2005-2009



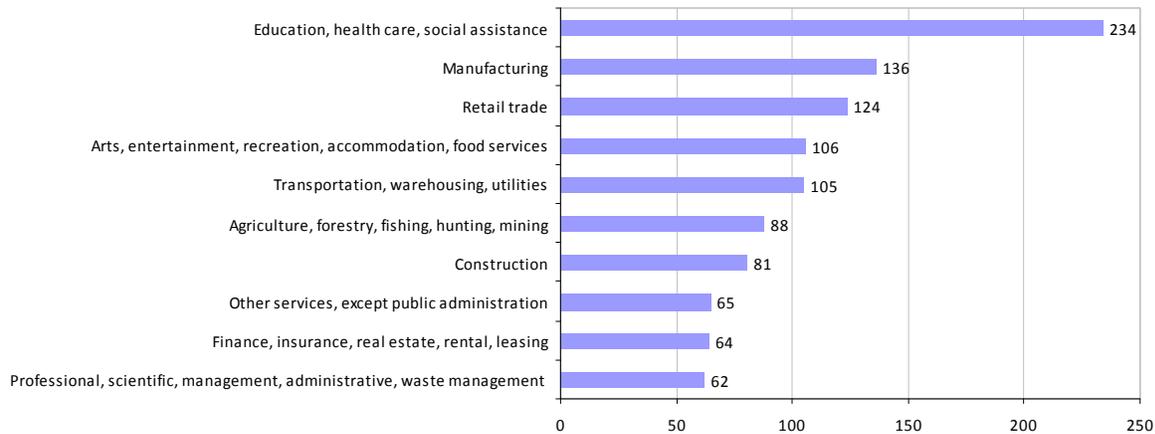
As shown in Table 3.23, resident employment in the Town of Sanford increased about 11 percent between 2000 and 2005-2009, which was a level that was greater than the State and Broome County.

Table 3.23: Town of Sanford Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Sanford	1,052	1,168	11.0%
Broome County	91,340	91,237	-0.1%
New York	8,382,988	9,102,596	8.6%

As demonstrated in Figure 3.15, in 2005-2009 about 20 percent of the Town of Sanford’s employed residents worked in education, health care and social assistance. Manufacturing accounted for 12 percent, retail trade for 11 percent, and arts, recreation and hospitality for 9 percent.

Figure 3.15: Town of Sanford Resident Employment - Top Employment Sectors, 2005-2009



As shown in Table 3.24, unemployment in the Town of Sanford increased to more than 10 percent in 2005-2009 – higher than the unemployment rates in Broome County and the State during the same period, whereas in 2000 Sanford’s unemployment rate was lower than the rates for the County and the State.

Table 3.24: Town of Sanford Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Sanford	3.7%	10.6%
Broome County	5.4%	6.1%
New York	7.1%	7.0%

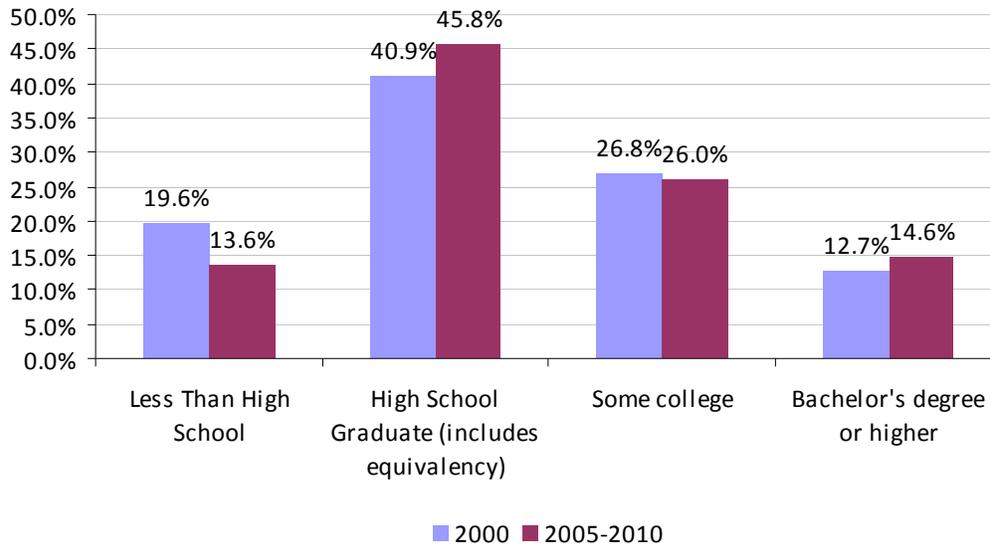
As Table 3.25 shows, the Town of Sanford experienced a drop in MHI greater than that which Broome County and State experienced during the same period. Sanford’s MHI for 2005-2009 was 12 percent lower than Broome County’s MHI and more than 30 percent below the State’s.

Table 3.25: Town of Sanford Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Sanford	\$42,893	\$38,365	-10.6%
Broome County	\$45,517	\$43,467	-4.5%
New York	\$55,879	\$55,233	-1.2%

Figure 3.16 shows that the Town of Sanford made gains in the area of secondary and post-secondary educational attainment between 2000 and 2005-2009. The Town saw an increase in the share of residents aged 25-and-older with a high school diploma and in the percentage that had at least a bachelor's degree. Also, there were fewer people who had not completed high school.

Figure 3. 16: Town of Sanford Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.1.6 Town of Walton

In 2010, the Town of Walton had a population of 5,576, making it the second largest town in Delaware County. As shown in Table 3.26, the Town of Walton's population declined by 0.6 percent between 2000 and 2010. The Town's low population density (57.6 persons per square mile) reflects its primarily rural character.

Table 3.26: Town of Walton Population, 2000 and 2010

Geography	2000	2010	% Change
Walton	5,607	5,576	-0.6%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

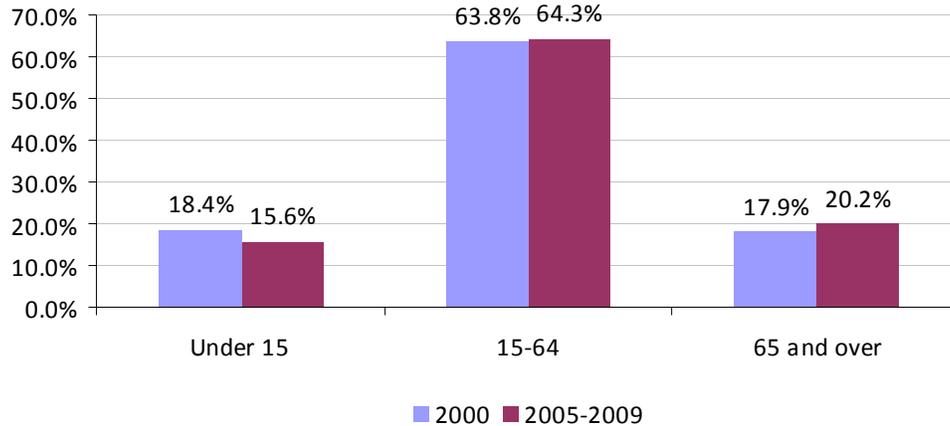
Between 2000 and 2010, as shown in Table 3.27, the Town's housing stock grew by 5 percent, to 3,106 units. In 2010, 14.5 percent of all units in the Town were for seasonal or recreational use – lower than the percentage of such units in many other towns in the region.

Table 3.27: Town of Walton Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Walton	2,958	3,106	5.0%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

The median age of Walton residents during 2005-2009 was 44.7 – slightly higher than the median age in 2000 which was 41.6. Between 2000 and 2009, the share of the Town of Walton’s population under the age of 15 declined, while, during the same period, the share of the Town’s population aged 65 and over increased, as shown in Figure 3.17.

Figure 3.17: Town of Walton Age Distribution, 2000 and 2005-2009



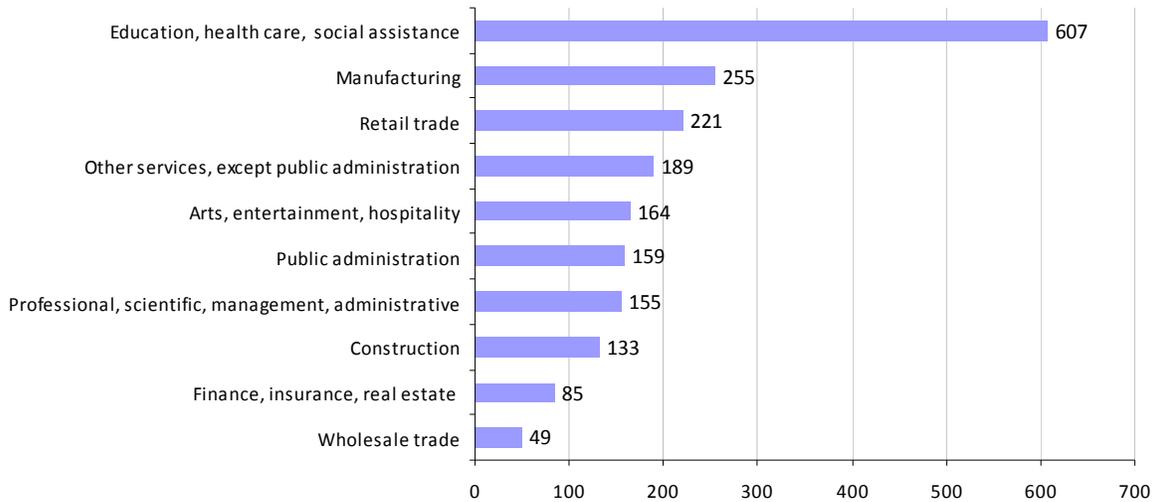
According to ACS data, as shown in Table 3.28, the number of employed Walton residents during the years 2005 through 2009 averaged 2,106 – a decline of 18.9 percent from the level reported in the 2000 census. This unusually steep decline may in part reflect the effects of severe flooding that occurred in Walton in 2006.

Table 3.28: Town of Walton Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Walton	2,596	2,106	-18.9%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As shown in Figure 3.18, the education, health and social assistance sector accounted for about 29 percent of all jobs held by Walton residents in 2005-2009; manufacturing accounted for 12 percent; and retail trade accounted for nearly 11 percent.

Figure 3.18: Town of Walton Resident Employment - Top Employment Sectors, 2005-2009



As shown in Table 3.29, the unemployment rate among Walton residents averaged 10.2 percent between 2005 and 2009 – a sharp increase from the 5.4 percent rate reported in 2000, it is clear from data on resident employment and unemployment that that the employment prospects of Walton residents had deteriorated significantly even before the full effect recession had been felt.

Table 3.29: Town of Walton Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Walton	5.4%	10.2%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

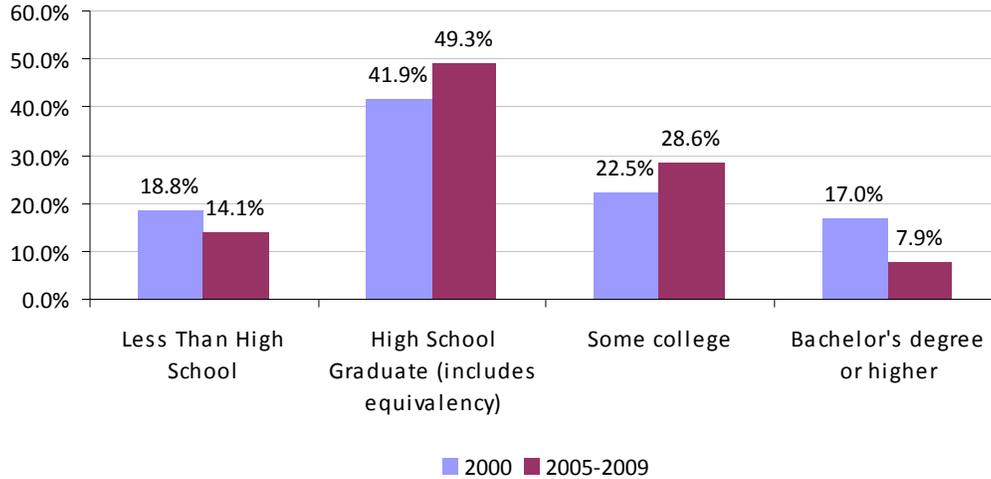
Consistent with the deterioration of the job market for Walton residents, the Town’s MHI – already well below the County-wide and State-wide MHI as of 2000 – fell even further. Walton’s MHI for 2005-2009 was 84 percent of the MHI for Delaware County and only 63 percent of the State MHI (Table 3.30).

Table 3.30: Town of Walton Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Walton	\$39,340	\$35,000	-11.0%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

With respect to educational attainment, ACS data for 2005-2009 (Figure 3.19) indicates that Walton is characterized by an unusual mix of strengths and weaknesses. Only 14.1 percent of all residents age 25-and-older lack a high school diploma; and about 78 percent have either a high school diploma or some education beyond high school. But only 7.9 percent of all 25-and-older Walton residents have at least a bachelor’s degree.

Figure 3. 19: Town of Walton Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.2 Pepacton Development

This section focuses on socioeconomic trends of four towns in the vicinity of the Pepacton Development: (1) Andes, (2) Colchester, and (3) Hamden in Delaware County; and (4) Rockland in Sullivan County.

3.3.2.1 Town of Andes

As Table 3.31 shows, the population of the Town of Andes in 2010 was 1,301 – a decline of 4.1 percent from 2000. Population density was 12.0 persons per square mile, which reflects the Town’s extremely rural character.

Table 3.31: Town of Andes Population, 2000 and 2010

Geography	2000	2010	% Change
Andes	1,357	1,301	-4.1%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

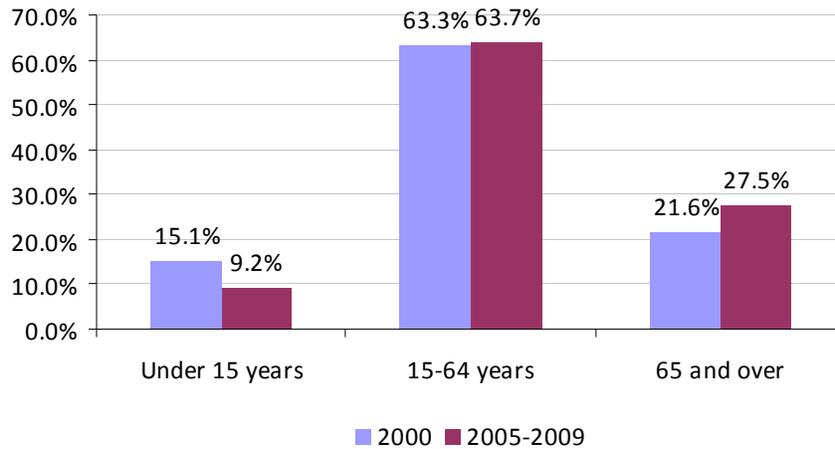
Despite the decline in the Town’s resident population noted above, the number of housing units in Andes (as shown in Table 3.32) increased by about 10 percent between 2000 and 2010. This may be due in part to the large number of seasonal and recreational units in Andes. In 2010, such units accounted for 52.4 percent of the Town’s housing stock; and between 2000 and 2010 they accounted for 88 percent of the total increase in housing units during that period.

Table 3.32: Town of Andes Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Andes	1,327	1,459	9.9%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

For 2005-2009, the median age of Andes residents was 52.3 – significantly older than the median age of 47.8 reported in the 2000 census, and among the oldest in the State. The share of the population below age 15 fell to just 9.2 percent, while those 65-and-older rose to 27.5 percent (Figure 3.20).

Figure 3.20: Town of Andes Age Distribution, 2000 and 2005-2009



ACS data indicates that between 2000 and 2005-2009, the number of employed Andes residents declined by more than 10 percent (Table 3.33). This trend may, in part, reflect the overall decline in the Town’s population, as well as the relatively large share of the Town’s population that is over 65.

Table 3.33: Town of Andes Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Andes	565	507	-10.3%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.21 shows, nearly 26 percent of the Town’s employed residents work in education, health and social assistance. The arts, entertainment and hospitality account for 15 percent – a figure that in part reflects the Town’s large second-home sector, construction accounted for 12 percent and manufacturing accounted for 11 percent.

Figure 3.21: Town of Andes Resident Employment - Top Employment Sectors, 2005-2009

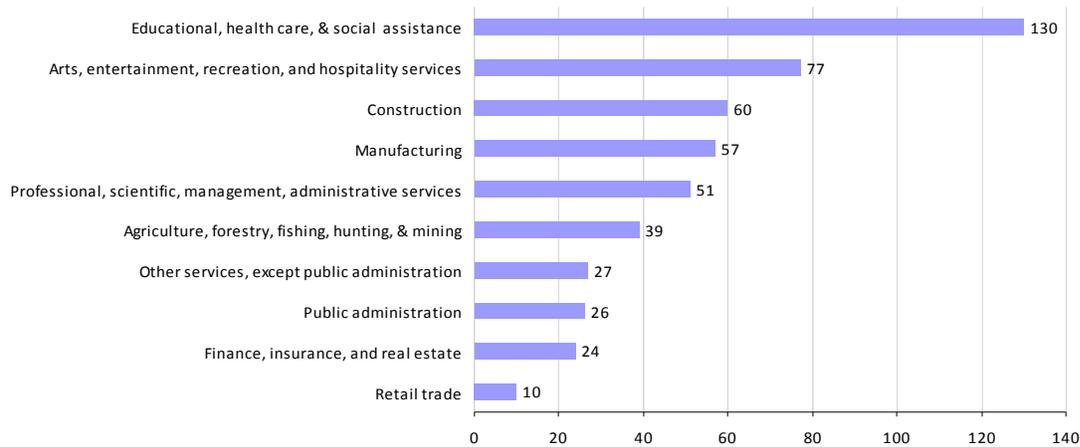


Table 3.34 shows that the unemployment rate for the Town of Andes – which had been very low in 2000 – rose sharply in the latter part of the decade; but for 2005-2009, was still only slightly higher than the unemployment rates for Delaware County and New York State.

Table 3.34: Town of Andes Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Andes	3.1%	7.3%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

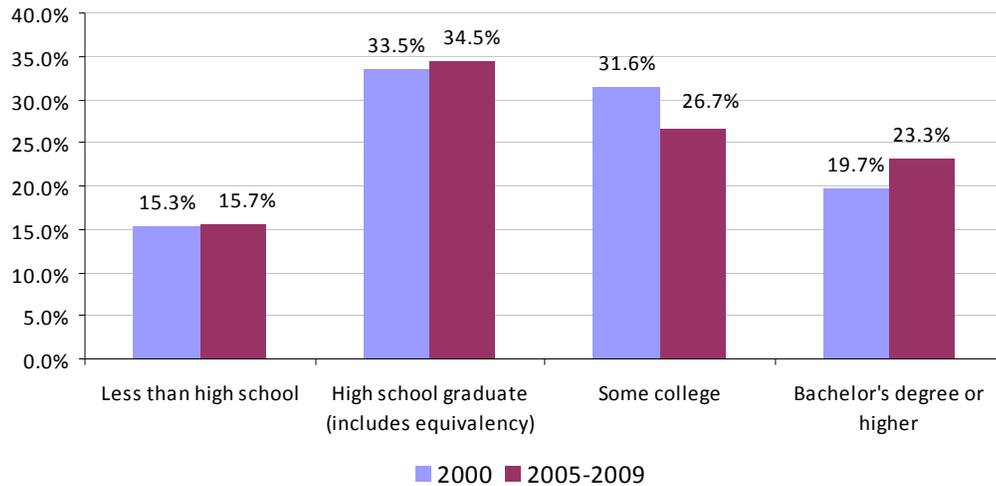
As shown in Table 3.35, the MHI for the Town of Andes was 8 percent higher than the MHI for Delaware County for 2005-2009, but still only 81 percent of the State-wide MHI. The Town’s MHI declined by about 0.5 percent in real terms between 2000 and 2005-2009.

Table 3.35: Town of Andes Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Andes	\$45,224	\$45,000	-0.5%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As demonstrated by Figure 3.22, the educational attainment rate for the Town of Andes’ population increased for the post-secondary education categories of bachelor’s and advanced degrees between 2000 and 2009. Additionally there were a higher percentage of people who were high school graduates.

Figure 3.22: Town of Andes Educational Attainment (population aged 25 and over), 2000 and 2005-2009



3.3.2.2 Town of Colchester

As Table 3.36 shows, the population of the Town of Colchester in 2010 was 2,077, an increase of 1.7 percent since 2000. Population density was 15.19 persons per square mile, making Colchester one of the lower density towns in Delaware County.

Table 3.36: Town of Colchester, 2000 and 2010

Geography	2000	2010	% Change
Colchester	2,042	2,077	1.7%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

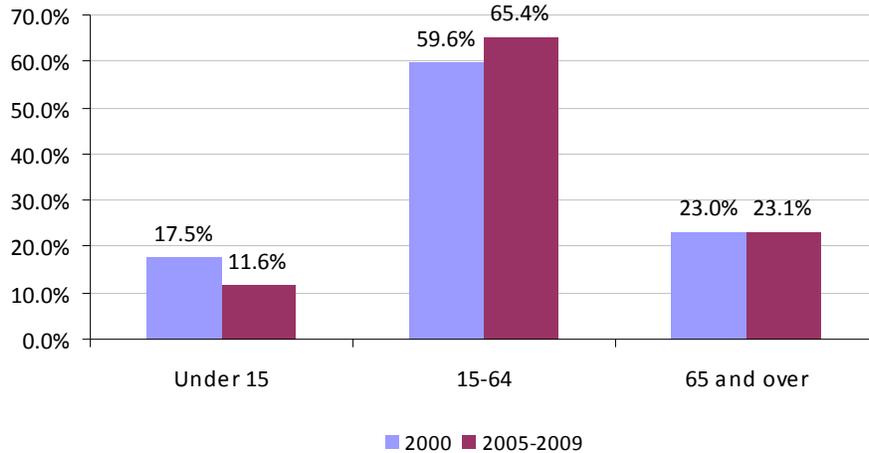
As shown in Table 3.37, the number of housing units in the Town of Colchester increased by 14.8 percent between 2000 and 2010. Seasonal and recreational units accounted for 45 percent of the Town’s housing stock in 2010 – and for 79 percent of the total increase in housing units between 2000 and 2010.

Table 3.37: Town of Colchester Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Andes	1,327	1,459	9.9%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

As shown in Figure 3.23, between 2000 and 2005-2009 the share of Colchester’s population below age 15 declined by nearly 6 percentage points, while those age 15 to 64 increased by a similar amount. Colchester’s median age in 2005-2009 was 48.7, which was a about a four year increase from the median age in 2000.

Figure 3.23: Town of Colchester Age Distribution, 2000 and 2005-2009



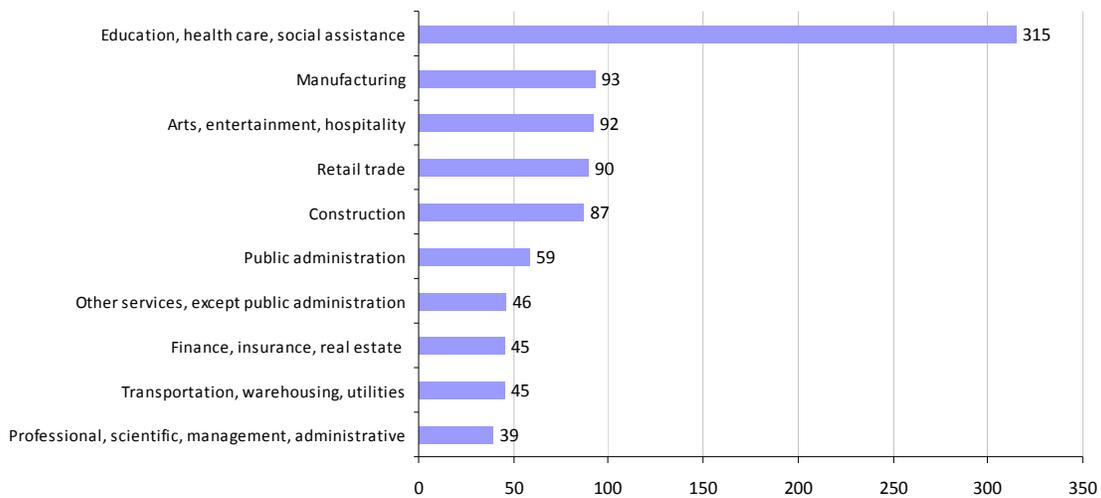
Between 2000 and 2005-2009 (according to ACS data), the number of employed residents of Colchester rose by nearly 22 percent, to 955 (Table 3.38)

Table 3.38: Town of Colchester Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	Growth
Colchester	784	955	21.8%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.24 shows, in 2005-2009 approximately 33 percent of the Town of Colchester’s employed residents worked in education, health and social assistance; nearly 10 percent each in manufacturing and arts, entertainment and hospitality; and 9 percent in retail trade.

Figure 3.24: Town of Colchester Resident Employment - Top Employment Sectors, 2005-2009



Consistent with the increase in resident employment, the Town's unemployment rate fell from 7.4 percent in 2000 to 6.6 percent in 2005-2009, as shown in Table 3.39.

Table 3.39: Town of Colchester Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Colchester	7.4%	6.6%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

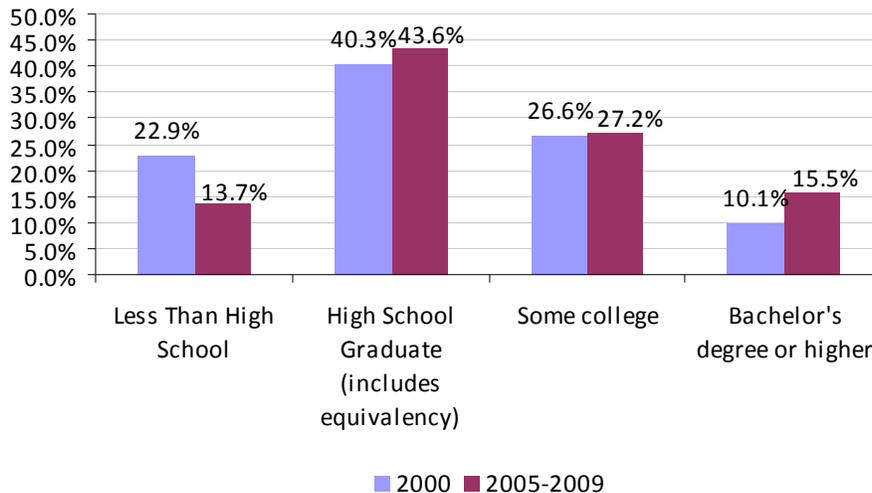
As shown in Table 3.40, the MHI for the Town of Colchester in 2005-2009 increased slightly from 2000, and virtually identical to the median income for Delaware County. The Town's MHI for 2005-2009 was about 25 percent below the MHI for New York State.

Table 3.40: Town of Colchester Median Household Income, 2000 and 2009 (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Colchester	\$41,397	\$41,696	0.7%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As demonstrated by Figure 3.25, the Town of Colchester made gains in the level of secondary and post-secondary educational attainment, with the number of high school graduates, bachelor's and advanced degree earners increasing between 2000 and 2009. At the same time, the number of people with less than a high school education declined moderately.

Figure 3.25: Town of Colchester Educational Attainment (population aged 25 and over), 2000 and 2005-2009



3.3.2.3 Town of Hamden

As depicted in Table 3.41, the population of the Town of Hamden increased by 3.4 percent between 2000 and 2010, which was slightly higher than the rate that the State experienced during

the same period. The Town’s population density was 22.1 persons per square mile, which was in line with many of the other towns in Delaware County.

Table 3.41: Town of Hamden Population, 2000 and 2010

Geography	2000	2010	% Change
Hamden	1,280	1,323	3.4%
Delaware County	48,040	47,980	-0.1%
New York	18,976,457	19,378,102	2.1%

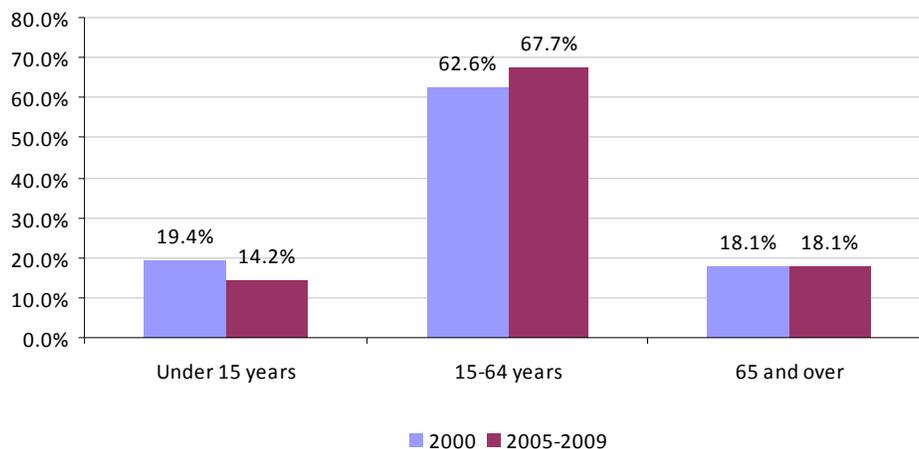
Between 2000 and 2010, the total number of housing units grew more slowly in the Town of Hamden than in Delaware County or in the State, as shown in Table 3.42.

Table 3.42: Town of Hamden Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Hamden	902	946	4.9%
Delaware County	28,943	31,222	7.9%
New York	7,679,307	8,108,103	5.6%

As depicted in Figure 3.26, the under-15 population of Hamden declined between 2000 and 2005-2009 as a share of total population, while the population age 15 through 64 increased in relative terms. The Town’s median age has also increased slightly from 43 in 2000 to 45.4 in 2010.

Figure 3.26: Town of Hamden Age Distribution, 2000 and 2005-2009



As shown in Table 3.43, there was a slight increase in resident employment in the Town of Hamden, which almost matched the rate of change in Delaware County between 2000 and 2005-2009, unlike for the State which experienced an 8.6 percent increase in employment.

Table 3.43: Town of Hamden Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Hamden	604	614	1.7%
Delaware County	20,840	21,111	1.3%
New York	8,382,988	9,102,596	8.6%

As Figure 3.27 demonstrates, in 2005-2009 approximately 24 percent of all employed residents of Hamden work in education, health care and social assistance; 14 percent in retail trade; 11 percent in manufacturing; and nearly 10 percent in construction.

Figure 3.27: Town of Hamden Resident Employment - Top Employment Sectors, 2005-2009

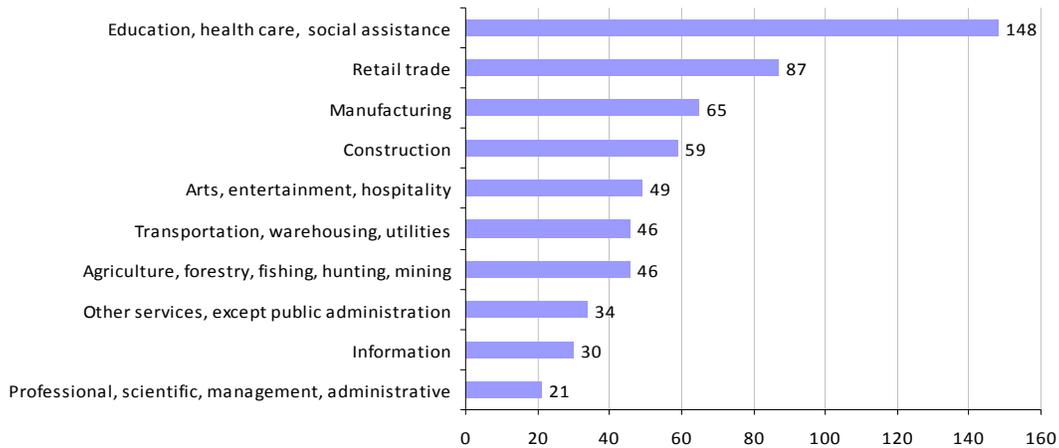


Table 3.44 shows that the unemployment rate for the Town of Hamden increased to 5.3 percent in 2005-2009 – significantly lower than the rates for the County and the State.

Table 3.44: Town of Hamden Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Hamden	3.1%	5.3%
Delaware County	6.2%	7.1%
New York	7.1%	7.0%

Table 3.45 shows that the MHI in the Town of Hamden fell by about 22 percent in real terms between 2000 and 2005-2009. The Town’s MHI in 2005-2009 was 14 percent below the MHI for the County and 36 percent below the MHI for the State.

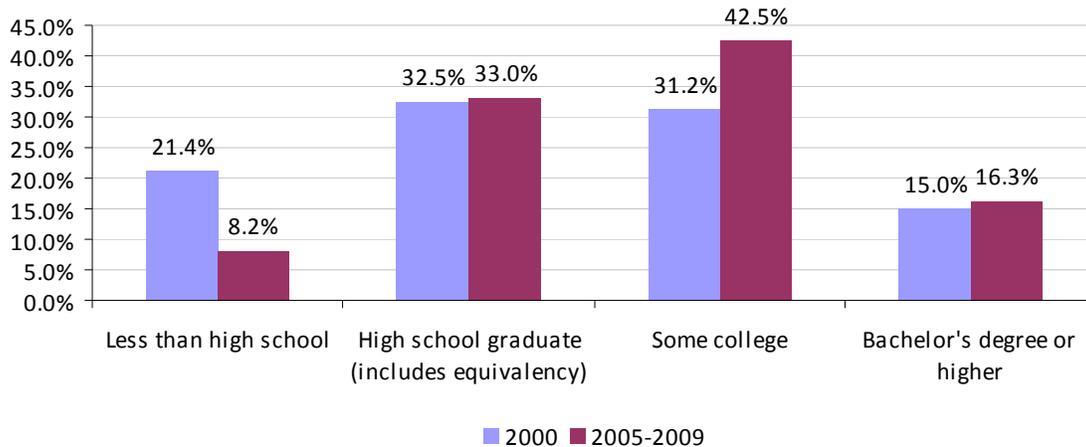
Table 3.45: Town of Hamden Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Hamden	\$45,474	\$35,625	-21.7%
Delaware County	\$41,801	\$41,656	-0.3%
New York	\$55,879	\$55,233	-1.2%

As Figure 3.28 shows, between 2000 and 2005-2009, the Town of Hamden made gains in the area of educational attainment. The percentage of all residents age 25-and-older who had not

completed high school dropped sharply, while the percentage of residents in this age group who had at least some college-level education rose correspondingly. The percentage of 25-and-older residents who have bachelor's or higher degrees nevertheless remained below the average for the State.

Figure 3.28: Town of Hamden Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.2.4 Town of Rockland

Table 3.46 shows that the population of the Town of Rockland decreased by a little fewer than 4 percent between 2000 and 2009, which was in contrast to the population growth that Sullivan County and the State experienced during the same period. Population density was 40.1 persons per square mile, which reflects its primarily rural character.

Table 3.46: Town of Rockland Population, 2000 and 2010

Geography	2000	2010	% Change
Rockland	3,915	3,775	-3.6%
Sullivan County	73,965	77,547	4.8%
New York	18,976,457	19,378,102	2.1%

As depicted in Table 3.47, the number of housing units in the Town of Rockland grew by 11.2 percent between 2000 and 2010, exceeding the rate of growth in Sullivan County and the State during the same period. There was significant growth in the number of seasonal and recreational units, which accounted for 34 percent of housing in the Town of Rockland in 2010, representing a 30 percent increase since 2000.

Table 3.47: Town of Rockland Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Rockland	2,477	2,755	11.2%
Sullivan County	44,730	49,186	10.0%
New York	7,679,307	8,108,103	5.6%

As demonstrated in Figure 3.29, the population of the Town of Rockland below age 15 declined between 2000 and 2005-2009, while the working-age and older population increased their share of the total. As a result of these changes, the Town’s median age increased from 40.4 in 2000 to 45.6 in 2005-2009.

Figure 3.29: Town of Rockland Age Distribution, 2000 and 2005-2009

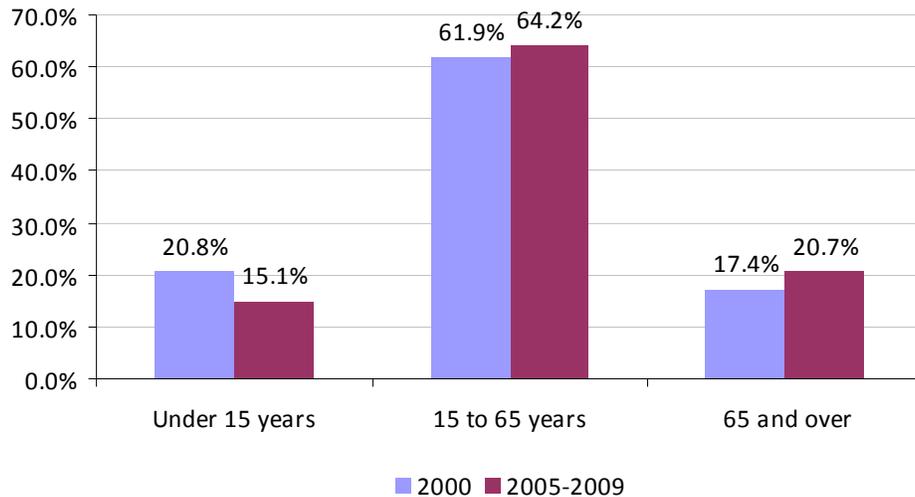


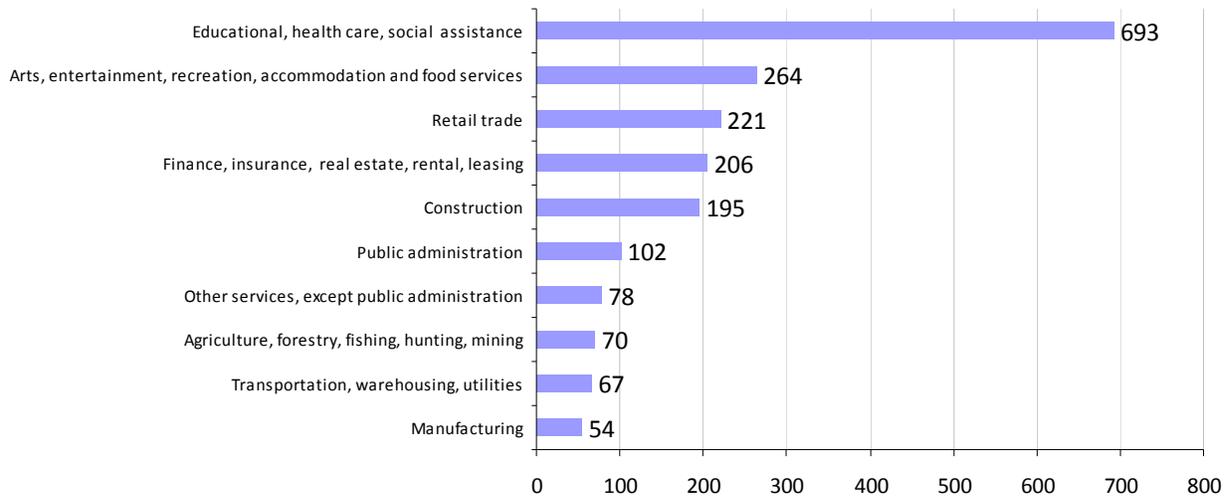
Table 3.48 shows that resident employment for the Town of Rockland increased between 2000 and 2005-2009 by almost 28 percent, which was almost double the rate of employment growth in Sullivan County and triple the growth rate experienced in the State during the same period.

Table 3.48: Town of Rockland Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Rockland	1,602	2,048	27.8%
Sullivan County	30,244	34,440	13.9%
New York	8,382,988	9,102,596	8.6%

Figure 3.30 shows that more than one-third of all employed Rockland residents work in education, health care and social assistance. Nearly 13 percent work in the arts, recreation and hospitality; and nearly 11 percent in retail trade. In contrast to the pattern found in much of Delaware County, the manufacturing sector accounts for less than 3 percent of resident employment in Rockland, which is located in Sullivan County.

Figure 3.30: Town of Rockland Resident Employment - Top Employment Sectors, 2005-2009



As depicted in Table 3.49, the unemployment rate for the Town of Rockland increased between 2000 and 2005-2009, growing to a rate that exceeded the rates for Sullivan County and for the State.

Table 3.49: Town of Rockland Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Rockland	5.4%	7.7%
Sullivan County	9.2%	6.5%
New York	7.1%	7.0%

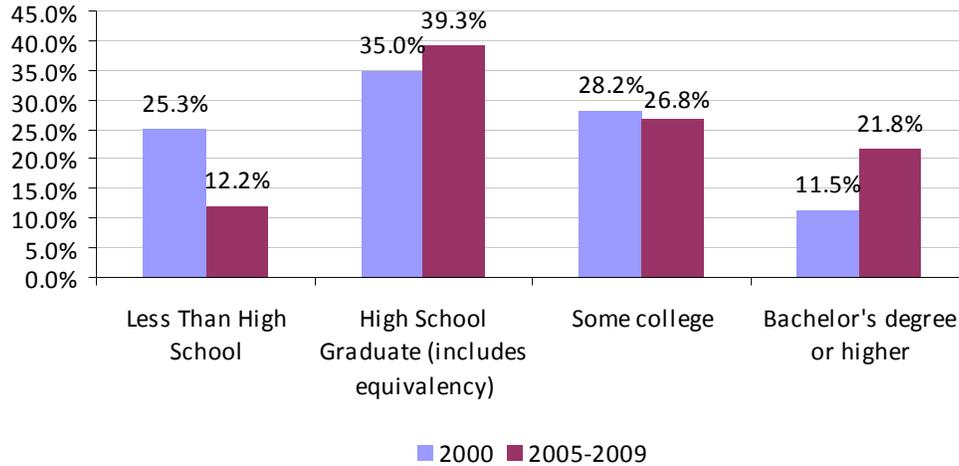
As shown in Table 3.50, the MHI for the Town of Rockland grew strongly in real terms between 2000 and 2005-2009, with growth exceeding that for both Sullivan County and the State. The Town's 2005-2009 MHI was about 91 percent of the State's.

Table 3.50: Town of Rockland Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Rockland	\$42,339	\$50,184	16.4%
Sullivan County	\$47,644	\$48,586	2.0%
New York	\$55,879	\$55,233	-1.2%

As shown in Figure 3.31 the Town of Rockland experienced significant gains in the areas of secondary and post-secondary educational attainment between 2000 and 2009, as reflected by a sharp drop in the percentage of all residents age 25-and-older who have not completed high school, and a sharp increase in the percentage of all residents in this age group who have a bachelor's degree.

Figure 3.31: Town of Rockland Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.3 Neversink Development

This section describes socioeconomic conditions and trends in five towns assessed in connection with the Neversink Development: (1) Neversink, (2) Fallsburg, and (3) Liberty in Sullivan County; and (4) Denning, and (5) Wawarsing in Ulster County.

3.3.3.1 Town of Denning

Table 3.51 shows that the population of the Town of Denning increased by 6.6 percent between 2000 and 2010 – although with just 551 residents in 2010 the Town is still very small. Population density in the Town of Denning was quite low, at a rate of 5.2 persons per square mile in 2010 – due in part to the fact that much of the Town’s land area consists of State, City or privately-owned protected land.

Table 3.51: Town of Denning Population, 2000 and 2010

Geography	2000	2010	% Change
Denning	517	551	6.6%
Ulster County	177,749	182,493	2.7%
New York	18,976,457	19,378,102	2.1%

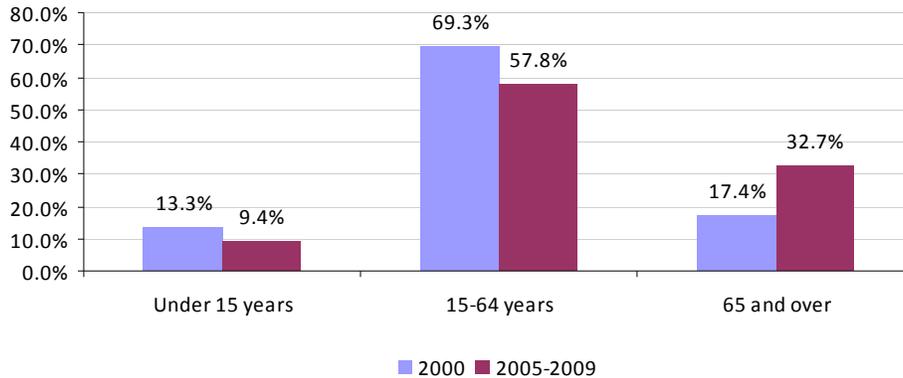
As depicted in Table 3.52, the number of total housing units in the Town of Denning rose by 2.5 percent between 2000 and 2010.

Table 3.52: Town of Denning Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Denning	518	531	2.5%
Ulster County	77,656	83,638	7.7%
New York	7,679,307	8,108,103	5.6%

For 2005-2009, the median age in Denning was 57.1, a sharp increase from 42.7 in 2000, which was considerably higher than Ulster County’s median age of 40.6. Figure 3.32 shows a sharp shift in the Town’s age mix during this period, with the under-15 population falling to a relatively low 9.4 percent of the total, while those age 65-and-older rose to a very large 32.7 percent of the total.

Figure 3.32: Town of Denning Age Distribution, 2000 and 2010



Resident employment in the Town of Denning decreased by almost 15 percent between 2000 and 2005-2009, as shown in Table 3.53, while resident employment in both Ulster County and the State rose by more than 8 percent. The decline in the number of employed residents no doubt reflects at least, in part, the growth of the Town’s 65-and-older population.

Table 3.53: Town of Denning Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Denning	247	211	-14.6%
Ulster County	83,748	90,507	8.1%
New York	8,382,988	9,102,596	8.6%

As Figure 3.33 shows, approximately 25 percent of all employed residents of the Town of Denning worked in the public sector in 2005-2009.

Figure 3.33: Town of Denning Resident Employment - Top Employment Sectors, 2005-2009

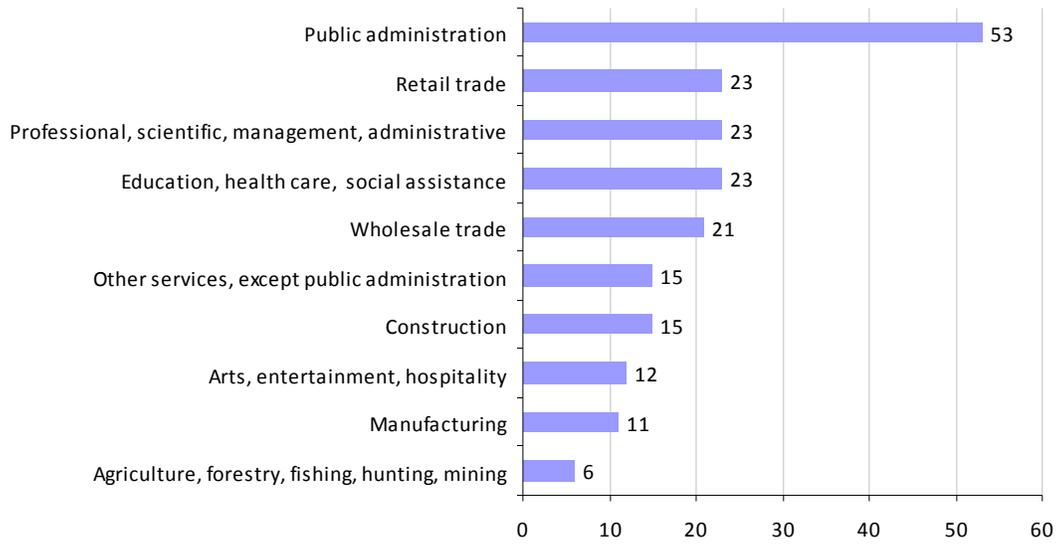


Table 3.54 shows that the unemployment rate for the Town of Denning more than doubled, to 6.6 percent, between 2000 and 2005-2009. The Town’s unemployment rate in 2005-2009 was about a percentage point higher than the rate for Ulster County and slightly less than in the Statewide rate.

Table 3.54: Town of Denning Unemployment Rate, 2000 and 2010

Geography	2000	2005-2009
Denning	2.8%	6.6%
Ulster County	6.3%	5.6%
New York	7.1%	7.0%

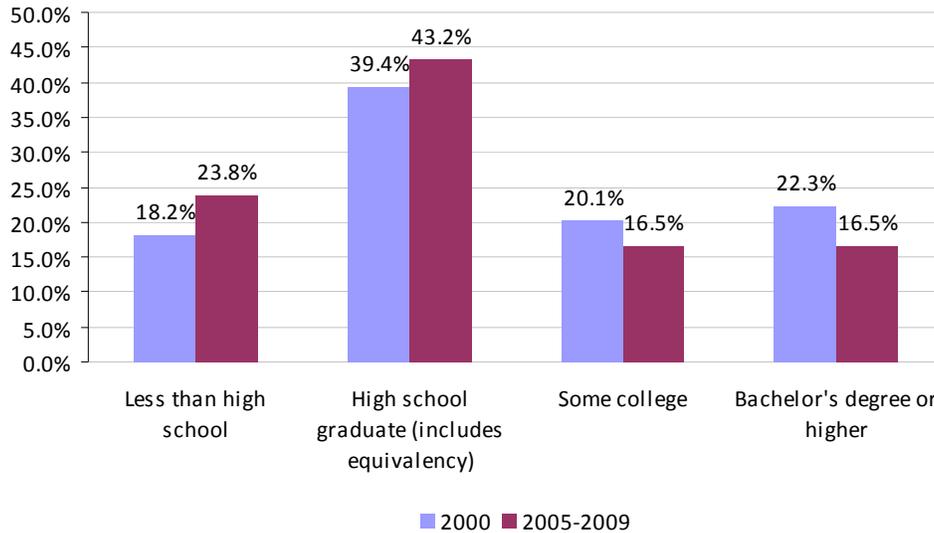
The MHI for the Town of Denning dropped by 9.2 percent between 2000 and 2005-2009, as shown in Table 3.55. This contraction was particularly notable in light of the increase recorded by Ulster County as a whole during the same period. It may reflect the decline in the number of employed residents, and the growth of the Town’s older population.

Table 3.55: Town of Denning Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Denning	\$52,659	\$47,833	-9.2%
Ulster County	\$54,795	\$57,485	4.9%
New York	\$55,879	\$55,233	-1.2%

In contrast to most other towns in the region, ACS data indicates (Figure 3.34) that educational attainment in the Town of Denning declined between 2000 and 2005-2009, as the percentage of those age 25-and-older who have not completed high school increased, and the percentage with at least some college-level education declined.

Figure 3.34: Town of Denning Educational Attainment (population 25 and over), 2000 and 2005-2009



3.3.3.2 Town of Fallsburg

In 2010, as shown in Table 3.56, the population of Fallsburg was 12,780 – an increase of 5.3 percent from its population in 2000. At a rate of 165.8 persons per square mile, the Town of Fallsburg had a relatively high population density compared to the other towns profiled in this report.

Table 3.56: Town of Fallsburg Population, 2000 and 2010

Geography	2000	2010	% Change
Fallsburg	12,223	12,870	5.3%
Sullivan County	73,965	77,547	4.8%
New York	18,976,457	19,378,102	2.1%

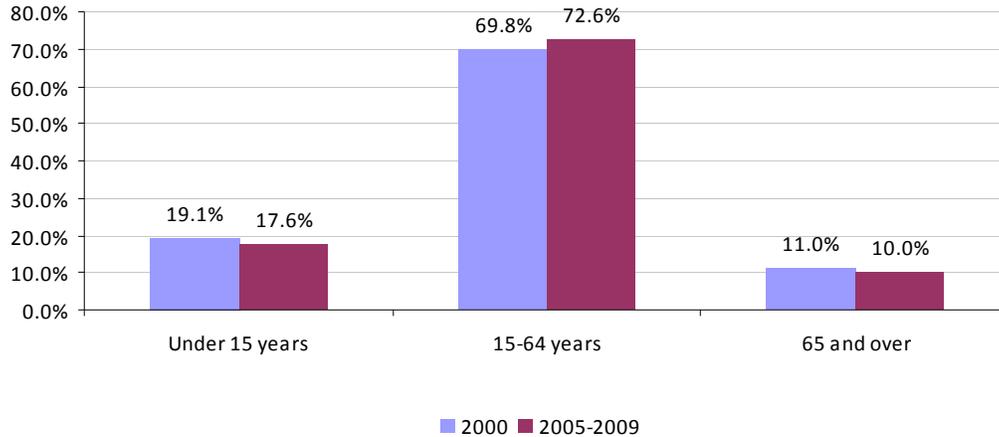
Since 2000, the Town of Fallsburg has experienced very strong growth in its housing stock, with the total number of units increasing by more than 28 percent between 2000 and 2010 (Table 3.57). This growth was driven primarily by growth in seasonal and recreational units. The number of such units in Fallsburg increased by nearly 58 percent over the course of the decade; and they accounted for more than two-thirds of the Town’s total increase in housing units. As of 2010, seasonal and recreational units accounted for nearly 41 percent of the Town’s housing stock.

Table 3.57: Town of Fallsburg Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Fallsburg	6,621	8,497	28.3%
Sullivan County	44,730	49,186	10.0%
New York	7,679,307	8,108,103	5.6%

As Figure 3.35 shows, the Town of Fallsburg has experienced modest change in terms of its age mix. Between 2000 and 2005-2009, the share of the population in the Town of Fallsburg under the age of 15 declined slightly, while the 15-64 age group increased to an unusually high 72.6 percent of the total population. The median age increased to about 40 years old, which represented an increase of approximately 6.2 percent from its 2000 level.

Figure 3.35: Town of Fallsburg Age Distribution, 2000 and 2005-2009



As shown in Table 3.58, the number of employed Fallsburg residents grew significantly between 2000 and 2005-2009, experiencing an increase of approximately 22 percent. This employment growth rate was greater than that experienced in Sullivan County and significantly more than the State’s growth rate during this period.

Table 3.58: Town of Fallsburg Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Fallsburg	4,318	5,256	21.7%
Sullivan County	30,244	34,440	13.9%
New York	8,382,988	9,102,596	8.6%

As Figure 3.36 shows, more than 35 percent of all employed residents of the Town of Fallsburg worked in education, health and social assistance in 2005-2009. The miscellaneous services sector accounted for about 14 percent; arts, entertainment and hospitality accounted for nearly 8 percent; and retail trade accounted for 7 percent.

Figure 3.36: Town of Fallsburg Resident Employment - Top Employment Sectors, 2005-2009

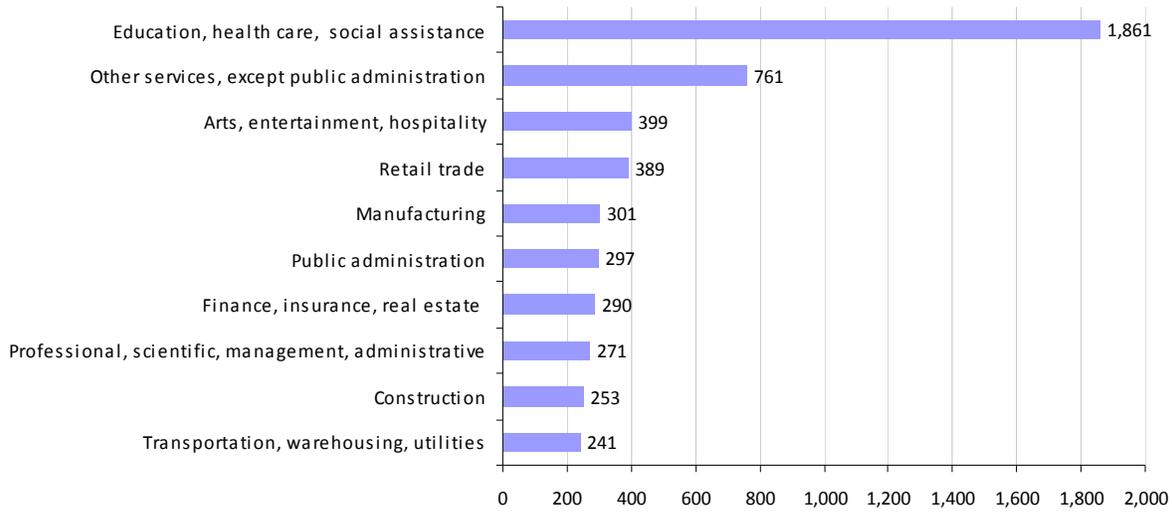


Table 3.59 shows that the unemployment rate for the Town of Fallsburg declined by 1.5 percentage points between 2000 and 2005-2009, which was slightly less than the rate for Sullivan County as a whole.

Table 3.59: Town of Fallsburg Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Fallsburg	8.8%	7.3%
Sullivan County	9.2%	6.5%
New York	7.1%	7.0%

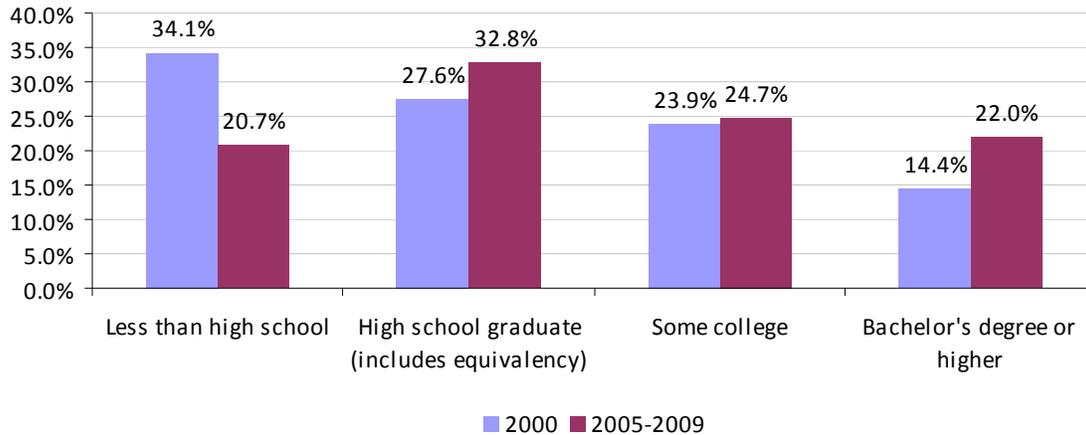
As shown in Table 3.60, the Town’s MHI dropped by 3.2 percent between 2000 and 2005-2009. This slight decrease was opposite the trend experienced by Sullivan County during this period, which experienced a slight increase in MHI, but was more than the decline in MHI experienced in the State.

Table 3.60: Town of Fallsburg Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Fallsburg	\$42,542	\$41,178	-3.2%
Sullivan County	\$47,644	\$48,586	2.0%
New York	\$55,879	\$55,233	-1.2%

As shown in Figure 3.37, between 2000 and 2005-2009 the Town of Fallsburg progressed significantly in the area of secondary and post-secondary educational attainment, with an increase in the percentage of those who were high school graduates, had college experience, or bachelor’s degrees or higher.

Figure 3.37: Town of Fallsburg Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.3.3 Town of Liberty

In 2010, the population of the Town of Liberty, as shown in Table 3.61, was 9,885 – an increase of 2.5 percent since 2000. The Town’s population grew somewhat more slowly during this period than that of Sullivan County as a whole. In 2010, the Town had a relatively high population density of 124.2 persons per square mile.

Table 3.61: Town of Liberty Population, 2000 and 2010

Geography	2000	2010	% Change
Liberty	9,644	9,885	2.5%
Sullivan County	73,965	77,547	4.8%
New York	18,976,457	19,378,102	2.1%

Between 2000 and 2010, the Town of Liberty experienced a modest increase in its housing stock, with a growth rate of nearly 2 percent during this period (Table 3.62). Slow growth in Liberty may, in part, be related to the Town’s relatively small second-home sector; in 2010 fewer than 17 percent of its housing units were used for seasonal or recreational purposes.

Table 3.62: Town of Liberty Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Liberty	5,391	5,495	1.9%
Sullivan County	44,730	49,186	10.0%
New York	7,679,307	8,108,103	5.6%

As demonstrated by Figure 3.38, the Town of Liberty experienced relatively few changes in its age distribution. The population under 64 years old declined slightly and the population 65 and over increased nominally (less than a percent). Meanwhile, the median age rose slightly from 39.3 in 2000 to 41.7 in 2005-2009.

Figure 3.38: Town of Liberty Age Distribution, 2000 and 2005-2009

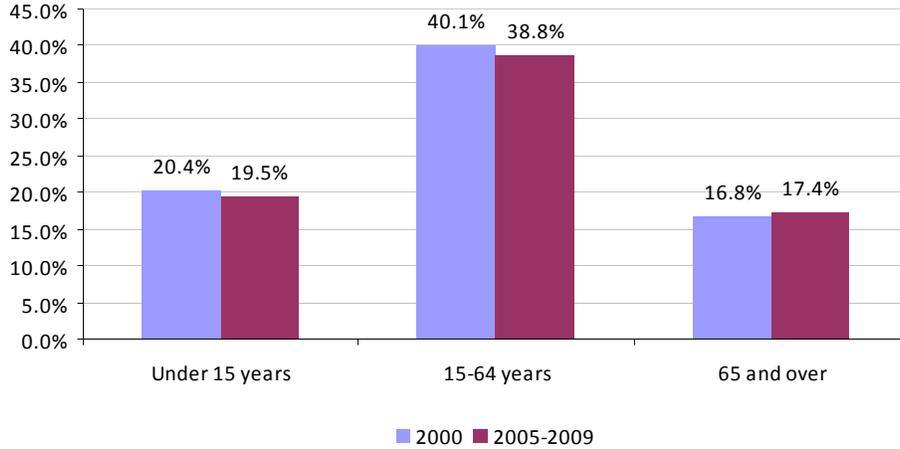


Table 3.63 shows that resident employment for the Town of Liberty increased by 9.6 percent between 2000 and 2005-2009 – not as fast as resident employment in Sullivan County as a whole, but faster than employment growth statewide.

Table 3.63: Town of Liberty Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Liberty	3,850	4,218	9.6%
Sullivan County	30,244	34,440	13.9%
New York	8,382,988	9,102,596	8.6%

As Figure 3.39 shows, nearly 30 percent of all employed residents of the Town of Liberty worked education, health and social assistance in 2005-2009. Nearly 11 percent were employed in retail trade; and a similar percentage in arts, entertainment and hospitality, reflecting the important role that the latter sector plays in Sullivan County’s economy.

Figure 3.39: Town of Liberty Resident Employment - Top Employment Sectors, 2005-2009

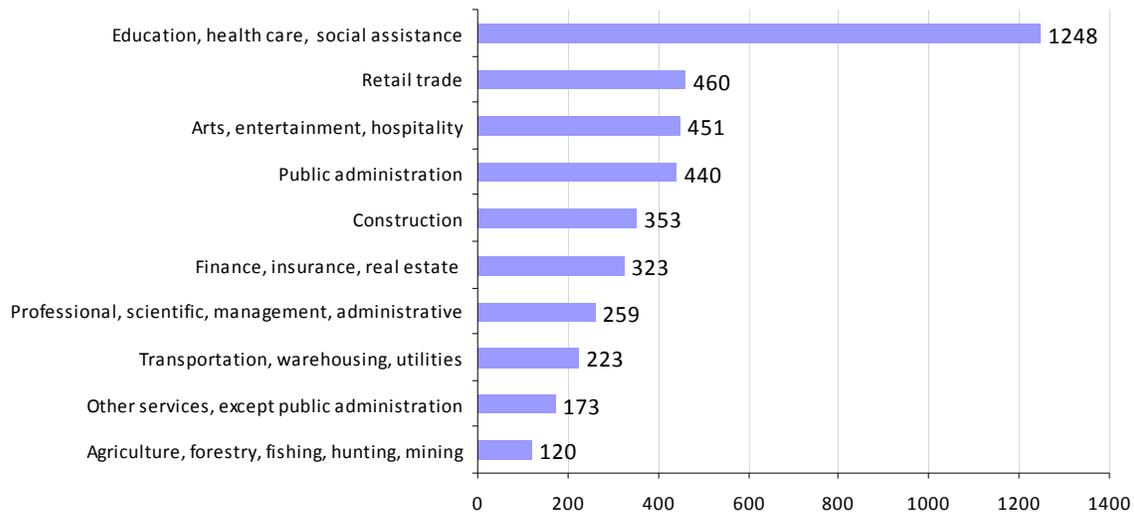


Table 3.64 shows that the unemployment rate for the Town of Liberty declined between 2000 and 2005-2009, consistent with the declining trend experienced in Sullivan County and the State during this period. However, the Town of Liberty’s unemployment rate remained higher than in Sullivan County and the State.

Table 3.64: Town of Liberty Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Liberty	10.7%	8.6%
Sullivan County	9.2%	6.5%
New York	7.1%	7.0%

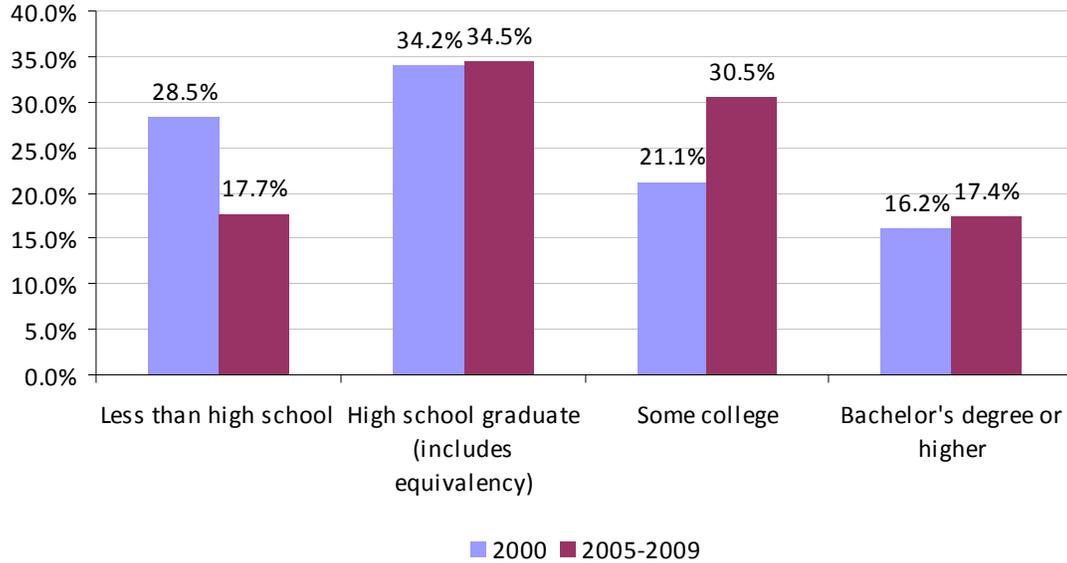
The MHI for the Town of Liberty increased by more than 18 percent in real terms between 2000 and 2005-2009 – far exceeding the increase in Sullivan County during this period, and contrasting sharply with the decline that occurred at the State level. Nevertheless, Liberty’s MHI was still 12 percent below the MHI for New York State in 2005-2009 (Table 3.65).

Table 3.65: Town of Liberty Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Liberty	\$41,236	\$48,730	18.2%
Sullivan County	\$47,644	\$48,586	2.0%
New York	\$55,879	\$55,233	-1.2%

As shown in Figure 3.40, the Town of Liberty has experienced significant progress in the area of secondary and post-secondary educational attainment. Between 2000 and 2005-2009, the percentage of the Town's residents that were age 25-and-older who had not completed high school declined sharply, while the percentage of this age group with at least some college-level education increased.

Figure 3.40: Town of Liberty Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.3.4 Town of Neversink

At 3,557, as Table 3.66 shows, the population of the Town of Neversink was virtually unchanged between 2000 and 2010. Population density in 2010 was approximately 43.0 persons per square mile, reflecting a community more rural in nature than either the Towns of Liberty or Fallsburg.

Table 3.66: Town of Neversink Population, 2000 and 2010

Geography	2000	2010	% Change
Neversink	3,553	3,557	0.1%
Sullivan County	73,965	77,547	4.8%
New York	18,976,457	19,378,102	2.1%

The number of total housing units in the Town of Neversink grew by 4.3 percent between 2000 and 2010 (Table 3.67), a slower rate of growth than was experienced in Sullivan County. Seasonal and recreational units accounted for virtually all of this growth, and in 2010 accounted for more than 28 percent of Neversink's housing stock.

Table 3.67: Town of Neversink Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Neversink	1,960	2,045	4.3%
Sullivan County	44,730	49,186	10.0%
New York	7,679,307	8,108,103	5.6%

Neversink's median age rose slightly between 2000 and 2005-2009, to 40. Nevertheless, in contrast to many towns in the surrounding region, Neversink has a significantly larger number of residents below age 15 than of those age 65-and-older. Moreover, the under-15 group increased as a percentage of total population between 2000 and 2005-2009, while those over 65 declined (Figure 3.41).

Figure 3.41: Town of Neversink Age Distribution, 2000 and 2005-2009

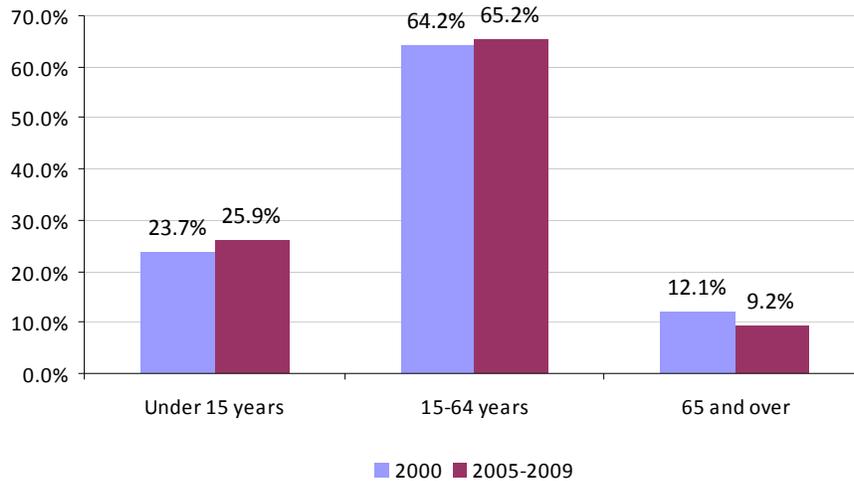


Table 3.68 shows that resident employment for the Town of Neversink increased by 4.9 percent between 2000 and 2005-2009, lagging somewhat behind the growth that occurred elsewhere in Sullivan County.

Table 3.68: Town of Neversink Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Neversink	1,483	1,556	4.9%
Sullivan County	30,244	34,440	13.9%
New York	8,382,988	9,102,596	8.6%

As Figure 3.42 shows, more than one-third of the employed residents of the Town of Neversink worked in education, health and social assistance in 2005-2009. About 14 percent worked for government agencies, nearly 11 percent in construction, and more than 9 percent in the arts, recreation and hospitality.

Figure 3.42: Town of Neversink Resident Employment - Top Employment Sectors, 2005-2009

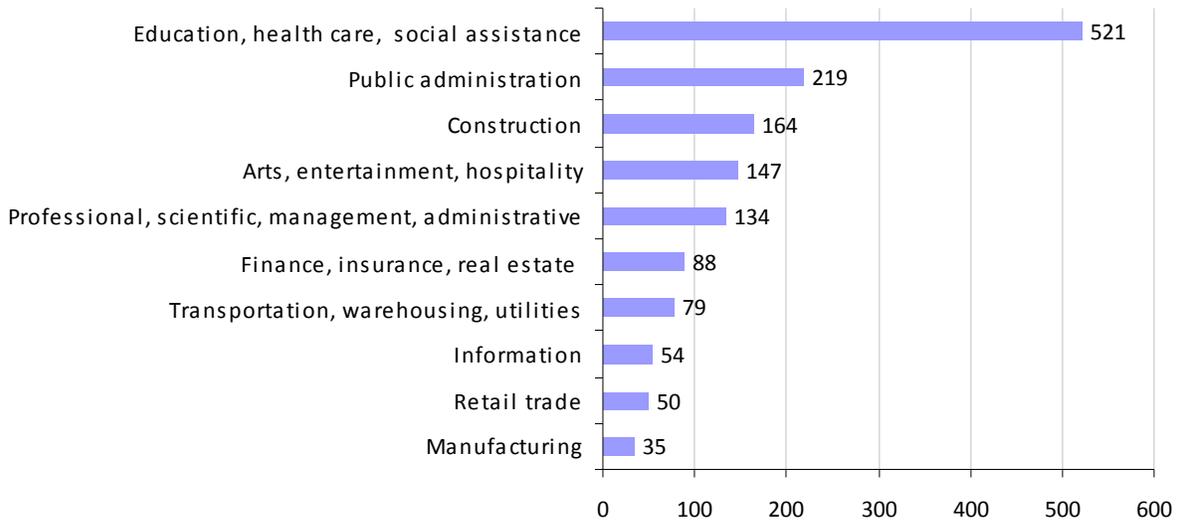


Table 3.69 shows that the unemployment rate for the Town of Neversink averaged 4.7 percent during 2005-2009, below the unemployment rates reported by ACS for both Sullivan County and the State during this period.

Table 3.69: Town of Neversink Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Neversink	5.8%	4.7%
Sullivan County	9.2%	6.5%
New York	7.1%	7.0%

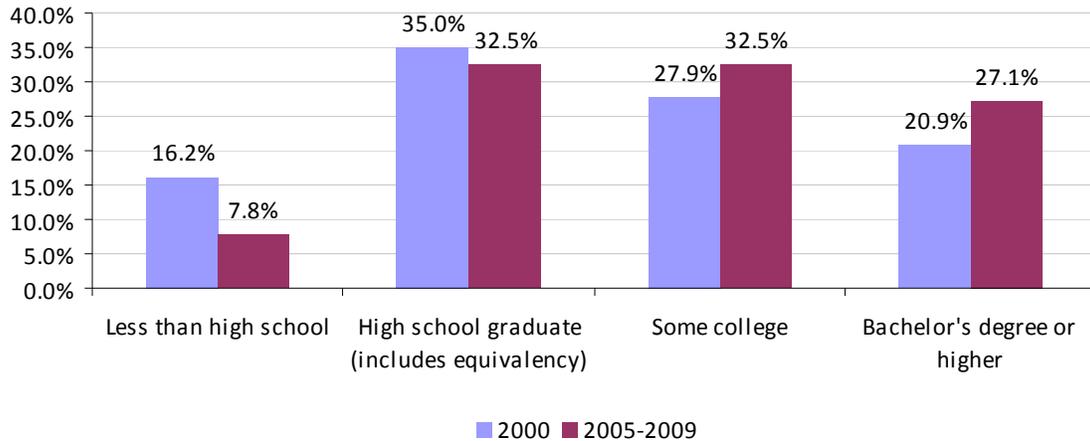
According to ACS data, the MHI for the Town of Neversink increased by more than 16 percent between 2000 and 2005-2009, as depicted in Table 3.70. The Town's MHI for 2005-2009 was 22 percent higher than the Statewide MHI, and 39 percent higher than that for Sullivan County.

Table 3.70: Town of Neversink Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Neversink	\$58,172	\$67,708	16.4%
Sullivan County	\$47,644	\$48,586	2.0%
New York	\$55,879	\$55,233	-1.2%

As shown in Figure 3.43, the percentage of Neversink residents age 25-and-older who lacked a high school diploma declined between 2000 and 2005-2009 to 7.8 percent, while the percentage of this age group that had at least some college-level education rose to nearly 60 percent, including 27.1 percent who had at least a bachelor's degree.

Figure 3.43: Town of Neversink Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.3.5 Town of Wawarsing

As shown in Table 3.71, the Town of Wawarsing’s population in 2010 was 13,157. The Town’s population grew by 2.1 percent between 2000 and 2010, slower than the growth rate for Ulster County as a whole, but equal to the growth rate for New York State. With a population density of 100.8 persons per square mile in 2010, Wawarsing is more densely populated than many of the more rural towns in vicinity of the Project, but less densely populated than Ulster County as a whole.

Table 3.71: Town of Wawarsing Population, 2000 and 2010

Geography	2000	2010	% Change
Wawarsing	12,889	13,157	2.1%
Ulster County	177,749	182,493	2.7%
New York	18,976,457	19,378,102	2.1%

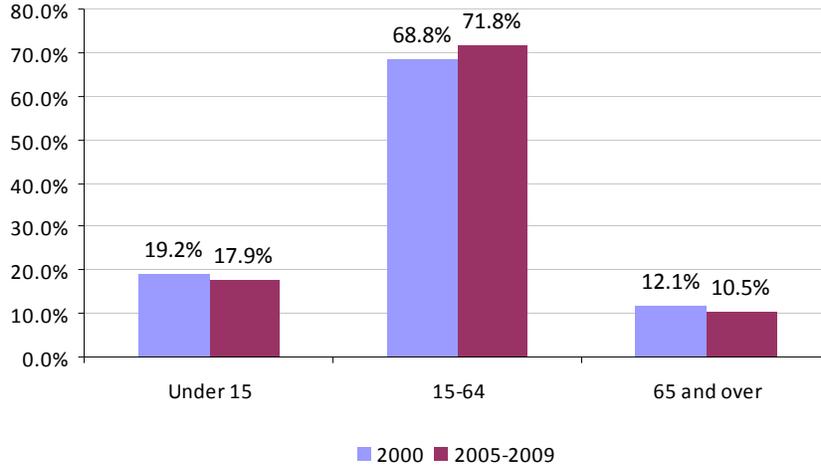
The number of housing units in the Town of Wawarsing grew by 6.7 percent between 2000 and 2010 (Table 3.72). About 16 percent of all housing units in the Town in 2010 were for seasonal or recreational use.

Table 3.72: Town of Wawarsing Housing Units, 2000 and 2010

Geography	2000	2010	% Change
Wawarsing	5,821	6,211	6.7%
Ulster County	77,656	83,638	7.7%
New York	7,679,307	8,108,103	5.6%

The median age in the Town of Wawarsing in 2005-2009 was 40.0. Figure 3.44 shows that between 2000 and 2005-2009, the under-15 and 65-and-older age groups both declined as a share of Wawarsing’s population, while the share of all residents who are between 15 and 64 increased.

Figure 3.44: Town of Wawarsing Age Distribution, 2000 and 2005-2009



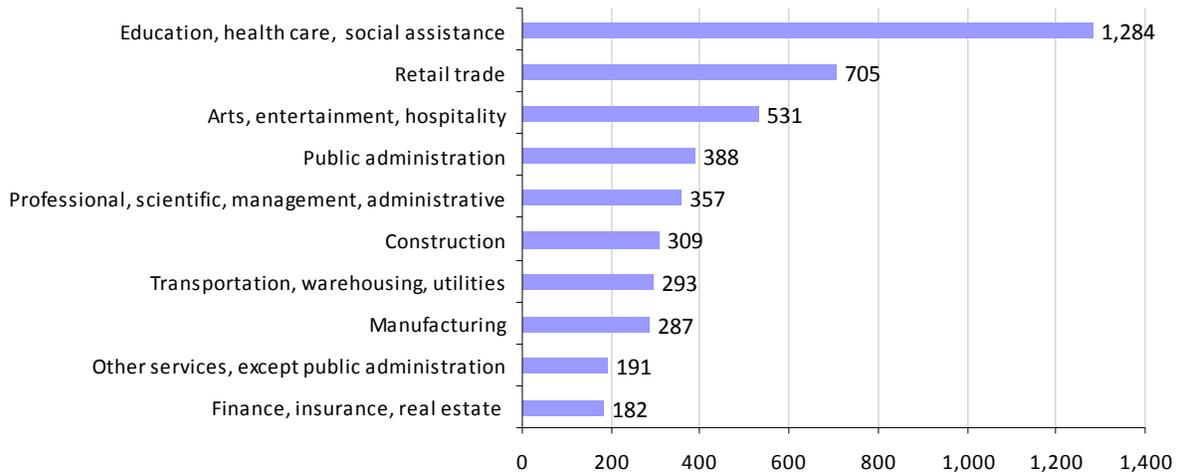
As shown in Table 3.73, resident employment in the Town of Wawarsing fell by 5.4 percent between 2000 and 2005-2009 – a sharp contrast with Ulster County as a whole, which saw an 8.1 percent increase in resident employment.

Table 3.73: Town of Wawarsing Resident Employment, 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Wawarsing	5,088	4,814	-5.4%
Ulster County	83,748	90,507	8.1%
New York	8,382,988	9,102,596	8.6%

As Figure 3.45 shows, in 2005-2009 nearly 27 percent of the Town of Wawarsing’s employed residents worked in education, health care and social assistance. Nearly 15 percent worked in retail trade, 11 percent in arts, recreation and hospitality and 8 percent in government.

Figure 3.45: Town of Wawarsing Resident Employment - Top Employment Sectors, 2005-2009



As Table 3.74 shows, the unemployment rate in the Town of Wawarsing for 2005-2009 was 8.2 percent, exceeding the rates for both Ulster County and the State.

Table 3.74: Town of Wawarsing Unemployment Rate, 2000 and 2005-2009

Geography	2000	2005-2009
Wawarsing	6.6%	8.2%
Ulster County	6.3%	5.6%
New York	7.1%	7.0%

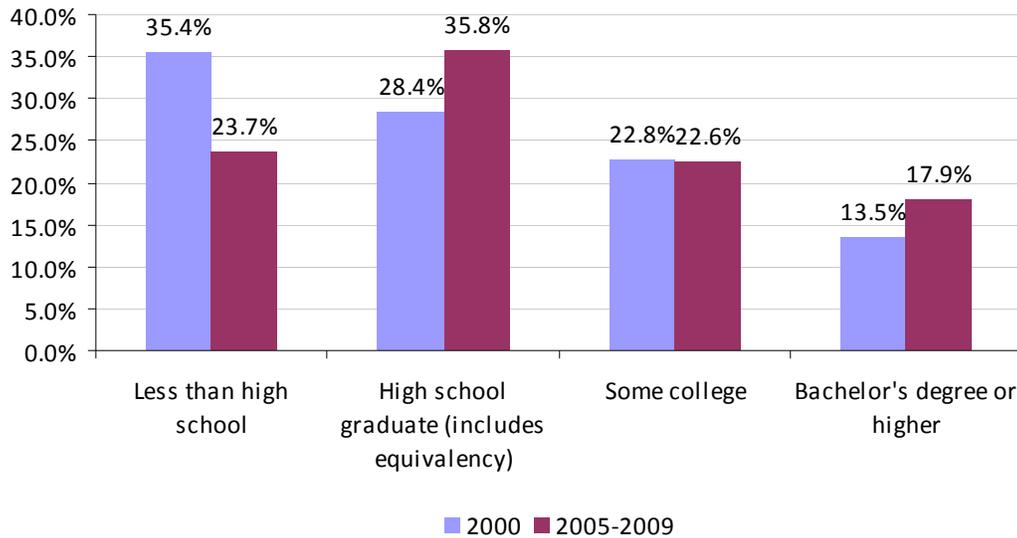
The MHI in the Town of Wawarsing dropped slightly in real terms between 2000 and 2005-2009, as shown in Table 3.75 – a trend that seems consistent with the decline in resident employment the Town experienced during this period, as well as its rising unemployment rate. For 2005-2009, the Town’s MHI was 20 percent below the MHI for Ulster County as a whole.

Table 3.75: Town of Wawarsing Median Household Income (2009 dollars), 2000 and 2005-2009

Geography	2000	2005-2009	% Change
Wawarsing	\$46,194	\$45,813	-0.8%
Ulster County	\$54,795	\$57,485	4.9%
New York	\$55,879	\$55,233	-1.2%

As depicted in Figure 3.46, educational attainment improved significantly in the Town of Wawarsing between 2000 and 2005-2009, with a substantial decrease in the percentage of the Town’s population age 25-and-older that had not earned a high school diploma, as well as a significant increase in the percentage of the Town’s population in that age group that earned a high school diploma, a bachelor’s or advanced degree. Despite this progress, the percentage of 25-and-older residents who have not completed high school remains relatively high, and the percentage of those with at least a bachelor’s degree remained relatively low.

Figure 3.46: Town of Wawarsing Educational Attainment (population 25 years and over), 2000 and 2005-2009



3.3.4 Socioeconomic Conclusions

During the past decade, many of the fifteen towns profiled above have struggled with a variety of long-term structural problems, combined more recently with the effects of the recession and financial crisis that began in 2008. Long-term issues include:

- Population losses – 6 of the 15 towns experienced a decline in resident population between 2000 and 2010;
- Weak overall job growth – resident employment declined in 7 of the fifteen towns;
- Rising unemployment – in 8 of the 15 towns resident unemployment exceeded both their County and the State unemployment rates in 2005-2009;
- Low incomes – in 2005-2009, median household incomes were less than 80 percent of the statewide median income in 8 of the 15 towns; and
- Relatively low levels of educational attainment – in 11 of the 15 towns, fewer than 20 percent of all residents age 25 and older had bachelor’s or higher degrees in 2005-2009 (as compared with 32 percent statewide); and 7 of the 15 towns have more residents who have not completed high school than they have four-year college graduates.

3.4 Economic Impact of Project Construction

The overall, anticipated economic impact of constructing the Project developments was assessed. For the Cannonsville and Pepacton Developments, the economic impact of constructing these Project developments on Delaware County was assessed. For the Neversink Development, the economic impact on Sullivan County was assessed. While the preceding description of current conditions and recent trends focused on town-level data, the analysis of the three developments’

economic impact focuses on county-level impact. This is because IMPLAN, like other input-output models, uses the county as its basic unit of economic analysis.

Based on the most recent estimates, the Cannonsville, Pepacton and Neversink Developments will cost approximately \$42.5 million, \$8.1 million and \$4.4 million, respectively. A breakdown of estimated costs for each development is shown below in Table 3.76.

Table 3.76: Estimated Construction Costs, by Development

Costs	Cannonsville	Pepacton	Neversink
Mobilization& Demobilization (330)	\$2,982,600	\$454,500	\$300,100
Powerplant Structures & Improvements (331)	\$4,207,000	\$181,000	\$75,000
Reservoir, Dam & Waterway (332)	\$6,330,000	\$1,532,000	\$842,000
Waterwheel, Turbines, and Generators (333)	\$15,270,000	\$1,828,000	\$1,278,000
Accessory Electric Equipment (334)	\$1,511,000	\$457,000	\$320,000
Substation and Switching Station Equipment (353)	\$2,100,000	\$542,000	\$269,000
Transmission, Poles, and Conductors (335/336)	\$408,000	\$5,000	\$217,000
Other Costs (including contingencies and services)	\$9,734,000	\$3,097,000	\$1,135,000
Total	\$42,542,600	\$8,096,500	\$4,436,100

In estimating the economic impact of construction of the Cannonsville, Pepacton and Neversink Developments in Delaware and Sullivan counties, as applicable, it is important to recognize that much of the work required for completion of the developments is likely to be performed by contractors and suppliers of specialized equipment that come from outside the two counties at issue. For purposes of this analysis, it was assumed that all of the major contracts for architecture, engineering, construction or procurement and installation of equipment will be awarded to firms based outside the county in which each respective development is located. It was further assumed that local economic impact of each development will be generated primarily through employment of local residents for part of the work done on-site, and to a lesser extent through local subcontracting.

Exactly how much work on any given project will be performed by local subcontractors or local workers is difficult to predict. Some assumptions can be made, however, based on information about the use of local subcontractors and local labor on other DEP construction projects in the vicinity of the Project region. For purposes of this analysis, the following assumption were utilized:

- None of the work done under waterwheels, turbines and generators (333), accessory electrical equipment (334), substation and switching station equipment (353), transmission poles and conductors (355/356), and other costs (including contingencies and services) will be contracted locally, or done by local workers;
- 10 percent of the work done under mobilization/demobilization (330), powerplant structures and improvements (331) and reservoirs, dams and waterways (332) will be done by local subcontractors; and

- 90 percent of the work done under mobilization/demobilization (330), powerplant structures and improvements (331) and reservoirs, dams and waterways (332) will be done by contractors from outside the local county, but 45 percent of all of the workers employed by these non-local contractors will be local residents.

Based on these assumptions, the direct and indirect and induced (or “multiplier”) effects of projected payments to local subcontractors and construction workers associated with each development were estimated using the IMPLAN input-output modeling system – an econometric modeling system commonly used in analyses of economic impact.

3.4.1 Economic Impact of Construction of the Cannonsville Development

Based on the assumptions outlined above and using the IMPLAN input-output modeling system, of the \$42.5 million estimated total cost of the Cannonsville Development, direct payments to Delaware County subcontractors and wages paid directly to Delaware County residents employed by contractors based outside the County would total approximately \$3.1 million. The development would directly generate approximately 49 person-years of employment for County residents in construction and related industries, with compensation paid to these employees totaling approximately \$2.1 million.

Through the multiplier effect, direct payments to local subcontractors and residents would generate approximately \$1.2 million in additional economic output in Delaware County, and 10 additional person-years of employment, with employee compensation totaling nearly \$380,000.

Taking into account both direct and indirect/induced effects, the Cannonsville Development would provide a one-time increase of approximately \$4.3 million in economic output in Delaware County during the estimated 36 month construction period associated with the development, 59 person-years of work, and approximately \$2.5 million in employee compensation.

Table 3.77: Impact of Cannonsville Development in Delaware County

<i>Cannonsville (Delaware County)</i>	<i>Impacts</i>	<i>Indirect and</i>		
		<i>Direct</i>	<i>Induced</i>	<i>Total</i>
Subcontractors	Output	\$1,351,960	\$408,604	\$1,760,564
	Employment	10	3	13
	Employee Compensation	\$422,424	\$139,953	\$562,377
Non-local contractors' local employee spending	Output	\$1,710,819	\$790,066	\$2,500,885
	Employment	39	7	46
	Employee Compensation	\$1,710,819	\$239,733	\$1,950,552
Total	Output	\$3,062,779	\$1,198,670	\$4,261,449
	Employment	49	10	59
	Employee Compensation	\$2,133,243	\$379,686	\$2,512,929

3.4.2 Economic Impact of Construction of the Pepacton Development

Of the \$8.1 million estimated total cost of the Pepacton Development, direct payments to Delaware County subcontractors and wages paid directly to Delaware County residents

employed by contractors based outside the County would total about \$491,000. The development would directly generate approximately 8 person-years of employment for County residents in construction and related industries, with compensation paid to these employees totaling \$342,000.

Through the multiplier effect, direct payments to local subcontractors and residents would generate approximately \$192,000 in additional economic output in Delaware County, and 2 additional person-years of employment, with employee compensation totaling nearly \$61,000.

Taking into account both direct and indirect/induced effects, the project would provide a one-time increase of \$683,000 in economic output in Delaware County during the estimated 21 month construction period associated with the development, 10 person-years of work, and \$403,000 in employee compensation (Table 3.78).

Table 3.78: Impact of Pepacton Development in Delaware County

<i>Pepacton (Delaware County)</i>	<i>Impacts</i>	<i>Indirect and</i>		<i>Total</i>
		<i>Direct</i>	<i>Induced</i>	
Subcontractors	Output	\$216,750	\$65,509	\$282,259
	Employment	2	1	3
	Employee Compensation	\$67,724	\$22,438	\$90,162
Non-local contractors' local employee spending	Output	\$274,283	\$126,665	\$400,948
	Employment	6	1	7
	Employee Compensation	\$274,283	\$38,435	\$312,718
Total	Output	\$491,033	\$192,174	\$683,207
	Employment	8	2	10
	Employee Compensation	\$342,007	\$60,873	\$402,880

3.4.3 Economic Impact of Construction of the Neversink Development

Of the \$4.4 million estimated total cost of the Neversink Development, direct payments to Sullivan County subcontractors and wages paid directly to Sullivan County residents employed by contractors based outside the County would total more than \$274,000. The development would directly generate approximately 5 person-years of employment for County residents in construction and related industries, with compensation paid to these employees totaling about \$190,000.

Through the multiplier effect, direct payments to local subcontractors and residents would generate nearly \$120,000 in additional economic output in Sullivan County, and one additional person-year of employment, with employee compensation totaling nearly \$40,000.

Taking into account both direct and indirect/induced effects, the project would provide a one-time increase of \$394,000 in economic output in Sullivan County during the estimated 21 month construction period associated with the development, 6 person-years of work, and \$230,000 in employee compensation (Table 3.79).

Table 3.79: Impact of Neversink Development in Sullivan County

<i>Neversink (Sullivan County)</i>	<i>Impacts</i>	<i>Indirect and</i>		<i>Total</i>
		<i>Direct</i>	<i>Induced</i>	
Subcontractors	Output	\$121,710	\$39,133	\$160,843
	Employment	1	0.3	1.3
	Employee Compensation	\$37,657	\$13,288	\$50,945
Non-local contractors' local employee spending	Output	\$152,512	\$80,629	\$233,141
	Employment	4	1	5
	Employee Compensation	\$152,512	\$26,442	\$178,954
Total	Output	\$274,222	\$119,762	\$393,984
	Employment	5	1	6
	Employee Compensation	\$190,169	\$39,730	\$229,899

3.5 Economic Impact of Project Operations

Estimates of the impact of operation of the three Project developments are based on the most recent estimates of operating revenues for each of the three facilities. Using IMPLAN, these revenue estimates can be translated into estimates of the number of people to be employed directly in the operation of the three facilities, their earnings, and the indirect and induced impact of spending within Delaware and Sullivan counties of plant operation and maintenance.

3.5.1 Economic Impact of Cannonsville, Pepacton, and Neversink Operations

Operating impacts for each of the three facilities in their first year of operation (assumed to be 2016 for Pepacton and Neversink and 2019 for Cannonsville) are shown below in Table 3.80.

- The Cannonsville Development operating revenue estimates would translate into the equivalent of approximately 5 full-time-equivalent (“FTE”) jobs, create two additional FTE jobs in Delaware County through the multiplier effect, and would increase the County’s total annual economic output in 2019 by more than \$2.7 million.
- Because of its smaller scale, the Pepacton Development operating revenue estimates would translate into the equivalent of less than one FTE job (*i.e.*, 0.6 FTE); and through the multiplier effect, would only generate 0.4 FTE jobs in Delaware County. The facility’s operations would thus translate into an equivalent increase in employment in the County by one FTE job; and increase the County’s total annual economic output in 2016 by about \$454,000.
- The still-smaller Neversink Development operating revenue estimates would translate into the equivalent of only 0.3 FTE jobs, with 0.3 additional FTE jobs created in Sullivan County through the multiplier effect. The facility’s operations would thus translate into an equivalent increase in employment by only 0.6 FTE, with the County’s total annual economic output in 2016 increasing by slightly less than \$273,000.

Table 3.80: Impact of Ongoing Operations, by Development

Project	Impact	Indirect and induced		Total
		Direct	impacts	
Cannonsville (Delaware County)	Output	\$2,473,177	\$261,635	\$2,734,812
	Employment	5	2	7
	Employee Compensation	\$448,114	\$78,295	\$526,409
Pepacton (Delaware County)	Output	\$408,939	\$44,815	\$453,754
	Employment	0.6	0.4	1
	Employee Compensation	\$77,187	\$13,487	\$90,674
Neversink (Sullivan County)	Output	\$241,644	\$31,186	\$272,830
	Employment	0.3	0.3	0.6
	Employee Compensation	\$45,788	\$10,170	\$55,958

It should be noted that in contrast to the one-time impact of spending on construction (that is, lasting only for the duration of the Project-related construction activities for each development), the operating impacts cited above and summarized in Table 3.80 would be ongoing annual impacts.

3.5.2 Tax Impacts of Operations

Given potential changes in the market value of properties, variations in local assessment practices, and potential variability in local tax rates from year to year, estimates of the impact of the proposed developments on real property tax revenues are inevitably somewhat speculative. For purposes of this analysis, it was assumed that the market value of each facility is initially set at a level equal to the cost of construction. An estimated assessed value for each development was then calculated based on the equalization rate for the applicable town in which each development is located (as reported by the New York State Office of Real Property Services) and estimated real property taxes based on county, municipal and school tax rates for 2010.

As set forth in Table 3.81 the results of this analysis were as follows with respect to annual property tax payments for each development:

- The Cannonsville Development would pay approximately \$1.7 million annually in county, municipal and school taxes;
- The Pepacton Development would pay approximately \$158,000 annually in county, municipal and school taxes; and
- The Neversink Development would pay approximately \$112,000 annually in county, municipal and school taxes.

Table 3.81: Estimated Real Property Tax Revenues Generated, by Development

Project	Town	Construction cost	Equalization rate, 2010	County tax rate (per \$1,000), 2010	Municipal tax rate (per \$1,000), 2010	School tax rate (per \$1,000), 2010	Estimated property tax
Cannonsville	Town of Deposit	\$42,542,600	10.0%	82.96	59.81	258.91	\$1,708,851
Pepacton	Town of Colchester	\$8,096,500	4.1%	126.31	82.26	268.50	\$158,366
Neversink	Town of Neversink	\$4,436,100	3.7%	141.64	105.27	443.98	\$111,867

3.5.3 Impact on Local Government Services and Local Government Expenditures

Beyond their direct impact on real property tax revenues, the overall impact of the three Project developments on the overall financial condition of the affected local governments and school districts is likely to be positive. None of the development would displace any other, potentially more lucrative development projects in the vicinity of the Project area. Moreover, for reasons discussed below, any increases in demand for local public services associated with the operation of the developments are likely to be minimal.

Because of the relatively small number of equivalent jobs associated with the operations of the Project developments (fewer than 6.0 FTE jobs across all three proposed developments), and because neither the major inputs to nor major outputs from the facilities are transported by road, the impact on traffic and wear-and-tear on public roadways associated with the Project is likely to be minimal. Moreover, it is important to note that DEP maintains its own roadways in the immediate vicinity of the reservoirs associated with the Project developments. Thus none of the three developments would add significantly to local governments' road construction or maintenance costs – which in many of the region's towns constitute the single largest area of local government expenditure.

In addition, DEP maintains its own police force of approximately 185 officers to secure City-owned land and infrastructure in the watershed, including the lands and infrastructure associated with the Project. Accordingly, any additional local government expenditures for public safety incurred by local communities in the Impact Area as a result of the Project are likely to be minimal.

The number of equivalent jobs created by the developments is relatively small, and, thus, it is likely that they can be filled from within the existing work force of the affected communities. Because it is unlikely that the developments would draw new workers and their families from outside the region, they are unlikely to generate significant new demands on local school systems or for other local government services.

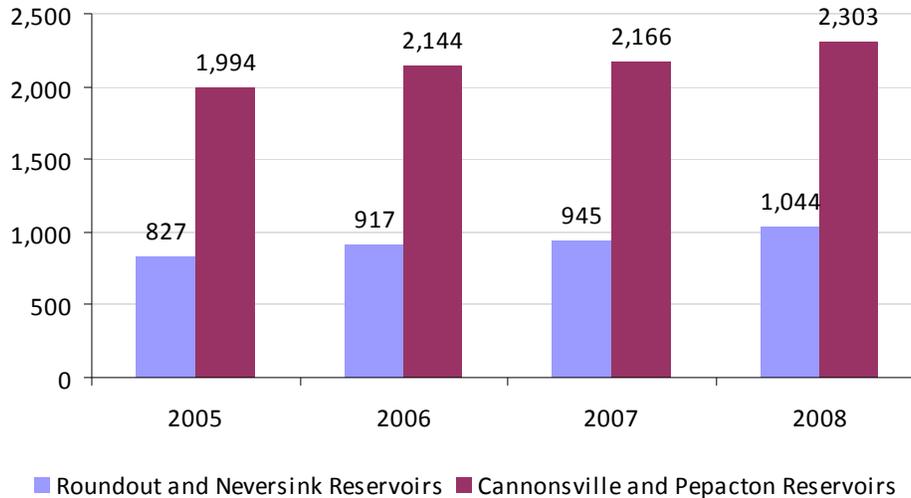
3.6 Project Impact on Community Character and Recreation

The DEP has made significant investments in opening up City-owned watershed lands for outdoor recreation during the past decade. The City's reservoirs and the streams into which they flow also comprise an important dimension of the region's recreational offerings – and thus a valuable asset for recreation and tourism-related businesses, which together constitute one of the most significant sectors of the economy in the vicinity of the Project area. One example of the City's investment and promotion of recreational use of the watershed is the Cannonsville

Recreational Boating Pilot Program. This three-year program was launched in 2008 to improve regional recreational activities and environmentally sound development for activities that ranged from kayaking to canoeing and sailing.

Overall, the use of the watershed has been increasing. As Figure 3.47 shows, the number of active boating permits on the Cannonsville, Pepacton, Neversink, Reservoirs steadily increased between 2005 and 2008.

Figure 3.47: Active Boating Permit Holders for Cannonsville, Pepacton, Neversink, and Rondout Reservoirs⁶



DEP surveyed holders of its Access Permits in 2009, regarding the most common activity such permit holders participated in while on City-owned lands and/or reservoirs. As Figure 3.48 shows, about 60 percent of respondents' most common activity was fishing from shore or by boat.

In the same survey, DEP inquired of Access Permit holders that had fished (via shore or boat) on City-owned reservoirs which reservoir was used most by such permit holders for fishing purposes. Of those permit holders responding that they did use the reservoirs for fishing purposes, as shown in Table 3.82, Pepacton Reservoir ranked second among use, Cannonsville Reservoir ranked fourth, and Neversink Reservoir ranked eighth.

⁶ Boating permits are issued for pairs of reservoirs. In the case of the Project, the applicable pairings are the Rondout and Neversink Reservoirs, and the Cannonsville and Pepacton Reservoirs. Accordingly, individual reservoir data regarding boating permits is not available.

Figure 3.48: 2009 Survey of Access Permit Holders Responses Regarding Most Common Activity Undertaken

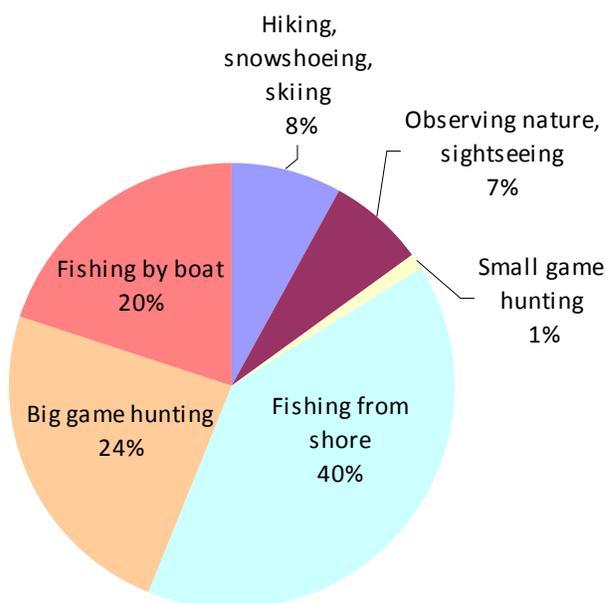


Table 3.82: Response to 2009 Survey of Access Permit Holders Regarding Reservoir Use for Fishing

Reservoir	Used most
Ashokan	18%
Pepacton	14%
Kensico	10%
Cannonsville	8%
Croton Falls	8%
New Croton	7%
Rondout	7%
Neversink	4%
West Branch	4%
Cross River	3%
Schoharie	3%
All others	14%
Total	100%

The DEP intends to continue operating the Cannonsville, Pepacton, and Neversink Reservoirs according to the currently effective operating protocol agreed to by the parties to the 1954 U.S. Supreme Court Decree (“Decree Parties”).⁷ Accordingly, the water available for hydroelectric

⁷ The Decree Parties are the City of New York, the States of Delaware, New Jersey, and New York, and the Commonwealth of Pennsylvania. In the event that the operating protocol is modified in the future, DEP intends to operate the reservoirs in accordance with any such modified protocol agreed to by the Decree Parties. For general information regarding the 1954 U.S. Supreme Court Decree please see *New Jersey v. New York*, 347 U.S. 995 (1954).

generation at the Cannonsville, Pepacton, and Neversink Developments will be comprised of conservation releases, directed releases, and water that would otherwise spill to the extent that such releases are consistent with discharge mitigation releases as outlined in such operating protocol. All such releases would be drawn by the existing release intake structures of the reservoirs associated with the Project developments, which are deep water intakes that draw from the deeper, cold portions of the water column. The City is currently not proposing to modify the magnitude, frequency, duration, and/or timing of discharges due to the addition of the hydropower facilities associated with the Project.

Accordingly, because (i) the City is not proposing to modify discharges as a result of the Project and is merely seeking to generate power from the discharges it is already obligated to provide; and (ii) the Project developments are being constructed at existing facilities, the Project is expected to neither create new recreational opportunities nor impair existing recreational activities undertaken on the reservoirs or downstream environs associated with the proposed Project developments.

3.6.1 Conclusion: Overall Impact on Socioeconomic Conditions and Community Character

The preceding analysis indicates that construction and operation of the Cannonsville, Pepacton and Neversink Developments would have a modestly positive impact on demand for labor, employment and earnings, and overall economic output in Delaware and Sullivan counties.

For example, of the approximately 100 person-years of construction work that the Cannonsville Development would entail, 49 would be performed by Delaware County residents. Over the three-year construction period, this would equate to an average of about 16 FTE jobs per year. To put this number in context, between 2005 and 2009, according to the Census Bureau's ACS, an average of 2,051 Delaware County residents were employed in construction.

For the Pepacton and Neversink Developments, the direct impact of construction would be smaller during the less than two year estimated construction period associated with each development – fewer than three FTE jobs per year for Pepacton, and fewer than two FTE per year for Neversink (as compared with an average of 3,178 Sullivan County residents employed in construction between 2005 and 2009).

The impact of ongoing operations would similarly be modest, with the employment equivalent of the operating revenues at all three facilities totaling approximately 6 FTE jobs.

Because of the relatively small numbers of jobs the three developments would create and the following factors, other types of socioeconomic impacts are likely to be minimal or non-existent:

- Very small increases in labor demand are unlikely to affect wages in either the directly affected industries or in the labor force more broadly.
- Because the resident labor force in the two counties and in the surrounding area would easily absorb the modestly-increased demand for labor that the three projects would generate, they are unlikely to affect either housing demand or housing costs.

- The three developments are not expected to affect recreational opportunities either at the reservoirs themselves or downstream. They will neither create new recreational opportunities nor impair existing recreational uses.
- As noted above, the impact of the three developments on local government and school district finances is likely to be positive.
- Because they would not affect the rural character of the communities in which they are located, the population of those communities, local patterns of land use and development, or the overall mix of local economic activity, the three projects would have little or impact on the character of the towns in which they are located, or other nearby communities.

4.0 ASSESSMENT OF ENVIRONMENTAL BENEFITS, RELIABILITY BENEFITS AND WHOLESALE PRICE IMPACTS

The three proposed Project developments would be interconnected to the NYSEG transmission and distribution systems. Early design activities and a feasibility assessment are currently under way. According to the latest available information, the Cannonsville Development is currently anticipated to have a generating capacity of approximately 14.08 megawatts (“MW”), while the Pepacton and Neversink Developments are currently anticipated to have nominal generating capacities of 1.70 MW and .94 MW, respectively.

4.1 Impacts of Project Generation on Wholesale Energy Prices

The proposed Cannonsville, Pepacton and Neversink Developments are essentially zero variable cost generation resources. As such, they would be expected to operate whenever available (*i.e.*, it will virtually always be economic to generate electricity from the facilities),⁸ and whenever they do operate and generate electricity, they will displace an equivalent amount of generation from higher-cost, fossil-fuel fired generation sources. Such displacement not only reduces pollutant emissions from the burning of fossil fuels, which will be discussed in detail in the next section of this report, but in addition tends to reduce the overall wholesale market price of energy. This price reduction effect was estimated using a statistical analysis of actual NYISO historical wholesale market data.

The NYISO-administered day-ahead and real-time energy markets establish wholesale clearing prices for electricity based on supply and demand bids from market participants. These bids determine which generation resources will be dispatched to generate electricity, thereby meeting electricity demand at the lowest cost, while simultaneously protecting the transmission system from overload.⁹ The price of electricity in any given hour (or fraction thereof) is determined by the price of the last generation unit needed to serve the load. Prices rise when demand increases (or when available low-cost generation decreases), because more expensive oil and gas units need to be run to serve customers.

Figure 4.1 shows a stylized illustration of how generation is deployed to serve load. The load curve represents hourly demand for electricity, ordered from low to high over a year.¹⁰ Generation resources are ordered from low-cost to high-cost from the bottom of the figure to the top. Hydroelectric generation and nuclear generation have very low variable operating costs and so would run around the clock to the extent they are available. Coal generation has a wider variation in variable operating costs, with higher cost units operating less often. Large, natural

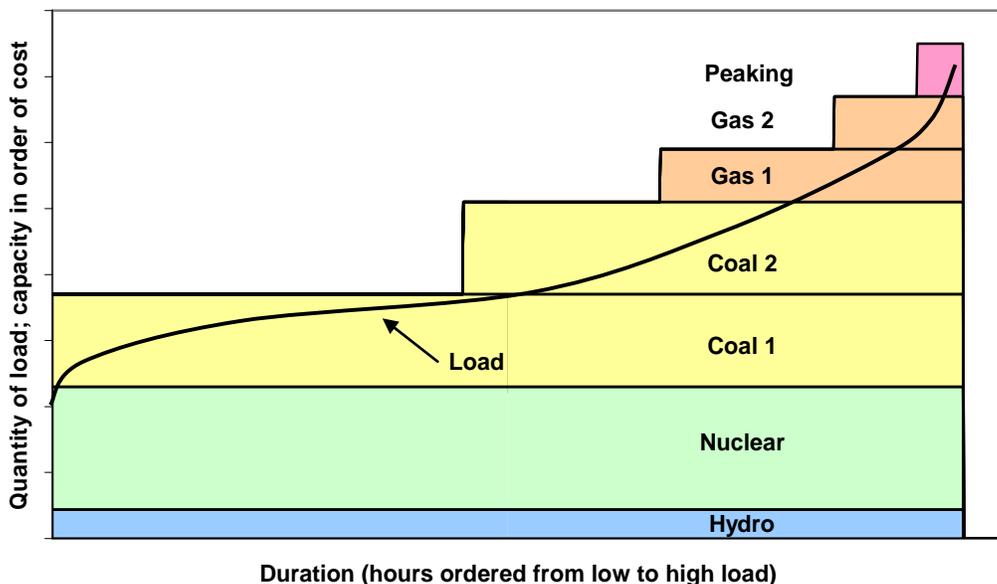
⁸ There are occasional hours when NYISO locational energy prices are in fact negative, during which it would in principle be uneconomic to generate power from a zero variable cost resource.

⁹ This is known as “security constrained economic dispatch.”

¹⁰ When load is considered chronologically it displays high variability within each day, in response to weather patterns, and according to season. The stylized figure shows load in order of increasing magnitude to illustrate how existing resources are deployed to meet load requirements at different levels.

gas-fired plants meet intermediate needs, while high variable cost peaking units, running on oil or natural gas, are used to meet peak demand.¹¹

Figure 4.1: Illustration of Electricity Demand Supply



Hydroelectric generation can take several forms: (a) so-called “run-of-river”, which is relatively constant; (b) peaking hydro, where generating is based on directed releases at periods of peak demand; and (c) pumped storage, where water is pumped up to a reservoir when electricity prices are low and then is released to generate electricity when prices are high. For the purposes of this assessment, it was assumed that output from the Project’s hydroelectric generation facilities would not be actively adjusted based on market conditions, and, therefore, will effectively be run-of-river, corresponding to depiction of “Hydro” generation in **Figure 4.1**.

Consistent with other centralized markets, in the NYISO-administered markets, the going price for electricity is set by the price of the last generating unit needed to meet demand. The underlying logic of the model used to value the impact of generation from the Project can be illustrated with reference to **Figure 4.1**. If hydroelectric generation capacity is increased, there is reduced need to run higher cost generation resources, and the market will tend to clear at a lower corresponding price at each point on the load curve. Of course, this will not occur each and every hour, because the relatively small amount of generation output associated with the Project will often not be enough to displace the marginal (*i.e.*, highest cost) generation unit required to meet load; however, on average and over time, such a price-reduction effect would be expected.

Because low-cost, hydroelectric generation is at the bottom of the supply resource stack, demand is always sufficient to justify its operation, and hydroelectric generation plants will run

¹¹ The relative capacity volumes in the figure are illustrative only, and, thus, are not intended to reflect the actual, current generation mix in New York. In reality, there are many more gradations in price, as well as overlap of fuel types.

regardless of the prevailing market clearing price. As a consequence of its place in the supply resource stack, an increase in the available quantity of hydroelectric generation has the same effect on the market clearing price as a decrease by the same amount in load.¹² In other words, changing the height of the hydroelectric segment in **Figure 4.1** has the same effect as would shifting the load curve.

To estimate the economic benefit of generation output from the Project, historical NYISO wholesale energy market data were used to develop a statistical model that describes the relationship between overall demand and prevailing market prices in western New York State for the period June 2008 to May 2011. This model estimates how wholesale energy prices change in response to a given change in load, while controlling for changes in natural gas prices.¹³

As noted above, the effect on market prices of an increase in hydroelectric generation is equivalent to that from a corresponding decrease in load, holding generation constant. Accordingly, the load-price model determines the value of an increase in hydroelectric output by estimating the price impact of an equivalent *decrease* in demand. The model controls for natural gas prices because natural gas-fired generation often sets the market clearing price in the NYISO-administered markets. By controlling for the effect of natural gas prices on market energy prices, the model is better able to isolate the effect of increased hydroelectric output.

To estimate the impact of increased hydro generation from the Project, expected market prices were first estimated from a regression of the load-price relationship based on historical data. Then, market prices were estimated again using the same function, but decreasing load each hour by an amount equal to the expected incremental hydro generation from the Project. The resulting price changes were then translated into an annual dollar value using the hourly load for western NYISO, by seasonal period.¹⁴ The calculated reductions in wholesale power costs for the western NYISO region resulting from generation output is presented in **Table 4.1**.

¹² The same is true in the reverse: a decrease in hydroelectric generation capacity is equivalent in its effect on market clearing prices to an increase by the same quantity in load.

¹³ The model covers the western NYISO region, comprising Zone A (West), Zone B (Genesee), Zone C (Central), and Zone E (Mohawk Valley). Appendix B includes a further discussion of the statistical model.

¹⁴ The model distinguishes seasonal periods in two-month segments (e.g., January through February, March through April, etc.). Price impacts are calculated for each of these periods and applied across the corresponding average load.

Table 4.1: Estimated Reduction in Western NYISO Wholesale Power Costs Resulting from Project Generation

Model Sub-period	Historical Load Weighted LBMP, \$/MWh	Estimated Decrease in Load-Weighted Avg Real-time price, \$/MWh	Annual Reduction in NYISO Wholesale Energy Cost, \$000s	% Reduction in Wholesale Energy Cost
Jan-Feb	\$45.80	\$0.30	\$2,569	0.7%
Mar-Apr	\$34.63	\$0.27	\$2,111	0.8%
May-Jun	\$43.09	\$0.31	\$2,486	0.8%
Jul-Aug	\$50.54	\$0.35	\$3,098	0.7%
Sep-Oct	\$40.02	\$0.23	\$1,789	0.6%
Nov-Dec	\$45.23	\$0.19	\$1,594	0.4%
Total	\$43.22	\$0.27	\$13,647	0.7%

The benefit to the western New York region is estimated to be approximately \$13.6 million annually, as indicated in Table 4.1. This value represents the benefit of lower electricity prices made possible by generation from the Project.

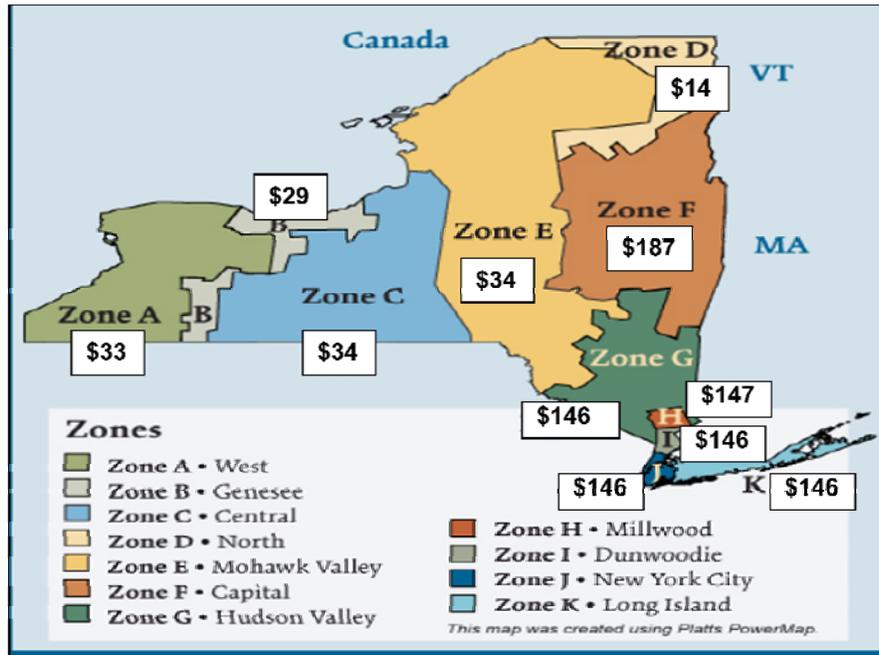
The model was constructed to cover the western portion of NYISO only,¹⁵ because there is significant transmission congestion between this region and parts of NYISO to the east. During periods of transmission congestion, output from the Project would not be able to affect energy prices to the east and, consequently, the model of western NYISO was deemed to be more reliable than a NYISO-wide model. In addition to the estimated benefit to western New York presented above, there is likely an additional benefit to load in the east during zero-congestion periods that is not captured by the model.

4.2 Modeling Issues and Sensitivities

NYISO wholesale energy prices are determined on a locational basis, accounting for generation costs, transmission constraints and power losses when energy is moved over distance. Because regional demand is concentrated in New York City and the surrounding region in the southeast part of the State, power tends to flow from western New York State to the east. In periods of high demand, transmission from west to east is often constrained, meaning that it is not possible to move more power to the east. When this occurs, more expensive generating units must be operated in the east to meet demand, and locational market prices are consequently higher in the east than in western and northern parts of the State. This is illustrated in Figure 4.2, which shows actual real time energy prices for the various NYISO load zones on January 12, 2011 at 11 a.m. eastern time.

¹⁵ The modeled region consists of the Mohawk Valley zone and market zones to the west (encompassing NYISO Zones A, B, C and E).

Figure 4.2: NYISO Real Time Energy Prices by Zone (\$/MWh), Jan 12, 2011, 11AM



Adapted from NYISO system map; NYISO.

The significance of such price differences is that it indicates that the system is, in a sense, separated into distinct markets. When transmission congestion prevents more power from moving from the west to the east, increased generation in the west can affect prices in the “west market”, but not in the “east market”.

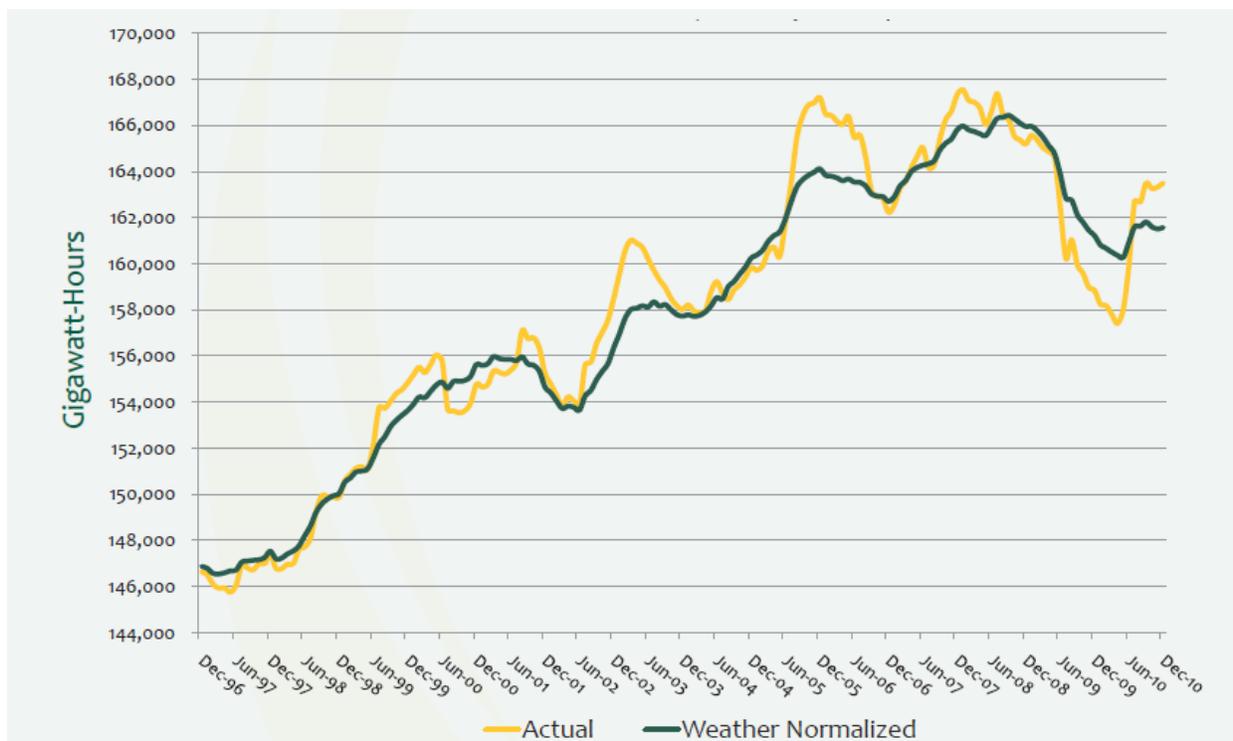
4.2.1 Model Sensitivity Case

Since power from the Project would be delivered into the NYISO Zone E (Mohawk Valley), and energy prices for this zone tend to correspond closely to those in zones to the west, but often show significant price separation with respect to prices in eastern NYISO zones, the load-price model was specified over Zones A, B, C and E only. This focus on the western NYISO region produces a more reliable estimate of price effects, but, by excluding benefits that may flow to eastern zones in some hours, would be expected to underestimate the effect for the NYISO as a whole. To examine the potential significance of such model-specification effects, a sensitivity case was run for all of NYISO. The sensitivity model showed an estimated dollar benefit \$4 million greater than that estimated using the western New York model specification. However, part of this additional benefit results from the incorporation of periods when eastern NYISO energy prices are very high because of transmission congestion – periods when output from the Project could have no effect on prices in eastern zones. It is estimated that there may be up to \$2 million of additional benefit, not captured in the estimates shown in **Table 4.1**, that accrues to load in eastern NYISO zones.

4.2.2 Decline in NYISO Demand During the Model Period

The data used in the load-price model cover a period during which there was a notable decline in electricity demand in NYISO, presumably reflecting the effects of the economic downturn. This decline can be seen in **Figure 4.3**, particularly during 2009.

Figure 4.3: NYISO Energy Usage, 12-month Rolling Total, 1996-2010¹⁶



Beginning in mid-2010, there was a sharp recovery in electricity demand, and load is currently trending roughly at 2007 levels (around 165,000 GWh over the past 12 months). The effect of this lull in demand on the model estimates of wholesale price effects is very modest. Alternative regressions were estimated excluding months from the decline period, and the results were found to be very similar to those for the full three-year data set. The price-load model does not include adjustments either to reflect unusual circumstances during the historical model period or to anticipate potential future market circumstances. Such an exercise would involve substantial speculation, and we believe the model results are more informative in unadjusted form. As discussed below, there are a number of factors that may influence the actual wholesale price impact of generation from the Project.

¹⁶ NYISO, *Power Trends 2011: Energizing New York's Legacy of Leadership* at 20, available at http://www.nyiso.com/public/webdocs/newsroom/power_trends/Power_Trends_2011.pdf.

4.3 Interpretation of Benefits from Wholesale Energy Price Reduction

Factors Influencing Future Wholesale Price Benefits

There are a number of important factors to consider in interpreting the benefit estimates in Table 4.1. The statistical model utilized accounts for a variety of market factors over the historical period June 2008 to May 2011. For example, demand spikes, unexpected plant outages, variations in regional imports and exports, and the associated responses from market participants and the system operator are all reflected in the historical relationship of price and load, and this relationship is captured by the statistical model. Thus, the estimates are likely to be a reasonable estimate of short-term market impacts associated with the Project. However, the reliability of these estimates with respect to *future* generation from the Project depends on a number of factors, including:

- **Natural gas prices.** The statistical model reflects a period when there was substantial variation in natural gas prices, with a three year average of approximately \$4.98/MMBtu.¹⁷ Current natural gas futures prices for 2018 and 2019, the period during which the Project developments are currently anticipated to become operational, average approximately \$6.46/MMBtu, 30% higher than the average over the historical period underlying the model.¹⁸ Higher future natural gas prices will tend to increase the impact of hydroelectric generation on wholesale prices, because this will tend to magnify the cost difference between generators at the margin. The reverse is true for lower future natural gas prices.
- **Generation Supply.** During the modeled period, the summer capacity reserve margin (*i.e.*, the excess of capacity relative to peak demand) for the New York Control Area as a whole averaged approximately 23%. However, NYISO forecasts show a higher projected summer reserve margin of greater than 30% for 2018 and beyond.¹⁹ A higher capacity reserve margin means that marginal generating units that set the market clearing price for energy will generally be lower down the stack, and that the value of displacing that generation through increased hydroelectric generation will be lower, all else equal.
- **Electricity Demand.** As noted above, the historical data used to estimate the load-price model cover a period that includes a notable, if transitory, decline in electricity demand.

¹⁷ Calculated as a simple average of daily closing prices at Henry Hub for the model period, June 2008 through May 2011.

¹⁸ Calculated as a simple average of NYMEX natural gas futures for the corresponding months, quoted June 29, 2011.

¹⁹ NYISO, *2011 Load & Capacity Data* (April 2011), available at http://www.nyiso.com/public/webdocs/services/planning/planning_data_reference_documents/2011_GoldBook_Public_Final.pdf.

Higher demand levels and rates of load growth in the future would tend to increase the wholesale price benefit from Project generation.

- **Limited new baseload capacity.** Projected new baseload capacity (*i.e.*, resources such as nuclear, coal and large run-of-river hydro, at the bottom of the resource stack) is quite limited, and is dwarfed by the expected growth of peak load. As load continues to grow beyond the existing volume of baseload capacity, the benefit from increased hydroelectric generation increases because there are an increasing number of hours when higher cost resources are necessary to serve load. This effect will tend to offset that of the projected increases in system reserve margin, discussed above.
- **Regulation of greenhouse gases.** The potential for new state and federal controls on greenhouse gas emissions, particularly a carbon tax or cap-and-trade limits on carbon output, will tend to increase the cost of generating electricity from fossil fuels, and reduce the viability of baseload coal generation. This will increase the value of the generation from the proposed Project development hydroelectric generation relative to that estimated in our model.

On balance, it is expected that the future market price reduction benefits of generation from the Project stated herein are likely to be conservative.

4.3.1 Interpretation of Economic Benefits

The estimated benefits of lower wholesale energy prices would be expected to flow over time to consumers, mediated by the various rate setting mechanisms that apply in New York's utility service territories. While lower electric energy costs would seem an unalloyed benefit to the economy, the interpretation of estimated cost reductions as a net economic impact must be approached with caution. It must be recognized, for instance, that the benefit to consumers of slightly cheaper electricity is mirrored by the dis-benefit to certain suppliers of reduced revenue. For the economy as a whole, it is difficult to determine the net economic impact. If one were to consider such effects by modeling them in an economic impact analysis model, such as IMPLAN, it might be possible to specify a slight increase in overall demand in the economy resulting from increased disposable income and increased business expenditures made possible by reduced expenditures on energy, but the reduced expenditures on energy would need to be modeled as reduced demand in the energy sector. It is very likely that there would be a net positive effect from an overall increase in economic efficiency resulting from decreased energy costs, but this net effect is difficult to quantify, and such an analysis was not conducted as part of this assessment.²⁰

Another potential complication is that, all else equal, a price reduction will tend to increase energy consumption. This must be considered a net benefit to energy consumers (otherwise

²⁰ Evaluating the effect of changes in input costs is difficult in a model such as IMPLAN because it is effectively specified with fixed input prices. With IMPLAN, economic impacts are estimated from dollar changes in demand for each industrial sector, and it is difficult (or practically infeasible) to modify the model matrices and inputs to reflect a change in input prices.

there would be no increase in consumption), yet such an effect will tend to offset such benefits as reduced emissions of pollutants, addressed below.

4.4 Environmental Externality Benefits

Generation from the Project, estimated at approximately 57,000 MWh per year of emissions-free electricity, would provide environmental benefits by displacing generation of electricity from fossil fuels. **Table 4.2** shows the annual tons of emissions associated with generating an equivalent amount of energy from coal, oil and natural gas.

Table 4.2: Emissions from Generating 57,000 MWh of Energy from Fossil Fuels²¹

Fuel	Tons of emissions		
	SO ₂	NO _x	CO ₂
Coal	370	171	64,066
Oil	342	114	47,629
Natural Gas	3	48	32,332

Source: U.S. Environmental Protection Agency, based on data from eGRID 2000

To provide some further context for the data in **Table 4.2**, the potential CO₂ emissions reductions resulting from output associated with the Project was translated into the number of passenger vehicles removed from the road that would provide an equivalent reduction, as shown in **Table 4.3**.

Table 4.3: Passenger Vehicle Equivalent Output of CO₂ Relative to Generating 57,000 MWh by Fuel Type²²

	# of Passenger Vehicles
Coal	11,088
Oil	8,244
Natural Gas	5,596

The reduction in pollutant emissions from displaced fossil generation would be a very concrete benefit of generation by the Project developments. It is necessarily true that output from the plants, though small, would cause output from fossil-fueled generation that is virtually always on the margin in NYISO to be reduced. This highlights another, closely related, benefit of an

²¹ Emissions rates used for calculation are the U.S. national average rates for electric generation for each fuel type.

²² Motor vehicle equivalent of CO₂ output is based on U.S. EPA calculations, available at <http://epa.gov/otaq/climate/420f05004.htm>.

increase in hydroelectric generation, which is simply the reduced consumption of non-renewable fossil resources.

4.5 System Reliability Benefits

The City retained the services of PowerGem, LLC (“PowerGEM”), a power grid engineering and markets consulting firm, to perform a preliminary transmission assessment of the Project in order to determine whether there are any transmission limitations at the Project development sites that may restrict the dispatch of the full output of the proposed plants. The preliminary assessment was conducted by PowerGem in a manner reflecting system reliability interconnection study requirements and practices, concluded that the interconnection of the Cannonsville Development is feasible as proposed. However, the assessment of the feasibility of interconnecting the Pepacton and Neversink Developments has not been fully completed to date.

As analyzed by PowerGem, the Cannonsville Development would be connected to one of two 46 kV NYSEG local transmission lines connected to the Stiles 115 kV substation. Both lines serve load in rural communities well below the lines’ normal pre contingency and post contingency capacity ratings, as established by NYISO reliability criteria. The transfer analysis and redispatch analyses performed by PowerGem indicate it is feasible to interconnect the Cannonsville Development and operate it at its full output without undue impact on the reliability of the NYISO bulk transmission system.

In the case of the Pepacton and Neversink Developments, PowerGem has preliminarily identified two nearby existing 4.8 kV lines as potential points of interconnection. Upon filing of an application by the City to request review of the proposed interconnections with NYSEG, NYSEG will determine whether interconnection to the selected points is feasible. However, it is important to note that the maximum output of each of these proposed Project developments (currently anticipated to be less than 2 MW each) is well below the typical 5-10 MVA rating of a 4.8 kV distribution network, thus, interconnection at this voltage would appear to be feasible.

In addition to not negatively affecting the reliability of the New York power grid, as preliminarily determined by PowerGem, the interconnection of the proposed Project developments may, in at least two of the three sites, provide additional reliability and power quality benefits to the grid. These benefits, derived from the design and operational characteristics of similar hydroelectric projects, and accrued at both the local and the Statewide level, are discussed in the following sections.

4.5.1 Ancillary Service Benefits

The balancing of supply and demand in the day-to-day operation of a power system in order to maintain reliability and security requires that the system’s operators manage the provision of ancillary services. These services are physically supplied by the generators, transmitters, and loads that are connected to the system.

Table 4.4: Ancillary Service Capabilities of Hydroelectric Generation Facilities

Regulation and Frequency Control Ancillary Services from Hydroelectric Generation	
Fast reserves (6 second response)	Not Fast Enough Potential negative initial response due to pressure drop upon opening gate valve.
Slow Reserves (60 seconds response)	Good Up and Down
Delayed Reserves (300 seconds response)	Good Up and Down
Fast start Up	Good
Regulation	Good Up and Down

Hydroelectric generators have technical advantages over other types of generation with respect to the supply of ancillary services. These advantages include: fast response, better part-load efficiency, better controllability, lower maintenance costs and minimal to no startup (unit commitment) costs; as illustrated in Table 4.4.

Two of the proposed hydroelectric generation facilities are well suited to provide at least two of these services: reactive supply and voltage control, and regulation and frequency response. In New York, these reliability-related services are the responsibility of the NYISO in its role as the balancing authority for the New York Control Area. NYISO operates a regulation service market in which the Cannonsville Development, in theory, could sell regulation services. As with the sale of the energy produced by the Project, the sale of ancillary services may have a similar price reducing impact on the market price for such services in the applicable NYISO pricing region for such services.

The Cannonsville and Pepacton Developments, as further explained below, may be entitled to compensation for their contribution to reactive power supply and voltage control under one of NYSEG's tariffs.

Reactive power is a concept used by engineers to describe the background energy movement in an Alternating Current ("AC") system arising from the production of electric and magnetic fields in electrical machinery used at consumers facilities, generators and transmission and distribution equipment. Different types of devices either generate or absorb reactive power. Since reactive power does not produce useful work while taking up transmission capacity and contributing to energy loss, utilities and system operators actively manage their occurrence. Reactive power flows can give rise to substantial voltage changes across the system, which means that it is necessary to maintain reactive power balances between sources of generation and points of demand on a "zonal basis". Unlike system frequency, which is consistent throughout an interconnected system, voltages experienced at different points across the system at different times are uniquely related to constantly changing local generation and demand profiles. Thus, power flows, both actual and potential, must be carefully controlled for a power system to operate within acceptable voltage limits. The local transmission and distribution utility is obligated to secure the transmission network to closely defined voltage and stability criteria, mainly through varying circuit arrangements, transformers and reactive compensation.

Most consumer equipment connected to an electricity system will generate reactive power, necessitating the application of devices that will absorb it, such as capacitors and synchronous generators, in order to control voltage. Synchronous generators are capable of producing and consuming reactive power (VARs) by varying the intensity of the magnetic field (excitation level) of the generator. When a synchronous generator is overexcited, it generates reactive power and delivers it to the system. When the generator is under-excited, negative reactive power flows from the system into the generator. When the generator operates at unity power factor it will neither draw from nor deliver reactive power to the system. Thus, a synchronous generator can provide a boost to the voltage at the point of interconnection akin to that provided by capacitor banks, which are often used by electric utilities to improve voltage regulation on their transmission and distribution lines.

The Cannonsville and Pepacton Developments will utilize synchronous generators, and will thus be able to provide reactive power support services to NYSEG, if necessary. This feature may prove of significant value to NYSEG depending on the topology of the transmission and/or distribution system at the respective points of interconnection. As noted previously, the Pepacton Development is currently proposed to be connected to 4.8 kV distribution lines serving relatively sparse load. Typically, the design and operation of this type of rural line is driven by voltage drop constraints and will thus likely benefit from the reactive and voltage support provided by the hydroelectric generation facility associated with the proposed Pepacton Development.

Figure 4.4: Line Voltage Regulation Benefit of Local generation

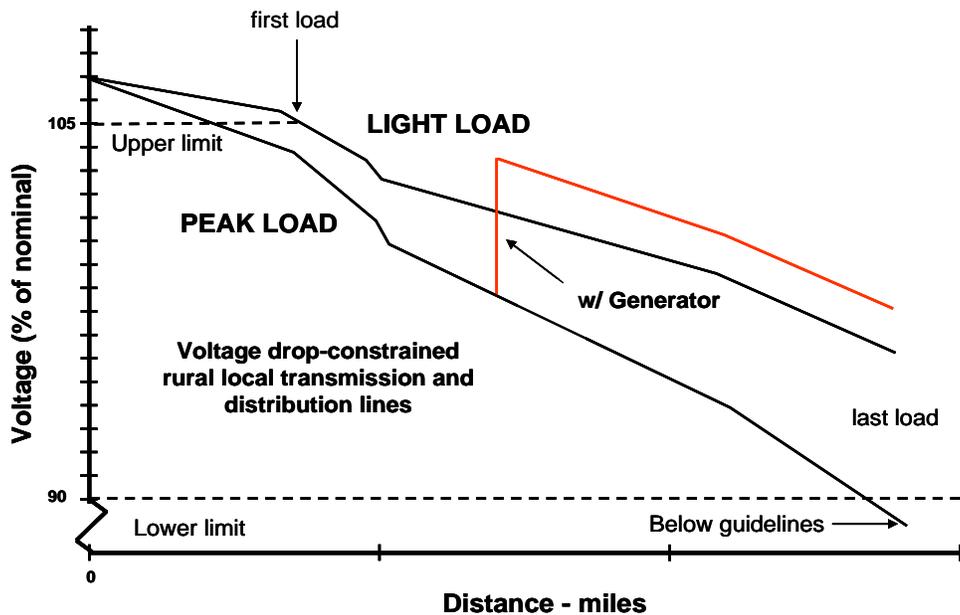


Figure 4.4 illustrates the potential impact of interconnecting a new synchronous generator to the voltage drop profile on an existing distribution line. Depending on the existing configuration of the distribution network and its capacity-demand balance, the Cannonsville and Pepacton

Developments may significantly improve the voltage regulation for the NYSEG customers downstream of the respective points of interconnection.

Another benefit potentially derived by NYSEG from the interconnection of the proposed Project developments may be the deferral of the need to add upstream capacity to meet growing demand. Distribution feeders, and the upstream transformers and switchgear that supply, are typically sized to accommodate growing demand for a number of years. As the growing load approaches the capacity limits of these components, the ability of the system to operate within the applicable service voltage standard during periods of high load, as illustrated in Figure 4.3, requires the utility to first rely on operational adjustments, such as raising the transformer's voltage at the substation where the feeder originates. As continued load growth eventually outstrips the capabilities of this solution, the utility can opt between adding capacitors and voltage regulators to keep all customers along the feeder within the minimum voltage standard; transferring part of the feeder's load to a new or existing feeder; or replacing the feeder's conductors with new ones of larger capacity (if the existing structures and conductor support hardware can accommodate it). The increasing load must also be accommodated by the existing switchgear, the voltage regulator and the distribution bus at the substation and, ultimately, by the substation transformer itself. As these components reach their capacity limits, additional substation equipment must be added to serve the increased load. In some cases, a new substation may be required.

With the exception of strictly operational methods to improve voltage regulation, the utility has to make capital investments to meet load growth for a number of years. However, upon interconnection, the energy and capacity produced by the Pepacton and Neversink Developments will help meet load growth, and, thus, may help to defer NYSEG's need for capital investment in upstream capacity.

5.0 CONCLUSION

The Cannonsville, Pepacton and Neversink Developments are projected to have a modestly positive impact on employment, earnings and economic output in Delaware and Sullivan counties. In part because of the relatively small number of jobs the three developments would create, adverse socioeconomic impacts are likely to be minimal or non-existent.

Moreover, the renewable electricity generated by the Project developments is expected to cause a small reduction in wholesale electricity market prices in New York and modest reductions in annual pollutant emissions from fossil-fuel fired generation sources by displacing the output from such sources. In addition, the Project developments may provide modest additional reliability and power quality benefits at both the local and statewide level.

APPENDIX A: IMPLAN MODEL AND THE MULTIPLIER EFFECT

Spending on the construction and operation of the Project – and the jobs associated with that spending – provide a direct measure of the Project’s impact on the local economy. The regional impacts, however, go beyond these direct measures. Each dollar spent in connection with the Project produces what economists sometimes call indirect and induced effects – commonly referred to as the “multiplier effect.”

The Project’s *indirect impacts* are products of spending by the local companies, contractors and vendors from which the City and the Project’s operators buy goods and services. Construction contractors, equipment suppliers, and other firms use the payments they receive to pay their employees, rent space, buy equipment, supplies and other services – all of these expenditures have an impact on the economy as well. The Project’s *induced impacts* represent the impact of routine household spending by employees of the contractors, employees of the Project’s operators, and by employees of the Project’s suppliers (e.g., expenditures for rent, food, clothing, transportation and child care).

There are several quantitative economic models that can provide an approximate measure of indirect and induced effects. Using one of these models – IMPLAN – the impact of spending in connection with the Project on total economic output, wages and employment in Delaware County and Sullivan County was estimated.

The IMPLAN model allows for the tracking of the impact of each dollar of spending as it ripples through other industry sectors in Delaware and Sullivan Counties, translating the allocation of spending across industries into estimates of employment and wages.

APPENDIX B: WHOLESALE ENERGY PRICE IMPACT MODEL

Consistent with other centralized markets, in the NYISO-administered markets, real-time energy prices are determined by the last generation unit required to meet demand, considering system transmission constraints. Output from the Project would reduce the need for higher-cost units to run in many hours, and thereby lower wholesale market-clearing prices. To assess the magnitude of the benefit of induced lower energy prices, a statistical model was developed to estimate the relationship between changes in generation capacity and changes in real-time energy prices. The statistical analysis for the NYISO-administered markets, the resulting model, and the underlying model logic are described in this Appendix B.

Fundamental to the estimation of economic benefits from the output of the Project is the fact that the generation facilities associated therewith are hydroelectric facilities with very low variable operating costs. It will therefore nearly always be economic to operate such facilities, and their output will displace generation of more expensive fossil-fuel fired generation setting the market price on the margin. The fact that the Project's proposed hydroelectric generation facilities operate at the bottom of the resource supply stack makes it possible to model the price impact of the generation output associated therewith as an equivalent, and opposite, change in load (i.e., electrical demand).

Using available historical market data (hourly loads, real-time clearing prices, and daily natural gas prices), a statistical model of the relationship between load and energy prices in the NYISO-administered markets was constructed. This relationship was then used to estimate the effect on prices of projected output from the Project.

For an arbitrary, short period of time, the availability of generation to serve load in a given area and the variable cost of such resources, can be considered fixed. In a system with economic dispatch and no transmission constraints, this amounts to a fixed supply curve, such that the market-clearing price is determined by the level of total demand. This is illustrated in Figure B.1, where a load of 8,500 MW results in a clearing price of approximately \$50/MWh.

Figure B.1: Illustrative Load-Price Relationship

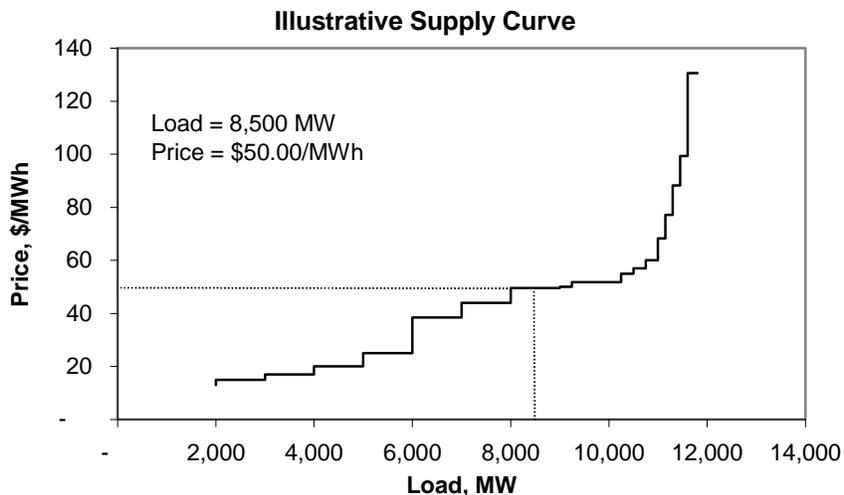
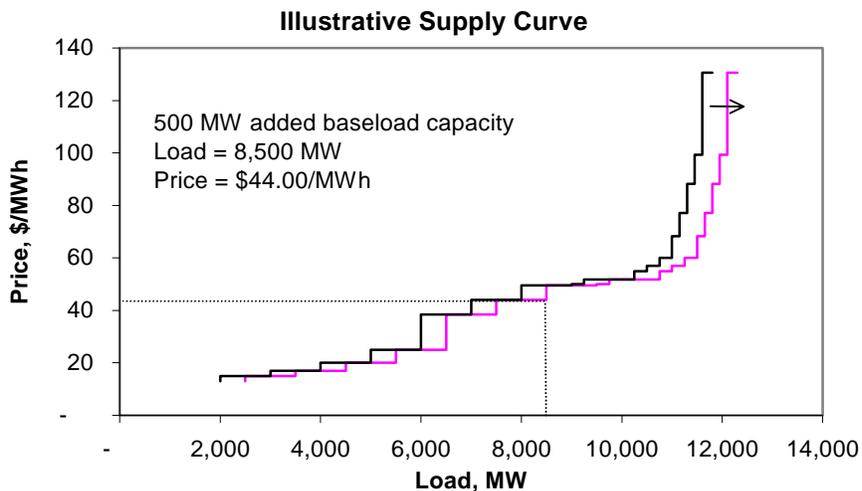


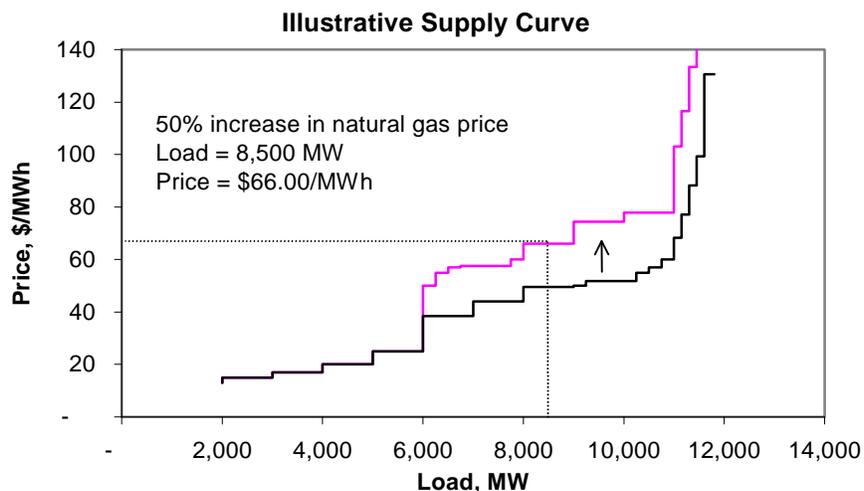
Figure B.2 illustrates what happens when baseload generation such as run-of-river hydroelectric or nuclear increases. The supply curve shifts to the right, eliminating the need for the \$50.00/MWh resource to run in order to meet load, thereby, allowing the market-clearing price to be set by the next lowest cost resource at \$44.00/MWh. This illustrative example shows the effect of adding 500 MW of baseload capacity, an amount far greater than the capacity associated with the proposed Project developments, in order to create a clear visual presentation. Though the magnitude of output from the proposed Project developments would be a fraction of that illustrated below, the fundamental principle is the same.

Figure B.2: Increased Baseload Generation



The shape of the supply curve is also sensitive to changes in fuel prices. The primary source of price volatility is the natural gas commodity price. Figure B.3 illustrates the impact on the supply curve of a 50% increase in natural gas prices.

Figure B.3: Natural Gas Price Increase



To account for changes in the shape of the supply curve, either resulting from fuel price changes or seasonal changes in resource capacity and availability, the load and price data were categorized by period and by the prevailing level of natural gas prices. Separate regressions of price on load were calculated for each grouping. The segmentation by natural gas price removes this factor as an explanatory variable and isolates changes in load as the explanatory variable determining price variation. The purpose of this analysis is not to forecast electricity prices, but, rather, to examine the relative impact of a change in baseload generation on energy prices.

This analytical approach offers some advantages over a structural model, particularly in reflecting market dynamics. For example, in a structural model (*i.e.*, a model that attempts to simulate the operation of individual generation resources) shocks to the system, such as unforced generation outages, must be either ignored or specified as probabilities. Moreover, other factors, such as the ability of some plants to operate beyond nameplate capacity for short periods, or other dynamic responses by market participants, are difficult to incorporate in structural models. However, information about such influences is implicit in the historical market data utilized by the model, and the statistical approach can account for it as a matter of course.

NYISO Price-Load Model Specification

Hourly loads and hourly real-time locational-based marginal prices (“LBMPs”) for the NYISO-administered markets were obtained from for the 36-month period June 2008 through May 2011. The 36-month period was selected to be long enough to encompass sufficient variation to produce meaningful statistical results, while not being so long as to invalidate the assumption of a reasonably stable generation supply curve.

The model was specified for the western part of NYISO, encompassing Zones A, B, C and E. Hourly load for the western region was determined as the simple sum of hourly zonal loads. Hourly prices were calculated on a load-weighted basis for the model region.

Daily natural gas spot prices at Henry Hub were obtained for the same June 2008 through May 2011 period.

The statistical model parses the year into six bimonthly groups. This segmentation accounts for seasonal differences in capacity availability and generation capability. The load and LBMP data were further parsed into subsets of the bimonthly groupings based on ranges of historical natural gas prices. Table B.1 shows the twelve parsed subgroups utilized by the model.

Table B.1: Regression Subgroups

Bimonthly Group	Gas Price Range, \$/mmBTU	Hours in Subgroup	Average NG Price, \$/MMBtu
Jan-Feb	Below \$5.00	2496	4.60
	Above \$5.00	1752	5.61
Mar-Apr	Below \$4.00	2232	3.72
	Above \$4.00	2160	4.27
May-Jun	Below \$5.50	3672	4.13
	Above \$5.50	696	12.64
Jul-Aug	Below \$5.00	2976	3.86
	Above \$5.00	1488	9.72
Sep-Oct	Below \$5.50	2928	3.58
	Above \$5.50	1464	7.20
Nov-Dec	Below \$5.00	2352	3.74
	Above \$5.00	2040	6.01

Regressions were then run for each of the subgroups, using the log-linear functional form shown below, where *LBMP* is taken to be the load-weighted average price,²³ and *Load* is the hourly New York Control Area load divided by 1,000.²⁴

$$\ln(LBMP) = \alpha + \beta_1 Load + \beta_2 Load^2 + \beta_3 Load^3 + \beta_4 Load^4 + \beta_5 Load^5$$

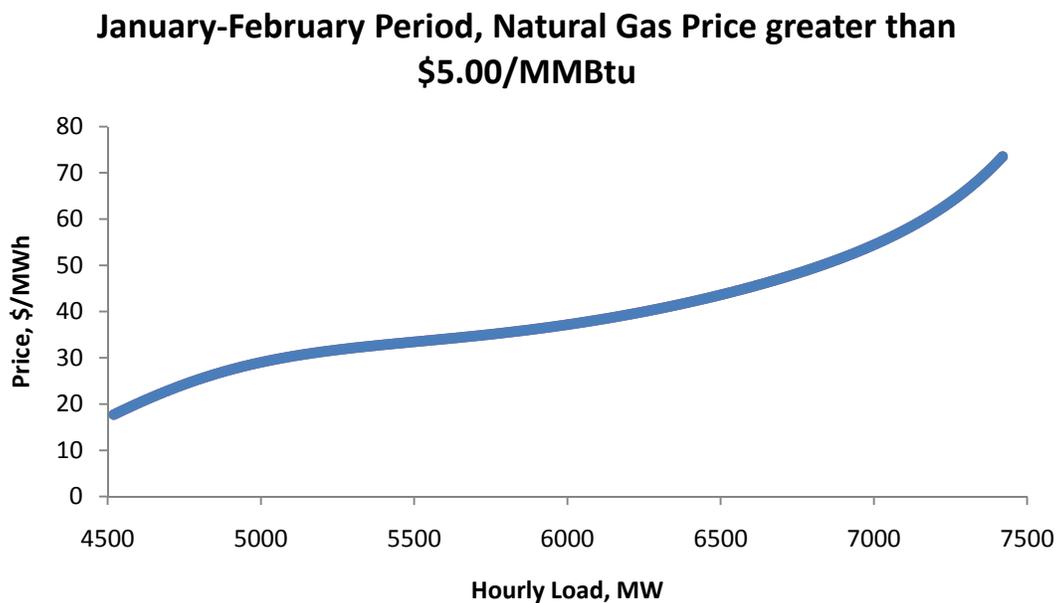
²³ Using the log of price in the regressions restricts the estimated prices to positive values. This is a commonly applied technique. In the occasional cases where negative hourly LBMPs occur (rendering the log of price meaningless) the previous hour's LBMP is used.

²⁴ The use of the divisor 1,000 prevents the power variables from exploding beyond the significant digit capability of Microsoft Excel, which was used to estimate the regressions.

The incorporation of the powers of load allows the estimated price curve to reflect the shape of the underlying, cost-based supply curve. For the NYISO-administered markets, the supply curve for a given period is generally characterized by: (1) a low and rising shape (*i.e.*, low price) for lower levels of demand (corresponding to supply from hydroelectric, nuclear and baseload coal generation resources); (2) a middle plateau (corresponding to intermediate fossil-fuel fired generation); and (3) a sharp rise at high loads (corresponding to expensive, peaking resources).

Figure B.4 depicts the price-load function based on the regression results for the first January-February subgroup itemized in Table B.1. The X-axis represents the approximate range of actual load during the relevant periods (January and February of 2009, 2010, and 2011) when the price of natural gas was greater than \$5.00/MMBtu.

Figure B.4: Example Estimated Price Curve



A reference series of hourly energy prices for each sub-period was first estimated to establish the status quo. Change cases were then calculated reflecting output from the Project. To do this, hourly loads for each estimation period were *reduced* by an amount corresponding to the projected average output from the Project.

The dollar benefit to load (consumers) in the western NYISO region from the generation associated with the Project was then calculated as the hourly price change, multiplied by the hourly load in each sub-period, summed over the three years of data and averaged to calculate an annualized value.

The base model assumed that daily generation associated with the Project would be spread evenly across all hours of each day.²⁵ An alternative representation of generation was also modeled as a sensitivity. For the purposes of such sensitivity, instead of modeling the impact of average hourly generation associated with the Project, the full capacity output of the Project's generation facilities was modeled for every hour, and the resulting impact was then reduced according to projected generator capacity factors.²⁶ The results of this alternative specification were very close to the base case results, reflecting the fact that total output and average output are both very small relative to the total NYISO system, and have effects at virtually the same part of the estimated load-price function.

²⁵ Daily generation was based on estimates provided by Gomez and Sullivan Engineers, PC – the City's lead consultant with respect to the Project – which was derived from 60 years of historical water release data.

²⁶ Capacity factor is a measure of actual or projected output as a percentage of theoretical maximum output across all hours.

**BEFORE THE FEDERAL ENERGY REGULATORY COMMISSION
APPLICATION FOR LICENSE FOR MAJOR PROJECT –
EXISTING DAM**

Cannonsville Hydroelectric Development

FERC Project No. 13287



VOLUME 10

**Appendix E-8: USGS Report: A Decision Support Framework for Water Management in
the Upper Delaware River**

City of New York



**Environmental
Protection**

September 2011



A Decision Support Framework for Water Management in the Upper Delaware River

By Ken D. Bovee, Terry J. Waddle, John Bartholow, and Lucy Burris



Open-File Report 2007-1172

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A Decision Support Framework for Water Management in the Upper Delaware River

By Ken D. Bovee, Terry J. Waddle, John Bartholow, and Lucy Burris ¹

Introduction

The Delaware River Basin occupies an area of 12,765 square miles, in portions of south central New York, northeast Pennsylvania, northeast Delaware, and western New Jersey (fig. 1). The river begins as two streams in the Catskill Mountains, the East and West Branches. The two tributaries flow in a southwesterly direction until they meet at Hancock, N.Y. The length of the river from the mouth of Delaware Bay to the confluence at Hancock is 331 miles. Approximately 200 miles of the river between Hancock, N.Y., and Trenton, N.J., is nontidal.

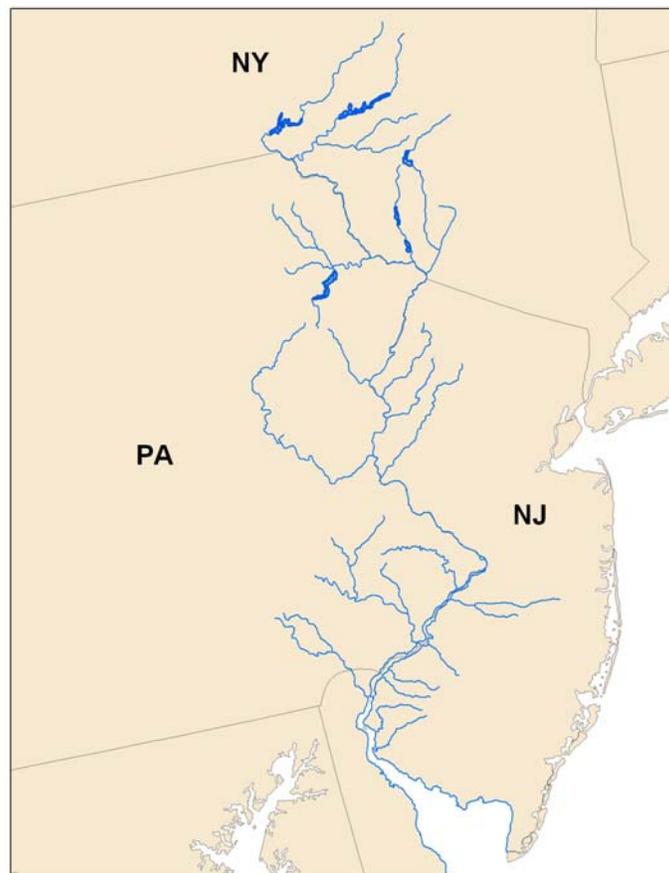


Figure 1. Tristate map of the Delaware River Basin (Scale = 1:1,500,000).

¹ U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Avenue, Building C, Fort Collins, Colo., 80526.

New York City's Delaware system impounds three tributaries at Cannonsville Reservoir on the West Branch, Pepacton Reservoir on the East Branch, and the Neversink Reservoir on the Neversink River (fig. 2). Approximately 895.5 million m³ (725,985 acre feet) is diverted out of the Delaware River Basin from these reservoirs each year through the Delaware Aqueduct. Typically, more than one fourth of the diverted water is from Neversink Reservoir while Cannonsville Reservoir supplies less than a quarter and Pepacton Reservoir provides the remaining half.

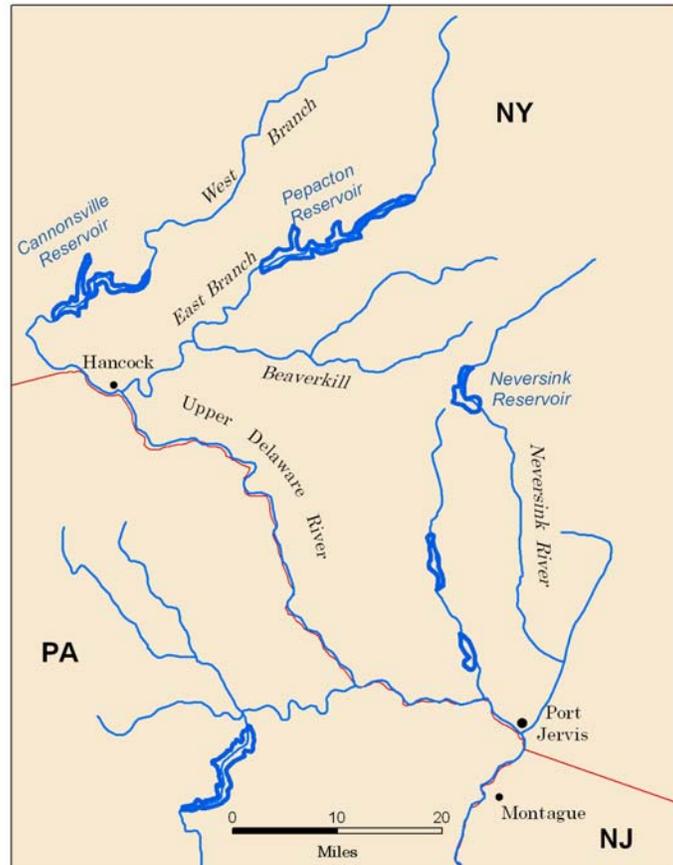


Figure 2. Upper Delaware River and reservoirs (Scale = 1:500,000).

The river is currently managed under the terms of a 1954 Supreme Court Decree (henceforth the Decree), the result of a series of lawsuits brought by New Jersey and Pennsylvania to regulate New York City's diversions from the Delaware River Basin. The diversion rights and release requirements created under the Decree cannot be changed without unanimous consent from the Decree parties (Delaware, New Jersey, New York, Pennsylvania, and New York City.) Numerous adjustments to the Decree's diversion and release formula have been made to modify the operations of the three New York City reservoirs in the Delaware River Basin. A coldwater fishery developed in response to the cold releases from the three New York City reservoirs. During the past 25 years, the Decree parties, at the request of the New York State Department of Environmental Conservation, have established schedules for minimum releases and have set aside a thermal bank for fishery protection. This program has been established, and on several occasions has been experimentally modified.

Several operational and management factors affect the flow regime in the upper Delaware River Basin. Among these are the use of the Montague flow target formula, minimum New York

City reservoir releases, New York City Department of Environmental Protection reservoir management decisions, the rule curves pertaining to the operation of the reservoirs, and reservoir capacity. Information in the following sections was extracted largely from “Preliminary list of flow management issues,” prepared by the Greeley-Polhemus Group, West Chester, Pa. and provided courtesy of the Delaware River Basin Commission, January, 2004.

Montague Target Formula

During normal conditions as defined by the operating rule curves, New York City can divert up to 3.03 million m³ (2,456 acre feet) per day, provided that a flow target of 49.6 m³/s (1,750 ft³/s) is met at the Montague, N.J., gage. The Delaware River Master, a position within the U.S. Geological Survey established by the Decree, directs New York City reservoir releases on a daily basis for the purpose of meeting the Montague flow target. New York City must comply with this direction but may use any of the three upper Delaware reservoirs to do so. In computing the directed release for the New York City reservoirs, the River Master must account for releases from the Lake Wallenpaupack and Rio hydropower facilities toward the Montague flow. These reservoirs are located downstream of the New York City reservoirs but upstream of Montague. Because the power releases and forecast precipitation are highly variable, the directed release requirements fluctuate, resulting in a highly variable flow regime in the upper Delaware River and tributaries.

Minimum Reservoir Releases

In 1977, the New York State Department of Environmental Conservation issued regulations that required minimum releases from the three reservoirs for conservation purposes. These mandatory releases have been revised a number of times by unanimous consent of the Decree parties. During periods of drought watch, drought warning, and drought, as defined by the operating rule curves, flow targets and minimum releases are reduced. The minimum releases may drop to the basic rates during drought conditions in the event that fishery protection banks are not available. In addition, thermal releases can be made when needed to protect coldwater fisheries below the reservoirs, provided that water is available in the thermal bank or can be traded from another allocation.

New York City Department of Environmental Protection Operating Decisions

Releases among the three reservoirs are not evenly divided. The water stored at Neversink Reservoir and Pepacton is of higher quality than that at Cannonsville. Consequently, more water is diverted from the East Branch and the Neversink than from the West Branch. Cannonsville releases to the West Branch equal approximately 61 percent of total storage. In contrast, the release from Neversink Reservoir is approximately 19 percent of its total storage, and the Pepacton release is approximately 24 percent of total storage.

Operating Rule Curves

The rule curves defining drought watch, drought warning, and drought conditions represent a seasonal water allocation of New York City reservoir storage among the Decree parties. They do not necessarily reflect observed hydrologic conditions elsewhere in the Delaware Basin. Drought or drought warning operations have been invoked frequently in recent history. For example, from 1991 through 1998, a drought warning was declared for a portion of every year except 1996. The

result of the current definition has been the frequent enforcement of the basic conservation release, resulting in abnormally low flows for extended periods of time, frequently during fall and winter.

Reservoir Capacity

The converse of frequent use of the drought declaration is reservoir spillage, often the result of a large runoff event occurring when a reservoir is full or nearly full. Under natural conditions, peak flows would normally occur in April and May in response to snowmelt runoff and rainfall. Under current operations, reservoir volumes are maintained as full as possible to maximize deliverable water supplies. Consequently, there is little buffering capacity to reduce flood events during periods of high inflow and uncontrolled spills are common events. Attenuation of peaks is greatest in the Neversink River and least in the West Branch due to differences in reservoir capacity and inflow.

Goals and Objectives

Involvement of the U.S. Geological Survey in the Delaware River was the result of Congressional funding directed towards the study of instream habitat needs in the upper portion of the river basin. This project was proposed for Federal funding by a coalition of non-profit groups (including The Nature Conservancy, Trout Unlimited, and the Delaware River Foundation) and supported by the Delaware River Basin Commission (henceforth referred to as the Commission). The study plan was developed in collaboration with the Subcommittee on Ecological Flows for the Delaware Basin (henceforth, the Subcommittee). The Subcommittee serves the Commission's Flow Management Technical Advisory Committee, composed of State, Federal, non-profit, and academic representatives engaged in resource management and assessment in the Delaware Basin.

The goal of the present study was to provide information relating instream habitat characteristics and streamflow, integrated with the Commission's reservoir operations and streamflow routing model, OASIS. The specific objectives of the study were:

1. The quantification of habitat metrics over a range of discharges and seasons at selected locations in the three tributaries and main stem Delaware.
2. Development and calibration of a network-wide temperature simulation model for the upper Delaware River basin.
3. Development of a prototype Delaware River Decision Support System (DRDSS) to assist the Commission and other stakeholders to analyze and interpret water management and reservoir operations alternatives.

Study Segments, Resource Issues, and Site Selection

To facilitate compatibility of the habitat analysis with the hydrologic simulations derived from OASIS, the upper Delaware River and its tributaries were divided into eleven river segments (fig. 3, table 1) following the guidelines presented in Bovee and others (1998). Segment delineations were based on the following criteria, roughly in order of descending priority:

1. The flow regime was relatively homogeneous from the top of segment to the bottom (for example, boundaries were placed at confluences of major tributaries).
2. General temperature classification (for example, coldwater, transitional, or warmwater).
3. Resource issues, target species, and species of concern.

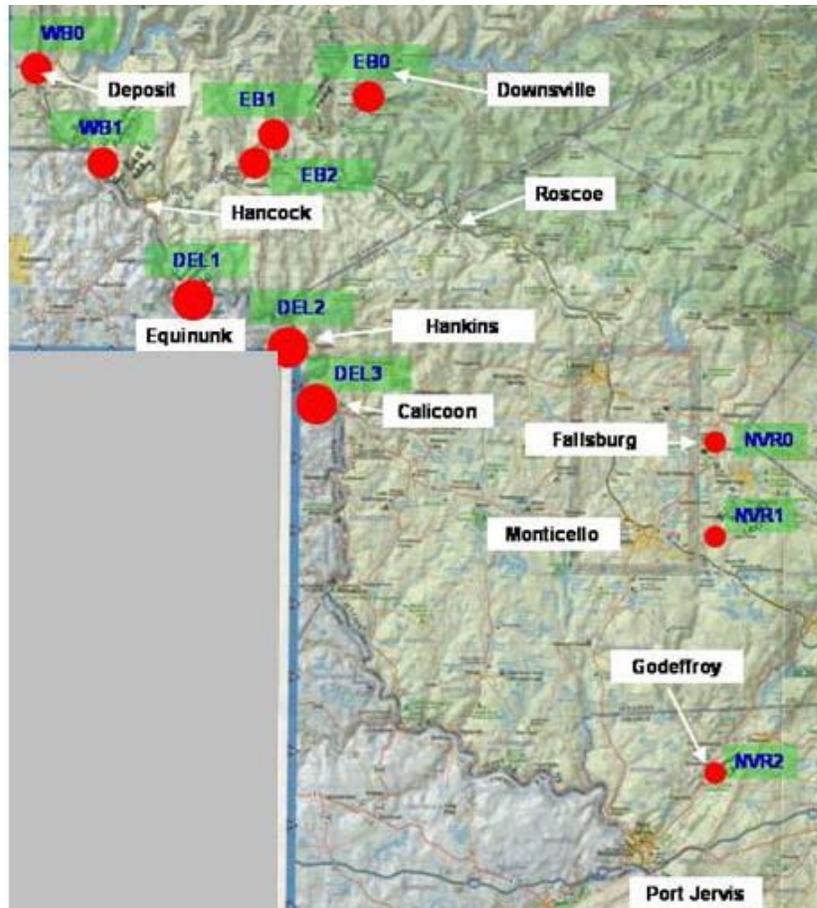


Figure 3. Segmentation and study site locations in the upper Delaware Basin.

Resource Issues

The natural resource issues associated with the upper Delaware varied by location within the system. Resource issues in the three tributaries were related primarily to production of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). The upper Delaware main stem, from Hancock to the vicinity of Lordville, N.Y., is also very popular for sport fishing, and trout production was considered in this reach as well. Issues related to trout production in these segments also included provisions for adequate riffle habitat for macroinvertebrates, flow stability during the spawning-incubation period, and occasional high temperatures during the summer.

In the main stem Delaware River, the lower East Branch (EB2), and lower Neversink (NVR2), factors affecting the recruitment and rearing of juvenile American shad (*Alosa sapidissima*) were added to the list of issues. Because American shad are anadromous, and because the juveniles rear in the Delaware system only from June until August or September, streamflow management in support of this species was considered seasonal, rather than year-round. Other species of interest included the bridge shiner (*Notropis bifrenatus*), blue spotted sunfish (*Enneacanthus gloriosus*), eastern mudminnow (*Umbra pygmaea*), American eel (*Anguilla rostrata*), margined madtom (*Noturus insignis*), fallfish (*Semotilus corporalis*), and cutlips minnow (*Exoglossum maxillingua*).

Table 1. Segment boundaries and resource issues associated with upper Delaware Basin.

River	Segment	Location	Resource issues
West Branch	WB0	Cannonsville to Oquaga Creek	Brown trout
	WB1	Oquaga Creek to Hancock	Rainbow trout Shallow-fast guild Shallow-slow guild
East Branch	EB0	Downsville to Shinhopple	Brown trout
	EB1	Shinhopple to Beaver Kill	Rainbow trout Shallow-fast guild Shallow-slow guild
	EB2	Beaver Kill to Hancock	Brown trout Rainbow trout American shad Shallow-fast guild Shallow-slow guild
Delaware main stem	DEL1	Hancock to Lordville	Rainbow trout
	DEL2	Lordville to Hankins	American shad
	DEL3	Hankins to Callicoon	Shallow-fast guild Shallow-slow guild
Neversink	NVR0	Neversink Reservoir to Fallsburg	Brown trout
	NVR1	Fallsburg to Bridgeville	Shallow-fast guild Shallow-slow guild
	NVR2	Bridgeville to Port Jervis	Brown trout American shad Shallow-fast guild Shallow-slow guild

Two species guilds were included in the list of issues for all sites and segments, following the basic concepts described by Bain and others (1988), Knight and others (1991), and Bowen (1996). The shallow-fast (SFCV) guild was intended to represent habitat for riffle-dwelling species of fish and aquatic macroinvertebrates. Of the species of concern not listed in table 1, the margined madtom can be considered a member of the SFCV guild (Lee and others, 1980). Juvenile fallfish and American eels may also use this habitat type extensively, but not exclusively (Scott and Crossman, 1973; Bain and others, 1982). The shallow-slow (SSCV) guild was designed to represent habitat necessary for young of the year for virtually all species, and for species found primarily in slack water areas. The bridle shiner, blue spotted sunfish, eastern mudminnow, and cutlips minnow all utilize subsets of this habitat guild, with the first three species highly associated with fine substrates and aquatic vegetation (Scott and Crossman, 1973; Lee and others, 1980). From our observations, fine substrates and aquatic vegetation were rare in most places, being most commonly found in backwater mesohabitat types. The cutlips minnow is also commonly associated with shallow, slow water, but in silt-free, unvegetated areas (Scott and Crossman, 1973). Although the habitats for these species were not studied specifically, their general habitat responses were assumed to correspond to the SSCV guild.

Four subpopulations of the Federally endangered dwarf wedgemussel (*Alasmidonta heterodon*) exist in the upper Delaware basin. Dwarf wedgemussel populations were discovered between the towns of Equinunk, Pa., and Callicoon, N.Y., depicted in table 1 as sites DEL1, DEL2, and DEL3. The lower Neversink River also reportedly supports a large population of dwarf wedgemussel, although this study investigated only the main stem Delaware mussel beds.

Site Selection

The rationale for the selection of study sites was that the habitat characteristics of the site should represent those of the segment. Habitat is related to hydraulics, channel structure, and edge effects. Hydraulics, channel structure, and edge effects are all related to planform. Therefore, we used planform as our initial criterion for site selection. Selections were based on how well the proportional distribution of channel types in the candidate site matched those of the total segment. Channel types were digitized from 1:40,000 scale digital ortho quarter quadrangles (DOQQ), and classified as:

1. divided channel on a bend (BDC),
2. single-thread channel on a bend (BSC),
3. delta/tributary confluence (DELTA),
4. multiple channel (MC),
5. straight, single-thread channel (SSC), and
6. straight, divided channel (SDC).

A divided channel (of either category) differed from a multiple channel according to the number of islands evident in the photographs or verified by site visitations. A divided channel was designated where there was a single island, usually in midriver, with approximately equal-sized channels on either side of the division. Multiple channel sectors were defined where two or more clearly defined islands were adjacent to one another. Unvegetated midchannel bars were not considered to be islands, even though multiple channels formed around them at low flows. In some cases the distinction between a divided channel and multiple channel was blurred by the presence of small secondary channels cutting across a single, dominant island. In these cases, a judgment was made regarding the dominant feature of the planform type. Although we strived for consistency, the subjectivity of these decisions may have influenced the site-segment comparisons somewhat.

The proportional distribution of each channel type was calculated by dividing the summed lengths for each type by the total length of the segment. The segment was then subsampled to find a shorter, contiguous reach that closely approximated the proportions of channel types in the segment (see appendix 1). This procedure was followed rigorously during the initial selection of study sites. After review by the Subcommittee, however, several members recommended the addition and modification of sites. Sites WB0, EB0, and NVR0 were added to the West Branch, East Branch, and Neversink, respectively, to better describe habitat conditions in the tailwaters areas of the three tributaries. The main stem sites (DEL1, DEL2, and DEL3) were concentrated in the Hancock-to-Callicoon reach, to correspond to areas of active dwarf wedgemussel research. Finally, the reach farthest downstream on the Neversink (NVR2) proved to be inaccessible, and was moved to a more accessible location. One consequence of the re-selection process was that the lower portion of the main stem of the Delaware from Callicoon to Port Jervis was not included in the study.

Methods

Three basic types of information were generated for this study. The first category included the development of various habitat patch metrics as a function of discharge. The second type was the simulation of daily temperatures at specified locations in the system under different input conditions of meteorology, reservoir releases, and network hydrology. The third category, used

primarily for calculating summary statistics in the DRDSS, was the generation of time series of habitat metrics and temperature. Information related to other decision variables in the DRDSS, including reservoir storage, spills, downstream deliveries, and exports, were derived directly from the OASIS model. This section briefly describes the methods used to derive each of the three types of information and concludes with a description of the organization and functionality of the DRDSS.

Habitat Patch Metrics

Habitat patch metrics were derived from a combination of stream bathymetry, hydraulic model output, and spatially explicit patch morphometry utilizing ArcGIS (ESRI, Version 9.0). Development of this database involved seven steps: collection of bathymetric data, preparation of input to the hydraulic simulation model, determination of boundary conditions, model calibration, simulation of unmeasured discharges, classification of habitat for target organisms and guilds, and geographic information system operations to generate patch metrics as functions of discharge.

Bathymetric Data

Bathymetric data were collected remotely using boat-mounted echo sounders for deep-water areas and directly via ground surveys of shallow-water and exposed areas. At each study site, a semipermanent benchmark was established using the Wide Area Augmentation System (WAAS) differentially-corrected Global Positioning System. In effect, our benchmarks were considered as “local controls,” but the submeter accuracy of the positions and elevations were well within acceptable mapping tolerances for our study. Secondary benchmarks were installed at additional locations within the sites by real-time kinematic Global Positioning System in the event that the primary benchmark was disturbed and to ensure continuity in radio transmissions from the base station. Precision estimates for survey data relative to the primary benchmarks were approximately 2 cm horizontally and vertically.

Hydroacoustic mapping was conducted using procedures described in Bowen and others (2003b). Bathymetric data were collected with Biosonics DT4000 and DE-X echosounders equipped with a single beam, 6° transducer mounted in an inboard acoustic well. The echosounders were calibrated by comparing depths recorded on the echogram with depths measured with a survey rod at stationary locations in a lake. In this setting, the accuracy of depth measurements was approximately 3 cm.

Five or more longitudinal bed profiles were measured in the main channel and all large side channels (20 m or wider), with two profiles tracing each bank, one profile down the centerline of the channel, and two other profiles at quarter-channel intervals between the centerline and the bank. In channels less than 20 m wide, at least three longitudinal traces were measured. In all channels, the longitudinal profile data were augmented by two or more bank-to-bank diagonals for the length of the site. All data were georeferenced in the field with a survey-grade Global Positioning System mounted adjacent to the acoustic well.

Direct survey measurements were made with real-time kinematic Global Positioning System (Trimble 5800 rover with model 5700 base station) and with an optical total station (Leica TC800) with 3-second horizontal and vertical angle precision. Direct survey measurements were taken along breaklines defining the toes and tops of banks, cross-sections of floodplain areas and islands, and in areas that were too shallow to measure with the echo sounder. All data were projected to the Universal Transverse Mercator coordinate system, zone 18 N, using the WGS1984 datum, and the CONUS99 geoid model.

Data Preparation

Raw bathymetry data are rarely, if ever, suitable for immediate use in the hydraulic simulation model. Echosounder depths must be converted into elevations, and these elevations merged with direct survey data. The resulting three-dimensional topography file (known as a bed file) must be edited to connect features such as bank edges or thalweg points and to smooth jagged contour lines that result from spurious triangulations among measured points. Finally, a computation mesh must be constructed as input to the simulation program.

Conversion of Echosounder Depths to Elevations

The elevation of the river bed at any point can be calculated as the elevation of the transducer face minus the depth. Echosounder data were recorded as binary files of depths and geographic locations in latitude and longitude. These data were converted to ASCII format using Biosonics Visual Bottom Typer software and projected from latitude-longitude geographic reference into the Universal Transverse Mercator coordinate system used with the direct survey data. The data were screened for duplicate points and obvious outliers and converted to a 0.5 m by 0.5 m grid in ArcGIS. Transducer data consisted of x, y coordinates and elevations measured at the transducer face using real-time kinematic Global Positioning System recorded at 10-m intervals along each of the boat traces.

Two different approaches were used to calculate the elevations of the transducer face. Where data were collected under steady flow conditions, a surface of transducer elevations was constructed by interpolation, using the TIN (Triangular Irregular Network) function in ArcGIS. The TIN surface was smoothed by removing obvious outliers and converted to a 0.5 m by 0.5 m grid, from which the depth grid was subtracted. The resulting grid of bed elevations was then converted back to point data that could be used compatibly with the direct ground survey data.

Where data were collected under unsteady flow conditions, the ping depth was subtracted from a transducer elevation interpolated between the two transducer positions bracketing the ping. The transducer pair to use was determined by looking up the time stamp of the ping in the time stamp list of the transducer points and interpolating a position on the basis of time differential. The ping depth was subtracted from the interpolated transducer elevation to obtain a bed elevation.

Quality Control for Echosounder Data

Prior to constructing the bed files, we conducted an error analysis by comparing the bed elevations derived from echosounder data with those obtained by direct survey. We located comparable points that were within 1 m of each other and found the difference in surveyed elevations from those measured by the echosounder. The error distribution chart (fig. 4) indicated that 92 percent of the elevations derived from echo-sounding were within ± 15 cm of the surveyed elevation, 78 percent were within ± 10 cm, and that the errors were nearly normally distributed. Differences in elevations were related to the size of the bed materials, in that echosounders measure to the tops of the rocks, whereas the range poles used for direct surveys tend to slip into the low places between the rocks. The typical bed materials in our sites were commonly in the 20–30 cm range, so these differences were considered reasonable and acceptable. Because direct survey measurements are inherently more precise than echosounder data, however, precedence was given to surveyed data points when disparities in contoured elevations were apparent in the bed file.

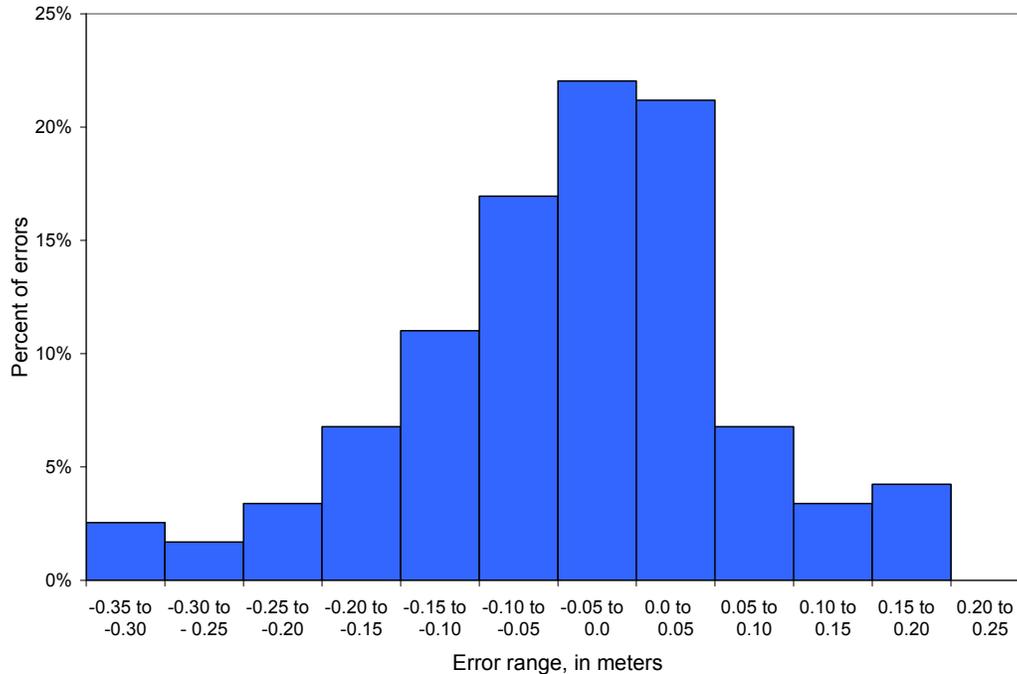


Figure 4. Error distribution of streambed elevations derived from echosounder data compared with those obtained by direct survey methods.

Bed Topography

The River2D model (Ghanem and others, 1995, 1996) was used to perform all the hydraulic simulations in this study. According to the authors of River2D (University of Alberta, 2006), “Accurate representation of the physical features of the river channel bed is probably the most crucial factor in successful river flow modeling. In addition to accurate and extensive field data, judgment and experience are necessary to connect the scattered data points into a digital surface representation.” One of the components of the River2D suite of programs is a bed-topography editor, capable of rapid triangulation and contouring of point data. Generally, elevation transitions in rivers are relatively smooth (except for the toe-of-bank contour) and highly anisotropic (continuous features are aligned longitudinally in correspondence to the banks and thalweg, Turner and others, 1989). Triangulation of the raw elevation data invariably results in localized areas of sharp transitions, discontinuities of contours in continuous features, and other unrealistic geometry. By addition or deletion of points and by connecting points with breaklines, a contour is forced to override the River2D default computation. The locations and orientations of the “correct” contours were usually fairly obvious, based on DOQQ imagery we used as background, and from descriptive coding (for example, for edge-of-bank measurements) in the direct survey data. Where definitive information was unavailable, we relied on our collective experience and knowledge of each of the sites to modify contours.

Computational Mesh

The bed topography file is used in R2D_Mesh to develop a computational discretization as input to River2D. The mesh provides a template through which River2D solves for water depths and velocities. Generally speaking, larger mesh elements (less discretization) can be used in

uniform or gradually-varying features, such as deep pools, and smaller elements where transitions are abrupt, such as along the edges of banks. Shallow water areas can be problematic in River2D because localized areas of super-critical flow may be computed, resulting in serious errors such as unrealistically high velocity predictions, recirculation (water running uphill), or both. In anticipation of such problems, we preemptively increased the mesh density at riffles, runs, delta areas, and over bars. As the simulation flows deviated from the calibration flow, new areas of shallow water appeared and old ones disappeared, so the mesh was revised accordingly for each run.

There is an inherent trade-off in mesh-building. The rate at which a run can be completed is a function of mesh density and mesh quality. Mesh quality refers to the degree to which the triangular mesh elements approach equilateral triangles. As mesh density and quality increase, problems with abrupt topographic changes and super-critical flow decrease (resulting in better accuracy of model predictions), but the time required for the model to converge to a stable solution can increase exponentially. Consequently, we used the fewest and highest quality mesh elements where appropriate (with at least 10 elements for each channel over 5 m wide), but increased mesh density where necessary to achieve high quality simulation runs in a reasonable amount of time.

Boundary Conditions

River2D requires the discharge at the inflow boundary and the water surface elevation at the outflow boundary as inputs for a simulation run. The boundary conditions for a study site were defined by a rating curve or table that related the stage at the outflow with the discharge at the inflow. Owing to the compact size of most of our segments, nearly all of the study sites were in close proximity to a USGS stream gage. Rating tables for appropriate gages were provided to us by the USGS New York Water Science Center located in Troy, N.Y. We translated the gage reading associated with a particular discharge with a reference water surface elevation measured at the site outflow for calibration purposes. At different simulation discharges, we determined the change in stage from the reference discharge and adjusted the outflow elevation by a like amount.

Model Calibration

Concurrent with the collection of bathymetric data, a direct-measurement survey of the water surface profile was conducted at each site. The discharge associated with the water surface profile was either determined from the USGS website for real-time discharge data, or measured in the field.

With the measured inflow discharge and the measured outflow water surface elevation as boundary conditions, River2D was run to produce a predicted water surface profile corresponding to the measured profile. Adjustments were made to the mesh where increased discretization was warranted, and the parameter for roughness height adjusted upward or downward to alter the resistance to flow provided by friction. For example, if the predicted water surface profile was uniformly lower than the measured profile, roughness height was increased. The increase in resistance caused the velocity to decrease and the depth to increase, thereby raising the elevation of the predicted water surface profile. This procedure was repeated until a reasonable match between the predicted and measured water surface profiles was obtained.

What constituted a reasonable match depended on the complexity of the profile, the elevation differential between the top of the site and the bottom, the behavior of the model during the calibration runs, and the potential error associated with individual water surface elevation measurements. In general, we attempted to match the measured water surface elevation to ± 5 cm or less at all measurement points, with the goal of minimizing residuals throughout the profile. While

it is possible to adjust the roughness at specific locations to match the predicted and measured water surface elevations exactly, past experiences in hydraulic modeling have demonstrated that doing so is inadvisable. Such tight calibration can introduce instabilities in the model that actually make subsequent simulations less accurate.

To avoid mathematical instabilities, we adopted the general guideline that regional adjustments to roughness height should not deviate from the site average by more than 50 percent without compelling empirical evidence to the contrary. In some cases, no amount of local roughness adjustment changed the predicted water surface elevation significantly. In several instances, the mismatch between measured and simulated elevations was associated with erroneous recording of water surface elevation (for example, miscoding a bed measurement as a water surface). Otherwise, the discrepancy was related to the conveyance area through the problem section as depicted in the bed file. When large differences (greater than 5 cm) between measured and simulated water surface elevations persisted, we first checked the quality of the measurement. If the calibration measurement was judged not to be the source of the error, we re-investigated the editing (especially breaklines) of the bed topography and modified it where changes were justified by the data. Final calibration results for all 11 sites can be found in appendix 2.

Simulation of Unmeasured Discharges

A range of simulated discharges was selected to bracket most of the discharges that would occur in the baseline or alternative hydrologic time series produced by OASIS. We constructed flow duration curves of the average daily discharges for the USGS gages associated with each of our study sites, and selected a range representing the 1 percent to 99 percent exceedance probabilities. We then applied a logarithmic sampling of this range to select 15 simulation discharges between and including these extremes. The effect of the logarithmic sampling process was to simulate discharges at closer intervals in the low end of the range, with fewer, more widely-spread discharges at the high end. For each of the simulation discharges, an outflow water surface elevation was derived using the procedure described previously under “Boundary Conditions.”

Habitat Classification

Ranges of suitable depths and velocities for each of the target species and habitat use guilds were defined (table 2) using the Delphi technique as described by Zuboy (1981). A small monitoring team devised a questionnaire that was sent out to a larger respondent group of experts. Each respondent was asked to provide his or her estimate of the maximum and minimum depths and velocities considered to be suitable for each of the target organisms and habitat use guilds. After the questionnaire was returned to the monitors, group opinion was summarized by providing the median and inter-quartile ranges of the initial responses. These estimates of group opinion were then returned to the respondents, who were asked to answer the questionnaire again in light of the new information. Anonymity of individual responses was maintained throughout this process to minimize the bandwagon effect associated with roundtable discussions. If a respondent's second response was outside the inter-quartile range of the previous round, he or she was asked to provide a brief explanation in support of the response. These explanations were provided to the respondent group, along with the revised median and inter-quartile ranges of the responses, and the process was repeated until the group converged to a consensus of opinion or at least attained a stability in the distribution of responses.

Table 2. Suitable depth and velocity ranges for target organisms, as defined by the Delphi panel.

Target Organism	Depth Range (m)	Velocity Range (m/s)
Brown trout adult	0.3–100 ¹	0.0–1.0
Brown trout juvenile	0.2–0.8	0.0–0.7
Brown trout spawning	0.2–0.6	0.3–0.81
Brown trout incubation	0.2–1.0	0.15–1.2
Rainbow trout adult	0.3–100 ¹	0.0–1.2
Rainbow trout juvenile	0.2–1.0	0.0–0.8
American shad spawning	0.3–3.0	0.2–0.7
American shad juvenile	0.25–1.6	0.0–0.6
Shallow-fast guild	0.05–0.3	0.3–1.2
Shallow-slow guild ²	0.05–0.3	0.0–0.3

¹ 100 m set to represent no effective upper limit.

² Includes fry for both trout and shad species.

Geographic Information System Operations

Several types of map layers and intermediate products were generated under the general heading of habitat maps. The hydraulic habitat layer consisted of a series of habitat classification polygons depicting the spatial distribution of suitable depths and velocities for each target organism at each simulated discharge. The hydraulic habitat layer was the source of metrics considered to be steady-state functions of discharge (for example, total area of adult brown trout habitat at a specific discharge). The mesohabitat layer was a spatial interpretation of larger scale habitat characteristics controlled mostly by planform and channel structure (for example, the spatial extent of riffles or pools at different discharges). Habitat persistence maps were constructed to quantify the spatial stability of habitat for brown trout spawning and incubation and for dwarf wedgemussels under conditions of unsteady flow.

The Hydraulic Habitat Layer

Output from a River2D simulation run for a particular discharge was exported as a text file containing the coordinates, depths, and velocities for each node in the computational mesh. This information was used to generate a map layer of the nodes and the attributes of depth and velocity. An interpolated surface (a Triangular Irregular Network, or TIN) was constructed for each hydraulic variable, using the nodal data as mass points. Each TIN was converted to a 0.5 m x 0.5 m grid, reclassified according to the habitat classification criteria (table 2), and the reclassified grids combined to create a single grid depicting suitable depth and velocity conditions for each target organism and guild. The composite grids were converted to polygon format and the area for each polygon was calculated. The attribute tables were exported to a spreadsheet for subsequent extraction of habitat metrics and development of the flow versus habitat lookup tables used in time series analysis.

The Mesohabitat Layer

The mesohabitat layer served two purposes in our analysis. First, this layer provided a context for the distribution of suitable hydraulic habitat within the channel. For example, several authors have suggested that habitat for young of the year fish (our shallow-slow guild) may be more valuable if located along shoreline margins than if located in the main channel where zooplankton production is lower and predation vulnerability is higher (Kwak, 1988; Freeman and others, 2001; Bowen and others, 2003a, b). The second application of the mesohabitat layer was to associate suitable spawning habitat with a specific mesohabitat type, defined as the pool tailout. Pool tailouts were identified as those portions of the channel having an adverse bed slope (the bed slope is opposite the direction of the water surface slope). This mesohabitat type occurs almost universally in the region between the deepest portion of a pool and the crest of the riffle downstream from the pool (fig. 5). Consensus among the Delphi participants, supported by visual observations of brown trout redds in the Neversink River, indicated that the pool tailout provided suitable substrates for salmonid spawning and created a favorable hyporheic environment that ensured interstitial flow through the redds during incubation.

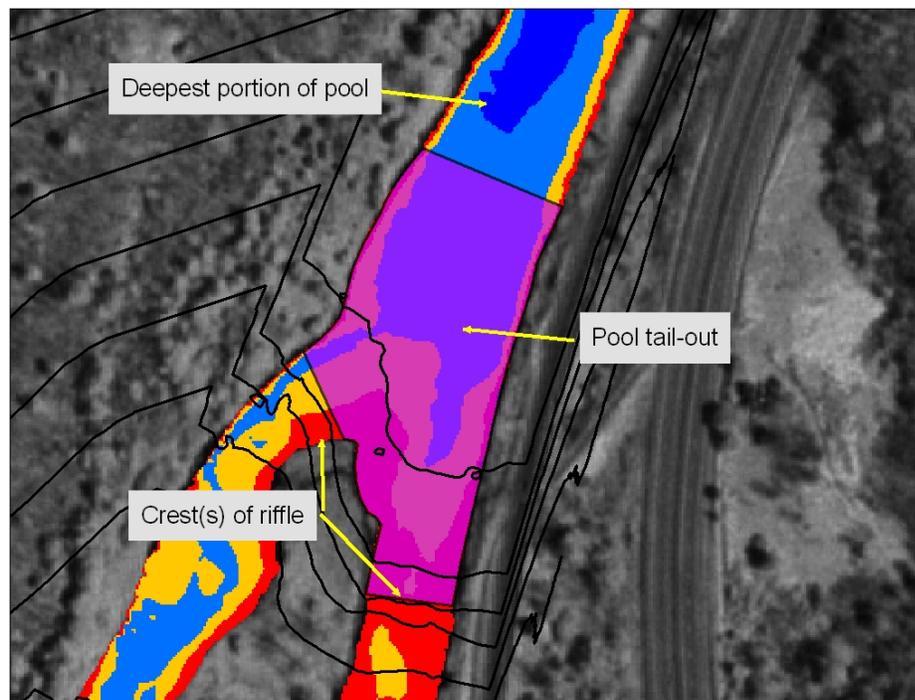


Figure 5. Digital representation of a pool tailout. Deepest portion of pool indicated by dark blue polygon and crest of riffle by compressed contours of water surface elevations.

Mesohabitat types were digitized using the water's edge contour from River2D for each of the simulated flows and 1:40,000 scale DOQQ images as templates. For the most part, we codified mesohabitat polygons using the definitions provided by Parasiewicz (2001). To ensure consistency in coding, we applied specific criteria to each of the mesohabitat types, rather than relying solely on the descriptions provided by Parasiewicz (2001). In addition, we added several mesohabitat types we considered to be potentially important, most notably the pool tailout, inundated terrestrial vegetation, and disconnected areas (table 3). The latter were included because they can either serve as refuges or as stranding areas, depending on their size and how long they persist.

Table 3. Hydromorphic units, descriptions, and codification criteria used to classify mesohabitat types.

Hydromorphic Unit	Description	Criteria
Riffle	Shallow stream reach with moderate current velocity, some surface turbulence, and high gradient. Convex streambed shape.	Water surface slope ≥ 0.002 , depth < 1 m.
Rapid	Higher gradient reach than a riffle with faster current velocity, coarser substrate, and more surface turbulence.	Water surface slope ≥ 0.002 , depth > 1 m.
Run	Deeper stream reach with moderate current velocity but no surface turbulence. Laminar flow.	$0.0005 <$ water surface slope < 0.002 , depth < 1 m
Fast run	Uniform fast-flowing stream channel.	$0.0005 <$ water surface slope < 0.002 , Depth > 1 m
Pool	Deep water impounded by a channel blockage or obstruction. Slow with concave streambed shape.	Slope < 0.0005 regardless of depth.
Side arm	Channel around an island, smaller than half the width of the river.	Channel around an island, smaller than half the width of the river. Connected to river at inflow and outflow.
Backwater	Slack area along channel margins caused by eddies behind obstruction.	Standing water connected to the river only at its outflow.
Pool tailout ¹		Channel areas between deepest portions of pools and crests of riffles.
Inundated vegetation ¹		Areas containing perennial vegetation, inundated at high discharges.
Disconnected area ¹		Standing water with no surface connection to the river.

¹ Added definition. Not described by Parasiewicz (2001).

A special case of a mesohabitat treatment was our application of a shoreline buffer restriction to the calculation of habitat area for the shallow-slow habitat use guild. A 5-m shoreline buffer polygon was created around the water's edge arc at each simulated discharge. The hydraulic habitat polygons for the shallow-slow habitat use guild were intersected with the shoreline buffer polygon for each flow, resulting in polygons representing suitable hydraulic conditions within five meters of the shoreline. The attribute tables for the intersections were exported as lookup tables for subsequent use in the habitat time series analyses.

Habitat Persistence

Habitat persistence is a measure of the stability of individual habitat patches, applicable primarily to organisms with limited mobility (Bovee and others, 2004). Although habitat persistence can influence the well-being of many organisms, we confined our analysis to brown trout spawning and incubation and to patch stability for dwarf wedgemussels. The conceptual model for the spawning-incubation analysis was that trout would spawn in suitable hydraulic habitats within pool tailout areas and that hatching success would be related to the continued suitability of conditions over the redds throughout the incubation period. Incubation flows that were appreciably lower than the spawning flow could result in dewatering of redds, whereas high flows could result in their destruction by erosion. Similarly, unsteady flows can be detrimental to

mussels by desiccation or stagnation at low flow and by excessive shear stress at high flow (Layzer and Madison, 1995). Whereas the effects of rates and magnitudes of change differ between spawning-incubation (measured over months) and mussels (measured over days), the process for measuring patch persistence was similar for both phenomena.

To quantify the persistence of spawning-incubation habitat we performed a multilayer intersection of the pool tailout polygons and suitable hydraulic habitat for spawning and incubation, respectively (fig. 6). Persistence of spawning patches is a time and flow dependent phenomenon. That is, for the same combination of flows, habitat persistence differs depending on whether the spawning flow was higher or lower than the incubation flow. Consequently, it was necessary to construct overlay maps for all 15 simulated spawning flows and all 15 simulated incubation flows (a 15x15 cell matrix). Areas of persistent spawning-incubation habitat were calculated in the attribute table for each composite map layer and exported to a persistence table (table 4) for subsequent use in the time series analysis.

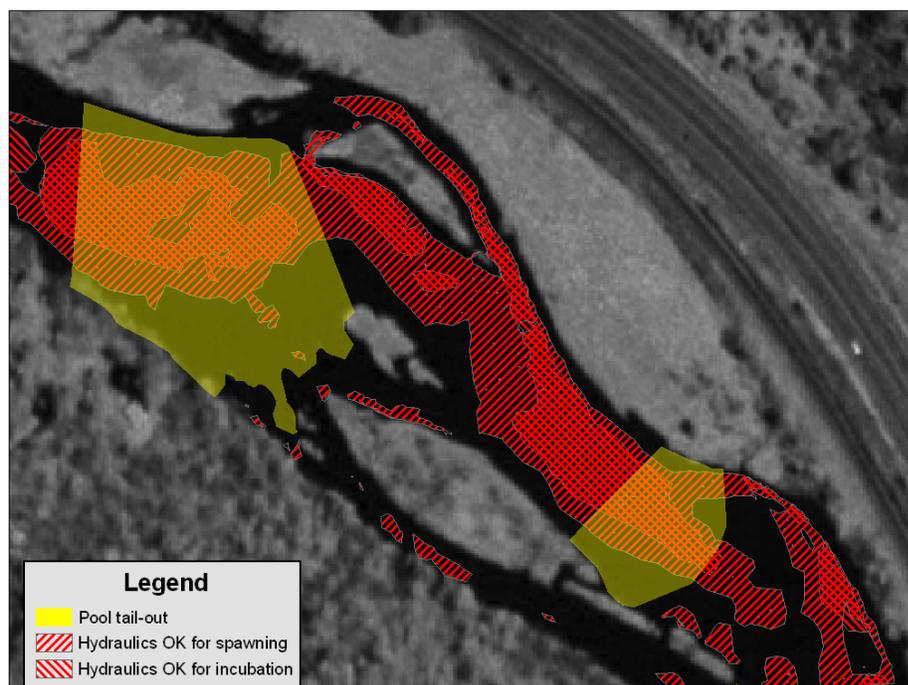


Figure 6. Illustration of a persistence map for a spawning discharge of $10 \text{ m}^3/\text{s}$ ($350 \text{ ft}^3/\text{s}$) and an incubation discharge of $2.5 \text{ m}^3/\text{s}$ ($88 \text{ ft}^3/\text{s}$).

For dwarf wedgemussels, we used surveyed mussel locations heuristically with hydraulic information generated from River2d to estimate suitable conditions for their survival. We obtained locations of individual mussels from a survey conducted in the summer of 2002 (personal communication, Dr. William Lellis, USGS Northern Appalachian Research Laboratory, Wellsboro, Pa., November 17, 2005). Overlays of low flow depths and velocities, high flow shear stresses, and mussel locations were developed to estimate the lower suitable limits of depth and velocity and the upper suitable limit for shear stress. In consultation with Dr. Lellis and his associates, and by recommendations provided by Layzer and Madison (1995), we developed the following interim habitat suitability criteria for the dwarf wedgemussel: minimum depth = 10 cm, minimum velocity = 2 cm/s, and maximum shear stress = 0.2 pound per square foot. We stress that these criteria are

interim and are subject to change pending a more rigorous analysis by Dr. Lellis and others involved with dwarf wedgemussel research.

Table 4. Example of a persistence table for brown trout spawning and incubation¹.

		Spawning Discharge (ft ³ /s)												
		64	88	125	177	247	353	494	706	953	1,341	1,906	2,683	3,777
Incubation Discharge (ft ³ /s)	64	58	59	59	59	59	59	59	59	59	59	45	23	23
	88	233	482	483	483	483	483	483	483	483	483	405	107	80
	125	493	862	1,153	1,152	1,153	1,152	1,153	1,153	1,153	1,152	933	280	192
	177	1,077	1,606	2,095	2,530	2,530	2,530	2,532	2,531	2,531	2,530	2,242	844	420
	247	1,505	2,661	3,403	3,979	4,603	4,600	4,602	4,602	4,601	4,598	4,300	2,063	695
	353	1,422	2,647	3,952	4,838	5,705	6,645	6,643	6,645	6,642	6,632	6,338	3,851	1,381
	494	1,266	2,421	3,767	5,381	6,888	8,172	9,044	9,043	9,041	9,028	8,742	6,143	3,329
	706	849	1,844	2,978	4,550	6,127	7,791	8,939	9,644	9,640	9,625	9,506	7,002	4,438
	953	411	932	1,521	2,614	3,758	5,195	6,413	7,276	7,608	7,593	7,590	6,481	4,515
	1,341	120	263	410	686	1,217	2,114	2,992	3,834	4,260	4,298	4,295	4,275	3,483
	1,906	0	0	1	21	71	212	512	1,020	1,336	1,405	1,429	1,429	1,369
	2,683	0	0	0	0	0	0	1	76	191	236	257	262	260
	3,777	0	0	0	0	0	0	0	0	2	3	8	12	13

¹To read table 4, find the row representing the spawning flow and the column representing the incubation flow. The normalized persistent habitat (expressed as m² of suitable habitat per kilometer of stream) is listed in the cell of intersection. For example, a spawning flow of 350 ft³/s and an incubation flow of 177 ft³/s yields a persistent habitat value of 2,530 m² per kilometer, shaded gray.

We used these criteria to develop polygons of suitable mussel habitat patches for each simulated flow using the same techniques for hydraulic habitat mapping described previously. We then conducted paired-flow polygon intersections for all combinations of simulated flows. This procedure was similar to the one used for spawning-incubation persistence, with the following exceptions:

1. A “mussel bed” mesohabitat polygon was digitized to encompass the general region of mussel locations from the 2002 survey, rather than using individual sightings. This polygon functioned in a manner similar to the pool tailout for spawning-incubation, but was more restrictive in that it applied only to known mussel beds.
2. Because mussels exhibit some mobility, the order of flows is less an issue for mussels than for spawning and incubation. Although the magnitude of change is important to both, the rate of change is more important for mussel survival. Consequently, we developed simple paired-flow (7x15 rather than 15x15) persistence tables for dwarf wedgemussels. In contrast, the analysis of short-term rates of change was considerably more sophisticated for mussels than for spawning-incubation (discussed in the section on habitat time series).

Temperature Analysis

Previous methods for predicting temperatures in the upper Delaware system have relied on a set of nomograms that had a tendency to overestimate the volume of water necessary to support thermal requirements at specific downstream locations. The goal of our analysis was to test

alternative approaches to temperature predictions as potential replacements for the currently-employed nomograms. The test objectives included the determination of historical data sufficiency, calibration of the model, and validation to objective standards.

The upper Delaware study area was divided into two parts. The first portion included the West and East Branches from their respective reservoirs to their confluence at Hancock, and approximately 40 km (25 miles) downstream to Callicoon, N.Y. This portion included the Beaverkill upstream to the USGS gaging station at Cooks Falls, N.Y. The second portion included the Neversink River from the reservoir approximately 27 km (17 miles) to Bridgeville, N.Y.

Model Selection

The Stream Network Temperature model (SNTEMP; Theurer and others, 1984) was chosen for our initial investigations. This is a well-tested model, though most use has been in the western United States. The model has proven especially robust in predicting mean daily water temperatures. SNTEMP is normally capable of predicting mean daily water temperatures $\pm 0.5^{\circ}\text{C}$ (0.9°F), and almost always to within 1°C (1.8°F), depending on the quality of the input data (Bartholow, 1989). In addition, SNTEMP is far less demanding than many other models in terms of data requirements.

SNTEMP was an appropriate model to test for this application because of its public domain status and support. The model was readily available, as was its source code, allowing modification as necessary. In addition, a considerable body of material was available for technology transfer, including documentation (Theurer and others, 1984), self-paced learning material (Bartholow, 2000) and background on data collection techniques (Bartholow, 1989).

In spite of this model's advantages, there were also some potential disadvantages. One data input item, "percent possible sun" or cloud cover, is no longer regularly collected by National Climatic Data Center stations and often requires additional effort to estimate. Also, the model assumes steady state hydrologic conditions, which might signal problems when abrupt changes to reservoir releases or short term rainfall-driven runoff events occur. Though none of the existing reservoirs has a peaking power release, they can and do spill. The SNTEMP model is not a reservoir water temperature model, and requires reservoir release temperature estimates as a boundary condition. The model operates on a daily time step under steady-state conditions. Consequently, the maximum extent of the study area should typically be no more than one day's travel time from the furthest upstream point to the furthest downstream point. This constraint can be compromised, but with some degradation in predictive power.

Data Gathering and Synthesis

Data gathering generally followed guidelines presented in Bartholow (1989). There are three broad categories of data required by SNTEMP: meteorological data, hydrologic data, and stream geometry data. Measured water temperature data were also required to perform an objective model calibration and validation.

Representative meteorological data included air temperature, wind speed, relative humidity, percent possible sun (cloud cover), and solar radiation. In addition, the elevation of the meteorological station must be known. On occasion, it is advantageous to use data from more than one meteorological station to enable cross checking for data outliers, filling missing values, or creating composite sets that might better represent the whole watershed. Table 5 lists the major meteorological stations evaluated for this project. Hydrologic data included the best estimates of streamflow throughout the basin. There appeared to be 14 gages with a useful complement of data, including long-term water temperature data (table 6).

Table 5. Summary of available meteorology data.

Location	Source	Period of Record
Binghamton	NCDC ¹	May 1, 1994—Sept. 30, 2004
Monticello	NCDC ¹	May 1, 1994—Sept. 30, 2004
Stonykill	MesoWest	May 1, 2003—Sept. 30, 2004
Sherburne	MesoWest	May 1, 2003—Sept. 30, 2004

¹National Climatological Data Center.

Table 6. U. S. Geological Survey discharge gages in the upper Delaware River study sites with four or more years of temperature data.

Gage Number	Name	Period of Record	Water Temperature Data?
1417000	East Branch Delaware River at Downsville, N.Y.	July 1, 1941—Sept. 30, 2003	No
1417500	East Branch Delaware River at Harvard, N.Y.	Oct. 1, 1934—Sept. 30, 2003	Yes
1420500	Beaverkill at Cooks Falls, N.Y.	July 25, 1913—Sept. 30, 2003	Yes
1420980	East Branch Delaware River above Read Creek at Fishs Eddy, N.Y.	Nov. 19, 1912—Sept. 30, 2003	Yes
1421000	East Branch Delaware River at Fishs Eddy, N.Y.	Nov. 19, 1912—Sept. 30, 2001	No
1425000	West Branch Delaware River at Stilesville, N.Y.	July 1, 1952—Sept. 30, 2003	Yes
1426000	Oquaga Creek at Deposit, N.Y.	Oct. 1, 1940—Sept. 30, 1973	No
1426500	West Branch Delaware River at Hale Eddy, N.Y.	Nov. 15, 1912—Sept. 30, 2003	Yes
1427405	Delaware River near Callicoon, N.Y.	Aug. 25, 1967—July 8, 1975	No
1427500	Callicoon Creek at Callicoon, N.Y.	Oct. 1, 1940—Sept. 30, 1982	No
1427510	Delaware River at Callicoon, N.Y.	June 27, 1975—Sept. 30, 2003	Yes
1436000	Neversink River at Neversink, N.Y.	Oct. 1, 1941—Sept. 30, 2003	No
1436500	Neversink River at Woodbourne, N.Y.	Oct. 21, 1937—Sept. 30, 1993	No
1436690	Neversink River at Bridgeville, N.Y.	Oct. 1, 1992—Sept. 30, 2003	Yes

Each of the rivers was partitioned into discrete segments according to aspect (direction of flow from the north-south axis). Channel geometry data for each segment included reach length, aspect, latitude, elevation, wetted width as a function of discharge, and Manning's roughness coefficient. Stream widths were generally characterized as power functions (for example, $w=aQ^b$) where the terms a and b were determined by regression of widths and discharges obtained from the River2D simulations.

The topographic elevation (the angle from the middle of the river to the average ridge line) was determined using the MapTech Terrain Navigator software and data base for New York. This software is composed of scanned 1:24,000 topographic maps that overlay a 10-m Digital Elevation Model (DEM). For each segment, a profile line perpendicular to the azimuth of the channel was constructed. The visual horizon was then estimated from the DEM and the distance from the river and the elevation change to the horizon calculated. The topographic altitude angle was calculated

from these measurements. Riparian vegetative shading was estimated for the same river segments. Unlike topography, estimated vegetative characteristics of tree height, crown diameter, and leaf density were relatively uniform throughout the various river basins. Differences occurred principally in the relative continuity of trees along each bank and their offset from the river's edge. Field measurements, supplemented by the digital 1:24,000 topographic maps, aided the development of segment-by-segment riparian shading estimates.

Measured water temperature data were derived from existing USGS water quality gaging stations (see table 6) as well as New York Department of Environmental Conservation measurements. Reservoir release temperature data were taken from the most upstream site available on each of the three rivers. Groundwater accretion was estimated by prorated mass balance between gaging stations and temperatures were approximated by mean annual air temperature adjusted for elevation.

Quality Assurance/Quality Control

Large compilations of data must be scrutinized for data quality. Water temperature or other data may contain spurious values that must be culled from the database. Few strictly objective measures exist for examining every data value, but obvious outliers were eliminated from each data set. Missing data were generated for meteorological, hydrological data, and estimates of release temperatures using station-to-station regressions.

Potential errors in measured water temperatures were evaluated by comparison of data collected at the same location from two independent sources. We compared data collected by USGS and the Department of Environmental Conservation for the Harvard site for 1997—1999 and they agreed very well. Median absolute differences between the two were 0.3°C (0.5°F) for mean daily temperatures and 0.2°C (0.4°F) for the maximum daily temperatures (n=316). Some of the differences may be explained by the minimum resolution of the data. USGS data were reported to the nearest 0.5°C, whereas the Department of Environmental Conservation data were reported to the nearest 0.1°C.

Initial Model Simulations

SNTEMP models for both the Neversink River, and the Delaware network (East Branch-West Branch-Delaware main stem) were run with data available for the summers of 1997 through 1999, May 1 through September 30. We determined that the models performed best using meteorological data from Monticello, N.Y.

With current data limitations, but without calibration, the Neversink model performed passably. The correlation between predicted and measured values was relatively high ($r=0.84$), the mean error was 0.12°C, and the probable error 1.16°C. Initial model runs for the Delaware network showed that model performance was adversely affected by large amounts of missing data at some river locations. Although the correlation between measured and simulated temperatures was higher ($r=0.89$), so were the mean error (0.55°C) and the probable error (1.23°C). Maximum errors were -7.23°C in the Delaware network and -5.88°C on the Neversink River. These errors appear to be directly attributable to missing Monticello meteorological data and do not necessarily reflect on the model's overall predictive ability.

Model Calibration

Well-formulated temperature models with high quality input data require little or no calibration. Data are always limited to some degree, however. The ability of meteorological data to

truly represent conditions at and along extensive stretches of a river is a universal problem. The goal of model calibration is to simultaneously minimize bias and error while maximizing correlation. Typical calibration criteria include: (1) near-zero bias, (2) 50 percent of the errors in mean daily temperatures less than 0.5°C, (3) absolute maximum errors under 4°C, and (4) overall model correlation greater than $r=0.9$. Criteria for maximum daily temperatures would be similar. The general philosophy in model calibration is to vary the least well-known input values within a representative range to maximize the model's goodness-of-fit.

Mean daily water temperatures were the initial focus of model calibration. Once mean daily temperature predictions were as accurate as possible, the focus shifted to maximum daily water temperatures. Calibration of maximum temperatures was accomplished via several empirical coefficients that account for heat gained over and above the daily average, depending on hydrologic and meteorological conditions.

An extensive analysis was made of the potential sources of model error by correlating many of the model inputs or calculated values with the model's residuals. Because of the preponderance of wide, shallow pools on these rivers, air temperature and relative humidity might tend to dominate the thermal response rate when discharge was low. However, only air temperature was marginally statistically significant in both models. Discharge was also a statistically significant contributor to model error on the Neversink River, a result that may have been attributable solely to outlying points that represented spills or rainstorms rather than more "normal" reservoir release conditions.

Development of Statistical Models

The accuracy of the SNTTEMP models did not universally meet our initial calibration criteria. For this reason, we developed purely statistical models for several important locations throughout the two networks as a possible alternative to SNTTEMP. Although somewhat less flexible in predicting temperatures at unmeasured locations, statistical models might correct for systematic biases in the SNTTEMP models that we were unable to eliminate otherwise.

According to Theurer and others (1984), there are several forms of regression models that appear to provide a high degree of correlation in predicting stream temperatures, at least for "natural" conditions. They range from simple harmonic models:

$$T_w = T_{avg} + \Delta T_0 \cdot \cos[(2\pi/365)(D_i - P)] \quad (1)$$

Where T_w = estimated water temperature (mean or maximum),

T_{avg} = average water temperature over all observations,

T_0 = half the initial temperature range over all observations,

D_i = Julian day number for day i , and

P = Phase delay in timing of the maximum seasonal temperature.

to polynomial models:

$$T_w = a_0 + a_1 T_a + a_2 W + a_3 R + a_4 S + a_5 H + a_6 Q + a_7 T_a^2 + a_8 W^2 + a_9 R^2 + a_{10} S^2 + a_{11} H^2 + a_{12} Q^2 \quad (2)$$

where T_w = estimated water temperature (mean or maximum),

T_a = air temperature (maximum or mean),

W = wind speed,

R = relative humidity,

S = percent possible sun (cloud cover),

H = maximum possible solar radiation for the latitude and time of year, and
 Q = discharge

to models that incorporate, at least to some degree, the physics of heat flux and heat transport. After a considerable amount of trial and error, we settled on a general regression model of the form:

$$T_w = k + a_1 T_a + a_2 T_a^2 + a_3 H + a_4 W + a_5 S + a_6 Q_1 + a_7 (Q_2 - Q_1) + a_9 Y T_w \quad (3)$$

where T_w = the estimated water temperature,
 T_a = air temperature,
 H = relative humidity,
 W = wind speed,
 Q_1 = the discharge at the temperature node,
 $(Q_2 - Q_1)$ = the upstream to downstream accretion volume, and
 $Y T_w$ = “yesterday’s temperature estimate.”

Though initially derived using standard minimization of residuals, final regressions were adjusted by weighting each daily squared residual by its dependent water temperature. This step was done because our experiments had shown that regressions of this type often tended to underestimate high water temperatures. The weighting served to improve the fit of the regressions at high temperatures.

Model Selection for the DRDSS

As a matter of operational efficiency, we selected the multivariate statistical model (equation 3) for use in the DRDSS. Use of SNTEMP as a data source for the DRDSS would have required generating the system hydrology in OASIS as input to SNTEMP, and then running the temperature model for each scenario to be tested. The advantage of the statistical model was that the meteorological data and model parameters could be incorporated directly into the DRDSS, along with hydrologic information from OASIS, to produce daily predicted temperatures of the same general accuracy as those produced by SNTEMP. Whereas SNTEMP can be used in the absence of calibration water temperatures, however, these data are necessary to calibrate the statistical model. Sufficient water temperature data for this purpose were not available for the Neversink River, so temperature simulations for that river were not included in the prototype version of the DRDSS.

A second disconnect in the scenarios generated for the DRDSS was that the meteorological records available for use in equation 3 extended only from 1994–2004 whereas the period of record for the hydrologic time series was from 1977–2003. We considered several options for matching the periods of record, including the generation of a stochastic meteorological series to use as input to equation 3, irrespective of the period of record. We also considered simple repetition of the meteorological data series as necessary to fill in all the dates in the hydrologic series. After weighing the advantages and disadvantages of the various models, we determined that using actual meteorological data from an actual period of record was preferable to the stochastic model. Consequently, the DRDSS contains three options for meteorological data. The first is the simple repetition model, which is basically a copy and paste of the existing record over previous decades. The second option is to use “normal” meteorological conditions for each day, calculated as the average air temperature, humidity, cloud cover, and wind speed from the 10-year period of record. The third option is a “worst case” meteorological scenario, developed as a combination of daily

maximum air temperature, humidity, and wind speed, and minimum cloud cover. Although none of the options is completely realistic, in combination they can provide a range of “expectable” water temperatures for different water management scenarios and meteorological conditions.

Time Series Generation and Summarization

The structure of the DRDSS requires baseline and alternative management scenarios (or two competing alternatives), typically derived by changing the operating rules for one or more of the reservoirs in the OASIS model. Management scenarios translate into changes in flow regime, reservoir storage, temperature, habitat suitability, and other decision variables. DRDSS scores are based on the amount of change each decision variable exhibits between the alternative and the baseline over a specified time period.

Habitat Time Series and Metrics

The habitat time series is the fundamental building block for quantifying the effect of an alternative on the habitat for a target organism (Bovee and others, 1998). Construction of a habitat time series (fig. 7) is relatively straight-forward, requiring two essential components: a time series of discharges (either baseline or alternative) and a relationship between discharge and habitat area. Units of habitat can be expressed as the actual area of habitat within the study site (m^2), normalized habitat area expressed as an area per unit length of stream (m^2/km), or as total habitat (in hectares) for the entire segment, calculated by multiplying the normalized habitat area by the length of the segment. The third option was preferred by the Subcommittee and the Commission, so habitat areas in the DRDSS were expressed accordingly.

For every discharge in the flow series, there is a corresponding habitat value from the discharge-habitat function. Assembling a time series of habitat is merely a matter of translating the discharges for each time step (hours, days, weeks) into their associated habitat values and recording the translated values back to the time step.

Hydroperiods and Habitat Persistence

The year was divided into three hydroperiods, representing distinct hydrologic and biological conditions: October 1–April 15 (spawning/incubation period for brown trout), April 16–June 30 (emergence of young of the year fish), and July 1–September 30 (summer growing season). The October–April hydroperiod was further subdivided to quantify habitat persistence for brown trout spawning and incubation. October and November were considered the spawning months, and incubation was designated for the period from December 1 through April 15. Habitat time series as shown in figure 7 were constructed for pertinent target organisms for each hydroperiod, with the exception of habitat persistence for brown trout spawning-incubation and for dwarf wedgemussels.

We selected a spawning discharge to be used as input to the persistence table by calculating a trimmed mean discharge based on the central 60 percent of the flows for the months of October and November for each year to represent a “typical” discharge that would have occurred during spawning. Because habitat persistence is a function of the difference between the spawning flow and the incubation flow, we found the maximum and minimum discharges occurring between December 1 and April 15 to determine the persistent habitat areas for both combinations of spawning and incubation flow-pairs. The smaller of the two areas was then retained as the spawning-incubation value for a given year. The habitat time series for spawning-incubation was thus constructed as an annual series of these least-area values.

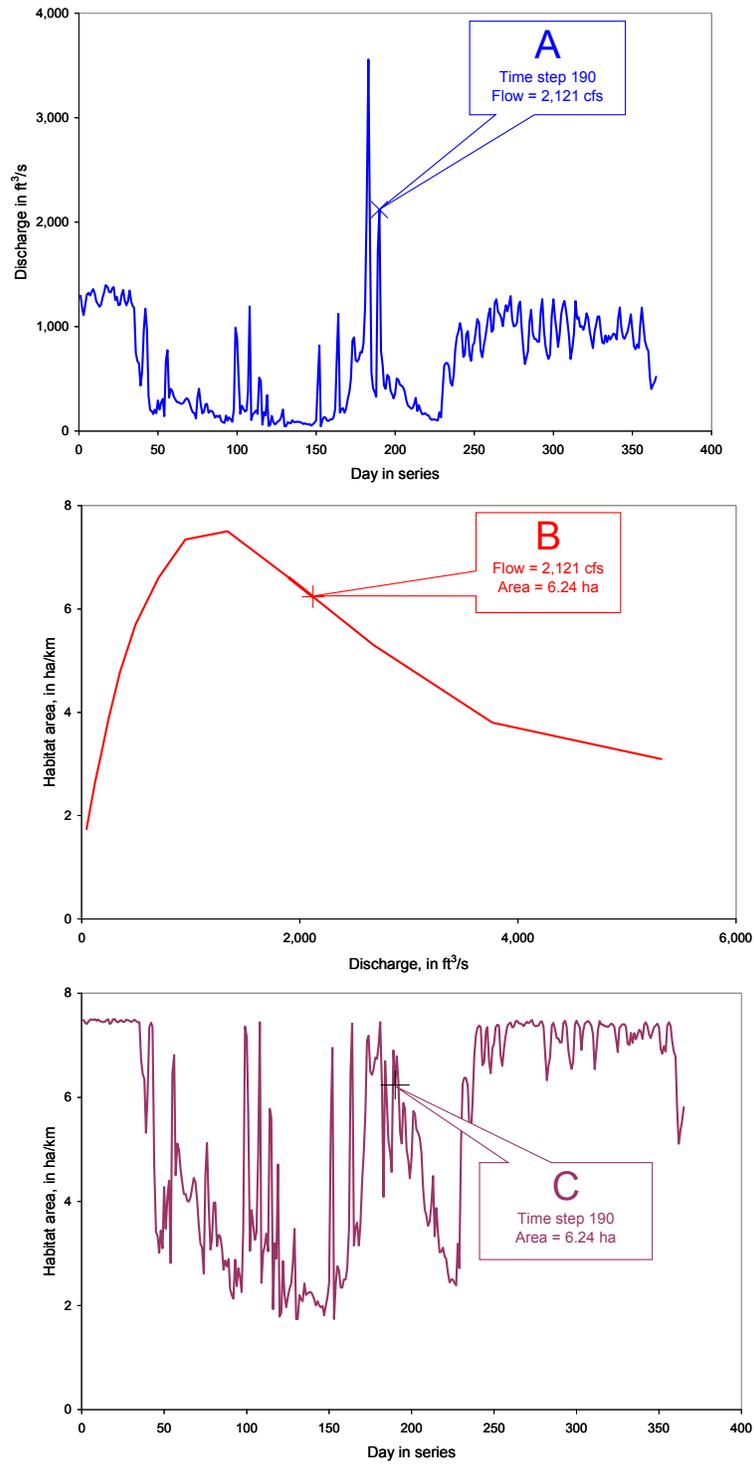


Figure 7. Elements used in the construction of a habitat time series: *A*, flow time series, *B*, flow versus habitat function, and *C*, the resulting habitat time series.

Habitat persistence for the dwarf wedgemussel differed from spawning-incubation in two significant ways. First, dwarf wedgemussels reside in the system year-round, rather than being confined to a single hydroperiod. Second, spawning-incubation persistence is primarily affected by the maximum differential between the spawning flow and the limiting incubation flow, regardless of the time interval between the two events. Dwarf wedgemussels are much more sensitive to rapid changes in flow, as they have the capacity to move to suitable habitat if the change is slow enough. To mimic this phenomenon, we conducted a search of the daily flows for each hydroperiod to find the largest flow differential over any consecutive five-day period. The maximum and minimum flows associated with this flow differential were then selected as the two flows to input to the persistence table for each hydroperiod, for each year.

Habitat Duration Statistics

Comparisons of baseline versus habitat time series plots or data may be qualitatively informative, but not very useful for quantification of potentially limiting events. There is a general consensus that the most likely habitat limitations for a life stage or species occur during periods when habitat is restricted (Bovee and others, 1998). These habitat bottlenecks are defined by episodes when the habitat value falls below the median of the habitat time series. More restrictive definitions of limiting events can be applied, and in the case of the DRDSS, we used the average of the lowest 25 percent of the habitat values in the time series as the criterion for comparison.

The determination of the cut-off point for any quartile or probability in a habitat time series is based on the concept of the habitat duration curve. Such curves were constructed for baseline and alternative conditions by the following method:

1. Habitat time series for each target organism and hydroperiod were sorted from highest to lowest and assigned a rank.
2. The probability that any particular habitat value would be equaled or exceeded was calculated as:

$$P = r/(n+1) \quad (4)$$

Where P = the probability that a value in the series will be equaled or exceeded,
 r is the rank of the sorted data, and
 n is the number of values in the series.

For comparative purposes in the DRDSS, the average of the lowest 25 percent of the values in the series was calculated and retained as the habitat metric for the series representing baseline and alternative scenarios, respectively. This metric was chosen for two specific reasons. First, biological populations tend to be limited during periods when resources (including space) are most restricted (Nehring and Anderson, 1993; Bovee and others, 1994). These values represent a compilation of the potentially limiting habitat events associated with either series. Second, the metric is a special case of a trimmed mean that removes the possibility that an increased occurrence of large values could offset an increased occurrence of small values. In essence, this combination could be worse from a biological perspective, but the average for the two series could be the same, indicating no impact.

Habitat Duration Series

This variation of the habitat duration concept is used to illustrate daily variability in a time series. In essence, the habitat duration series is a box-and-whisker plot for every day in the year.

The habitat duration series plot (fig. 8) was constructed by sorting the data hierarchically by month and day in ascending order, and magnitude of habitat in descending order. Probabilities of exceedance were calculated for each day using equation 4, and the lowest 25 percent of the values for baseline and alternative were plotted. Baseline habitat values in figure 8 are depicted as a light blue band. The solid lines on figure 8 represent the boundaries for the lowest-quartile habitat values for the alternative.

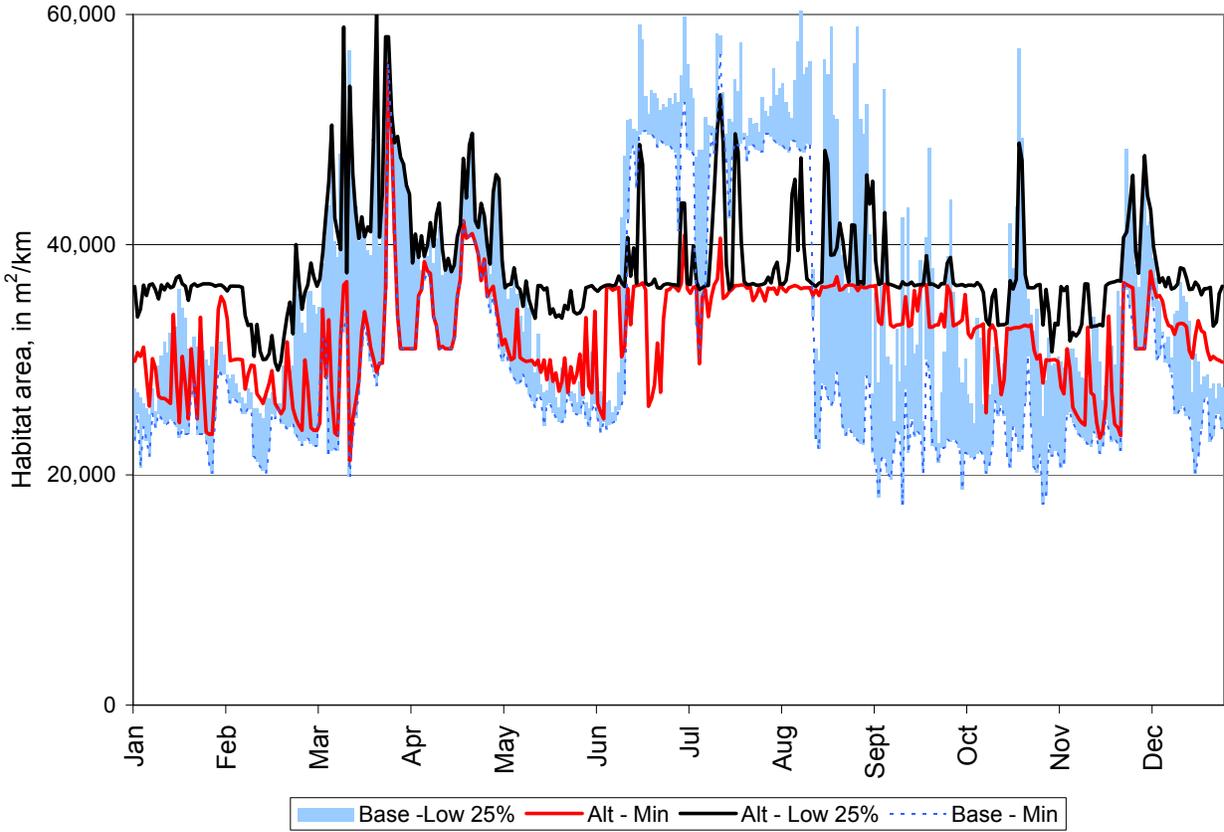


Figure 8. Comparison of habitat duration series for baseline and alternative scenarios.

The purpose of presenting information in this format is to allow decisionmakers to check for potentially adverse habitat conditions that might be masked by aggregation and summarization. The scoring metric derived from the habitat duration curve is an average from several month's data. It is possible to increase the metric during part of the hydroperiod and reduce it during another part, resulting in no change to the average. An example of this phenomenon can be seen in figure 8 during the months of July and August. For much of July, the light blue band for the baseline appears above the red and black quartile boundaries for the alternative. During August, the pattern is reversed. Compared to the baseline, the magnitude of the lowest 25 percent of the habitat events was reduced during July but elevated during August under the alternative scenario. Although the average of this metric over both months might show little or no difference between the baseline and alternative, the duration series plot indicates that this conclusion would not be entirely correct from a biological perspective.

Structure and Functions of the DRDSS

A prototype DRDSS (Version 1.0) was developed for presentation to the Commission and Subcommittee in October 2005. Version 1.0 was intended to have operational functionality (input data would provide real results) but not operational efficiency. Its primary purpose was to demonstrate the organization of the DRDSS and its use as a decisionmaking tool. During the developmental stages of the DRDSS, an Excel® spreadsheet was used as the computational platform. The advantages of this format were that changes could be made rapidly and transparently. The disadvantages were that the spreadsheets were very large (>160 MB), cumbersome to modify, and not portable to routinely available computers (required 2 GB of RAM and 3.0 MHz processor or better). However, given the volatility of earlier versions of the DRDSS, we believed that the advantages outweighed the disadvantages. Owing to the size of the files and slow turn-around on runs, however, Version 1.0 provided information only for a limited number of sites (7), and a small, fixed number of flows (10 years).

As a result of the October meeting and subsequent discussions with the Commission and Subcommittee, a number of revisions were suggested for a more operational Version 2.0. This version involved improvements in operational efficiency, expansion of capability to all study sites, and a more extensive set of decision variables and scoring mechanisms. Minor modifications have been made to version 2.0 as a result of extensive beta-testing performed by members of the Commission and Subcommittee, as well as debugging and quality assurance testing within the USGS Fort Collins Science Center. The current version (2.11) operates identically to version 2.0, but owing to the modifications, results from comparable runs using the two versions will deviate slightly from one another.

Structure and Organization

One of the most noticeable changes from Version 1.0 to Version 2.11 is that all the calculations in Version 1.0 were done in a single, very large spreadsheet. Version 2.11 is organized differently, having a master spreadsheet (DSS_AGG.xls) and four subsidiary spreadsheets (henceforth referred to as SUBS) for each of the river segments (DSS_WB, DSS_EB, DSS_DEL, and DSS_NVR). Reformatted output from OASIS, selected meteorological data, and user-supplied parameters are entered directly to the master spreadsheet, but the calculations for each of the decision variables occurs in the SUBS (fig. 9). Results from all the computations in the SUBS are then returned to the master spreadsheet, both as a whole system summary, and as segment-specific raw scores. Thus, the user can review the overall system response to an alternative, and also examine the details about each segment.

Functionality

The DRDSS requires as input two continuous (no days or flows missing) streams of daily flows for each of the identified study sites. One data set is for a baseline case and the other for an alternative. These data are derived from the OASIS model. Scoring comparisons are made for changes in habitat characteristics for pertinent target species and guilds, water temperature characteristics, spill and reservoir storage, and water deliveries and exports.

Habitat Time Series Metrics

Two types of habitat area calculations are used in the DRDSS. The first type is defined as “instantaneous habitat,” derived from the hydroperiod habitat time series and habitat duration statistics. This is the habitat area for a target species that occurs at a specific discharge, with no

consideration of antecedent or subsequent discharges in the series. The second type is based on a time series of persistent habitat, where antecedent or subsequent discharges are directly accounted for in the calculation of the habitat metric. Habitat persistence analyses were performed for trout spawning-incubation and dwarf wedgemussel habitat only.

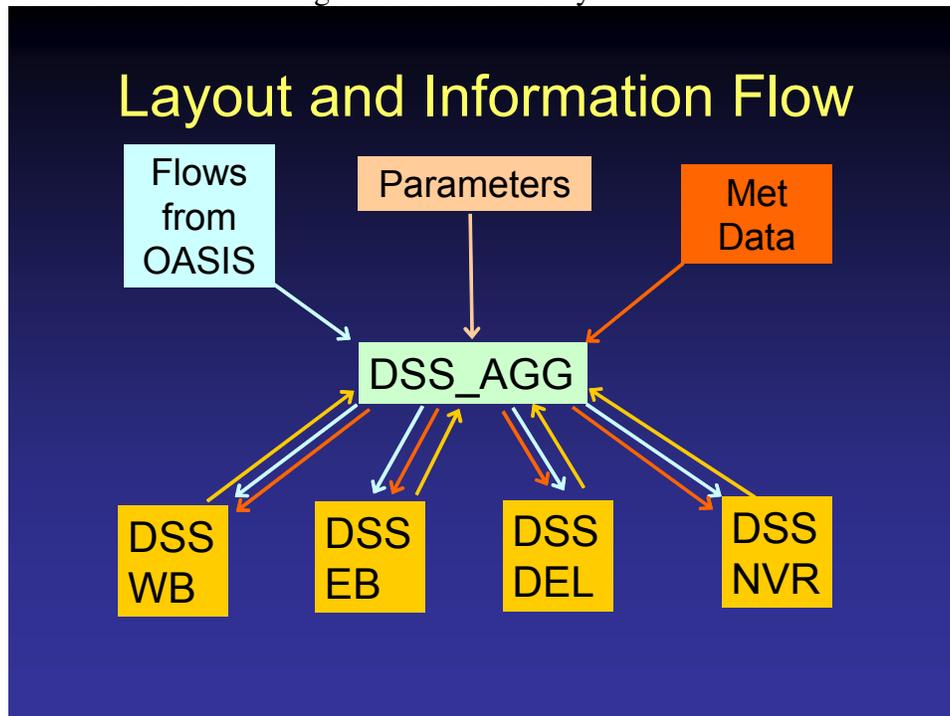


Figure 9. Layout and information flow in DRDSS Version 2.11. Blue arrows indicate the pathways for hydrologic data, orange arrows indicate temperature-related information, and gold arrows are for habitat metrics returned from each site to the master spreadsheet. The tan arrow represents user-supplied options that select different computational algorithms and scoring criteria. DSS_AGG; master spreadsheet. DSS_WB, DSS_EB, DSS_DEL, DSS_NVR; subsidiary spreadsheets for the West Branch, East Branch, Delaware main stem, and Neversink River, respectively.

Temperature

Water temperature was calculated using equation 3 with meteorological data from the Monticello weather station and streamflow data from OASIS as inputs. Temperatures were calculated only from May 1 to September 30. Three sets of meteorological data, as described in the section “Model Selection for the DRDSS” can be found in a separate database, met_data.xls. The first set of meteorological input data consists of a replication of the Monticello data to corresponding days for the period of record 1954–2003 (for example, May 1, 1954, has the same meteorological data as May 1, 1993; May 1, 1955, is the same as May 1, 1994; and so forth). The two sets of pseudometeorological data (normal and worst-case) for the 50 year period 1953–2003 contained in the met_data.xls file are repetitive (for example, each May 1 has the same data).

Temperature is accounted for in two separate places in the DRDSS scoring summary. First, the number of days when temperatures exceed the specified thresholds are counted for the baseline and alternative conditions, with scores reported as percent change (in day counts), change in the number of days, and change in degree-days. Threshold temperatures can be adjusted by the DRDSS operator for each river segment on the page labeled “Parameters.” The second reference to

temperature is defined as “Temperature-conditioned habitat.” If temperature in a given segment exceeds the temperature threshold on a particular day, the habitat value for that day is set to zero. The zero-habitat days are then included in a time series analysis following the same protocols explained above for steady-flow habitat.

Spills

Spills are calculated as the difference between the discharge measured immediately downstream from a dam and the outlet capacity of the dam. If the discharge in the tailwater exceeds the outlet capacity, then a spill has occurred by definition. The severity of the spill is calculated as the proportion of the total flow in the tailwater that is attributable to the spill. There are three default levels of spill intensity. If the spill accounts for 10 percent or less of the tailwater discharge, it is considered minor. If it accounts for 50 percent or more of the discharge, it is considered major. Spills between 10 and 50 percent of the total discharge are considered moderate. Thresholds for each class of spill intensity can be adjusted by the user on the “Parameters” page. Spills are counted by hydroperiod for each category, and scores are reported as percent changes and as day-counts.

Storage Volume

Reservoir storage volume and triggers representing drought watch, drought warning, and drought are obtained directly from the OASIS model. Scores are derived by computing the number of days that reservoir storage fell into one of the three drought categories under the baseline and the alternative. Scores are reported as a percent change in the number of days within each drought category, and also as the difference in days counted in each category.

Montague Deliveries

Delivery of Decree flows at Montague is calculated in the OASIS model for both the baseline and alternative operations. Scoring of Montague deliveries is based on the number of days under each scenario when the specified delivery is not met. Delivery targets are variable, depending on system water supply, and the rules determining the targets are coded into OASIS. Three scoring criteria are used on the summary page of the DRDSS. A minor violation is scored if the delivery is less than 10 percent below the target, and a major violation is recorded if the delivery is more than 50 percent below the target. Moderate violations are recorded for deliveries between 10 and 50 percent below target. Scores are recorded as percent change in frequency of violations within each category and also as the actual change in frequency.

Out of System Deliveries

Similar to the scoring for Montague, deliveries to New York City and to the diversion at the Delaware-Raritan (D& R) Canal near Trenton, N.J., are calculated in OASIS, as are the delivery targets. In both cases, scoring is reported as both percentage and frequency. The defaults for minor, moderate, and major shortages are the same as for the Montague targets, and the classification criteria are likewise user-adjustable.

DRDSS Output and Displays

Decision support systems can be developed in a bewildering array of styles, functions, and purposes. The philosophy guiding our development of the DRDSS was that it should concisely display the consequences of a management alternative to a wide array of competing resource values, yet should be sufficiently transparent to allow diagnosis of causes and effects. The

following sections describe some of the tabular and graphical outputs that are produced by the DRDSS, and how they can be accessed. For full user documentation, the reader is referred to appendix 5.

The Summary Scoring Page

The summary scoring page is the second page in the DSS_AGG.xls master spreadsheet, but is generally the initial focal point when reviewing the outcome of a scenario run. Figure 10 shows the layout and some of the features associated with the scoring summary.

Delaware DSS Provisional Version 2.11 Summary		Run Date: Baseline: 11/06/06 Alternative: Rev1 Rev 7		Start date 10/1/1990 to 10/1/1990		End date 9/29/2000 to 9/29/2000		
October - April 15								
Resource	West Branch		East Branch		Main Hancock-Callicoon		Neversink	
	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
	21%	13.50	8%	12.31	2%	7.80	16%	13.42
	91%	2.39	3%	0.10	1%	0.06	155%	4.79
	8%	1.11	-9%	-2.54	0%	0.04	18%	3.83
SFCV, ha	52%	2.44	41%	1.04	1%	0.02	27%	3.79
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha					3%	0.08		
Spills, minor, count	-6%	-1.00	14%	1.00			0%	Base, Alt =0
Spills, moderate, count	13%	2.00	15%	2.00			-17%	-1.00
Spills, major, count	-13%	-2.00	-14%	-4.00			0%	0.00
April 16 - June								
Resource	West Branch		East Branch		Main Hancock-Callicoon		Neversink	
	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
	16%	11.47	16%	11.41	4%	6.77	4%	6.84
	2%	0.24	2%	0.24	-4%	-0.84	-3%	-0.77
	11%	0.40	11%	0.40	8%	0.24	8%	0.24
SFCV, ha								
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	0.00	16%	5.50	16%	5.50	5%	6.10
Spills, moderate, count	0%	0.00	14%	1.00	0%	-0.02	0%	0.00
Spills, major, count	0%	0.00	-21%	-8.00			-50%	-1.00
	0%	0.00	-5%	-2.00			-10%	-2.00
July - September								
Resource	West Branch		East Branch		Main Hancock-Callicoon		Neversink	
	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
	-2%	-1.45	-2%	-1.45	16%	23.40	16%	22.86
	22%	3.06	22%	3.06	-10%	-3.29	-10%	-3.27
	85%	5.19	85%	5.19	-4%	-0.72	-4%	-0.71
SFCV, ha								
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	Base, Alt =0	0%	Base, Alt =0	0%	0.00	0%	0.00
Spills, moderate, count	0%	Base, Alt =0	0%	0.00	-1%	-2.52	-2%	-7.48
Spills, major, count	0%	Base, Alt =0	0%	0.00	2%	0.80	1%	0.44
					11%	1.50	10%	1.38
					1%	2.11	-1%	-1.59
							43%	10.85
							42%	7.08
							17%	7.00
							-5%	-0.34
							-50%	-1.00
							100%	1.00
							0%	0.00
Full Period Scores								
West Branch		East Branch		Main Hancock-Callicoon		Neversink		
Pct Chg	Δ Days	Pct Chg	Δ DegDays	Pct Chg	Δ Days	Pct Chg	Δ DegDays	
0%	0.00	-2%	-0.14	0%	0.00	-1%	-0.13	
						150%	6.00	
						399%	4.97	
Global Scores								
Montague Flow				Out of System Deliveries				
Pct Chg	Δ Days	Pct Chg	Δ Days	Pct Chg	Δ Days	Pct Chg	Δ Days	
-27%	-113.00	0%	0.00	0%	0.00	0%	0.00	
-22%	-19.00	0%	Base, Alt =0	0%	Base, Alt =0	0%	Base, Alt =0	
0%	0.00	0%	Base, Alt =0	0%	Base, Alt =0	0%	Base, Alt =0	
-24%	-12454.00	0%	0.00	0%	0.00	0%	0.00	
System Drought				System Storage, bg				
Pct Chg	Δ Days	Pct Chg	Δ Days	Pct Chg	Δ Days	Pct Chg	Δ Days	
-22%	-92.00	0%	0.00	0%	0.00	0%	0.00	
39%	89.00	0%	Base, Alt =0	0%	Base, Alt =0	0%	Base, Alt =0	
0%	0.00	0%	Base, Alt =0	0%	Base, Alt =0	0%	Base, Alt =0	
0%	0.00	0%	Base, Alt =0	0%	Base, Alt =0	0%	Base, Alt =0	
0%	-2358.70	0%	0.00	0%	0.00	0%	0.00	
Run Settings								
Maximum Water Temperature (degrees C)				New York Diversion Magnitude				
West Branch	20	East Branch	20	(% minimum delivery)	Major	10	50	
Main Stem	25	Neversink	20	(% minimum delivery)	Major	10	50	
Spill Magnitude (% outflow capacity)				Meteorological Series				
Mild, <	10					Actual		
Major, >	50							
Montague Shortage Magnitude (% minimum flow)								
Mild, <	10							
Major, >	50							

Figure 10. Layout of the scoring summary page in the DRDSS.

The header lines at the top of the page contain information regarding the dates of the run, the names of the baseline and the alternative used in the OASIS run, and the period of record used in the time series analyses. The top portion of the scoring summary reports the habitat time series outcomes of the scenario for each of the target organisms of concern. This section of the report is divided in rows by hydroperiod, arrayed in blocks from hydroperiod 1 to hydroperiod 3, and in columns by major river system. From left to right, information is provided for the West Branch, East Branch, Delaware mainstem, and Neversink River. Biological decision variables and resources of concern are listed in the first column and repeated for each hydroperiod.

The cells in the summary page are conditionally formatted such that the cell background turns green if the scenario results in an improvement for a decision variable and red if it results in a decrement. In this portion of the summary, a change in a decision variable of less than 10 percent (\pm) was considered to be undetectable, so the cells do not change color unless the habitat metric changes by an amount greater than 10 percent. Some of the cells have grey backgrounds, which

indicate that the decision variable is not applicable for that cell. For example, American shad do not inhabit the West Branch, and temperature conditioning of habitat was not performed for hydroperiod 1, so these cells all have grey backgrounds.

Also included in the upper portion of the scoring sheet are three rows of scores for spills, divided among hydroperiods and river components. The conditional formatting of these cells is different from that used to score changes in habitat. First, spills are tracked by magnitude and defined as minor, moderate, or major. The percentages refer to the proportion of spills in each category occurring under the two alternatives being compared. By definition, spills were considered to be undesirable, so any scenario that increases their frequency by 10 percent or more results in a red background. Conversely, if the scenario results in a 10 percent or greater decrease in the frequency of spills, the scoring cell turns green. The cell retains a white background if the change in frequency is less than 10 percent in either direction.

Figure 11 shows an expanded view of the biological resources and spills scores for the West and East Branches for hydroperiods 1 and 2. The various target species and guilds are shown listed under “Resource” in the leftmost column. Four columns appear for each resource under the header for the river system. Columns labeled “PctChg” contain the percentage change in the metric, whether change in habitat area or spill frequency. Columns labeled “ Δ Hab” refer to the change in habitat area in hectares for the entire river reach. This metric is based on the prorated sum of the calculated habitat areas for all the segments in the reach. Columns labeled “ Δ TCondHab” refer to changes in temperature-conditioned habitat area.

The lower portion of the summary page (fig. 12) contains “full period” and “global” variables. These include items such as the number of days when temperature thresholds were exceeded; violations of the delivery targets for Montague, New York City, and the D & R diversion; and changes in the frequency of drought warning and drought events caused by changes in system reservoir storage. Violations of temperature thresholds are considered full period rather than global because they are recorded separately by river component, but for the entire summer (hydroperiods 2 and 3) instead of each hydroperiod. Otherwise, the conditional formatting for this variable is the same as for spills. If the frequency of violations increases by more than 10 percent the cell turns red and if it decreases by more than 10 percent it turns green.

Resource	October - April 15				April 16 - June			
	West Branch		East Branch		West Branch		East Branch	
	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
Trout Adult, ha	21%	13.50			8%	12.31		
Trout Spawning/Incu, ha	91%	2.39			3%	0.10		
SSCV, ha	8%	1.11			-9%	-2.54		
SFCV, ha	52%	2.44			41%	1.04		
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	-6%	-1.00			14%	1.00		
Spills, moderate, count	13%	2.00			15%	2.00		
Spills, major, count	-13%	-2.00			-14%	-4.00		

Resource	April 16 - June				April 16 - June			
	West Branch		East Branch		West Branch		East Branch	
	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
Trout Adult, ha	16%	11.47	16%	11.41	4%	6.77	4%	6.84
Trout Spawning/Incu, ha								
SSCV, ha	2%	0.24	2%	0.24	-4%	-0.84	-3%	-0.77
SFCV, ha	11%	0.40	11%	0.40	8%	0.24	8%	0.24
Shad Juvenile, ha								
Shad Spawning, ha					16%	5.50	16%	5.50
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	0.00			14%	1.00		
Spills, moderate, count	0%	0.00			-21%	-8.00		
Spills, major, count	0%	0.00			-5%	-2.00		

Figure 11. Expanded view of the scoring summary page, showing details of the scores and metrics for biological resources and spills in the DRDSS.

Δ Days > Threshold C	Full Period Scores			
	West Branch		East Branch	
	Pct Chg	Δ Days	Pct Chg	ΔDegDays
	0%	0.00	-2%	-0.14

Global Scores					
Montague Flow			Out of System Deliveries		
	Pct Chg	Δ Days		Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	Base, Alt =0
Montague, major shortage	0%	Base, Alt =0	NYC, major shortage	0%	Base, Alt =0
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought			NJ, minor shortage		
Days at Level 1	-22%	-92.00	NJ, moderate shortage	0%	0.00
Days at Level 2	39%	89.00	NJ, major shortage	0%	Base, Alt =0
Days at Level 3	0%	Base, Alt =0	New Jersey, bg	0%	Base, Alt =0
System Storage, bg	0%	-2358.70			

Figure 12. Expanded view of the scoring summary page, showing details of the scores and metrics for the full period and global resources in the DRDSS.

Delivery targets and deliveries for Montague, New York City, and the D&R canal are reported daily from OASIS and are input directly into the DRDSS (on the “Flows” page). The DRDSS records the number of days under baseline and alternative when the delivery was less than the target. These shortages are then classified according to severity (minor, moderate, or major) using criteria similar to those applied to spills. The defaults are ≤10 percent, 10 to 50 percent not inclusive, and ≥50 percent for each classification, respectively, but can be changed by the user to impose more- or less-restrictive definitions of severity.

The system drought component tracks daily reservoir storage and records the number of times that total volume drops below the rule curves for drought watch (Level 1), drought warning (Level 2) or drought (Level 3). Like data for deliveries, this information is generated by OASIS and is imported directly into the DRDSS. Scoring for this component is nearly identical to that used for delivery targets, except that the criteria for the defaults (≤ 10 percent, 10–50 percent not inclusive, ≥ 50 percent) cannot be changed.

The column headers in figure 12 are fairly self-explanatory and follow labeling nomenclature similar to that described for the river-specific metrics. A primary difference is the column labeled “ Δ DegDays,” which refers to the difference in degree-days between the two alternatives. Degree days are calculated as the sum of temperatures greater than the threshold for all the days in the time series. Dividing “ Δ DegDays” by the term “ Δ Days” provides the average magnitude of the temperature change (unless Δ Days = 0).

The Raw Scores Page

The raw scores page (fig. 13) is the third page in the DSS_AGG.xls master workbook. The layout and format of this page is similar to the summary page, but information is provided at the segment level, rather than at the whole-river scale. Aside from being segment-specific, the raw scores page displays total segment habitat areas for the baseline and scenario, with and without temperature conditioning.

Delaware DSS		RunDate: 11/06/06								10/01/90			
Provisional Version 2.11		Baseline: Rev1								10/01/90			
Resource Scores		Alternative: Rev 7											
By Study Site		October - April 15											
Hydro Period													
October - April 15		WB0 No Temperature adjustment			WB0 Temperature adjustment			WB1 No Temperature adjustment			WB1 Temperature adjustment		
Resource	Base	Scenario	% Change	Base	Scenario	% Change	Base	Scenario	% Change	Base	Scenario	% Change	
Trout Adult, sq m	2967	5357	81%	2967	5357	81%	27001	32373	20%	27001	32373	20%	
Trout Spawning/Incu, sq m	0	27	26655%				1117	2134	91%				
SSCV, sq m	5358	6000	12%	5358	6000	12%	5083	5450	7%	5083	5450	7%	
SFCV, sq m	384	2458	539%	384	2458	539%	1950	2646	36%	1950	2646	36%	
Shad Juvenile, sq m													
Shad Spawning, sq m													
Dwarf Wedge Mussel, sq m													
Δ Days > Threshold													
April 16 - June		April 16 - June											
Resource	WB0			WB0			WB1			WB1			
Trout Adult, sq m	5848	6850	17%	5413	6277	16%	28979	33712	16%	28979	33712	16%	
Trout Spawning/Incu, sq m													
SSCV, sq m	4259	4516	6%	4004	4254	6%	4527	4589	1%	4527	4589	1%	
SFCV, sq m	2304	2759	20%	2138	2587	21%	1196	1293	8%	1196	1293	8%	
Shad Juvenile, sq m													
Shad Spawning, sq m													
Dwarf Wedge Mussel, sq m													
Δ Days > Threshold	12	12	0%				0	0	0%				
July - September		July - September											
Resource	WB0			WB0			WB1			WB1			
Trout Adult, sq m	15563	13183	-15%	15563	13183	-15%	36282	36057	-1%	36282	36057	-1%	
Trout Spawning/Incu, sq m													
SSCV, sq m	4565	5457	20%	4565	5457	20%	5304	6465	22%	5304	6465	22%	
SFCV, sq m	3800	4521	19%	3800	4521	19%	1974	4070	106%	1974	4070	106%	
Shad Juvenile, sq m													
Shad Spawning, sq m													
Dwarf Wedge Mussel, sq m													
Δ Days > Threshold	0	0	0%				0	0	0%				

Figure 13. Expanded view of the “Raw scores” page showing details of the segment-specific scores and metrics for habitat and temperature decision variables.

Flow and Storage Time Series Graphics

Time series plots of segment discharges and reservoir storage (fig. 14) can be found on the “FlowPlots” page of the DSS_AGG.xls master spreadsheet. These plots show the hydrologic outcomes of an OASIS run chronologically, comparing the baseline (dark blue) with the alternative (pink). The plots can be scrolled horizontally to examine selected portions of the record. These charts are useful in determining what really happened in OASIS as opposed to what the alternative was intended to do. When such disparities occur, they provide insights into the mechanics of implementing an alternative and may help link the means with the desired ends. Flow and storage time series are also valuable during interpretation and diagnosis of habitat time series results.

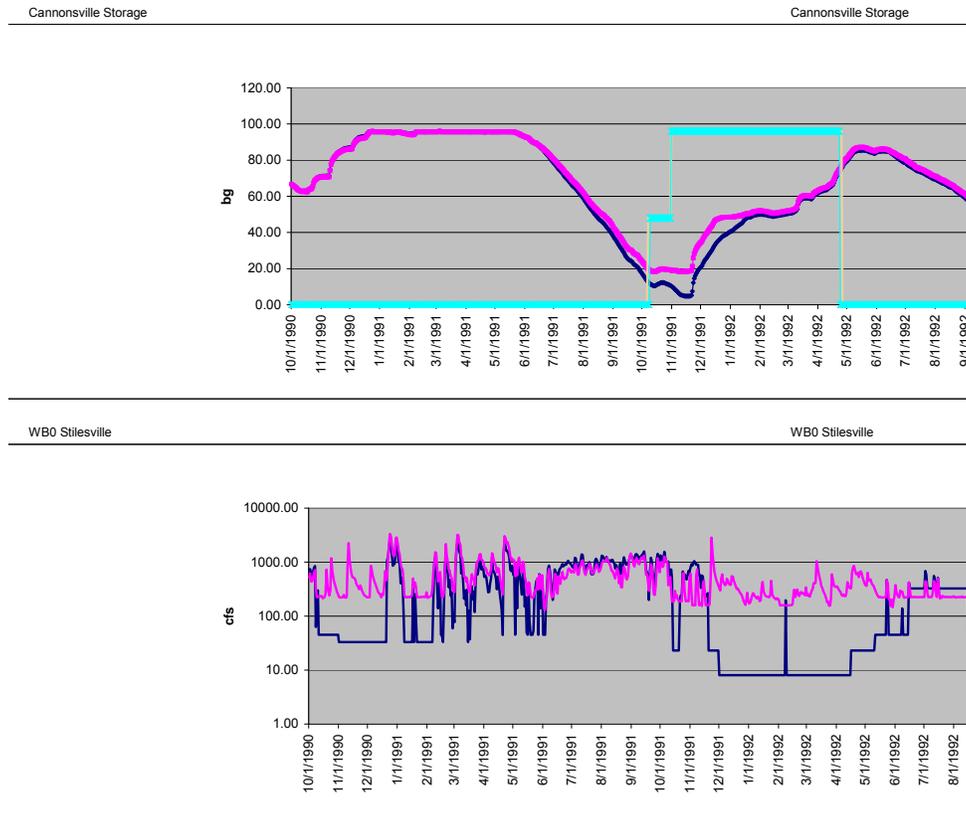


Figure 14. Time series of daily storage volumes and segment discharges from the “FlowPlots” page of the DSS_AGG.xls master spreadsheet.

Flow, Temperature, and Storage Duration Curves

Duration curves are commonly used to consolidate large masses of time series data, such as illustrated in figure 14, into a concise graphical form. Rather than depicting time series events chronologically, they are displayed as a cumulative probability function (fig. 15). Construction of a duration curve follows the same procedure described for “habitat duration statistics” except that daily flows, temperatures, or storage volumes are plotted instead of habitat areas. These curves are not restricted to the lowest quartile, but show the entire probability distribution. However, the Y-axis scaling can be changed to magnify portions of the curve that might be of greater interest, such as the low flow portion of a hydrograph.

The duration curves and the mechanisms for drawing them are located on the segment-specific SUBS workbooks. The variables and sites for which the duration plot are generated are selected on the page entitled “<site_name>DurCurve” as illustrated in figure 16. Drop-down menus of variables and sites are made available by clicking on the green activator buttons, and individual variables and sites selected by highlighting them. When the purple button is activated, the chart (fig. 15, for example) on the “DurCurveChart” page is automatically updated. An important distinction between this application and the chronological time series plots is that individual duration curve plots are not saved but change each time they are updated. Therefore, it is necessary to print each graph or save it to a separate file as it is generated if the information is to be saved for later reference.

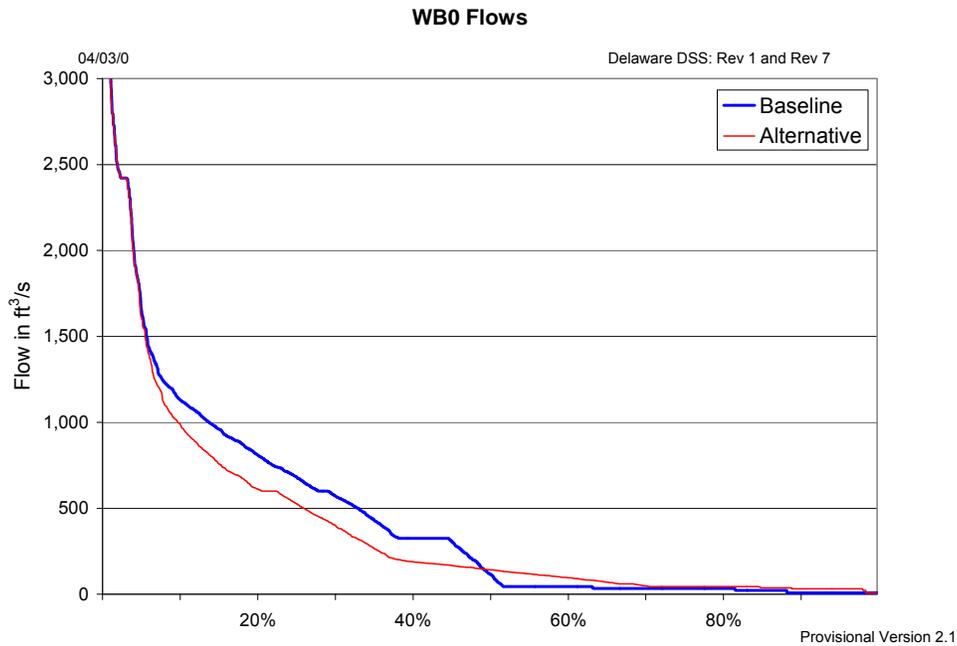


Figure 15. Example flow duration curves for site WB0. The Y-axis was truncated at 3,000 cubic feet per second in order to amplify the differences in the lower flow range.

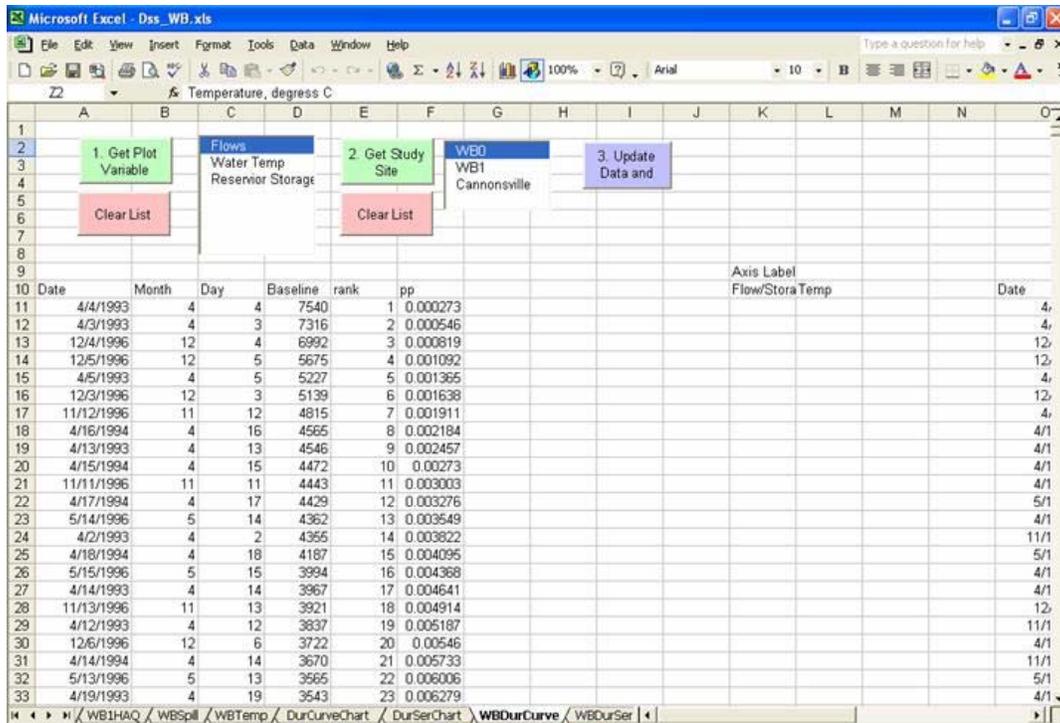


Figure 16. The “DurCurve” page of one of the subsidiary workbooks of the DRDSS, showing locations and functions of control buttons used to update a duration chart.

Habitat Duration Series Graphics

Habitat duration series charts are also site-specific and generated for only one habitat or flow variable at a time. Like the duration curves, these charts and their drivers are located in each of the SUBS workbooks under the pages entitled “DurSerChart” and “<site name>DurSer,” respectively. The target resource (either habitat for one of the target organisms or the flow) and the segment can be selected from dropdown menus in the “DurSer” pages (fig. 17). The period of record is predefined by the period extracted from OASIS, but the number of leap days in the record must be specified on this page. Leap days are eliminated, but the program must be able to find them in the record. Selection of the variable and site follows the same general procedure described for the duration charts, but the user can specify whether the habitat duration series are temperature-conditioned (button 4). Button 5 (Update Duration) activates a macro that re-sorts the data. Once the duration series has been updated, button 6 (Update Chart) activates a macro that re-draws the graph on the “DurSerChart” page (see fig. 8, for example). Like the duration curves, these graphs are not saved automatically. Users are advised to copy and export graphs before each update.

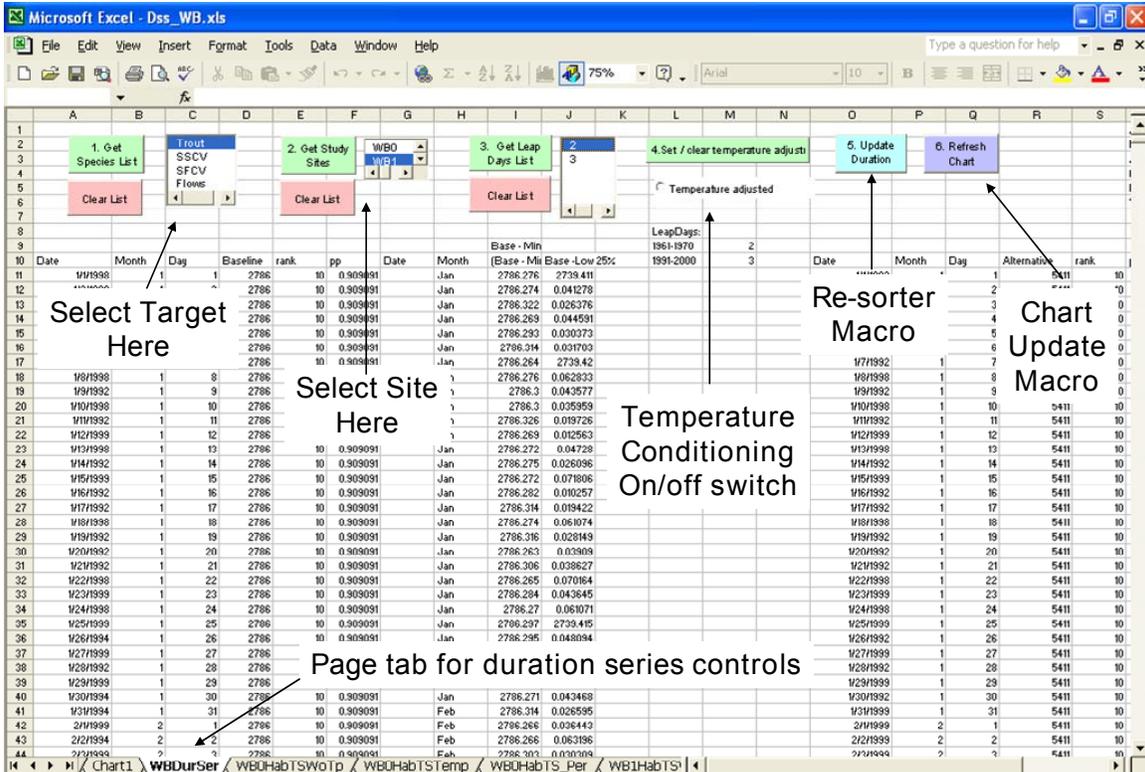


Figure 17. The “DurSer” page of one of the subsidiary workbooks of the DRDSS, showing locations and functions of control buttons used to update a duration series chart.

Results

Habitat Versus Discharge Functions

There are several ways to express the habitat versus discharge functions extracted from the map data. The discharges used to derive the habitat time series represent the average daily flows that would have occurred in a specific segment under baseline and alternative operating scenarios. This expression is necessary for generation of the habitat time series, but some form of normalized discharge may be more useful for comparing the habitat versus flow functions among the various sites. Similarly, habitat can be expressed as a total area for the segment or normalized for comparison. Discharge was expressed as segment-specific mean daily discharge and as “unit discharge,” calculated as cubic meters per second per square mile of drainage. Habitat areas are expressed as both normalized area (ha/km) and as total area for the segment (ha). Conversion constants for each of the study segments are summarized in table 7, and habitat versus flow statistics are presented in appendix 3.

Table 7. Conversion constants and normalizing terms by segment.

Segment	Length (km)	Drainage area (mi²)
WB0	3.9	456
WB1	23.2	595
EB0	12.2	372
EB1	15.1	458
EB2	25.6	784
DEL1	14.9	1,590
DEL2	17.1	1,668
DEL3	11.7	1,820
NVR0	12.9	113
NVR1	26	171
NVR2	23.7	307

Shallow-slow habitat types were maximized at the lowest range of flows, with peak areas occurring around 0.1 to 0.3 cubic feet per second per square mile (fig. 18). Shallow-fast habitat types were also maximized at relatively low flows (fig. 19), but not as low as shallow-slow habitat types. At discharges less than 0.3 cubic feet per second per square mile, water velocities tend to be too low to be suitable for this guild, but at discharges greater than 0.6 cubic feet per second per square mile, depths become too large to be considered “shallow.”

Habitat areas for juvenile trout (fig. 20) and juvenile American shad (fig. 21) behaved similarly with respect to discharge, both showing an increase in area at discharges up to about 0.6 cubic feet per second per square mile and then declining at discharges greater than 0.9 cubic feet per second per square mile. Habitat areas for adult trout (fig. 22) and American shad spawning (fig. 23) also show similar patterns, but are shifted slightly to the right on the discharge axis, reflecting a preference for deeper and faster water than juveniles as indicated in Table 2. Habitat areas for these two target organisms were maximized in the range of about 1–3 cubic feet per second per square mile. In all cases, depths are too shallow for discharges below the peaks of the curves and velocities are too high at discharges above the peaks.

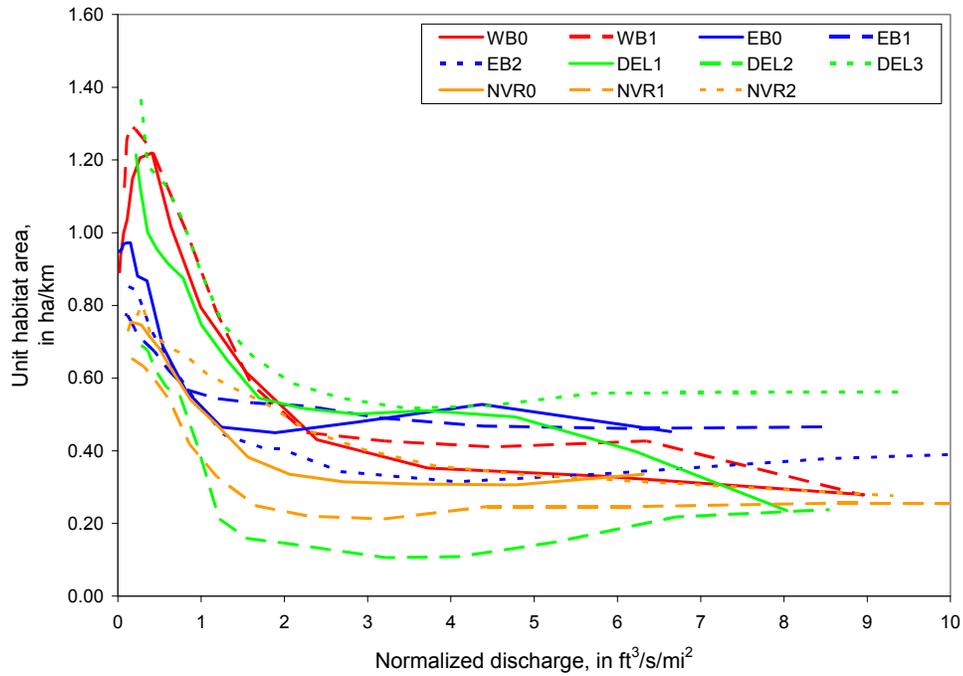


Figure 18. Normalized discharge versus unit habitat areas for the shallow-slow current velocity guild at 11 sites in the upper Delaware River.

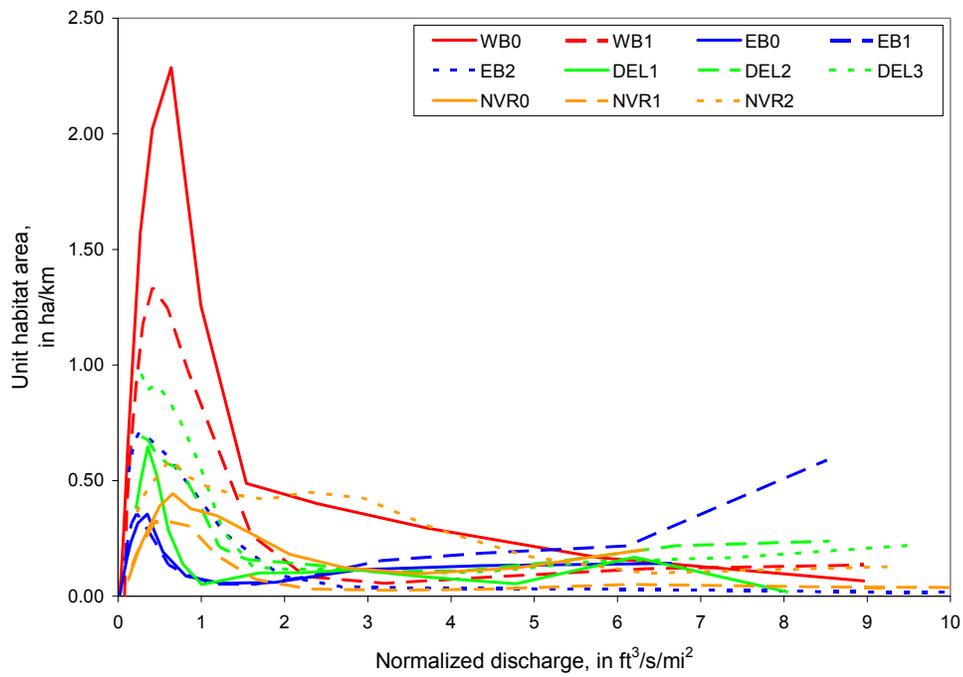


Figure 19. Normalized discharge versus unit habitat areas for the shallow-fast current velocity guild at 11 sites in the upper Delaware River.

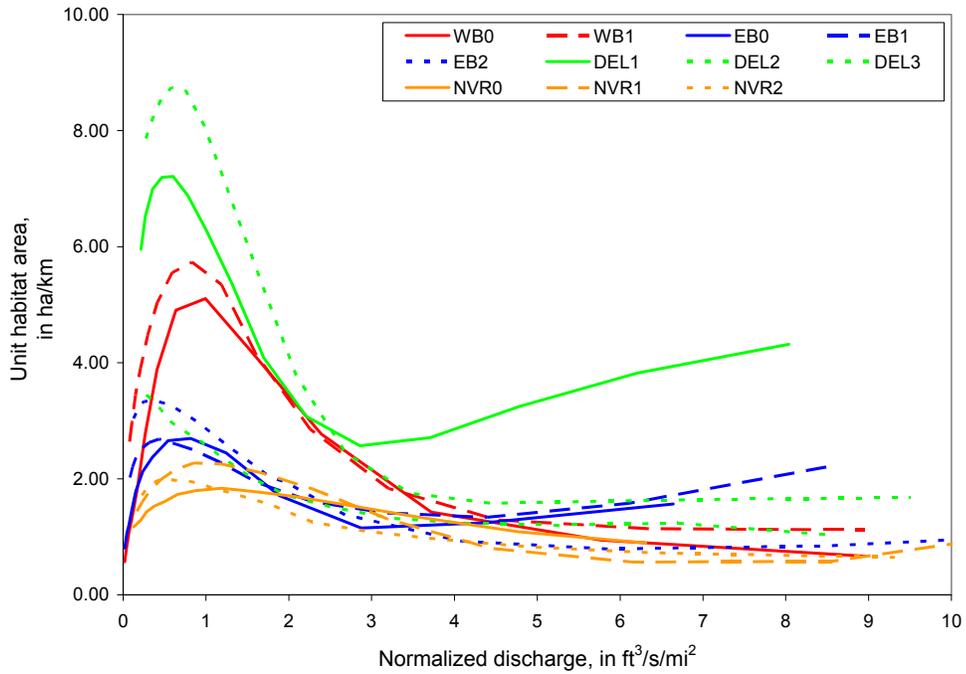


Figure 20. Normalized discharge versus unit habitat areas for juvenile trout (*Salmo trutta*) at 11 sites in the upper Delaware River.

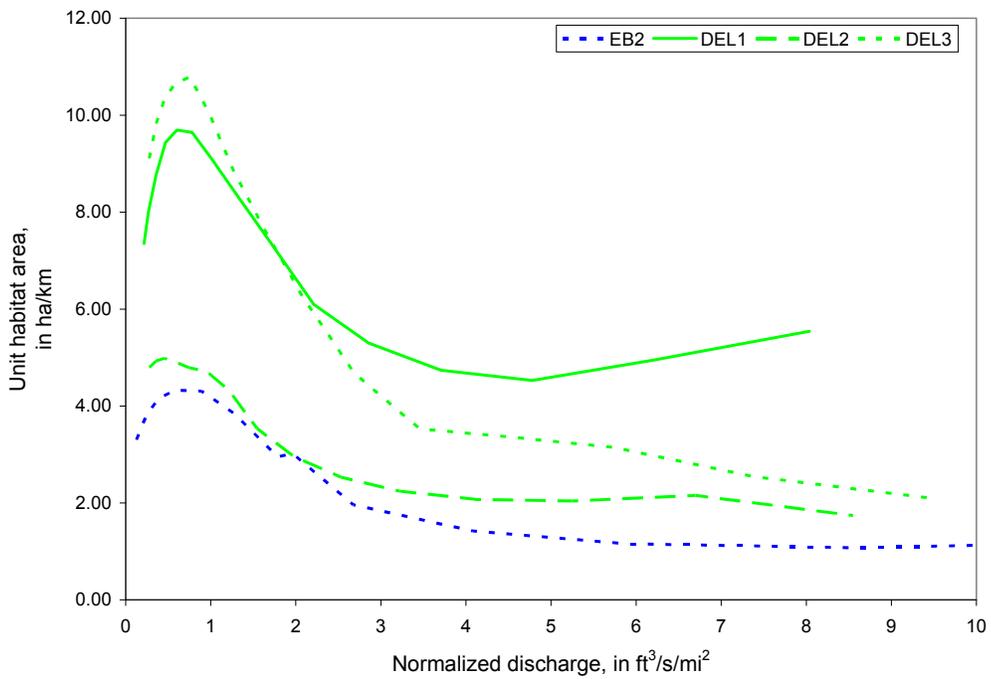


Figure 21. Normalized discharge versus unit habitat areas for juvenile American shad (*Alosa sapidissima*) at four sites in the upper Delaware River.

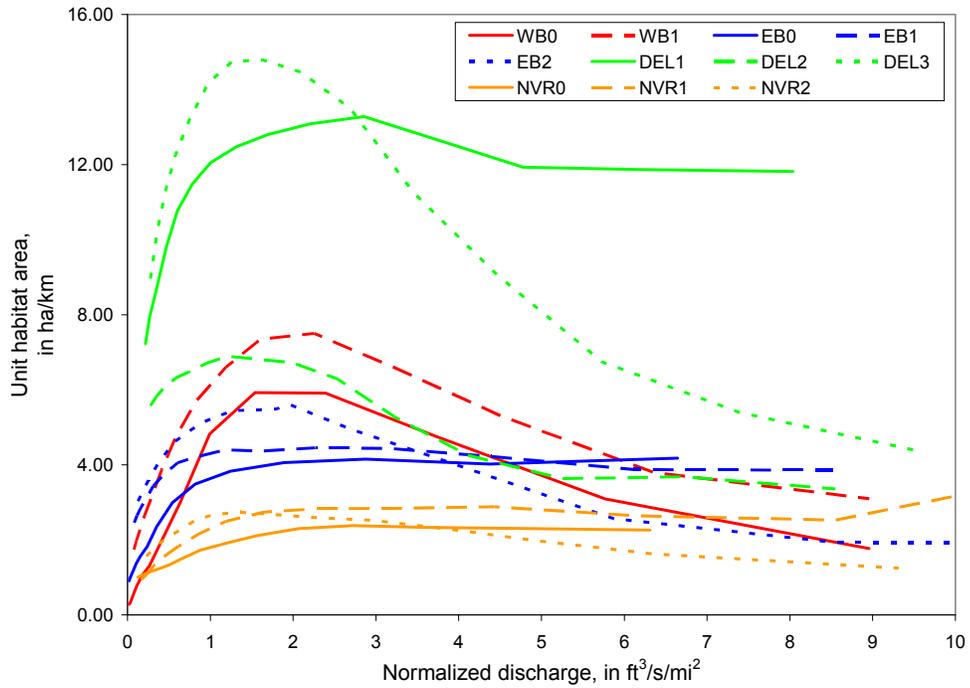


Figure 22. Normalized discharge versus unit habitat areas for adult trout (*Salmo trutta*) at 11 sites in the upper Delaware River.

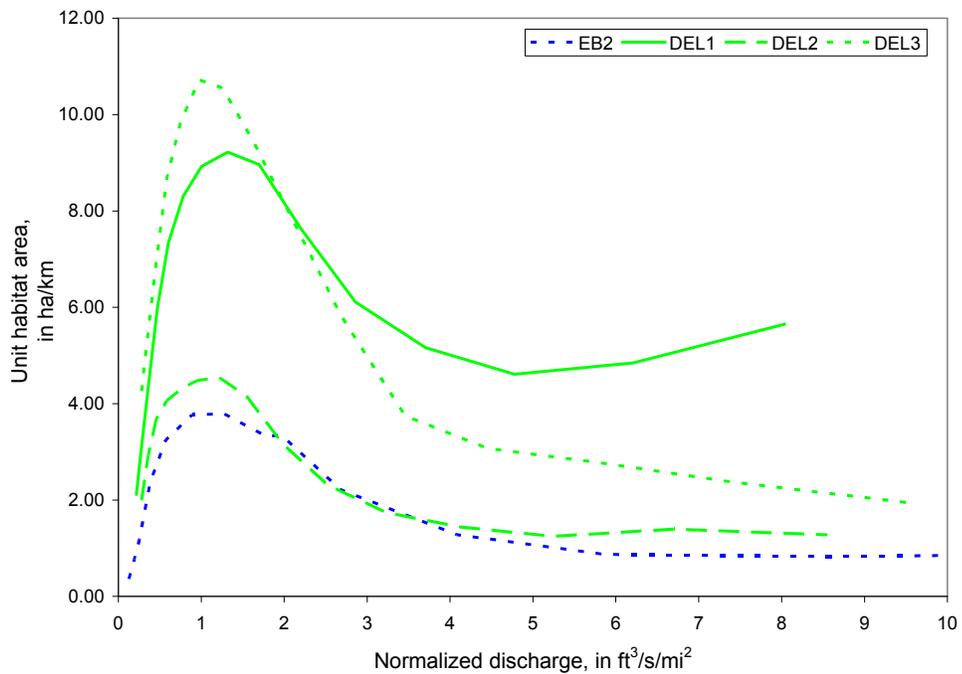


Figure 23. Normalized discharge versus unit habitat areas for spawning American shad (*Alosa sapidissima*) at four sites in the upper Delaware River.

Mesohabitat Versus Discharge

Patterns of mesohabitat distributions similar to those of the discharge versus habitat area functions were evident among the sites. Figures 24–29 and figures 31–32 illustrate the normalized areas of mesohabitat types, roughly in descending order of abundance. Pools were the most prominent mesohabitat types at low flows, but were replaced by fast runs at the higher flows (figs. 24 and 25). The shift from pool to fast run was indicative of the lesser influence of riffles as hydraulic controls (features in the stream that create backwater effects in an upstream direction) at higher discharges, resulting in an overall increase in hydraulic gradients. At low flows, runs were second in abundance to pools at most sites (fig. 26) and were also replaced by fast runs at the higher discharges. It is noteworthy that the two West Branch sites and the site farthest upstream on the Neversink (NVR0) did not develop very much fast run mesohabitat (except at WB1 at the highest flow), retaining about the same amount of pool and run mesohabitats across the entire range of discharges. We believe that this phenomenon may be related to the formation of very large deltas at tributaries in these sites. These deltas provided strong and stable hydraulic control over a wide range of flows, so the backwater effects needed to create pools were retained, rather than being “drowned out” at higher discharges.

Riffles (fig. 27) were comparatively less extensive than the other major mesohabitat types and generally mimicked the pattern of the shallow-fast habitat guild with respect to streamflow. The exceptions occurred at WB0 and in the Neversink (both for riffles and SFCV) where the amount of riffle habitat either remained constant or increased with increased discharge.

As might be expected, the area of inundated vegetation (fig. 28) was zero or near zero at all sites at low discharges and increased steadily as discharges increased. With the exception of DEL1, the area of inundated vegetation was minimal at discharges less than about 3 cubic feet per second per square mile.

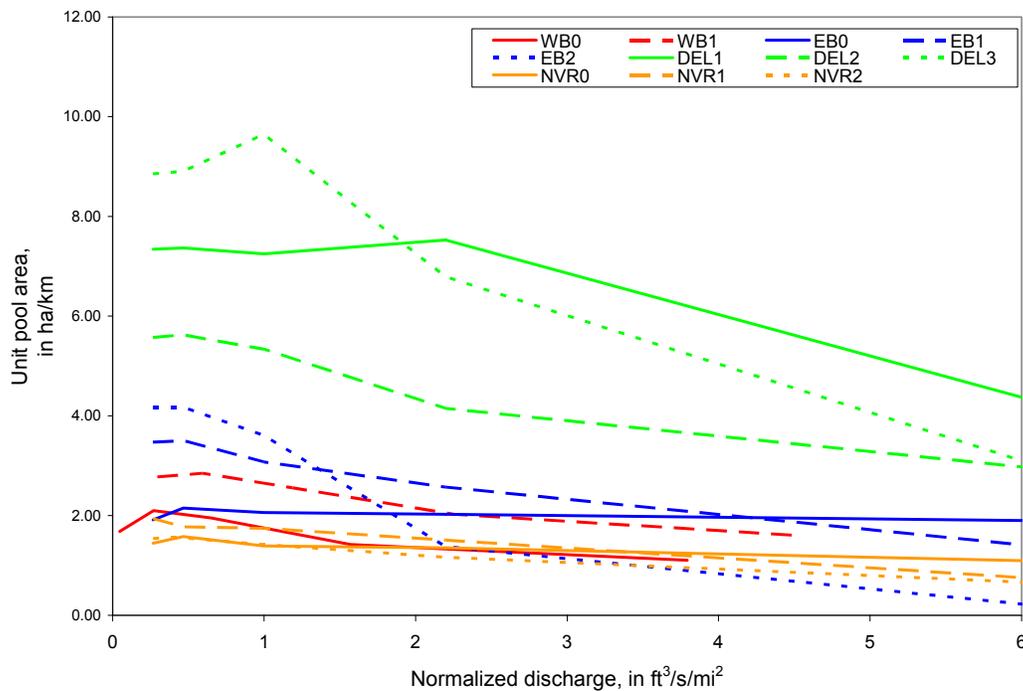


Figure 24. Normalized discharge versus unit areas of pool mesohabitat types.

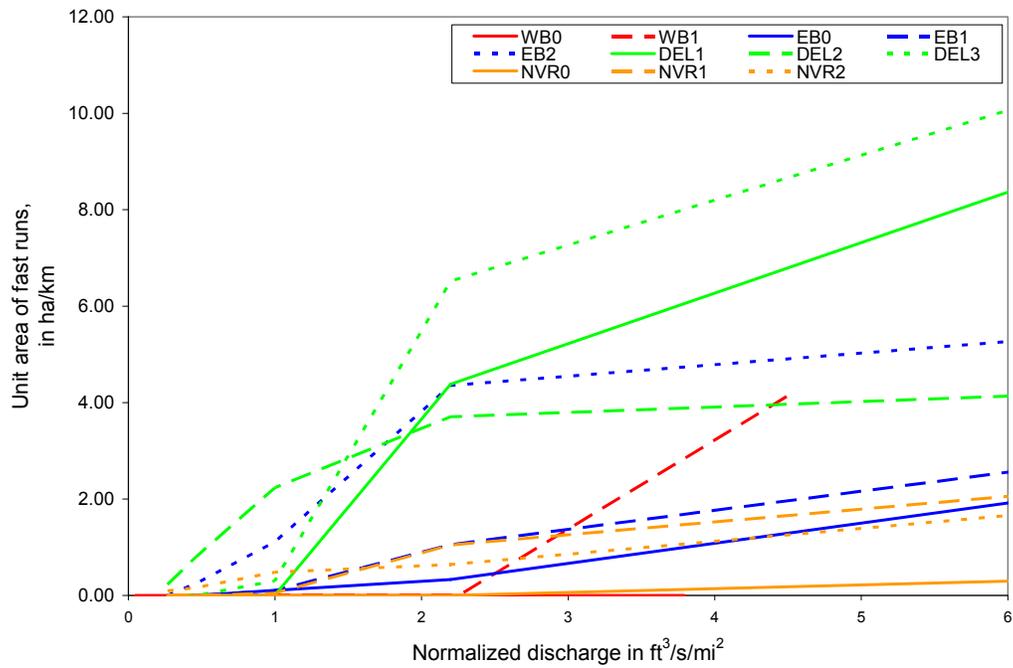


Figure 25. Normalized discharge versus unit areas of fast run mesohabitat types.

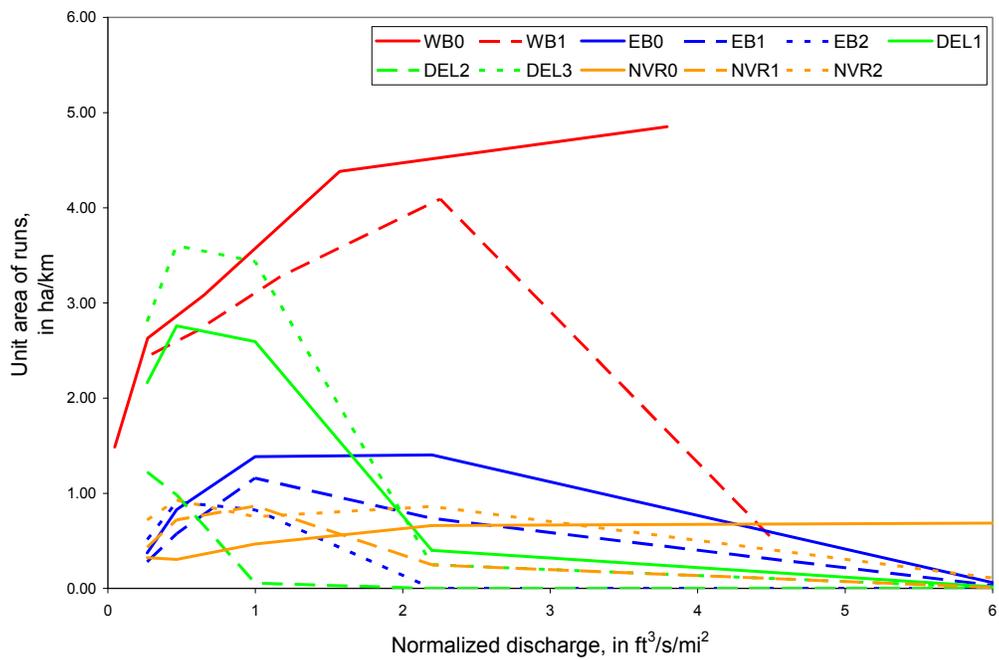


Figure 26. Normalized discharge versus unit areas of run mesohabitat types.

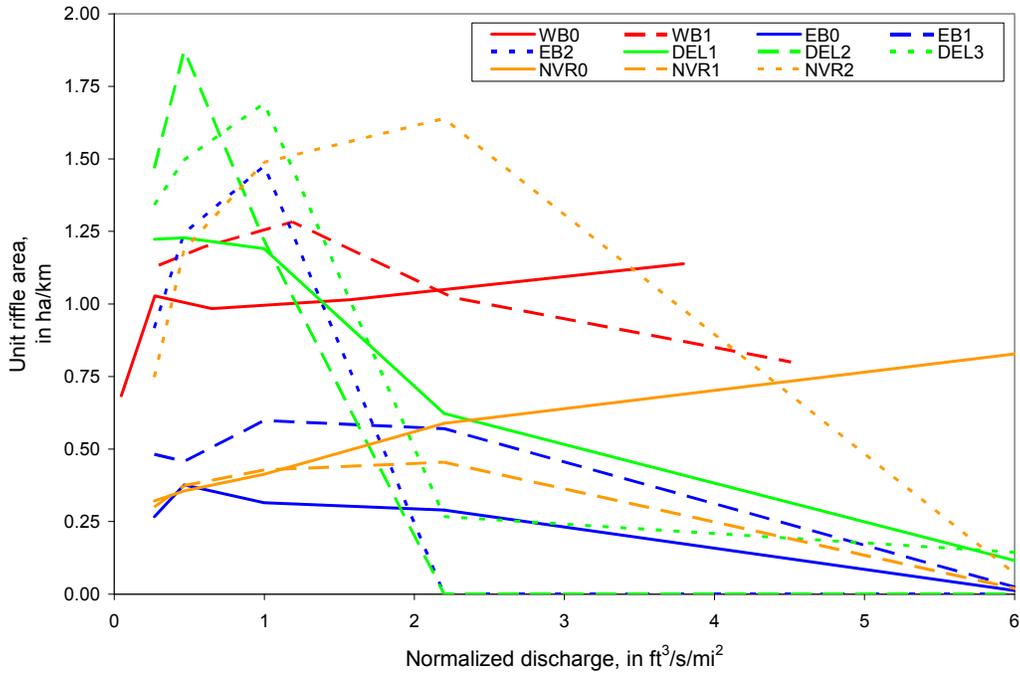


Figure 27. Normalized discharge versus unit areas of riffle mesohabitat types.

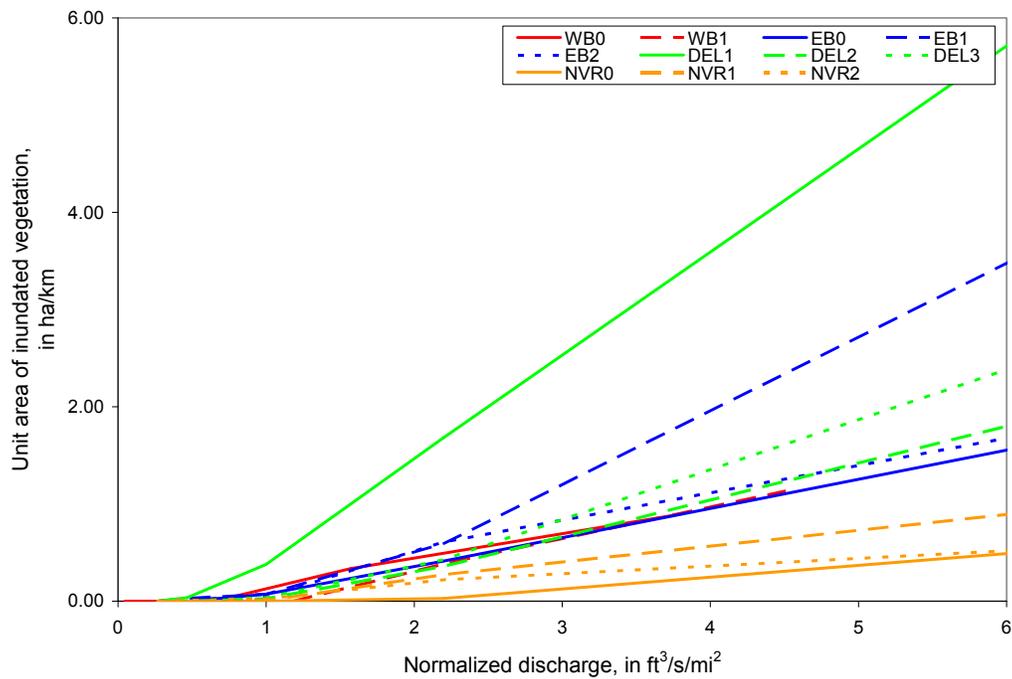


Figure 28. Normalized discharge versus unit areas of inundated vegetation.

The most dynamic mesohabitat types were side arms (fig. 29), backwaters (fig. 30), and disconnected areas (fig. 32). The variability in the areas of these three mesohabitat types occurred,

at least in part, because they would change from one type to another depending on the discharge. An area might be disconnected at a very low flow, become connected as a backwater at an intermediate flow, and connected from top and bottom (thereby becoming a side arm) at higher flows. Generally speaking, side arms tended to be most consistent in stream reaches containing large, highly dissected, and relatively high-elevation islands (for example, DEL3, WB1, EB0, EB1, and the Neversink sites), and most variable where the side channels were around midchannel, low-elevation bars (for example, DEL1, WB0, EB2). A complicating factor was that not all sections of divided channel were classified as side arms. According to our definitions, bisected channels were not classified as side arms, even though they may have exhibited some of the same properties.

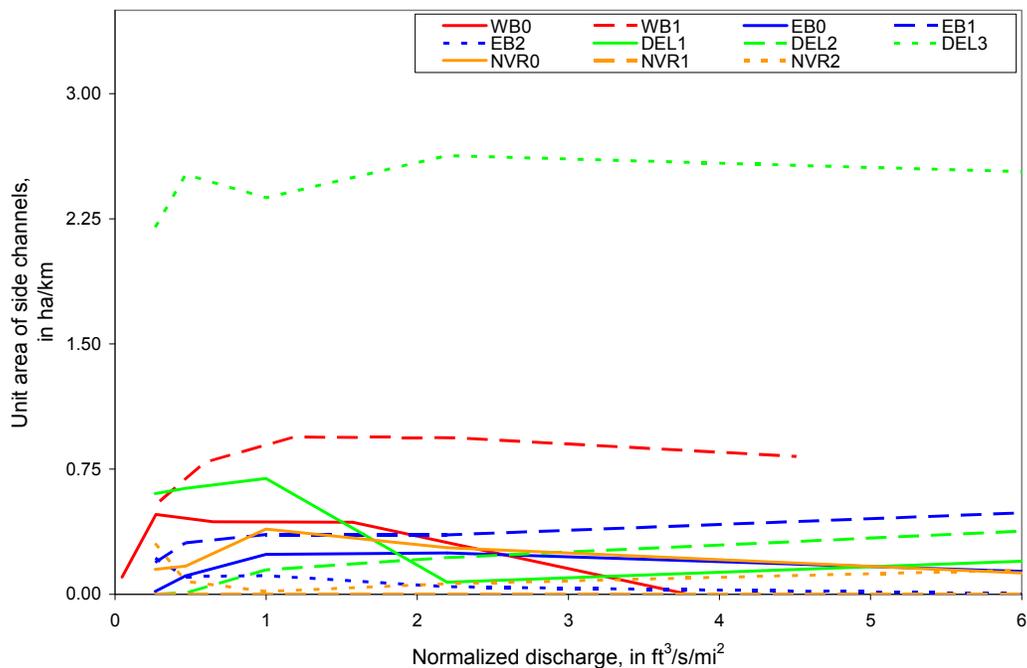


Figure 29. Normalized discharge versus unit areas of side arm mesohabitat types.

As discharge decreases, inflow to a side arm may cease and the extant channel will become a backwater or a disconnected channel (fig. 30). Although neither mesohabitat type accounted for a large proportion of the surface area of any of the sites, some were impressive nonetheless. At the lowest classified discharges, very large backwaters formed at EB0, WB1, WB0, DEL1, and NVR0 (fig. 31). In each instance, the channel was divided by a very long island, with inflow to one of the divisions cut off at low flows. A similar process occurred at intermediate flows at DEL1 and DEL3, both in perched side arms that were disconnected from the main channel at low flows and connected at the inflow and outflow at high discharges.

Disconnected mesohabitats (fig. 32) occurred wherever there was a depression of sufficient depth that water could be stored by groundwater connection, but with no surface connection. Disconnected areas did not account for a significant proportion of mesohabitat area, although relatively large disconnects occurred at WB0 and at DEL2. In both of these locations, the outflows of long side arm channels were elevated sufficiently to isolate the channels at low discharges. At DEL2, the isolated channel persisted at lower flows, but the surface area was smaller owing to lower ground water levels.

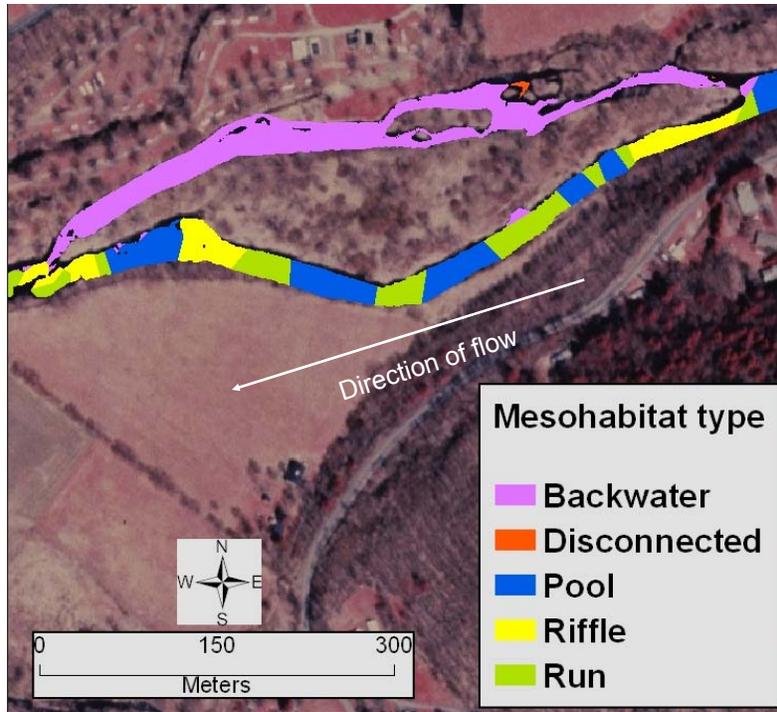


Figure 30. Backwaters and disconnected channels at 25 ft³/s (0.7 m³/s) in site EB0. Note the hydraulic connections or lack thereof at the outflow and the inflow in the north channel. At slightly higher discharges, the inflow is connected and the entire area is classified as a side arm.

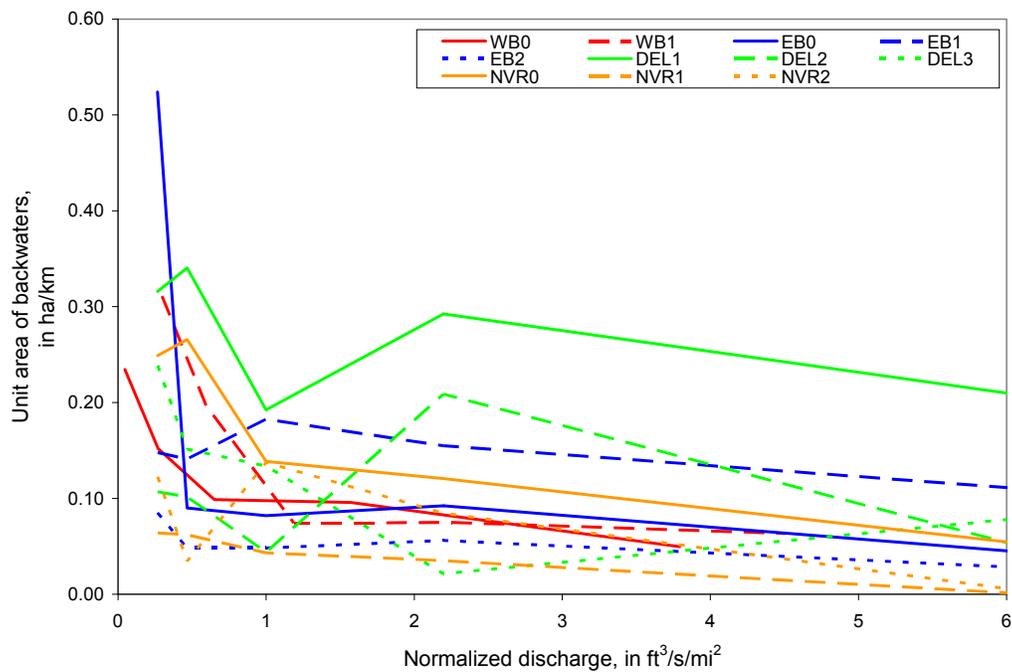


Figure 31. Normalized discharge versus unit areas of backwaters mesohabitat types.

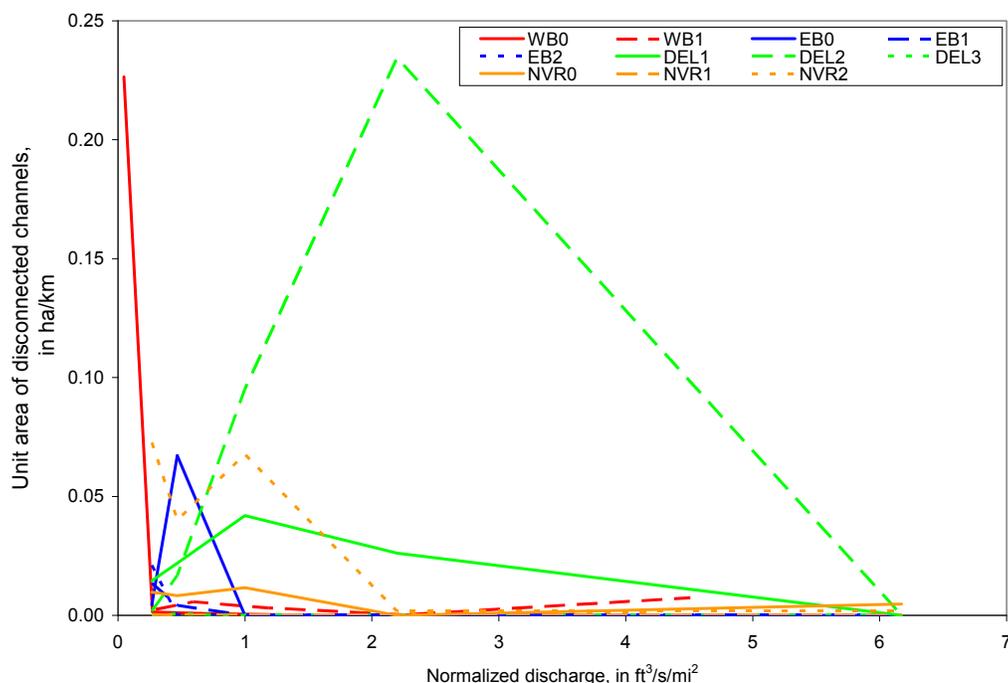


Figure 32. Normalized discharge versus unit areas of disconnected mesohabitat types.

Habitat Persistence

Habitat persistence was determined as the intersection of habitat patches for spawning and incubation and for dwarf wedgemussels for every combination of simulated discharges at each site. The exported and compiled persistence tables for both target organisms can be found in appendix 4.

Trout Spawning and Incubation

At most of the sites, maximum areas of persistent habitat appeared to be more influenced by the overlap of suitable incubation conditions than by the suitable spawning areas (figs. 33–43). This phenomenon was manifested by the maximum areas of the three-dimensional surfaces being elongated along the axes for spawning flows and narrowed along the incubation flow axis. The exception to this rule was at EB0 (fig. 36), which exhibited the opposite tendency. Here the maximum areas were associated with a fairly narrow range of spawning flows, but a relatively wide band of incubation flows.

At all sites, the axes of the maximum persistent area bands were essentially orthogonal, indicating a relatively independent relation between spawning and incubation flows in the optimal range. If the spawning and incubation flows were within their optimal ranges, it did not matter whether the incubation flows were higher or lower than the spawning flows. In contrast, all sites illustrated dependence among the smaller areas of persistent habitat, where the influences of the flow differential between spawning flows and the incubation flows were more evident. At higher spawning flows, more persistent habitat occurred if the incubation flows were also high. Likewise, persistent habitat associated with low spawning flows was more abundant if the incubation flows were also low.

We found distinct groupings of optimal flow ranges for spawning and incubation among the sites. In the West Branch, maximum persistent habitat occurred with spawning flows between approximately 0.8 and 3.8 ft³/s/mi² and incubation flows between 0.8 and 1.6 ft³/s/mi² (figs. 33 and 34). Regardless of discharge, however, WB1 contained a much larger area of spawning and incubation habitat than WB0, attributable primarily to the more extensive pool tail-outs that occurred at WB1. Overall, spawning and incubation habitat persistence at WB0 appeared to be somewhat more sensitive to incubation flows than at WB1, as indicated by the width of the polygons along the x (incubation) axis.

In the upper East Branch, maximum values of persistent spawning and incubation habitat occurred at much lower discharges than in the West Branch. At EB0, spawning flows between 0.4 and 1.0 ft³/s/mi² and incubation flows in the range of 0.2 to 4 ft³/s/mi² produced the maximum area of persistent habitat (fig. 35). At EB1, persistent habitat was maximized with spawning flows between 0.8 and 2.7 ft³/s/mi² and incubation flows between 0.5 and 0.8 ft³/s/mi² (fig. 36). Maximum habitat persistence at EB2 (fig. 37) was similar to the West Branch sites with respect to spawning flows (maximized between 0.8 and 2.7 ft³/s/mi²), but more like the other East Branch sites with respect to incubation flows (maximized between 0.8 and 0.9 ft³/s/mi²).

The habitat versus discharge response surfaces for the main-stem Delaware sites were similar to those of the West Branch and lower East Branch. DEL1 (fig. 38) exhibited the widest range of optimal spawning flows of any of the sites (0.3 to 6.2 ft³/s/mi²), but was constrained by a relatively narrow range of optimal incubation flows (0.5 to 0.9 ft³/s/mi²). Unlike most of the other sites, persistent habitat areas were not skewed at the upper and lower ranges of spawning and incubation discharges. Maximum areas of persistent habitat at DEL2 and DEL 3 (figs. 39 and 40) occurred over flow ranges more typical of the West Branch and exhibited the high-low flow skew observed at other sites. At DEL2, the largest areas of persistent habitat occurred with spawning flows in the range of 0.7 to 2.5 ft³/s/mi² and incubation flows of 0.7 to 1.0 ft³/s/mi².

Smaller areas of persistent habitat were highly skewed at DEL2, indicating that spawning and incubation at this site were relatively sensitive to flow differential. DEL3 provided the largest maximum area of persistent spawning and incubation habitat of all the sites (fig. 40). Maximum persistent habitat for this site occurred with a range of spawning flows from 0.8 to 3.5 ft³/s/mi² and incubation flows from 0.7 to 1.0 ft³/s/mi².

The maximum areas of persistent spawning and incubation habitat in the Neversink River occurred at higher ranges of normalized discharges than in any of the other rivers studied. Maximum persistent habitat at site NVR0 occurred with a range of spawning flows from 1.2 to 3.6 ft³/s/mi² and incubation flows from 1.5 to 1.7 ft³/s/mi² (fig. 41). Peak areas of persistent habitat at NVR1 occurred with spawning flows between 0.7 and 5 ft³/s/mi² and incubation flows ranging from 1.4 to 1.8 ft³/s/mi² (fig. 42). Both sites showed relatively little skew in persistent habitat areas at the high and low extremes of discharge, indicating somewhat lower sensitivity to flow differential than other sites. Persistent habitat at site NVR2 was maximized with spawning flows between about 1 and 3 ft³/s/mi² and incubation flows of 1 to 1.5 ft³/s/mi² (fig. 43). The differences in the response surfaces for the Neversink compared with those of the other sites may be an artifact of stream order and size. All the Neversink sites had considerably smaller drainage areas (our discharge normalizing term) than the other sites, and the overall slopes were greater by 50 to 300 percent (except at NVR1, which was comparable to EB0). Consequently, the Neversink may have resembled more of a headwater stream than the others we studied.

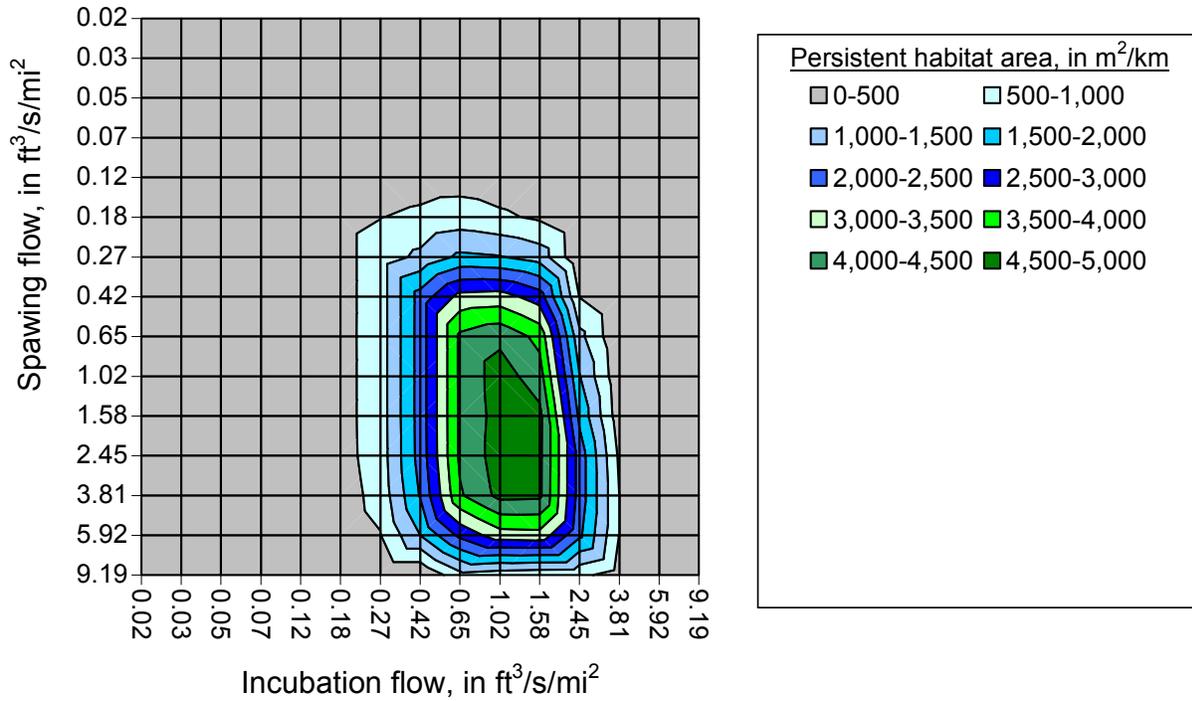


Figure 33. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site WB0.

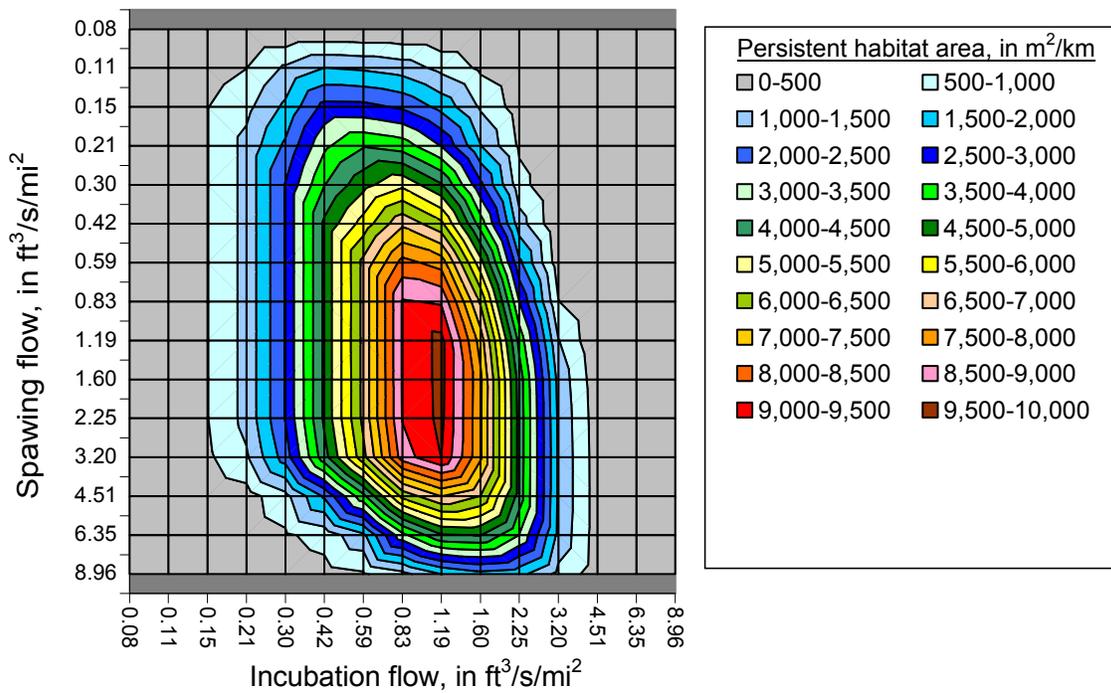


Figure 34. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site WB1.

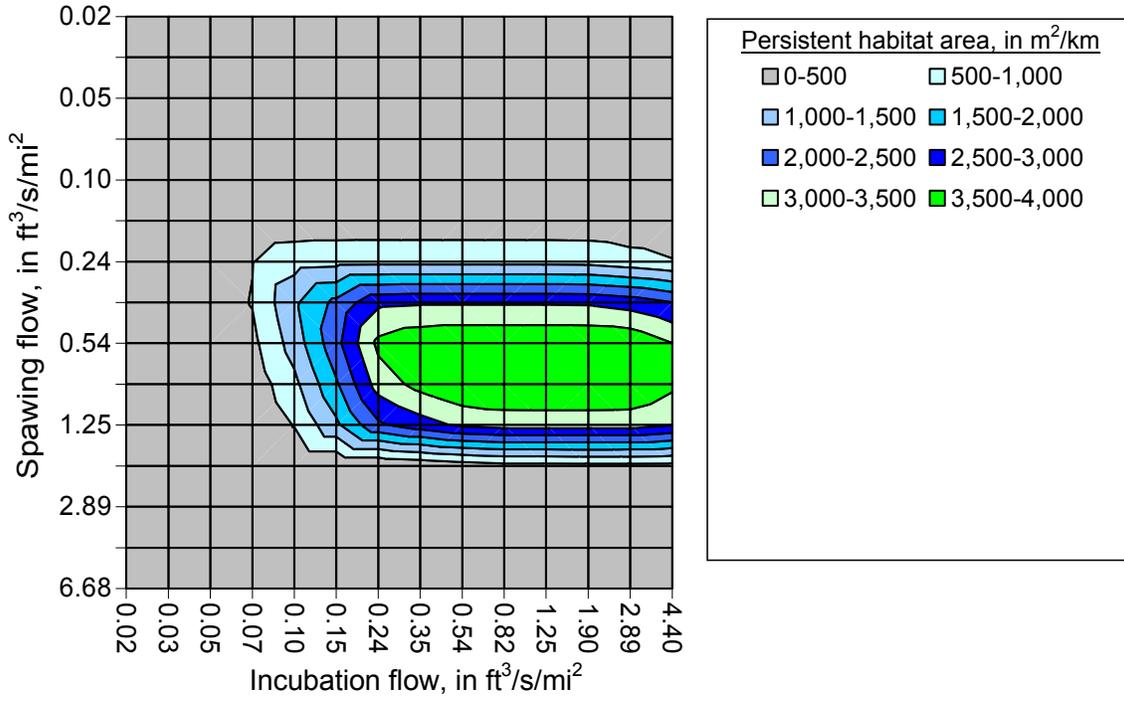


Figure 35. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB0.

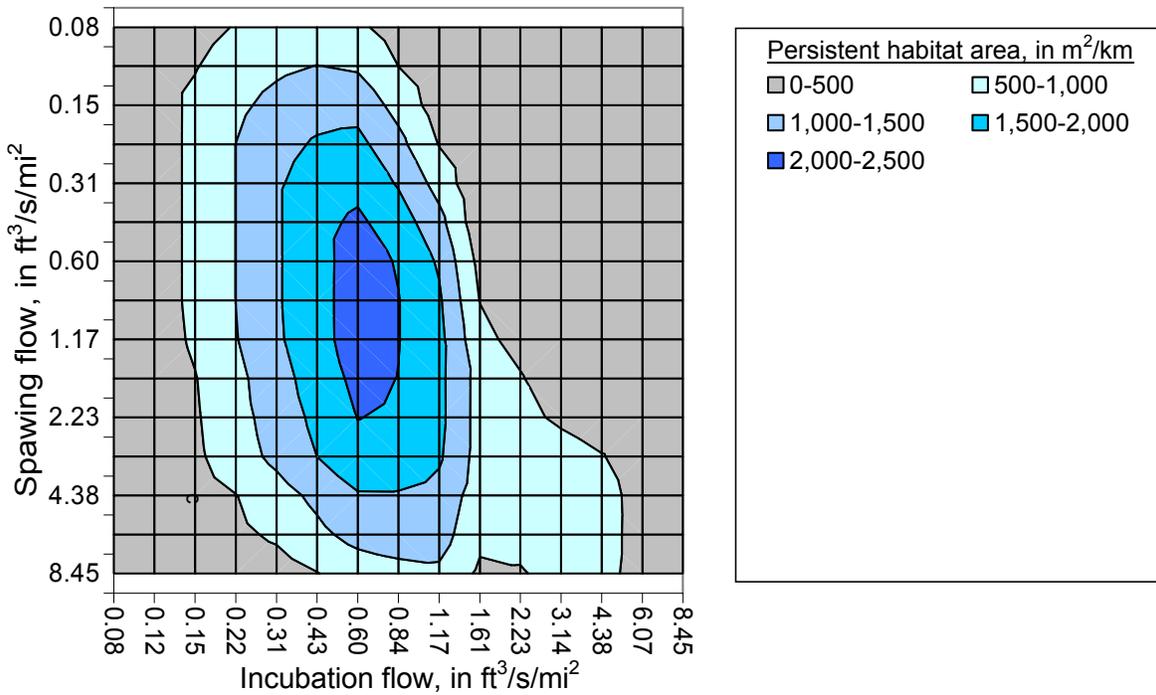


Figure 36. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB1.

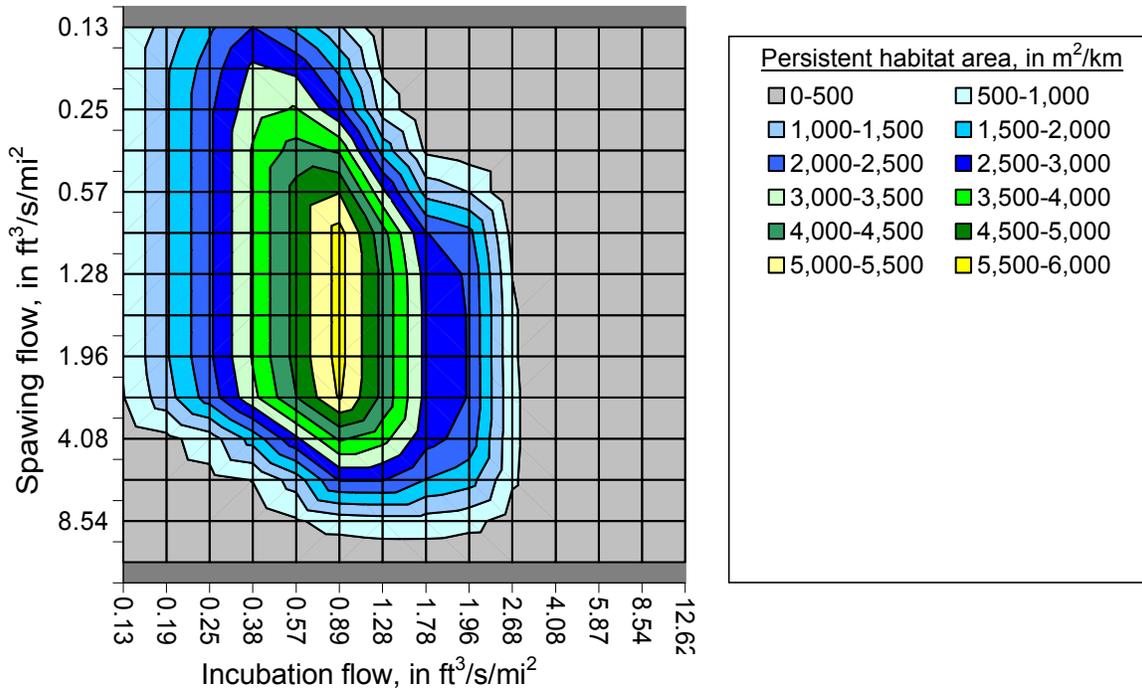


Figure 37. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB2.

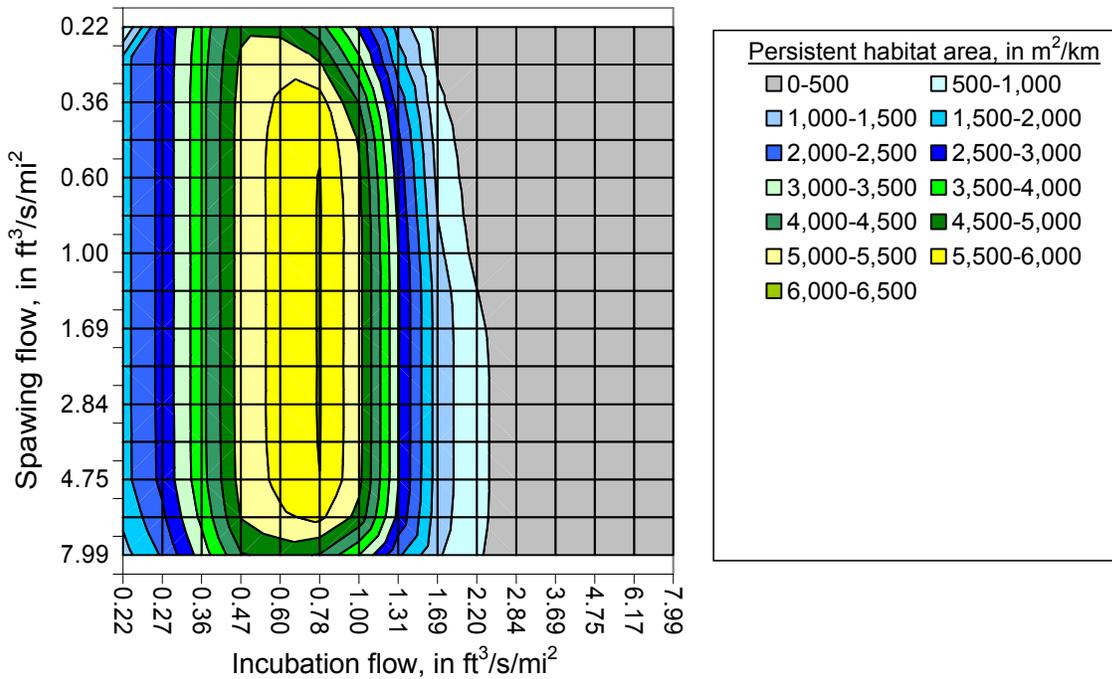


Figure 38. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL1.

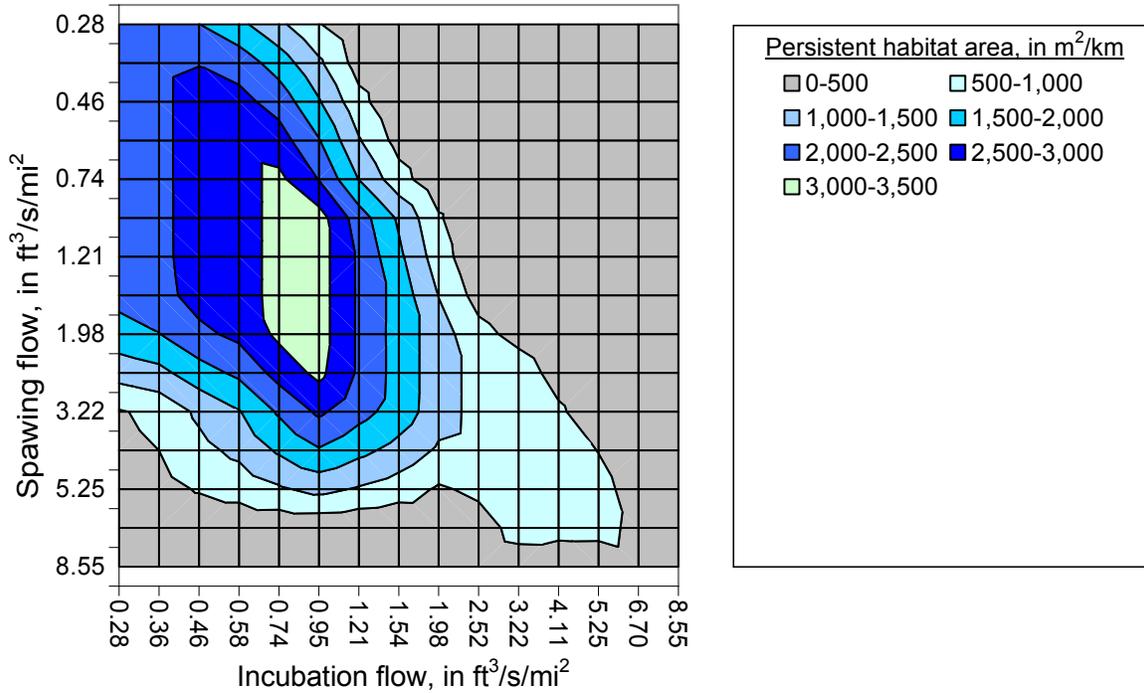


Figure 39. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL2.

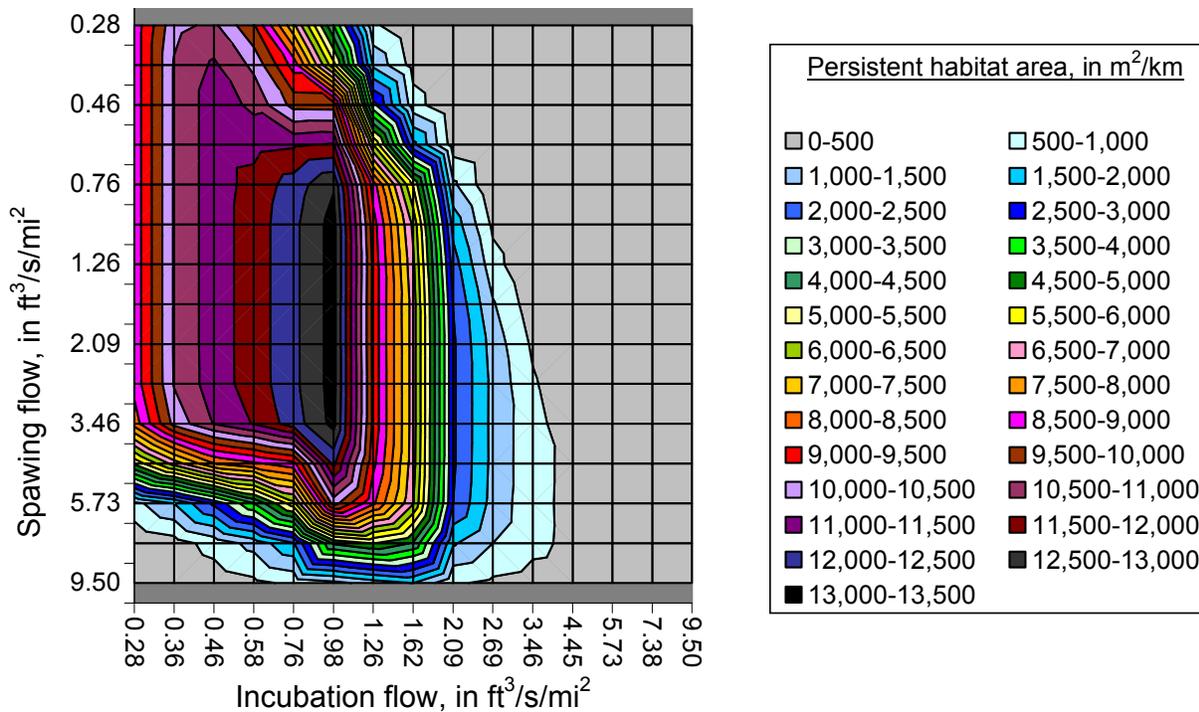


Figure 40. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL3.

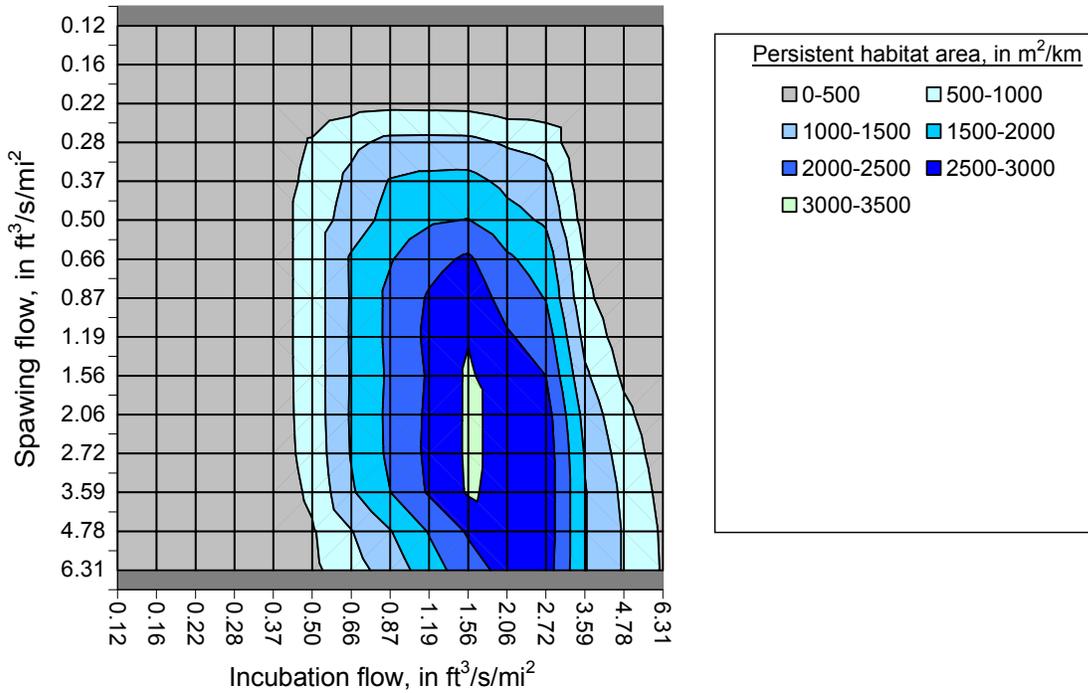


Figure 41. Normalized discharge versus unit area of persistent (*Salmo trutta*) trout spawning-incubation habitat at site NVR0.

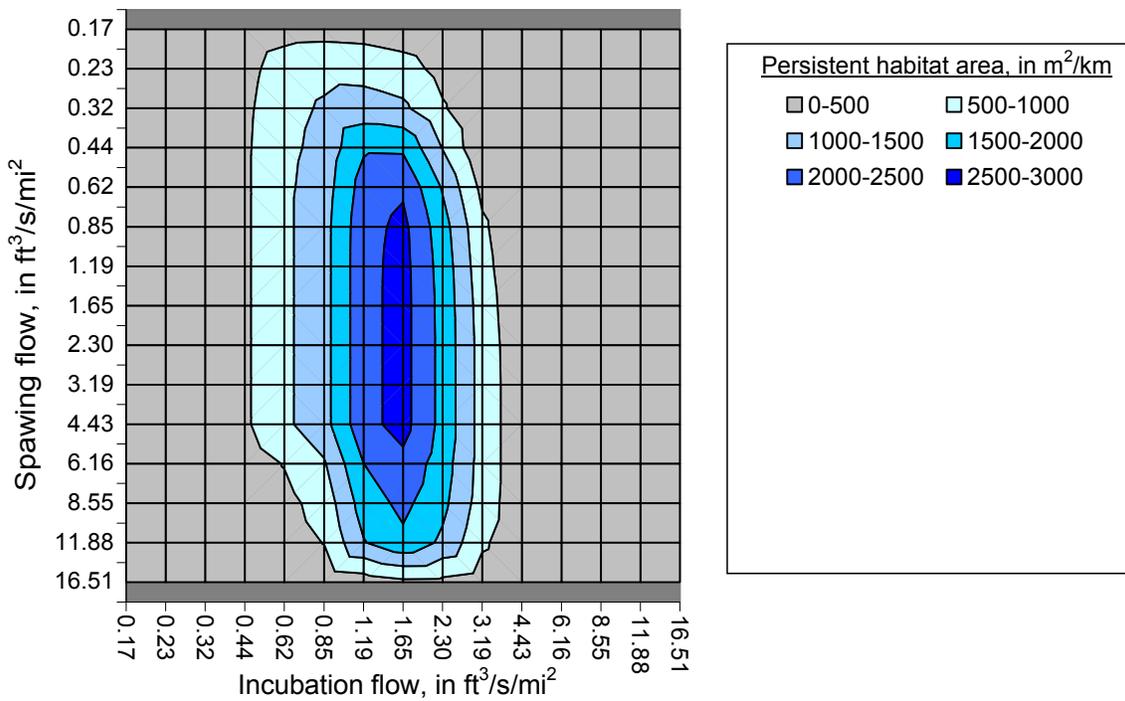


Figure 42. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site NVR1.

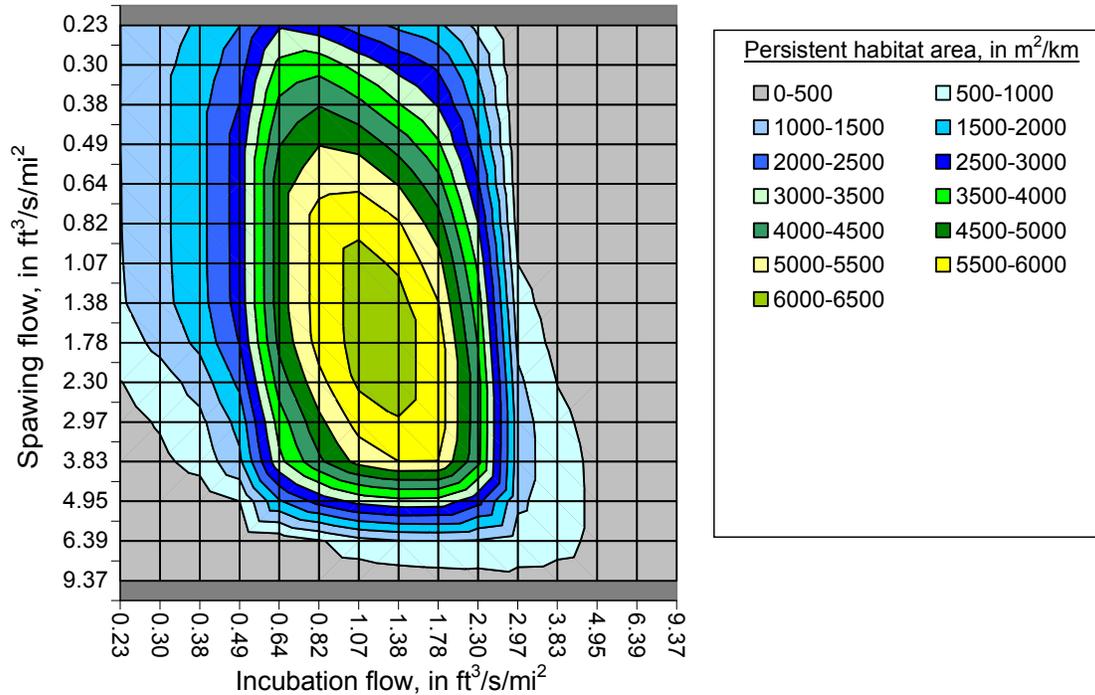


Figure 43. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site NVR2.

Dwarf Wedgemussel

The analysis of persistence in dwarf wedgemussel habitat differed from that of trout spawning and incubation in one significant aspect. Two different sets of habitat suitability criteria were used to define the polygons intersected in the spawning-incubation maps, whereas the same criteria were evaluated at combinations of paired discharges for dwarf wedgemussels. In the spawning-incubation case, the habitat polygons were independent spatially, but order-dependent. For dwarf wedgemussels, the opposite was true. Consequently, the three-dimensional habitat response surfaces (figs. 44, 45, and 46) for the dwarf wedgemussel were highly skewed along a diagonal between pairs of discharges. This bias occurred because the largest area of persistent habitat for any pair of discharges occurs when they are the same. As the two discharge pairs deviate from one another, the area of persistent habitat always decreases. In this sense, habitat persistence for the dwarf wedgemussel (as we described it) was more sensitive to flow differential than it was for spawning and incubation. The second obvious characteristic of the habitat response surfaces for dwarf wedgemussels is that they were highly symmetrical (kaleidoscopic), compared to the more amorphous surfaces for spawning and incubation. This phenomenon was an artifact of comparing pairs of discharge for the same target organism in an order-independent fashion. That is, a flow combination of 100 ft³/s and 1,000 ft³/s produced the same amount of persistent mussel habitat as a combination of 1,000 ft³/s and 100 ft³/s. This was decidedly not the case for spawning and incubation.

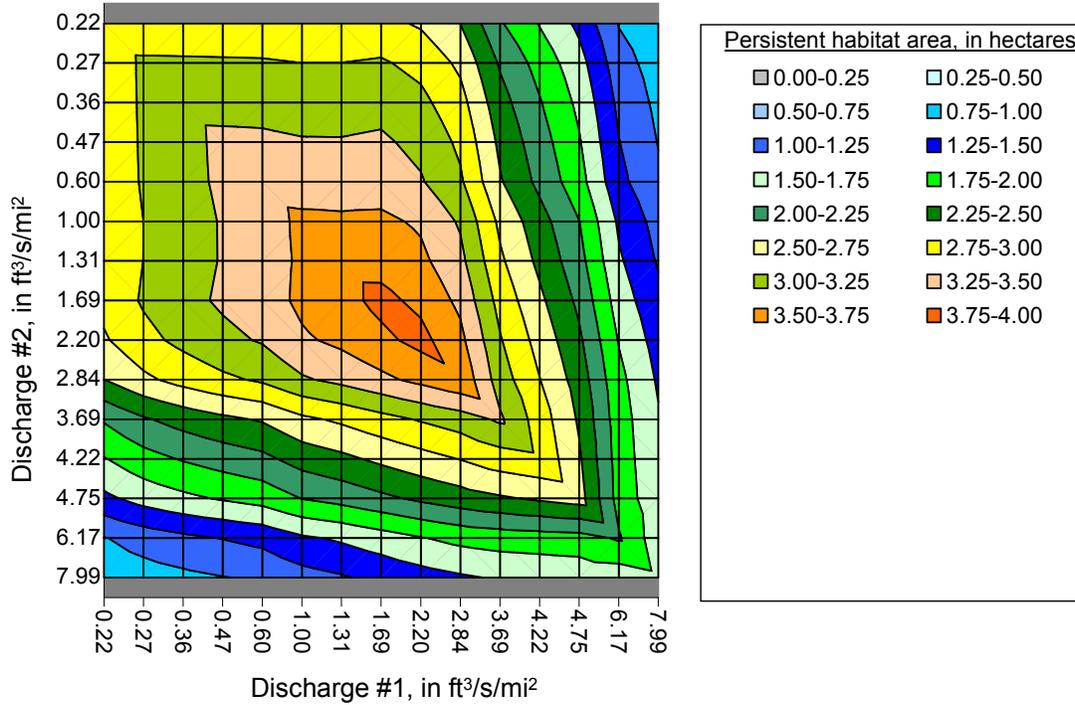


Figure 44. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL1.

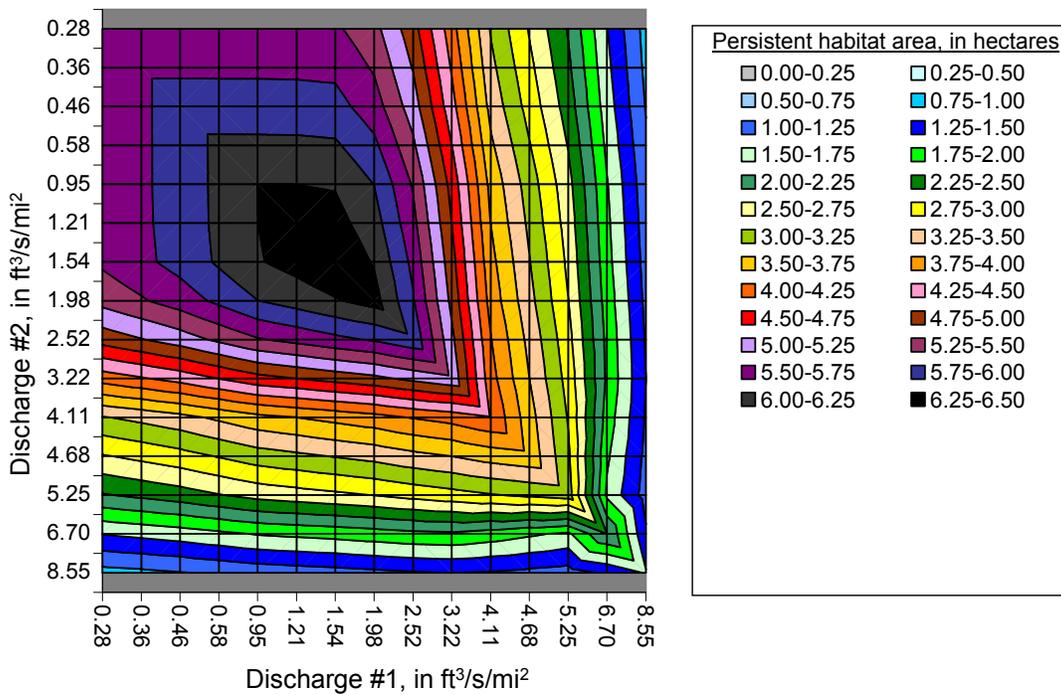


Figure 45. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL2.

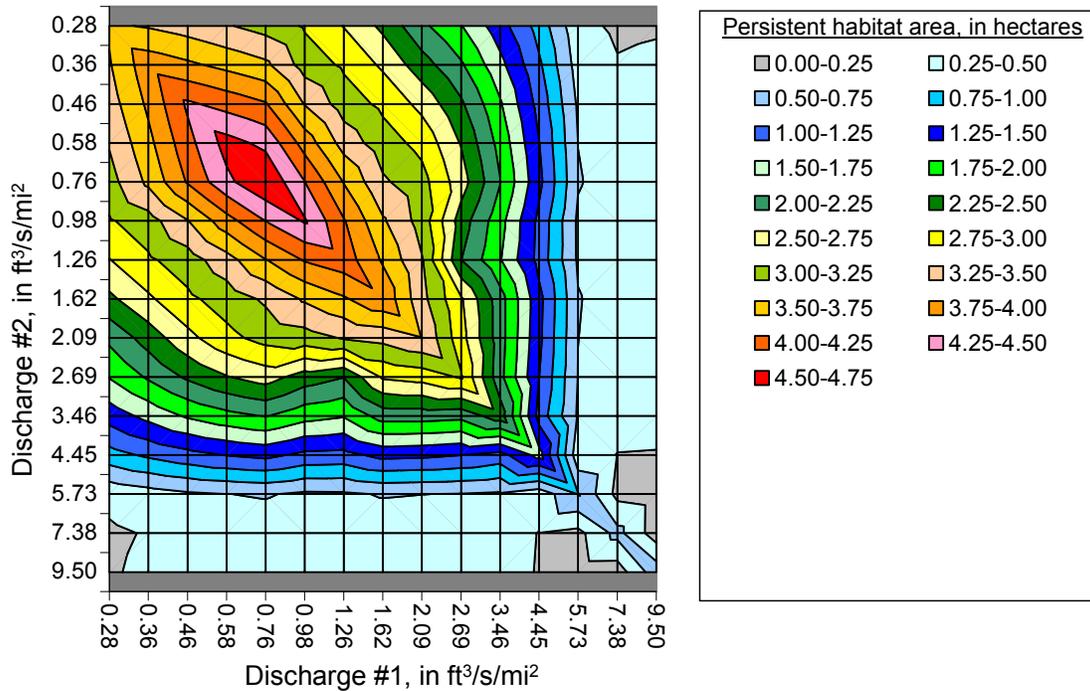


Figure 46. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL3.

The habitat response surfaces were also highly influenced by the characteristics of the mussel beds observed by Dr. Lellis and his colleagues during the 2002 survey. We did not normalize habitat areas for dwarf wedgemussels, so each response surface and persistence table reflects a site-specific total area. Because the mussel beds at DEL2 were much larger than those at the other two main-stem sites, the maximum area of the response surface for that site (fig. 45) was also considerably larger. The response to discharge for DEL1 and DEL 2 were quite similar, with the maximum area occurring at discharges in the range of about 0.9 to 2.5 ft³/s/mi² (figs. 44 and 45). In contrast to the upper two main-stem sites, persistent habitat at DEL3 was optimized at discharges between 0.5 and 1 ft³/s/mi² (fig. 46).

A review of the characteristics of the mussel beds at DEL1 and DEL2 revealed a high degree of hydraulic and spatial similarity. Mussels were primarily found near the south shoreline in low velocity (but not stagnant) shallow pools, typically less than 1 m deep (figs. 47 and 48). The observed locations of the mussels at DEL3 may have affected the lower range of optimal flows for its habitat response surface. Whereas mussels at the upper sites were observed in shallow, slow pools, a number of mussels at the DEL3 site were found along the margins of a fairly steep riffle (fig. 49). The distribution of mussels at DEL3 influenced our delineation of the mussel bed in the original mapping exercise. The optimal flow range for this site may be lower because a large portion of the mussel bed was included in the riffle. Consequently, shear stresses likely became limiting at higher flows, thereby reducing the utility of the area as habitat for mussels. It is probably not too surprising that after a flood event in 2005, mussels were found in about the same locations at the two upper sites, but were not found at DEL3 (William Lellis, USGS, oral commun., April 2006).

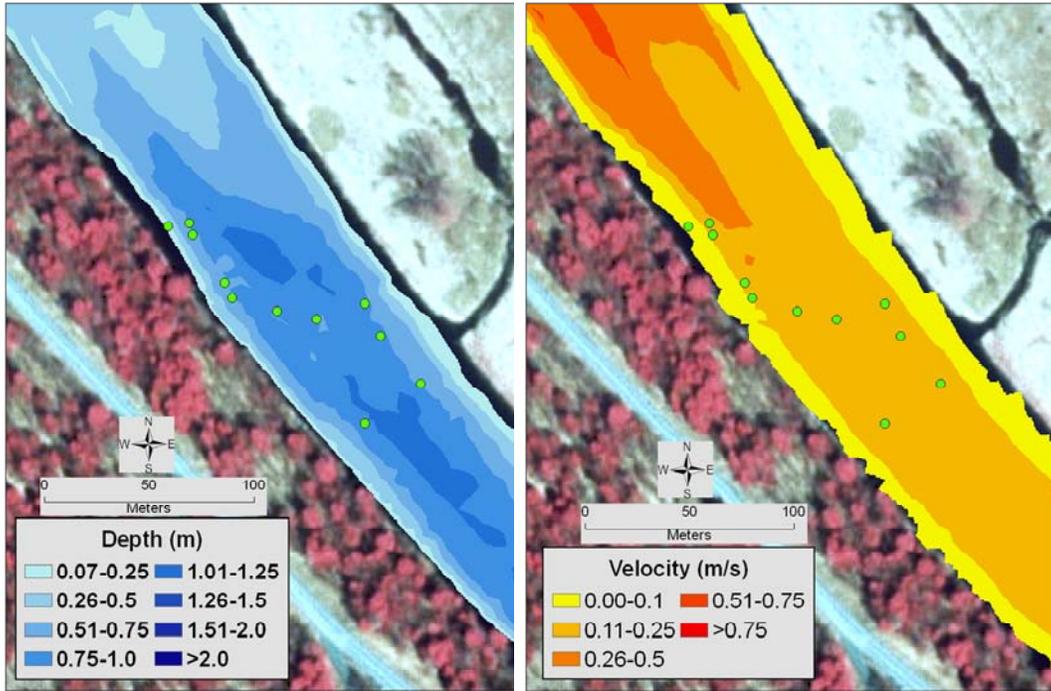


Figure 47. Depth and velocity distributions at DEL1 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

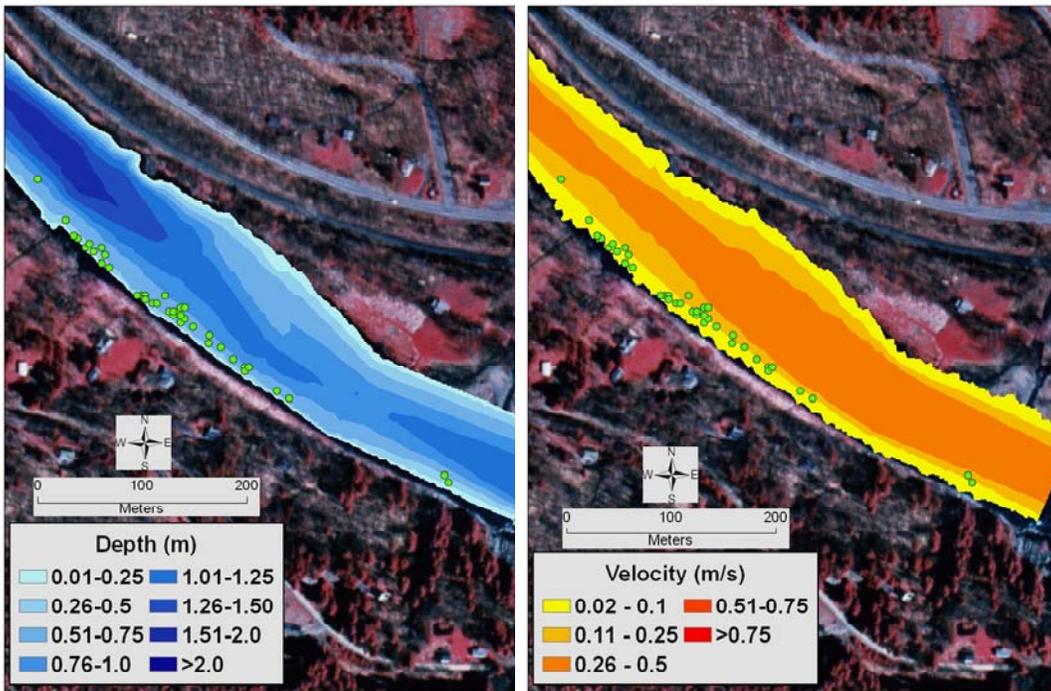


Figure 48. Depth and velocity distributions at DEL2 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

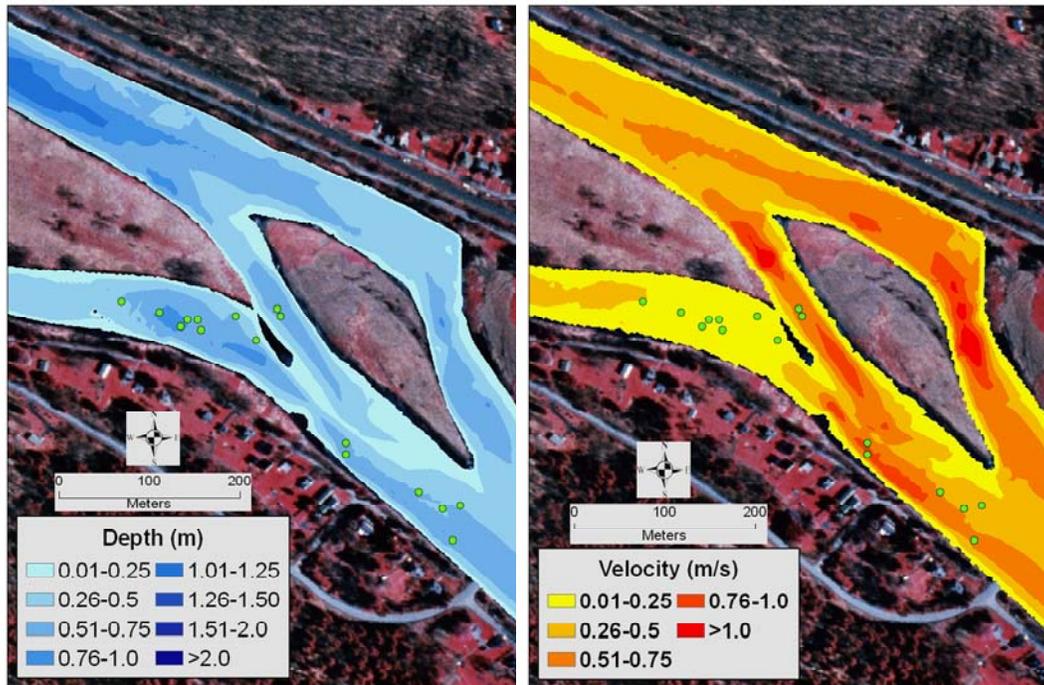


Figure 49. Depth and velocity distributions at DEL3 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

DRDSS Demonstration Run

To illustrate the operation and interpretation of Version 2.11 of the DRDSS, we performed an analysis of two alternative operating plans developed through the Commission and sanctioned by the Decree parties, known as Revision 1 and Revision 7. For this demonstration, we used the OASIS output for Revision 1 to serve as the baseline condition.

The intent of Revision 7 was to increase the lowest discharges that had occurred under Revision 1 to provide more habitat area during the (presumed) most limiting flow events in each hydroperiod. This objective was achieved in OASIS by withholding releases from the reservoirs during periods of relatively higher inflows, and releasing additional water when needed to meet downstream flow targets. Figure 50 shows flow duration curves for the two West Branch sites during hydroperiod 1 to illustrate the general changes in streamflow that resulted from the imposition of the Revision 7 rules for the water years 1990–2000. The basic pattern of change was to reduce flows in the intermediate range and increase the magnitudes of the lowest flows, as indicated by the differences between the solid and dashed lines on figure 50. Similar changes occurred in the other rivers and hydroperiods, with some subtle differences. Figure 51 shows the changes in storage volume at the three reservoirs that resulted from Revision 7. Essentially, storage was kept the same or somewhat higher under Revision 7, which may have provided the buffer needed for higher releases during low flow periods.

For this demonstration run, we used the “normal” meteorological data set and left all the adjustable scoring thresholds at their default values, except for the temperature threshold for the main stem Delaware, which was set to 25°C. Summary results for the run are shown in figure 52.

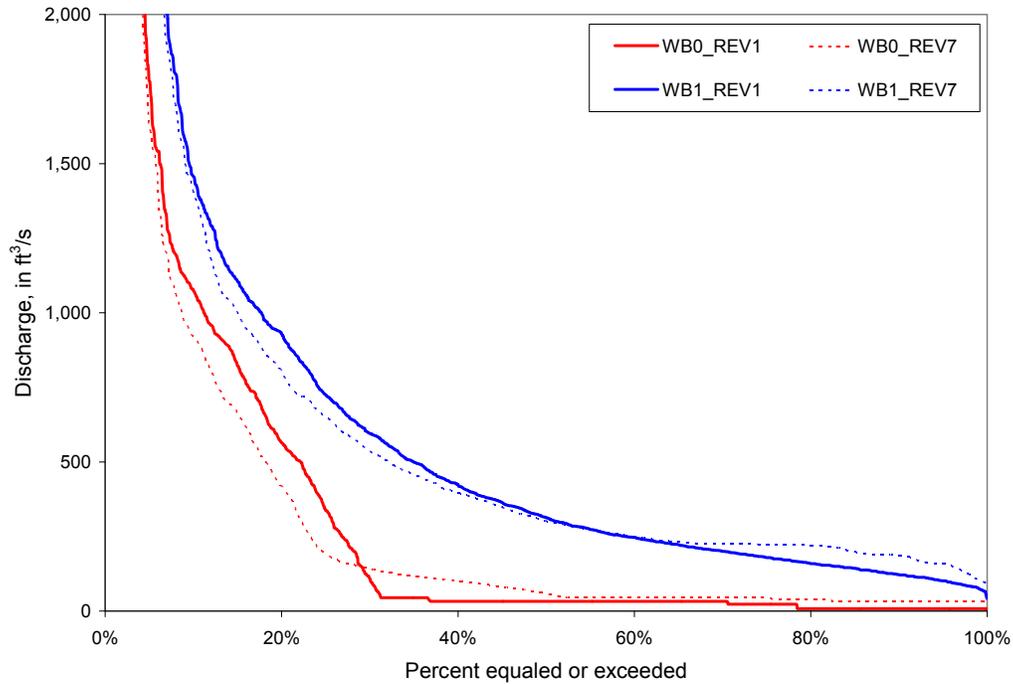


Figure 50. Flow duration curves for sites WB0 and WB1 on the West Branch, for hydroperiod 1 (October–April) from water years 1990–2000, under the operating rules for Revision 1 and Revision 7.

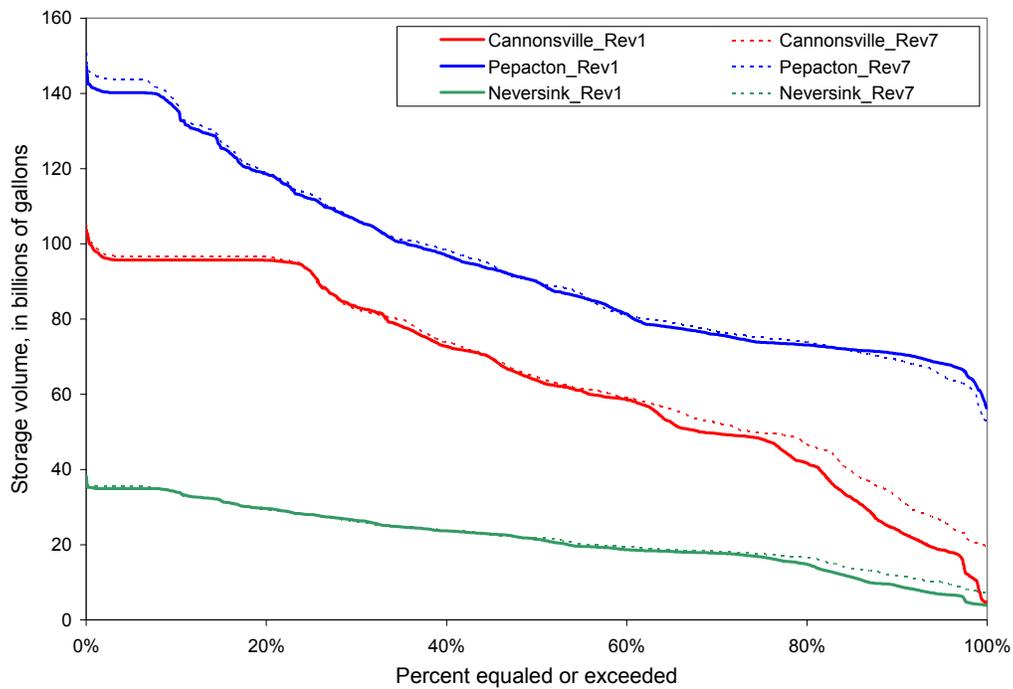


Figure 51. Storage duration curves for the three New York City reservoirs, for hydroperiod 1 (October–April) from water years 1990–2000, under the operating rules for Revision 1 and Revision 7.

October - April 15												
West Branch				East Branch				Main Hancock-Callicoon				Neversink
Resource	Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab	
Trout Adult, ha	21%	13.50		8%	12.31		2%	7.80				
Trout Spawning/Incu, ha	91%	2.39		3%	0.10		1%	0.06				
SSCV, ha	8%	1.11		-9%	-2.54		0%	0.04				
SFCV, ha	52%	2.44		41%	1.04		1%	0.02				
Shad Juvenile, ha												
Shad Spawning, ha												
Dwarf Wedge Mussel, ha							3%	0.08				
Spills, minor, count	-6%	-1.00		14%	1.00							
Spills, moderate, count	13%	2.00		15%	2.00							
Spills, major, count	-13%	-2.00		-14%	-4.00							

April 16 - June												
West Branch				East Branch				Main Hancock-Callicoon				Neversink
Resource	Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab	
Trout Adult, ha	16%	11.47		4%	6.77		1%	3.25		1%	2.50	
Trout Spawning/Incu, ha												
SSCV, ha	2%	0.24		-4%	-0.84		-3%	-0.77		0%	0.00	
SFCV, ha	11%	0.40		8%	0.24		8%	0.24		0%	0.01	
Shad Juvenile, ha												
Shad Spawning, ha				16%	5.50		16%	5.50		5%	6.50	
Dwarf Wedge Mussel, ha										4%	6.10	
Spills, minor, count	0%	0.00		14%	1.00					0%	-0.02	
Spills, moderate, count	0%	0.00		-21%	-8.00							
Spills, major, count	0%	0.00		-5%	-2.00							

July - September												
West Branch				East Branch				Main Hancock-Callicoon				Neversink
Resource	Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab		Pct Chg	Δ Hab	
Trout Adult, ha	-2%	-1.45		16%	23.40		16%	22.86		-1%	-2.52	
Trout Spawning/Incu, ha										-2%	-7.48	
SSCV, ha	22%	3.06		22%	3.06		-10%	-3.29		-10%	0.80	
SFCV, ha	85%	5.19		85%	5.19		-4%	-0.72		-4%	-0.71	
Shad Juvenile, ha							9%	7.48		9%	7.48	
Shad Spawning, ha										1%	1.59	
Dwarf Wedge Mussel, ha										1%	1.59	
Spills, minor, count	0%	Base, Alt =0		0%	Base, Alt =0							
Spills, moderate, count	0%	0.00		0%	0.00							
Spills, major, count	0%	Base, Alt =0		0%	0.00							

Full Period Scores												
West Branch				East Branch				Main Hancock-Callicoon				Neversink
Δ Days > Threshold C	Pct Chg	Δ Days		Pct Chg	Δ Days		Pct Chg	Δ Days		Pct Chg	Δ Days	
	0%	0.00		-2%	-0.14		0%	0.00		-1%	-0.13	
										150%	6.00	
										399%	4.97	

Global Scores						
Montague Flow	Pct Chg	Δ Days		Out of System Deliveries	Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00		NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00		NYC, moderate shortage	0%	Base, Alt =0
Montague, major shortage	0%	Base, Alt =0		NYC, major shortage	0%	Base, Alt =0
Montague, cfs-days	-24%	-12464.00		New York City, bg	0%	Base, Alt =0
System Drought	Pct Chg	Δ Days				
Days at Level 1	-22%	-92.00		NJ, minor shortage	0%	0.00
Days at Level 2	39%	89.00		NJ, moderate shortage	0%	Base, Alt =0
Days at Level 3	0%	Base, Alt =0		NJ, major shortage	0%	Base, Alt =0
System Storage, bg	0%	-2358.70		New Jersey, bg	0%	Base, Alt =0

Run Settings			
Maximum Water Temperature (degrees C)	West Branch	20	New York Diversion Magnitude (% minimum delivery)
	East Branch	20	
	Main Stem	25	
	Neversink	20	New York Diversion Magnitude (% minimum delivery)
Spill Magnitude (% outflow capacity)	Mild, <	10	
	Major, >	50	Meteorological Series
Montague Shortage Magnitude (% minimum flow)	Mild, <	10	
	Major, >	50	

Figure 52. Summary scores page for DRDSS demonstration run comparing Revision 1 and Revision 7 alternatives.

Based on the information summarized in figure 52, one could conclude that for most of the decision variables considered, Revision 7 resulted in improved or unchanged conditions compared to Revision 1, at least for the decade of the 1990's. The incidence of minor-to-moderate spill events from Cannonsville Reservoir increased during hydroperiod 1, from Pepacton Reservoir during hydroperiods 1 and 2, and from Neversink Reservoir during hydroperiod 3. Water deliveries to Montague, New York City, and the D&R diversion appeared to have improved or remained the same under Revision 7 operations. The only biologically-oriented warning flag occurred in the main stem Delaware, where the temperature threshold of 25°C was exceeded on six more days under Revision 7 than under Revision 1.

Discussion

One of the most important characteristics of the DRDSS is its feedback mechanism. The primary driver of the DRDSS is the OASIS model, the output of which serves as input to a network of linked habitat and temperature models. This characteristic results in a cascading effect among the decision variables. For example, a simple change to the rule curves for one reservoir in an OASIS run can propagate throughout the hydrologic network, influencing the operations of other

reservoirs, the magnitude and timing of stream discharges, the habitat dynamics of the receiving streams, and summer water temperatures. Feedback can be highly informative because it can reveal unanticipated consequences from a proposed action. Feedback can also be frustrating for the same reason, sometimes tempting decisionmakers to assume that something was wrong with the models, rather than examining their own paradigms and assumptions. From a pragmatic viewpoint, decisionmaking based on model output should consist of at least two separate processes: interpretation and evaluation. Interpretation refers to understanding the cause and effect relations between an input scenario and the results displayed in the decision support system. Evaluation refers to judging the relative degrees of success or failure to meet the multiple objectives of a scenario. Interpretation is necessary to determine why a certain outcome was produced. Evaluation is necessary to determine whether one alternative is substantially “better” than another. Both processes should include an understanding and acknowledgement of limitations of the models (including OASIS), as well as any preconceived notions of what the model results should have been.

Interpretation of Results

In the DRDSS, instream habitat is defined by the interactions among discharge, gradient, channel structure, and the physical requirements of the aquatic organisms. With a few exceptions, a typical response function between discharge and habitat area appears as a skewed bell-shaped curve, or in the case of persistent habitat, as a dome-shaped surface. The common characteristic of these functions is that habitat area tends to increase as discharge increases in the low-to-moderate flow range, but then decreases as discharge continues to increase. Where channel structure and gradient are similar, the peak of the habitat-discharge curve would be expected to occur at or near the same relative (normalized) discharge, although the magnitude of habitat area will vary as a function of channel width and concomitant surface area, as illustrated in figures 18–23.

In contrast, shallow-slow habitat types in streams dominated by single-thread channels (see appendix 1) generally exhibit a monotonic decline as discharge increases. Shallow-fast habitat types respond to flow in a similar fashion, but to a lesser degree (for example, figs. 18 and 19). This response is caused by increased depth and velocity as discharge increases, resulting in less area of shallow water (affecting habitat for both guilds) and slow water (affecting habitat for the shallow-slow guild). However, another characteristic of these habitat types is a leveling-off or increase in habitat area at very high flows, where new areas of shallow water are created as islands and floodplain areas are inundated. A comparison of figures 18 and 19 with figures 20–23 illustrates the fundamental conflict between shallow water habitats and the deeper habitats utilized by adult or juvenile fish. Flows that result in increased habitat for one group tend to reduce habitat for the other group.

Another common “within-resource” conflict occurs between shallow-slow habitat area and stream water temperature. Increasing flows to achieve lower temperatures will often result in a reduction in shallow-slow habitat areas. Conversely, attempts to mitigate habitat reductions associated with high flows may have the unintended consequence of elevated water temperatures, especially at downstream locations during late spring and summer.

A scenario designed to increase the magnitude of low flows is usually presumed to result in an overall increase in habitat area. When the results displayed in the DRDSS show no change or a negative change, one or two causal factors are often to blame. One common mechanism is reservoir depletion resulting from excessive releases to augment instream flows for habitat improvement. In this case, habitat area may be substantially increased during part of a hydroperiod, but decreased later in the season as reservoir storage is exhausted. The most immediate confirmation that this

phenomenon has happened is a review of the flow and storage time series plots on the “FlowPlots” page of the DSS_AGG.xls master workbook. Symptoms of the mechanism are also expressed on the summary scoring page by an increase in the frequency of drought watches and warnings associated with the scenario. Review of the habitat duration series in the subsidiary notebooks can also be used to determine the day-to-day response of habitat to a scenario. It is worthwhile to review these graphics routinely, because they may show a counterbalancing increase and decrease in habitat area throughout the hydroperiod despite little or no change to the average for the period. Then, the decisionmakers must evaluate the outcome to determine whether the change was positive, negative, or neutral.

The second common mechanism for a counterintuitive result (reduced habitat area associated with increased base flows) is that the scenario may have resulted in an increased frequency of high flow events. An increase in the frequency of spills displayed on the summary scoring page is symptomatic of this feedback mechanism. To help identify potential feedback surprises, it is advisable to generate flow duration and storage duration curves (for example, figs. 50 and 51) as routine input to the decision process. This simple step will provide early indications whether the scenario performed hydrologically as it was intended, or whether the scenario created unforeseen consequences.

Evaluation of Results

Public decisions are rarely made unilaterally. Those that are tend to be either inconsequential or short-lived. Nor are decisions made with complete and perfect information. Decisionmaking can be complicated by agency policies, values, assumptions, and paradigms that transcend the relatively simple processes of data interpretation and quantification. Not all the members of the Decree parties, the Commission, and the Subcommittee likely share a universal set of values, goals, and objectives related to the upper Delaware. One of the reasons for inclusion of global variables such as water deliveries to New York City, Montague, and the D&R Canal was to display the consequences of a management action to both water users and habitat resources. Developing shared ownership in the values and objectives of all parties is a worthwhile goal, and the DRDSS may facilitate progress toward that goal.

A frequent complaint of groups involved in multiple-use resource management is that there is insufficient (or irrelevant) information on which to base a decision. Through our interactions with the major stakeholders on the upper Delaware, we have attempted to provide accurate, realistic, and relevant information by way of the DRDSS. In contrast to the complaint of insufficient information, the DRDSS may produce too much information, in too many places, for easy comprehension. The structure of the system was designed to provide a broad overview for the “big picture” decisionmaker, with increasingly detailed information available for diagnostics and interpretation. The advantage of the summary scores page is that it provides a compact synopsis of the results of a scenario run. The disadvantage is that the synopsis can mask undesirable results (or causes) that can only be detected by examination of the duration series plots and duration curves. Therefore, the summary scoring page alone can be misleading.

Evaluation of alternatives also involves trade-offs, both between and among resources. It would be nearly impossible to derive an alternative that caused every cell on the summary page to turn green. Many of the values embodied by the scoring variables of the DRDSS work at cross purposes, which is a true reflection of the environment in which many water management decisions are made. In this sense, the DRDSS provides a modicum of realism with regard to the decision environment. Several techniques can be used to ameliorate some of these inevitable conflicts: establishing context, using adaptable management objectives, and developing contingencies.

Establishing Context

Loosely translated, establishing context means that a red cell on the summary scoring page is not necessarily a bad thing, and in fact, may be a positive outcome depending on one's perspective. For example, the summary scoring sheet for the Revision 1 and Revision 7 comparison (fig. 52) indicated an increase in temperature threshold violations in the main stem Delaware sites under Revision 7. In order to evaluate the biological ramifications of this temperature increase, the context of the change both in terms of magnitude and time scale should be examined. The average magnitude of the temperature change can be determined by dividing the degree-day sum in column M of the scoring summary by the days in column K (in this case, 4.97 °C-days /6 days = 0.83°C). Although the average threshold violation will not distinguish between six days at 0.83°C above the threshold or one day at 4.0°C and five at 0.2°C above the threshold, it provides an indication of the relative severity of the problem. Examination of the temperature duration curve for the period (fig. 53) shows that the incidence of temperature threshold violations increased from about 0.1 percent of the time under Revision 1 to 0.5 percent of the time under Revision 7. Although the change represents a fivefold increase in the frequency of threshold violations, the data indicated that violations in either case occurred less than 0.5 percent of the time. That fact, combined with knowledge of the probable magnitude of the temperature change for this example, may suggest that the temperature flag on the scoring summary is not serious and could be ignored. Figure 53 also reveals that temperature generally increased across all time periods under Revision 7, but consistently remained below the threshold. This result suggests that temperature conditions may not have deteriorated significantly for salmonids and may have improved for the native species of concern.

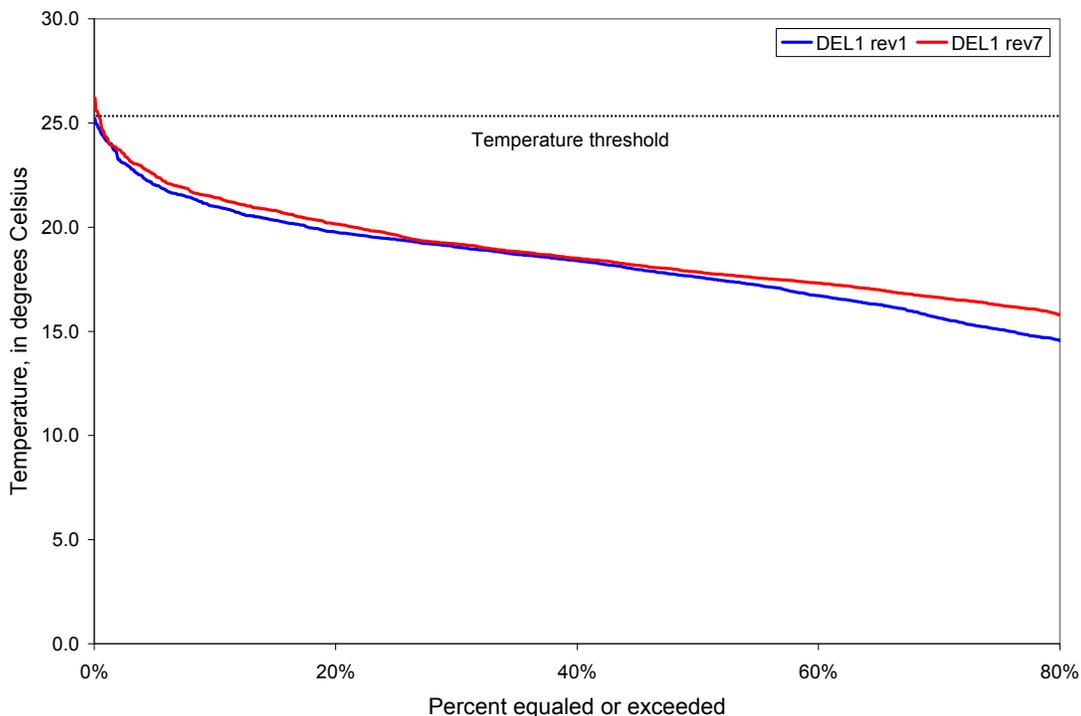


Figure 53. Temperature duration curves for the period May 1–September 30, 1990–2000, for Revision 1 and Revision 7 alternatives at site DEL1.

Adaptable Management Objectives

Habitat management decisions must evaluate the differential responses of multiple habitat types to changes in flow. The issue is whether stream fish populations actually respond to habitat changes described by the model over spatial and temporal scales that are relevant to the decisionmakers. For example, a system managed consistently (and successfully) to increase habitat types related to reproduction and recruitment may eventually experience an increase of juvenile and adult fish density to the point that habitat for these life stages becomes a limiting factor. Furthermore, one might expect a shift in the size distribution of the population, with an abundance of relatively small members and a paucity of large fish. Conversely, managing to consistently favor adult habitat could result in population decline over time owing to insufficient recruitment. Adaptive management objectives are designed to manage habitat for different life stages or species periodically and opportunistically. Because shallow-slow habitat tends to be limited at high flows (fig. 18), it might be advantageous to manage flows to favor adult and juvenile habitat during wet years, and flows favoring spawning-incubation and young of the year habitat during dry years.

Contingency Planning

The physical feasibility of a management alternative in the DRDSS is a function of water supply, storage volume, and cumulative demand. When the demand exceeds the supply for a sufficient time period, the alternative is considered infeasible, at least for that time interval. In this context, it is highly unlikely that a single-alternative operating policy will be feasible everywhere at all times. A contingency plan acknowledges this fact and anticipates operational changes needed to ameliorate the mismatch between supply and demand. In practice, contingency plans are already imbedded within the OASIS model. For example, the delivery targets for New York City, Montague, and the D&R canal are scaled back when system inflow and reservoir storage fall to specified trigger levels. Likewise, reservoir releases for habitat maintenance may be reduced during drought periods, although in some cases reserves may be released to reduce impacts of low flows on temperature or habitat.

Because contingencies are intrinsic to OASIS, it is incumbent upon users of the DRDSS to recognize that developing an operating scenario will likely involve modification or redefinition of the rules of engagement for those contingencies. Several aspects of contingency planning should be observed when such modifications are made. First, how often and under what circumstances will normal operations fail due to insufficient water supply? Second, what trigger levels are imbedded in the operational rule curves to modify releases or exports? Third, how are allocations changed among downstream releases, deliveries, and exports during shortages?

The frequency of failure under normal operating conditions is somewhat a matter of context. If an operating scenario only fails once every 20 years, it may not be worth worrying about in a strategic planning mode. If it fails over 75 percent of the time (for example), perhaps another alternative should be considered. Although failure might be too strong a term, an increase in the frequency of days under the various levels of system drought displayed on the scoring summary page (fig. 52) should serve as a warning that normal operations cannot be sustained without causing eventual problems. Review of the storage duration curves (fig. 51, for example) will reveal which reservoirs are most affected and the respective probabilities of contingency-triggering events.

The circumstances leading to imposition of one of the drought rule contingencies result from cumulative demands exceeding inflow for a sufficient period of time to draw the reservoirs down to their respective trigger levels. Whether this is a concern during development and evaluation of an alternative is once again a matter of context. An alternative that increases the frequency of drought watch designations, but decreases the frequency of drought warnings (the

opposite of the Revision1-Revision7 comparison in fig. 54) might be perfectly acceptable. One that increases the frequency of level 3 drought designations might be unacceptable regardless of changes to the lower categories.

Global Scores					
Montague Flow			Out of System Deliveries		
	Pct Chg	Δ Days		Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	Base, Alt =0
Montague, major shortage	0%	Base, Alt =0	NYC, major shortage	0%	Base, Alt =0
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought			New Jersey, bg		
	Pct Chg	Δ Days		Pct Chg	Δ Days
Days at Level 1	-22%	-92.00	NJ, minor shortage	0%	0.00
Days at Level 2	39%	89.00	NJ, moderate shortage	0%	Base, Alt =0
Days at Level 3	0%	Base, Alt =0	NJ, major shortage	0%	Base, Alt =0
System Storage, bg	0%	-2358.70	New Jersey, bg	0%	Base, Alt =0

Figure 54. Expanded view of the global scores box of the DRDSS, showing changes in system drought designations under Revision1 and Revision7 alternatives.

The trigger levels for each of the drought contingency rules, along with a recent history of system storage volume, can be viewed on the web page for the Delaware River Basin Commission (<http://www.state.nj.us/drbc/nyc.htm>). The reader is advised, however, that this display and all information derived as OASIS output refer to system-wide storage rather than for individual reservoirs.

For a normal operating scenario in the DRDSS, one of the primary changes customarily made will be seasonal or monthly release targets to maintain or improve habitat and temperature conditions. These targets will likely need to be modified as part of a contingency plan. In most cases, the releases would be reduced in order to conserve storage. However, if such reductions result in unacceptable decreases in habitat it may be necessary to revise the rule curves themselves. One potential modification would be to initiate the release reduction earlier, so that the impact to habitat is less in magnitude but longer in duration. To some extent, it may also be possible to spread the impact of drought to different locations in the system by reducing releases from one reservoir in order to allow near-normal releases from another. Under true drought conditions, however, this option would necessarily be considered a short-term solution because normal releases would eventually draw the reservoir down to its drought trigger anyway.

Model Limitations and Assumptions

Since the inception of this study, we have attempted to respond to suggestions provided by the Commission and the Subcommittee to make the DRDSS relevant, realistic, and accurate. We have also strived to produce accurate and realistic input data in the form of hydraulic simulations, habitat maps, and temperature predictions. Regardless of their complexity or sophistication, all models are simplifications of the real world. In application, they may be further simplified or limited by assumptions made by their users.

In this application, we have assumed that the channels of all measured rivers are currently in a state of dynamic equilibrium as described by Leopold and others (1964). We have taken a snapshot of the stream bathymetry as it existed in 2004 and 2005. When we suspected that a site might have been altered by a large flood event, the site was resurveyed. Nonetheless, if the channels are not in dynamic equilibrium, the results of our models will become less representative of the rivers with the passage of time.

We have also assumed that our selection process produced study sites that were representative of the stream segments, that the boundary conditions we obtained from gaging station rating curves closely approximated those at the sites, and that our survey data were accurate depictions of site bathymetry. To some extent, the validity of these assumptions was supported by the similarity of the normalized flow versus habitat functions. Each stream was sampled, measured, and modeled independently. If the bathymetric and hydraulic characteristics for a site were markedly different from those of other sites in comparable settings, its response functions would have been noticeably different from the others. The similarity of the functions suggests that errors associated with sampling and data collection were consistent across all the sites, final model outputs were insensitive to these errors, or both. It is important to remember that the comparative statistics generated in the DRDSS are relative, not absolute. The advantage of relative scoring is that any inaccuracies of the models will be equally distributed in both the baseline and alternative simulations. In that sense, the effects of modeling inaccuracies are neutral.

Decision Support and Adaptive Management

A fundamental paradigm underlying the entire habitat analysis portion of the DRDSS is that fish populations respond somehow to changes in habitat. The general hypothesis is that more habitat has the potential to support more fish (or mussels or aquatic insects). Relations between habitat dynamics and population responses are more complex, however, because populations can be affected by variables not included in the habitat models, at spatial and temporal scales that are different from those incorporated in this study. As previously mentioned, conditions favoring an increase in habitat for adults of a species commonly correspond to a reduction in habitat for young of the year. As a result, an increase in adult habitat may have the unintended consequence of reducing recruitment, thereby causing a reduction in adult population over time. Indeed, the few empirical studies that have examined linkages between habitat and biology have failed to identify a unifying connection between the two. Some studies have shown strong relations between fish population size and habitat dynamics (Jowett, 1993; Nehring and Anderson, 1993; Bovee and others, 1994; Bowen, 1996; Freeman and others, 2001; Capra and others, 2003; Fjellheim and others, 2003; Souchon and Capra, 2004). Some have found no relation at all (Irvine and others, 1987; Scott and Shirvell, 1987; Zorn and Seelbach, 1995), and at least one indicated a negative relation (García de Jalón and others, 1996). Dunham and others (2002) noted that the relations between habitat and fish populations in individual streams could be variable depending on biological factors, such as presence of non-native species, or spatial factors such as habitat connectivity.

Given the uncertainties of how populations or communities are influenced by habitat dynamics, the DRDSS should not be viewed as a precise indicator of population response to flow regime. The DRDSS, in its present form, can be used as a tool for strategic planning by the Commission, the Subcommittee, and the Decree parties. The DRDSS was not designed to perform as a tactical tool for daily operations and should not be used as such. Its strength is as a “hypothesis screener.” The DRDSS can be used to distinguish among alternatives that may be effective or ineffective, feasible or infeasible, high-risk or low-risk. In many decision environments, such information is sufficient for policy makers to decide on a course of action and implement it. Derivation of a “good enough” solution may be “good enough,” even though it may not be the most effective or lowest risk alternative.

To improve and refine the information base, the DRDSS could be used as a precursor to a process of adaptive management by identifying promising operational alternatives that could be implemented and monitored to determine outcomes. In a setting such as the upper Delaware,

limited reservoir capacity and uncertain and water supplies hinder full experimental control, but partial control is possible. Experimental control could be established by implementing the baseline operations of the reservoirs as depicted in the DRDSS for several years. During that time, reservoir releases, stream discharge, habitat dynamics, and population or community-level characteristics (for example, year class strength, growth rates, condition, adult populations, and size structure) would be monitored. The experimental treatment would consist of monitoring the same variables for a similar length of time, but operating the reservoirs according the alternative depicted in the DRDSS, such as those used to generate Revision 7. Advantages to this strategy include:

1. Follow-up monitoring of flows and population dynamics could provide validation of the physical models used in the DRDSS and help define habitat and biological linkages.
2. The feasibility of implementing the operational rules of the alternative could be physically tested through day-to-day operations. Furthermore, actual operations can be compared with simulated (OASIS) operations to monitor compliance and deviations thereof.
3. Ecological resets, such as catastrophic floods, could be adapted into the experimental design. A deficiency of “natural” experiments is that they cannot always be completely or rigorously controlled. Deviations from an experimental release plan can create serious problems with a purely empirical adaptive management study because the treatment may be overridden by an uncontrolled event. The habitat impacts of such deviations predicted with the DRDSS models could be compared with biological responses as part of a revised experiment.
4. The addition of information to the body of knowledge regarding habitat dynamics and biological responses is invaluable. Not only would such knowledge benefit stakeholders and decisionmakers in the Delaware River system, it would undoubtedly be of value to others facing similar situations elsewhere.

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References Cited

- Bain, M.B., Finn, J.T., and Booke, H.E., 1988, Streamflow regulation and fish community structure: *Ecology*, v. 69, no. 2, p. 382-392.
- Bain, M.B., Finn, J.T., Gerardi, L.J., Ross, M.R., and Saunders, W.P., 1982, An evaluation of methodologies for assessing the effects of flow fluctuations on stream fish: U.S. Fish and Wildlife Service, FWS/OBS-82/63, 199 p.
- Bartholow, J.M., 1989, Stream temperature investigations—field and analytic methods: U.S. Fish and Wildlife Service, Instream Flow Information Paper No. 13, Biological Report 89(17), 139 p.
- Bartholow, J.M., 2000, The stream segment and stream network temperature models—A self-study course, version 2.0: U.S. Geological Survey, Open File Report 99-112, 276 p., <http://www.fort.usgs.gov/products/publications/4090/4090.asp>.
- Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, J., and Henriksen, J., 1998, Stream habitat analysis using the instream flow incremental methodology: U.S. Geological Survey, Information and Technology Report USGS/BRD-1998-0004, 131 p.
- Bovee, K.D., Newcomb, T. J., and Coon, T.G., 1994, Relations between habitat variability and population dynamics of bass in the Huron River, Michigan: U.S. Department of the Interior, National Biological Survey, Biological Report 21, 63 p.
- Bovee, K.D., Waddle, T.J., and Jacobson, R.B., 2004, Quantification of habitat patch persistence in rivers affected by hydropeaking, in Lanfear, K.J., and Maidment, D.R., eds., GIS and Water Resources Conference III [Proceedings], Nashville, Tenn., 2004: Middleburg, Va., American Water Resources Association [not paginated]. [Available only on CD-ROM. Ordering information: http://www.awra.org/proceedings/cd_proceedings.html.]
- Bowen, Z.H. 1996, Relations between fishes and habitat in the Tallapoosa River system, Alabama: Alabama, Auburn University, Ph.D. dissertation, 109 p.
- Bowen, Z.H., Bovee, K.D., and Waddle, T.J., 2003a, Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity: *Transactions of the American Fisheries Society*, v. 132, p. 809-823.

- Bowen, Z.H., Bovee, K.D., and Waddle, T.J., 2003b, Effects of channel modification on fish habitat in the upper Yellowstone River: U.S. Geological Survey, Open File Report 03-476, 30 p., appendices.
- Capra, H., Sabaton, C., Gouraud, V., Souchon, Y., and Lim, P., 2003, A population dynamics model and habitat simulation as a tool to predict brown trout demography in natural and bypassed stream reaches: *River Research and Applications*, v. 19, no. (5-6), p. 551-568.
- Dunham, J.B., Cade, B.S., and Terrell, J.W., 2002, Influences of spatial and temporal variation on fish-habitat relationships defined by regression quantiles: *Transactions of the American Fisheries Society*, v. 131, p. 86-98.
- Fjellheim, A., Barlaup, B.T., Gabrielsen, S.E., and Raddum, G.G., 2003, Restoring fish habitat as an alternative to stocking in a river with strongly reduced flow: *International Journal of Ecohydrology and Hydrobiology*, v. 3, no. 1, p. 17-26.
- Freeman, M.C., Bowen, Z.H., Bovee, K.D., and Irwin, E.R., 2001, Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes: *Ecological Applications*, v. 11, no. 1, p. 179-190.
- García de Jalón, D., Mayo, M., and Molles, M.C., 1996, Characterization of Spanish Pyrenean stream habitat–relationships between fish communities and their habitat: *Regulated Rivers–Research and Management*, v. 12, p. 305-316.
- Irvine, J.R., Jowett, I.G., and Scott, D., 1987, A test of the instream flow incremental methodology for underyearling rainbow trout, *Salmo gairdnerii*, in experimental New Zealand streams: *New Zealand Journal of Marine and Freshwater Research*, v. 21, no. 1, p. 35-40.
- Jowett, I.G., 1993, Models of the abundance of large brown trout in New Zealand rivers: *North American Journal of Fisheries Management*, v. 12, p. 417-432.
- Knight, J.G., Bain, M.B., and Scheidegger, K.J., 1991, A habitat framework for assessing the effects of streamflow regulation on fish: Auburn, Ala., Alabama Cooperative Fish and Wildlife Research Unit, Completion Report #14-16-0009-1550, 161 p.
- Kwak, T.J., 1988, Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois: *American Midland Naturalist*, v. 120, p. 241-249.
- Layzer, J.B., and Madison, L.M., 1995, Microhabitat use by freshwater mussels and recommendations for determining their instream flow needs: *Regulated Rivers–Research and Management*, v. 10, p. 329-345.
- Lee, D.S., Carter, C.R., Hocutt, C.H., Jenkins, R.E., McAllister, D.E., and Stauffer, J.R., 1980, Atlas of North American freshwater fishes: North Carolina State Museum of Natural History, No. 1980-12, 854 p.
- Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: San Francisco, W.H. Freeman & Co., 522 p.
- Nehring, R.B., and Anderson, R.M., 1993, Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System: *Rivers*, v. 4, no. 1, p. 1-19.
- Parasiewicz, P., 2001, MesoHABSIM–A concept for application of instream flow models in river restoration planning: *Fisheries*, v. 26, no. 9, p. 6-13.
- Scott, W.B. and Crossman, E.J., 1973, Freshwater fishes of Canada: Ottawa, Fisheries Research Board of Canada, Bulletin 184, 966 p.
- Scott, W., and Shirvell, C.S., 1987, A critique of the instream flow incremental methodology and observations on flow determination in New Zealand, *in* Kemper, J.R. and Craig, C., eds., *Regulated streams–advances in ecology*: New York, Plenum Press, p 27-43.
- Souchon, Y., and Capra, H., 2004, Aquatic habitat modelling–biological validations of IFIM/Phabsim methodology and new perspectives: *Hydroecologie appliquée*, v 14, no. 1, p. 9-25.

- Theurer, F.D., Voos, K.A., and Miller, W.J., 1984, Instream water temperature model: U.S. Fish and Wildlife Service, Instream Flow Information Paper 16, FWS/OBS-84/15, 214 p.
- Turner, M., Costanza, R., and Sklar, F., 1989, Methods to evaluate the performance of spatial simulation models: *Ecological Modeling*, v. 48, p. 1-18.
- University of Alberta, 2006, River2D Description: Edmonton, <http://www.river2d.ualberta.ca>.
- Zorn, T.G., and Seelbach, P.W., 1995, The relation between habitat availability and the short-term carrying capacity of a stream reach for smallmouth bass: *North American Journal of Fisheries Management*, v. 15, no. 4, p. 773-783.
- Zuboy, J.R., 1981, A new tool for fisheries managers: the Delphi technique: *North American Journal of Fisheries Management*, v. 1, p. 55-59.

Appendix 1. Proportional Planform Comparisons for Sites and Segments of the Upper Delaware River.

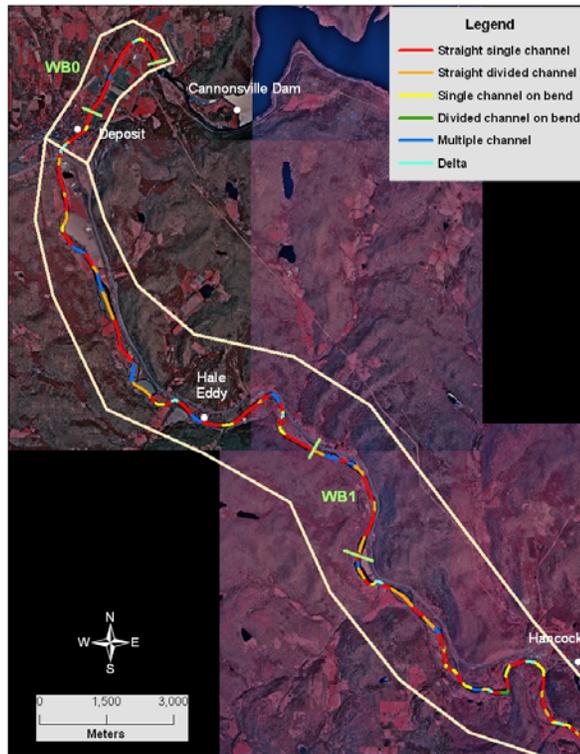


Figure 1-1. Planform map of segments and sites for the West Branch Delaware River.

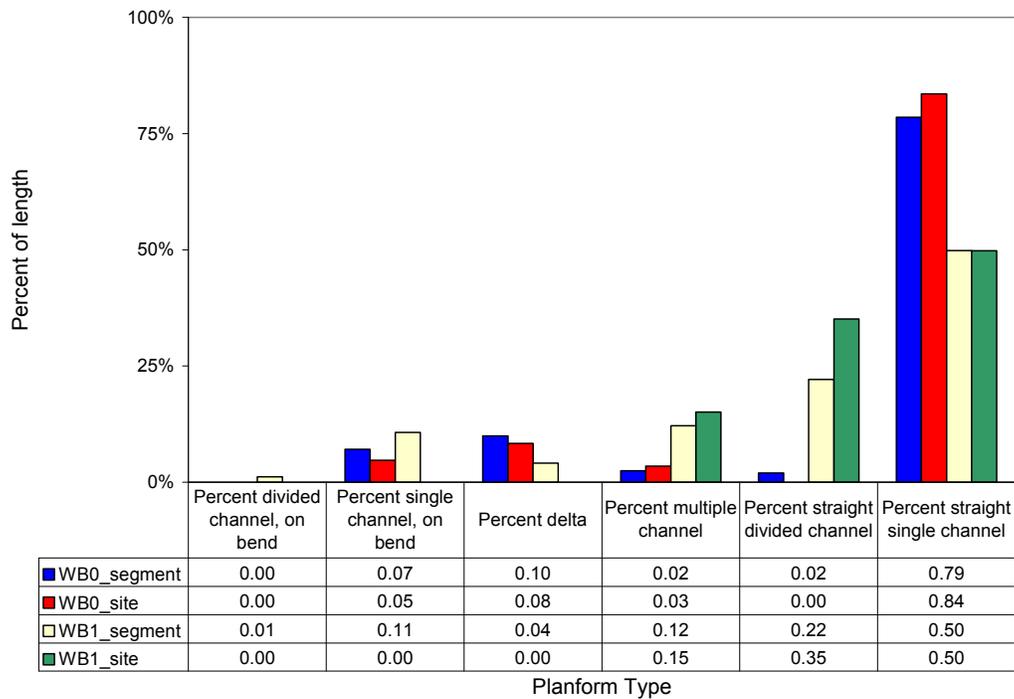


Figure 1-2. Comparison of planform distributions between segments and sites for the West Branch Delaware River.

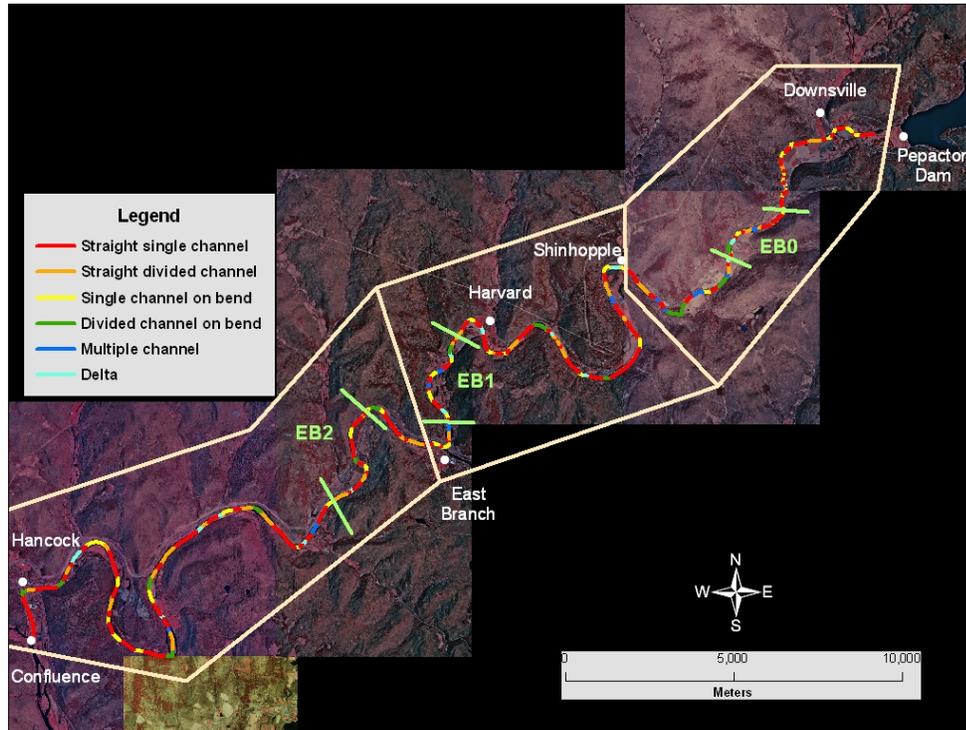


Figure 1-3. Planform map of segments and sites for the East Branch Delaware River.

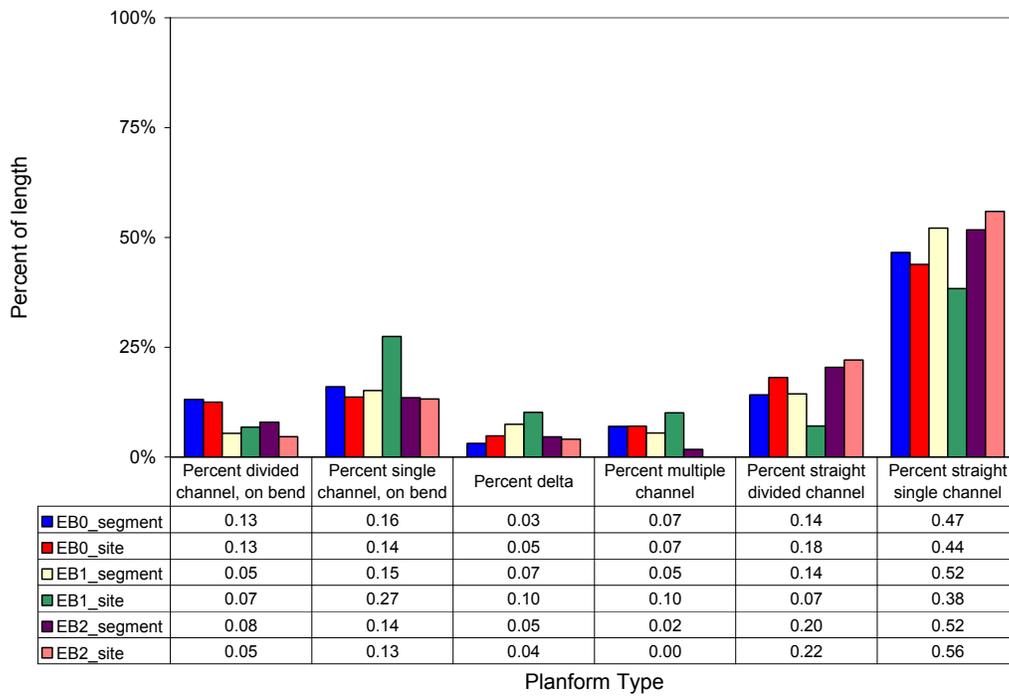


Figure 1-4. Comparison of planform distributions between segments and sites for the East Branch Delaware River.

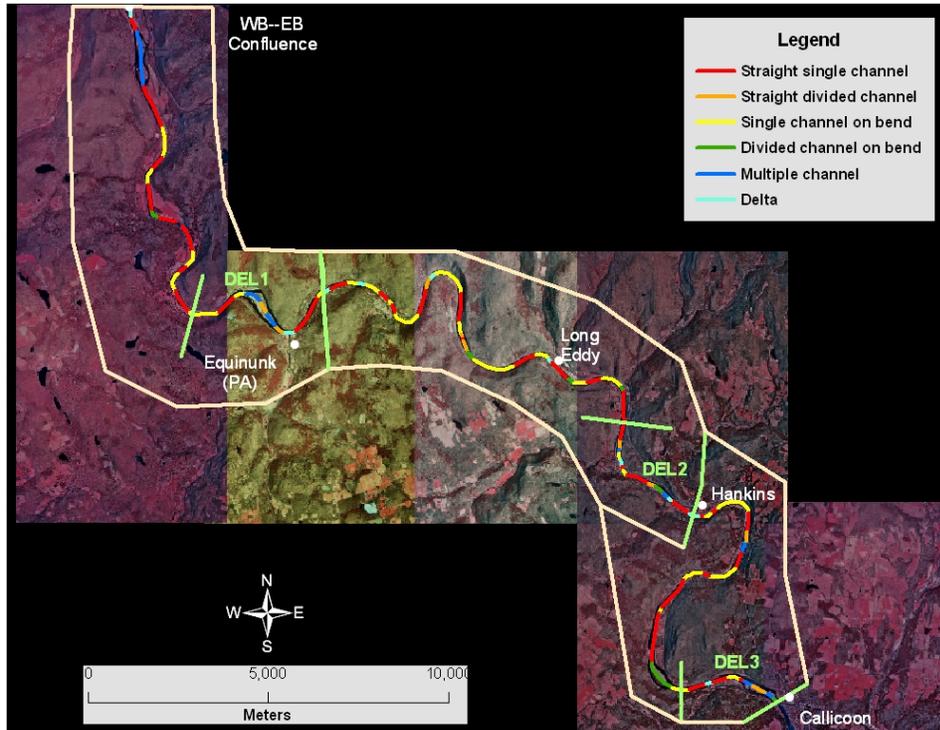


Figure 1-5. Planform map of segments and sites for the main stem Delaware River.

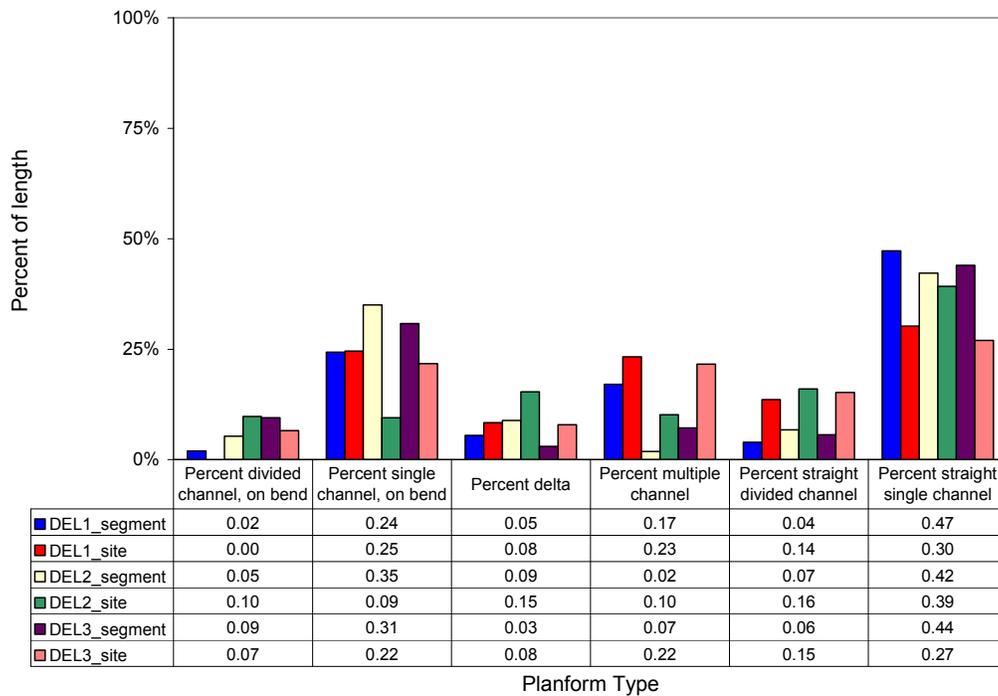


Figure 1-6. Comparison of planform distributions between segments and sites for the main stem Delaware River.

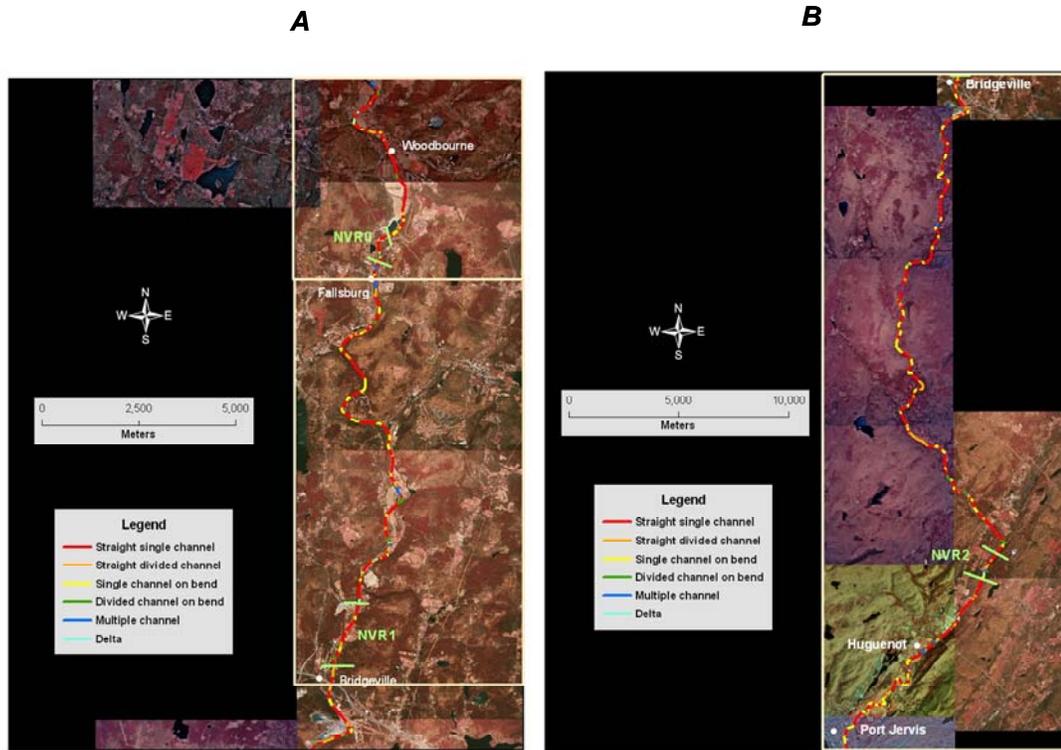


Figure 1-7. Planform maps of segments and sites for the upper (A) and lower (B) Neversink River.

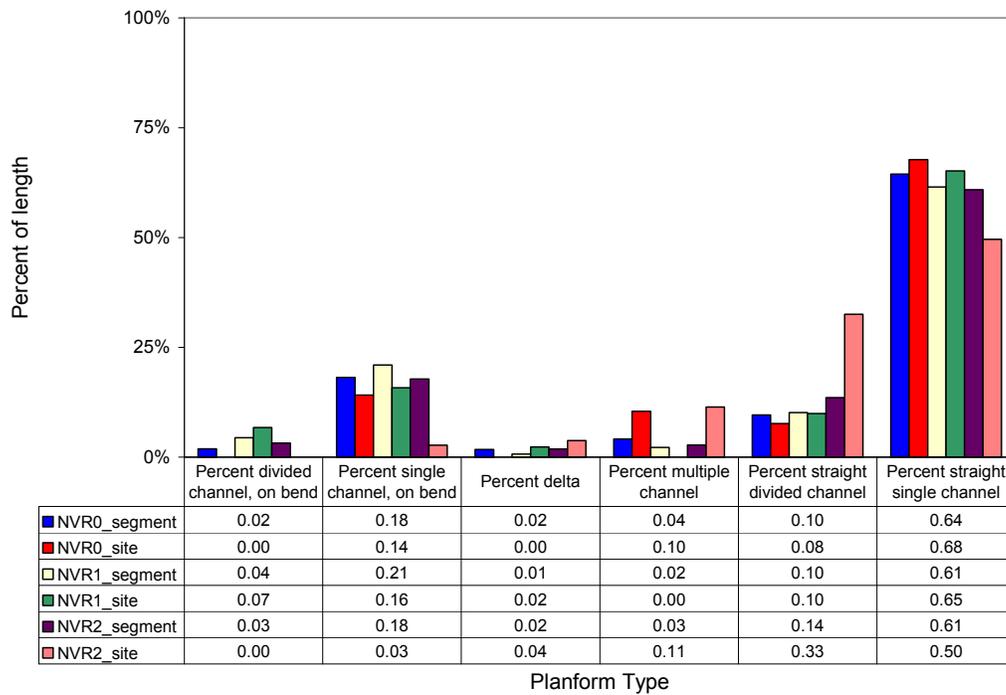


Figure 1-8. Comparison of planform distributions between segments and sites for the Neversink River.

Appendix 2. Final Calibration Results for the River2D Hydraulic Simulation Model at Study Sites in the Upper Delaware River.

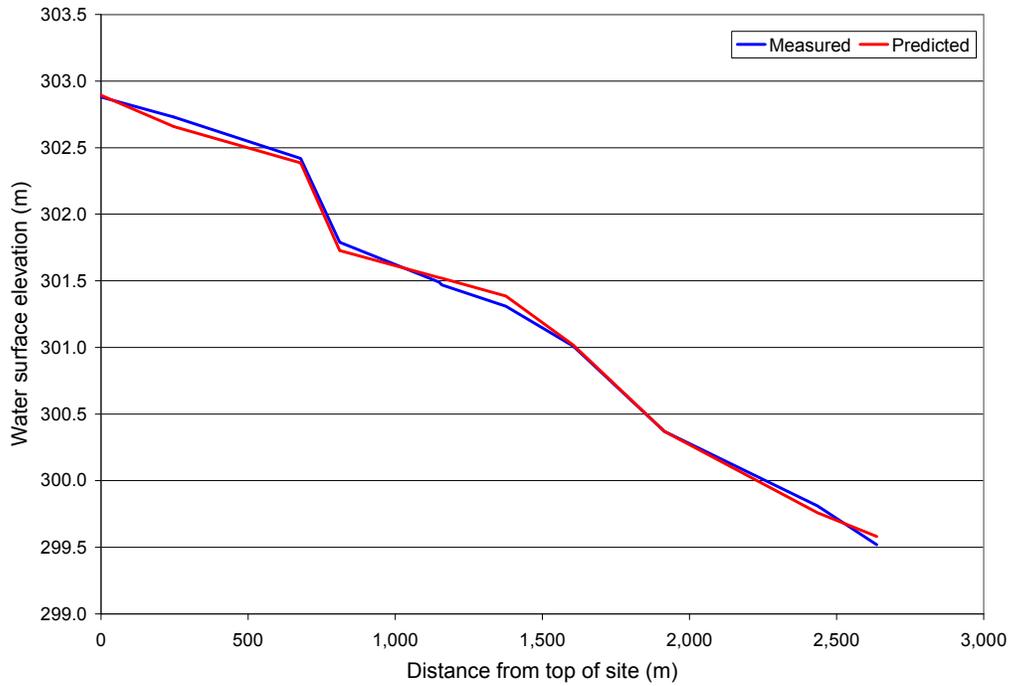


Figure 2-1. Comparison of predicted and measured water surface profiles for the final calibration run at site WB0.

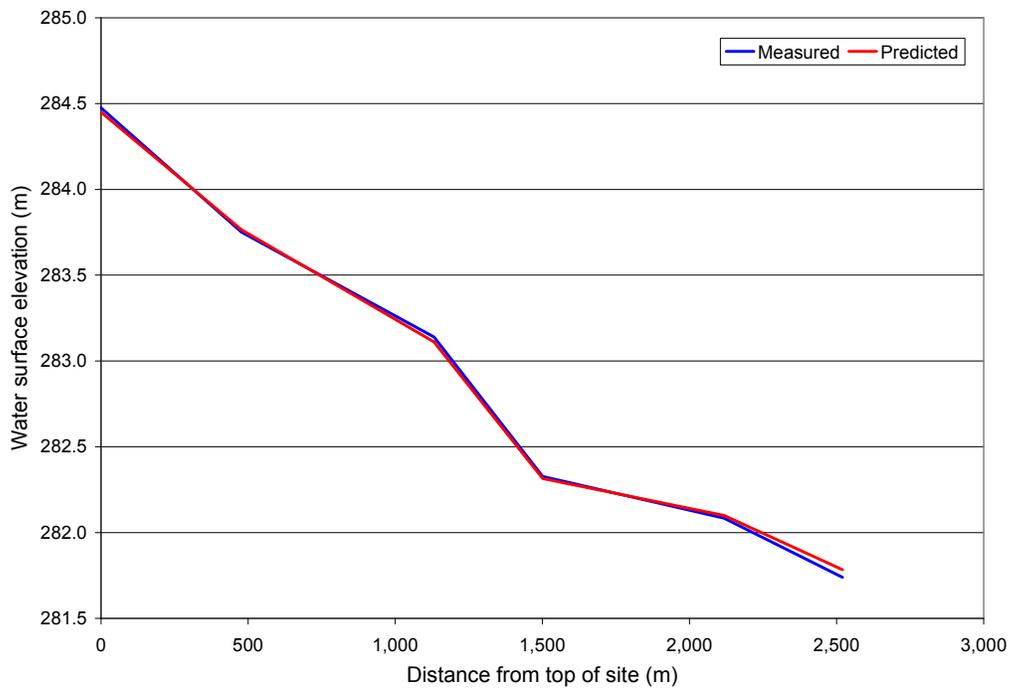


Figure 2-2. Comparison of predicted and measured water surface profiles for the final calibration run at site WB1.

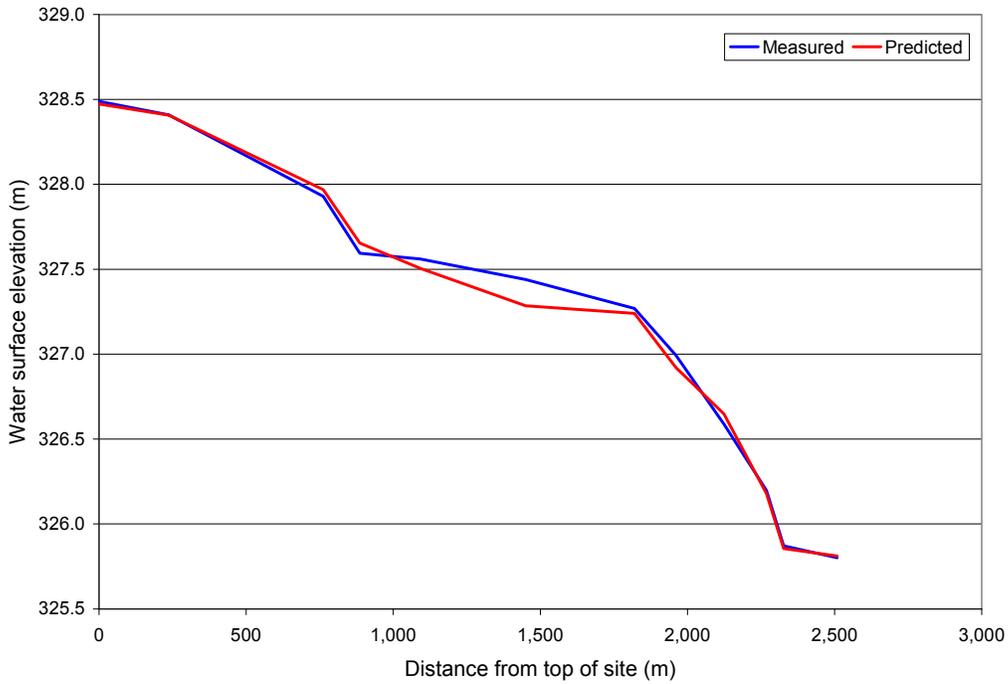


Figure 2-3. Comparison of predicted and measured water surface profiles for the final calibration run at site EB0.

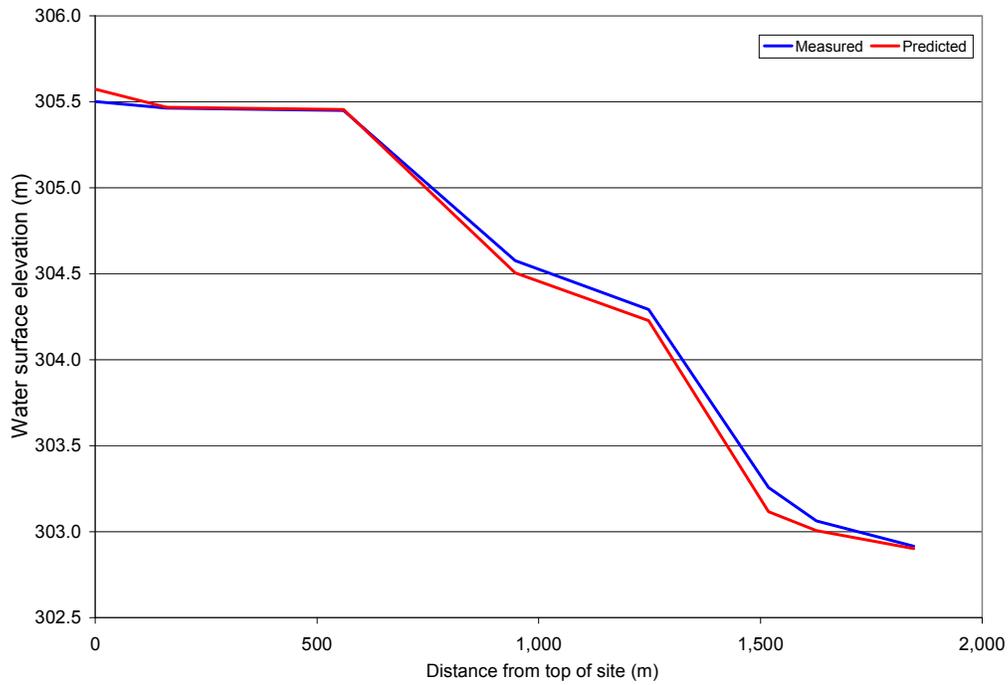


Figure 2-4. Comparison of predicted and measured water surface profiles for the final calibration run at site EB1.

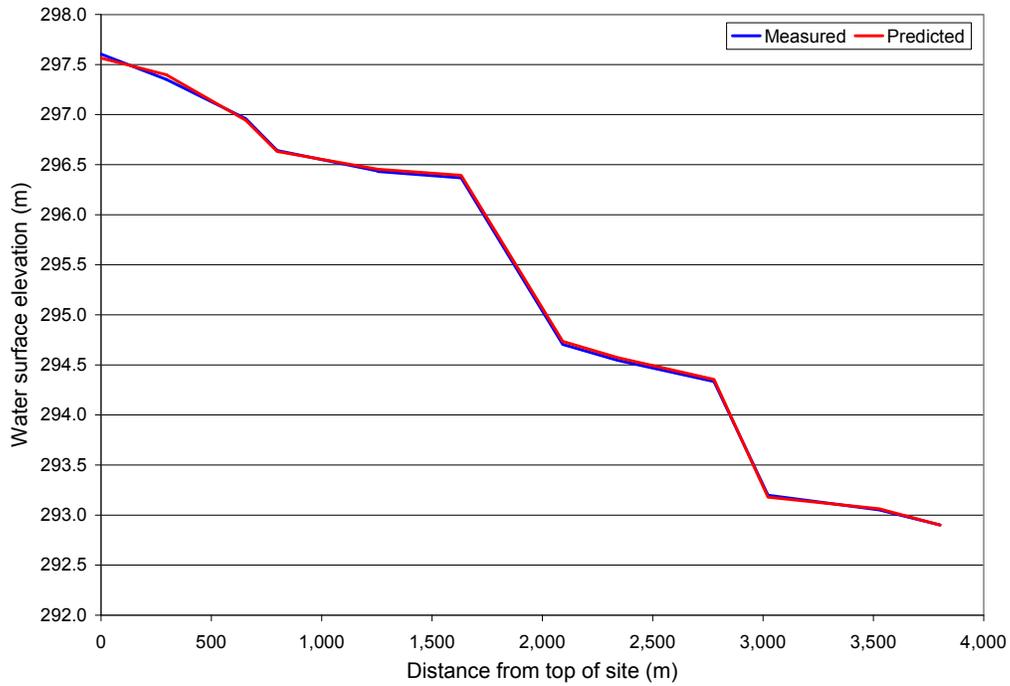


Figure 2-5. Comparison of predicted and measured water surface profiles for the final calibration run at site EB2.

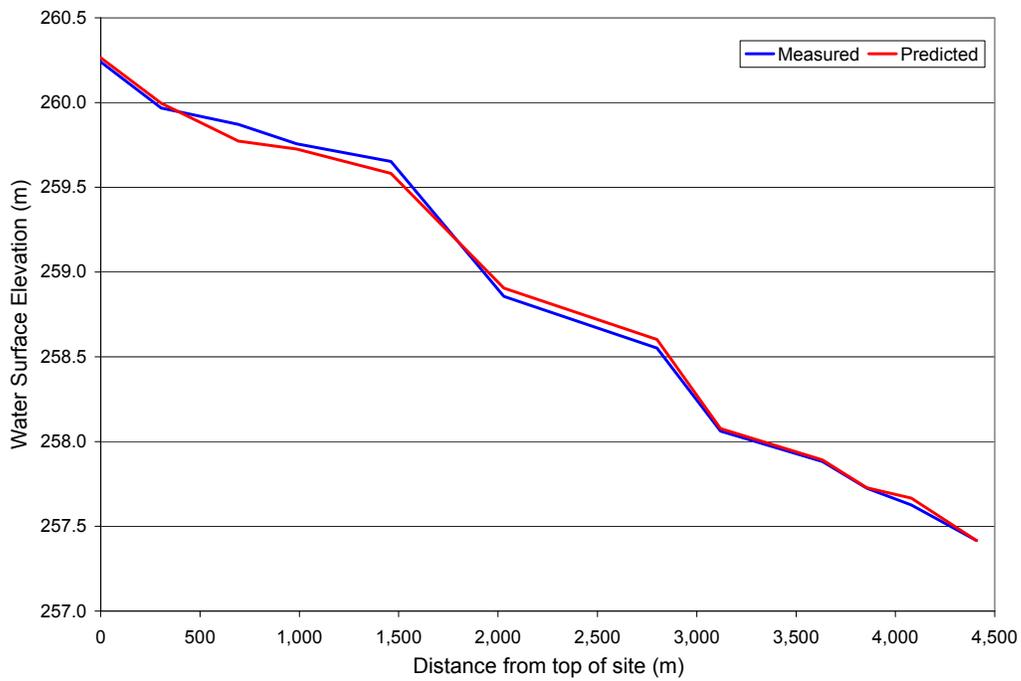


Figure 2-6. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL1.

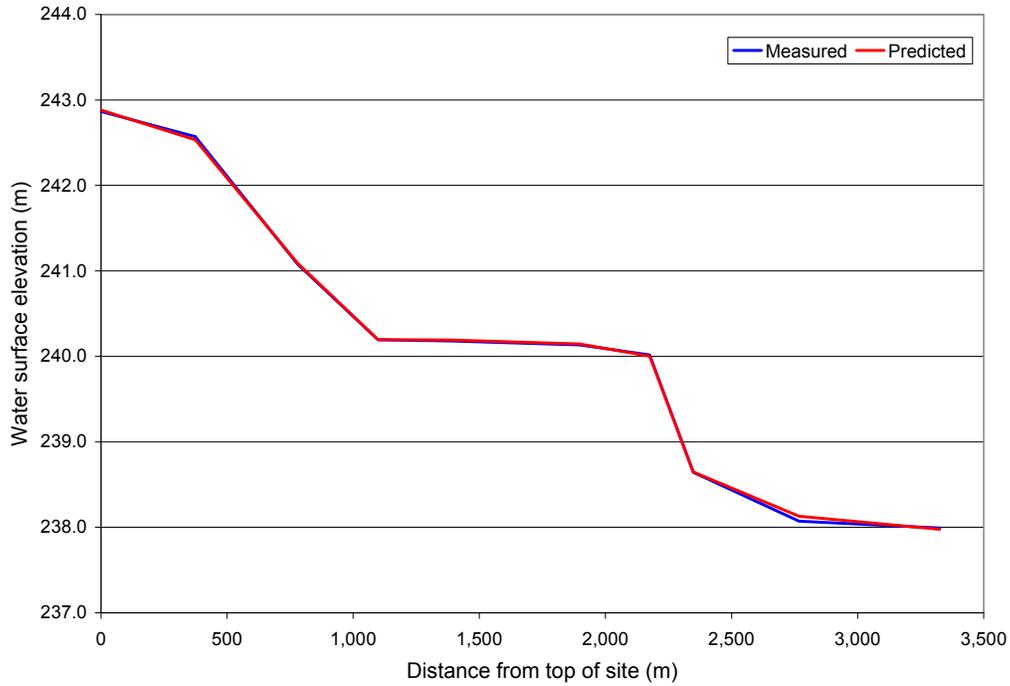


Figure 2-7. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL2.

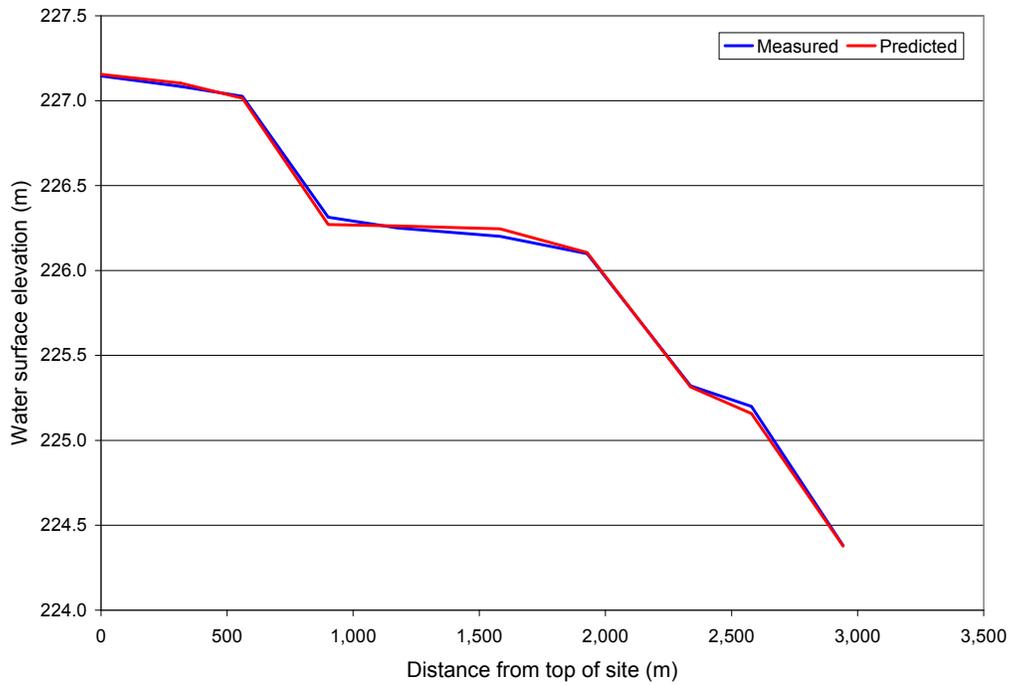


Figure 2-8. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL3.

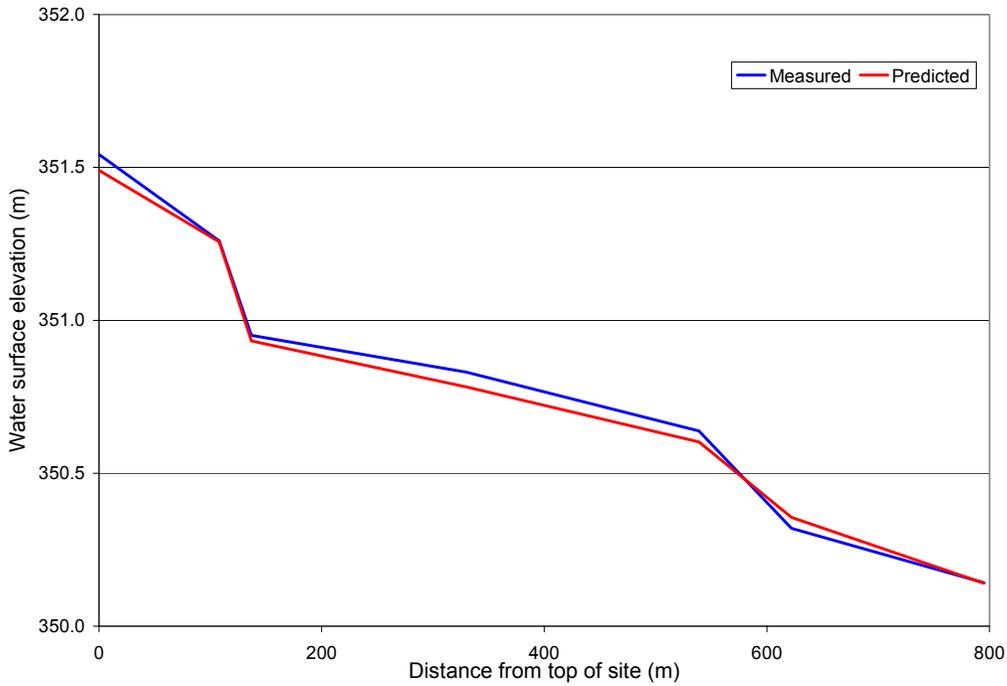


Figure 2-9. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR0.

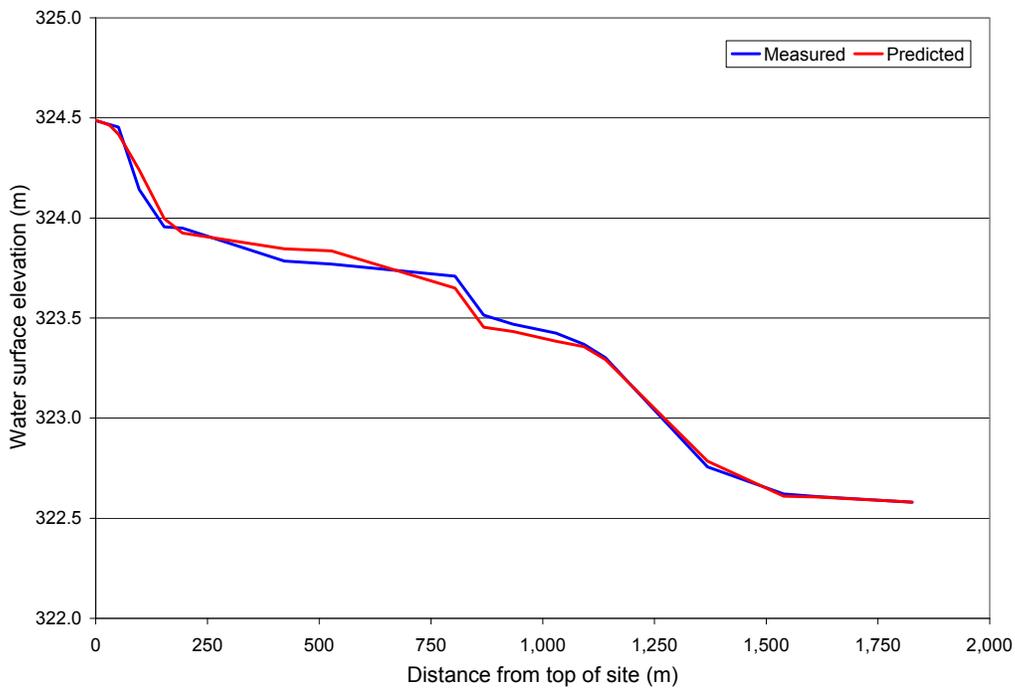


Figure 2-10. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR1.

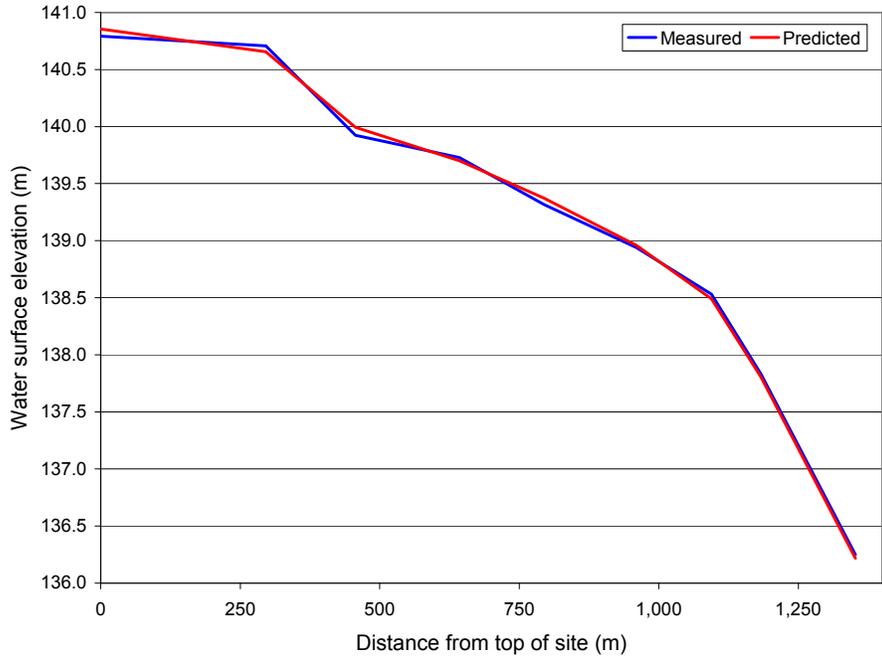


Figure 2-11. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR2.

Appendix 3. Discharge Versus Habitat Area Statistics for Study Sites in the Upper Delaware River.

Table 3-1. Habitat versus discharge relations for segment 0 West Branch Delaware River (WB0).

Discharge		Brown trout adult		Brown trout juveniles		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
9	0.02	1.09	2,786	2.23	5,720	0.09	218	3.48	8,913
14	0.03	1.26	3,242	2.75	7,047	0.27	686	3.65	9,364
21	0.05	1.49	3,826	3.27	8,395	0.59	1,505	3.74	9,587
32	0.07	2.10	5,375	4.17	10,686	1.10	2,830	4.05	9,983
53	0.11	3.04	7,790	5.38	13,785	2.44	6,264	4.48	10,379
81	0.17	4.08	10,460	7.20	18,451	3.96	10,159	4.70	11,486
124	0.27	5.11	13,091	10.78	27,647	6.14	15,734	4.76	12,059
191	0.41	7.70	19,751	15.16	38,871	7.88	20,202	3.96	12,196
297	0.64	11.72	30,041	19.13	49,048	8.92	22,870	3.10	10,160
462	0.99	18.83	48,283	19.91	51,040	4.90	12,557	2.40	7,946
717	1.54	23.11	59,255	16.40	42,046	1.90	4,877	1.68	6,158
1,112	2.39	23.06	59,119	10.81	27,710	1.56	4,011	1.37	4,304
1,730	3.72	18.57	47,611	5.56	14,263	1.15	2,937	1.29	3,523
2,683	5.77	12.07	30,938	3.67	9,418	0.65	1,675	1.09	3,302
4,165	8.96	6.90	17,688	2.60	6,666	0.26	659	0.00	2,792

¹Constrained by 5-m shoreline buffer.**Table 3-2.** Habitat versus discharge relations for segment 1 West Branch Delaware River (WB1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
46	0.08	40.39	1,7410	61.24	2,6399	0.01	6	26.07	11,235
64	0.11	45.72	1,9706	69.05	2,9765	9.10	3,923	29.11	12,547
88	0.15	52.29	2,2537	79.88	3,4429	14.65	6,316	30.01	12,934
125	0.21	61.75	2,6618	90.57	3,9041	20.66	8,904	29.79	12,842
177	0.30	73.47	3,1670	103.67	4,4685	27.31	11,772	29.22	12,594
247	0.42	89.91	3,8756	116.92	5,0398	30.97	13,349	28.38	12,233
353	0.59	110.98	4,7835	128.78	5,5511	28.88	12,447	26.10	11,251
494	0.83	132.19	5,6978	133.01	5,7331	22.80	9,827	23.14	9,973
706	1.19	153.12	6,6000	123.96	5,3433	15.10	6,507	18.11	7,805
953	1.60	170.43	7,3459	96.25	4,1488	6.14	2,648	13.52	5,827
1,341	2.25	174.09	7,5040	66.27	2,8563	1.98	853	10.44	4,499
1,906	3.20	153.29	6,6075	42.51	1,8322	1.30	558	9.90	4,265
2,683	4.51	123.01	5,3024	30.01	1,2933	1.95	841	9.53	4,107
3,777	6.35	88.13	3,7986	26.44	1,1395	2.76	1,189	9.90	4,266
5,330	8.96	71.82	3,0959	26.02	1,1216	3.12	1,346	6.43	2,773

¹Constrained by 5-m shoreline buffer.

Table 3-3. Habitat versus discharge relations for segment 0 East Branch Delaware River (EB0).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
7	0.02	11.10	9,096	9.85	8,071	0.08	63	11.56	9,477
11	0.03	11.83	9,700	11.05	9,053	0.25	208	11.60	9,511
18	0.05	13.12	10,755	13.05	10,699	0.71	585	11.64	9,542
25	0.07	14.28	11,703	14.48	11,866	1.12	917	11.82	9,687
39	0.10	16.70	13,691	17.79	14,586	1.95	1,597	11.85	9,716
56	0.15	18.95	15,531	21.73	17,808	2.81	2,305	11.86	9,720
88	0.24	22.13	18,142	25.90	21,229	3.85	3,154	10.74	8,805
131	0.35	28.66	23,493	28.90	23,685	4.33	3,553	10.58	8,675
201	0.54	36.48	29,898	32.42	26,570	2.32	1,905	8.38	6,867
304	0.82	42.53	34,862	32.89	26,961	1.06	867	6.90	5,657
462	1.24	46.70	38,278	29.82	24,443	0.68	558	5.67	4,645
702	1.89	49.55	40,617	20.82	17,067	0.73	599	5.48	4,493
1,070	2.88	50.66	41,526	14.06	11,523	1.39	1,141	5.84	4,790
1,627	4.37	49.06	40,216	15.14	12,414	1.61	1,323	6.43	5,274
2,471	6.64	50.97	41,778	19.11	15,665	1.73	1,421	5.52	4,524

¹Constrained by 5-m shoreline buffer.**Table 3-4.** Habitat versus discharge relations for segment 1 East Branch Delaware River (EB1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-fast guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
38	0.08	37.17	24,615	30.53	20,221	2.31	1,527	11.70	7,748
53	0.12	40.00	26,490	33.33	22,074	3.54	2,347	11.67	7,727
74	0.16	43.15	28,575	35.95	23,807	4.76	3,152	11.39	7,543
103	0.22	46.76	30,967	38.10	25,231	5.39	3,569	10.96	7,257
143	0.31	51.89	34,362	39.62	26,237	4.74	3,137	10.60	7,017
199	0.43	56.43	37,372	40.50	26,819	3.63	2,402	10.18	6,741
277	0.60	61.14	40,492	39.41	26,098	2.06	1,361	9.40	6,223
385	0.84	63.68	42,175	37.77	25,016	1.36	898	8.56	5,667
537	1.17	66.44	44,003	34.46	22,821	0.77	513	8.22	5,443
746	1.63	65.89	43,638	29.10	19,274	0.78	514	8.03	5,317
1,039	2.27	67.22	44,517	24.36	16,133	1.28	847	7.90	5,230
1,446	3.16	67.03	44,391	21.32	14,117	2.32	1,537	7.40	4,901
2,012	4.39	63.75	42,220	20.17	13,355	2.81	1,864	7.06	4,678
2,802	6.12	58.49	38,736	23.87	15,811	3.29	2,179	6.96	4,611
3,901	8.52	58.17	38,524	33.36	22,090	8.88	5,883	7.03	4,658

¹Constrained by 5-m shoreline buffer.

Table 3-5. Habitat versus discharge relations for segment 2 East Branch Delaware River (EB2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
100	0.13	77.55	30,292	77.74	30,366	13.73	5,364	21.81	8,519
150	0.19	85.28	33,313	82.97	32,411	17.04	6,657	21.63	8,447
200	0.25	91.92	35,908	85.31	33,325	18.15	7,089	21.04	8,218
300	0.38	104.82	40,947	85.69	33,473	17.36	6,782	18.90	7,382
450	0.57	118.20	46,170	83.68	32,687	15.69	6,130	16.87	6,589
700	0.89	131.09	51,206	76.43	29,855	11.82	4,616	14.09	5,502
1,000	1.28	139.34	54,430	65.34	25,524	7.02	2,744	11.35	4,435
1,399	1.78	140.32	54,812	51.67	20,185	3.41	1,331	10.35	4,045
1,539	1.96	143.28	55,967	49.72	19,424	2.27	887	10.35	4,042
2,099	2.68	127.04	49,623	35.34	13,804	1.07	418	8.78	3,428
3,199	4.08	100.25	39,159	23.74	9,274	0.86	336	8.06	3,149
4,598	5.87	65.68	25,656	20.27	7,919	0.76	298	8.63	3,369
6,697	8.54	49.51	19,338	21.72	8,484	0.49	193	9.70	3,787
9,896	12.62	48.71	19,028	28.87	11,279	0.25	98	10.47	4,090
21,191	27.03	73.87	28,855	42.89	16,753	0.12	48	12.15	4,748

¹Constrained by 5-m shoreline buffer.

Table 3-6. Habitat versus discharge relations for segment 2 East Branch Delaware River (EB2) –

Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km
100	0.13	84.58	33,038	9.31	3,636
150	0.19	91.86	35,884	19.69	7,690
200	0.25	97.95	38,263	30.36	11,858
300	0.38	105.93	41,377	60.60	23,673
450	0.57	110.72	43,250	83.21	32,503
700	0.89	110.25	43,067	96.55	37,716
1,000	1.28	98.42	38,445	97.06	37,914
1,399	1.78	75.53	29,506	84.93	33,176
1,539	1.96	77.25	30,175	85.74	33,490
2,099	2.68	50.26	19,632	56.64	22,123
3,199	4.08	36.37	14,206	32.79	12,808
4,598	5.87	29.65	11,582	22.32	8,719
6,697	8.54	27.54	10,759	21.06	8,226
9,896	12.62	31.17	12,176	22.99	8,982
21,191	27.03	51.77	20,224	38.07	14,870

Table 3-7. Habitat versus discharge relations for segment 1 Delaware River main stem (DEL1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
344	0.22	107.70	72,285	88.74	59,555	5.70	3,828	18.09	12,142
426	0.27	118.24	79,355	97.15	65,201	7.38	4,955	16.74	11,234
568	0.36	130.34	87,475	104.20	69,931	9.64	6,472	14.91	10,004
746	0.47	146.05	98,019	107.20	71,944	7.73	5,187	14.21	9,540
959	0.60	160.33	107,607	107.41	72,085	4.25	2,855	13.62	9,141
1,243	0.78	171.07	114,810	102.51	68,800	2.07	1,388	13.04	8,752
1,598	1.00	179.58	120,526	93.54	62,780	0.75	506	11.12	7,464
2,095	1.32	185.92	124,779	79.78	53,544	1.10	737	9.65	6,476
2,698	1.70	190.73	128,004	60.87	40,851	1.50	1,007	8.12	5,449
3,515	2.21	194.99	130,866	45.84	30,768	1.52	1,021	7.70	5,167
4,544	2.86	197.91	132,824	38.27	25,686	1.69	1,136	7.46	5,007
5,893	3.71	189.00	126,843	40.36	27,084	1.23	828	7.60	5,103
7,597	4.78	177.78	119,318	48.36	32,457	0.80	536	7.35	4,933
9,869	6.21	176.79	118,653	56.94	38,216	2.52	1,690	5.94	3,989
12,780	8.04	176.06	118,163	64.34	43,182	0.27	181	3.50	2,349

¹Constrained by 5-m shoreline buffer.**Table 3-8.** Habitat versus discharge relations for segment 1 Delaware River main stem (DEL1) –
Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km
344	0.22	109.52	73,505	31.53	21,163
426	0.27	119.34	80,092	43.29	29,056
568	0.36	130.70	87,718	64.02	42,969
746	0.47	140.62	94,373	89.16	59,837
959	0.60	144.41	96,918	109.30	73,355
1,243	0.78	143.68	96,427	123.69	83,010
1,598	1.00	135.79	91,137	132.97	89,244
2,095	1.32	124.12	83,304	137.40	92,215
2,698	1.70	110.12	73,909	133.57	89,641
3,515	2.21	90.82	60,953	113.43	76,125
4,544	2.86	78.96	52,992	91.08	61,126
5,893	3.71	70.55	47,348	76.91	51,618
7,597	4.78	67.45	45,268	68.70	46,106
9,869	6.21	73.77	49,508	72.20	48,460
12,780	8.04	82.60	55,435	84.22	56,521

Table 3-9. Habitat versus discharge relations for segment 2 Delaware River main stem (DEL2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
466	0.28	95.35	55,758	58.95	34,476	100.23	6,898	12.46	6,441
597	0.36	99.94	58,445	57.13	33,410	108.08	6,765	12.23	9,405
762	0.46	104.11	60,884	54.55	31,900	117.15	6,185	11.95	11,885
974	0.58	107.93	63,118	50.78	29,697	125.80	5,745	11.42	13,104
1,243	0.74	110.74	64,761	48.12	28,143	134.33	5,509	10.75	13,836
1,585	0.95	114.57	67,000	44.99	26,308	144.52	4,165	10.38	14,460
2,023	1.21	117.90	68,950	40.17	23,490	155.00	2,133	9.57	14,660
2,577	1.54	116.63	68,207	34.56	20,208	161.68	1,589	9.79	13,404
3,297	1.98	114.98	67,241	29.26	17,110	168.35	1,466	8.86	10,232
4,208	2.52	107.75	63,009	25.82	15,101	175.28	1,288	8.67	7,459
5,373	3.22	90.36	52,839	22.66	13,252	181.96	1,062	8.85	5,640
6,855	4.11	72.83	42,589	21.13	12,359	189.35	1,091	8.90	4,645
8,751	5.25	62.12	36,328	20.63	12,067	199.07	1,485	8.96	4,016
11,172	6.70	62.93	36,799	21.13	12,356	210.90	2,181	8.70	4,497
14,261	8.55	57.39	33,559	17.67	10,332	222.47	2,381	7.40	4,116

¹Constrained by 5-m shoreline buffer.

Table 3-10. Habitat versus discharge relations for segment 2 Delaware River main stem (DEL2) –
Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km
466	0.28	77.03	47,917	11.80	19,969
597	0.36	75.98	49,255	11.57	29,156
762	0.46	74.28	49,822	10.58	36,845
974	0.58	71.82	49,080	9.82	40,624
1,243	0.74	68.20	47,903	9.42	42,892
1,585	0.95	64.58	47,155	7.12	44,826
2,023	1.21	56.52	43,229	3.65	45,446
2,577	1.54	49.79	35,338	2.72	41,552
3,297	1.98	43.02	29,567	2.51	31,721
4,208	2.52	36.30	25,347	2.20	23,122
5,373	3.22	31.36	22,408	1.82	17,484
6,855	4.11	28.14	20,771	1.87	14,401
8,751	5.25	28.33	20,429	2.54	12,449
11,172	6.70	28.67	21,547	3.73	13,939
14,261	8.55	23.75	17,409	4.07	12,760

Table 3-11. Habitat versus discharge relations for segment 3 Delaware River main stem (DEL3).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
505	0.28	90.42	89,632	83.19	78,648	0.25	9,616	17.87	13,671
650	0.36	102.83	101,955	82.78	82,072	9.00	8,919	13.85	11,834
833	0.46	113.78	112,806	86.01	85,280	9.24	9,164	13.57	11,595
1,059	0.58	123.76	122,705	88.18	87,425	8.71	8,640	13.21	11,289
1,377	0.76	133.47	132,326	87.64	86,890	7.56	7,499	12.24	10,460
1,779	0.98	143.03	141,805	81.59	80,888	5.76	5,707	10.57	9,035
2,291	1.26	148.64	147,369	70.45	69,846	2.84	2,812	8.76	7,484
2,951	1.62	149.26	147,980	56.07	55,590	1.27	1,255	7.71	6,592
3,798	2.09	145.95	144,705	38.16	37,837	1.16	1,154	6.85	5,858
4,889	2.69	136.23	135,066	24.66	24,445	1.17	1,162	6.37	5,441
6,294	3.46	113.46	112,489	17.66	17,511	0.97	961	6.05	5,171
8,105	4.45	91.62	90,842	15.90	15,767	1.08	1,067	6.13	5,242
10,435	5.73	67.99	67,408	16.26	16,118	1.52	1,504	6.54	5,586
13,435	7.38	54.46	53,994	16.64	16,493	1.68	1,664	6.57	5,612
17,297	9.50	44.30	43,922	16.87	16,725	2.22	2,201	6.58	5,624

¹Constrained by 5-m shoreline buffer.

Table 3-12. Habitat versus discharge relations for segment 3 Delaware River main stem (DEL3) –
Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km
505	0.28	114.55	91,086	97.72	42593
650	0.36	78.13	98,197	99.04	54535
833	0.46	74.04	103,348	104.24	69793
1,059	0.58	68.30	106,551	107.47	86566
1,377	0.76	59.22	107,856	108.79	98783
1,779	0.98	43.01	100,496	101.36	107196
2,291	1.26	32.63	88,923	89.69	105451
2,951	1.62	27.03	76,806	77.47	94660
3,798	2.09	23.01	62,344	62.88	78693
4,889	2.69	18.81	46,805	47.21	58188
6,294	3.46	16.80	35,255	35.56	37469
8,105	4.45	17.69	33,698	33.99	30722
10,435	5.73	19.93	31,471	31.74	27913
13,435	7.38	17.22	25,411	25.63	23804
17,297	9.50	13.71	20,891	21.07	19517

Table 3-13. Habitat versus discharge relations for segment 0 Neversink River (NVR0).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
14	0.12	13.01	10,084	15.11	11,709	13.01	711	9.43	7,311
18	0.16	13.42	10,400	15.58	12,080	13.42	1,060	9.72	7,534
25	0.22	14.17	10,985	16.75	12,987	14.17	1,708	9.68	7,505
32	0.28	14.87	11,531	18.43	14,284	14.88	2,298	9.62	7,458
42	0.37	15.83	12,270	19.68	15,259	15.84	2,995	9.25	7,168
56	0.50	17.17	13,312	20.70	16,048	17.20	3,896	8.79	6,811
74	0.66	19.34	14,996	22.33	17,312	19.41	4,434	7.98	6,189
99	0.87	22.22	17,225	23.18	17,965	22.34	3,784	6.96	5,393
134	1.19	24.62	19,085	23.73	18,396	24.80	3,482	6.09	4,720
177	1.56	27.26	21,130	22.99	17,824	27.63	2,783	4.93	3,820
233	2.06	29.64	22,974	21.89	16,969	30.74	1,811	4.33	3,356
307	2.72	30.69	23,791	19.89	15,415	33.32	1,235	4.06	3,145
406	3.59	30.11	23,339	17.18	13,320	35.43	969	3.98	3,082
540	4.78	29.71	23,030	13.99	10,846	37.13	1,219	3.95	3,063
713	6.31	29.17	22,614	11.53	8,937	38.88	2,004	4.33	3,356

¹Constrained by 5-m shoreline buffer**Table 3-14.** Habitat versus discharge relations for segment 1 Neversink River (NVR1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
28	0.17	24.39	9,380	37.46	14,408	3.35	1,288	17.00	6,538
39	0.23	27.96	10,752	41.44	15,938	4.97	1,911	16.75	6,443
54	0.32	34.36	13,214	46.27	17,798	6.28	2,416	16.39	6,303
76	0.44	40.48	15,571	51.27	19,720	8.35	3,211	15.44	5,938
105	0.62	47.54	18,286	55.78	21,455	8.38	3,224	14.04	5,401
146	0.85	55.93	21,510	59.11	22,733	7.89	3,035	10.91	4,198
203	1.19	64.85	24,943	58.63	22,551	4.58	1,761	8.53	3,282
282	1.65	71.24	27,399	54.83	21,087	1.89	728	6.47	2,489
393	2.30	73.69	28,343	47.31	18,196	0.81	310	5.72	2,202
545	3.19	73.82	28,391	34.03	13,090	0.67	258	5.52	2,125
758	4.43	74.96	28,830	20.85	8,019	0.79	302	6.40	2,463
1,053	6.16	68.65	26,402	14.66	5,639	1.32	506	6.40	2,463
1,463	8.55	65.71	25,275	15.02	5,777	1.03	398	6.64	2,556
2,032	11.88	104.13	40,048	32.93	12,665	0.92	352	6.59	2,536
2,824	16.51	47.30	18,194	17.87	6,872	0.38	146	6.56	2,525

¹Constrained by 5-m shoreline buffer

Table 3-15. Habitat versus discharge relations for segment 2 Neversink River (NVR2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild ¹	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km	Ha	m ² /km
70	0.23	36.96	15,597	40.63	17,145	8.62	3,637	18.28	7,715
90	0.29	40.42	17,056	43.62	18,405	10.14	4,276	19.02	8,023
117	0.38	44.88	18,938	46.01	19,414	11.19	4,720	17.25	7,277
151	0.49	49.27	20,788	47.59	20,079	12.55	5,293	16.77	7,076
195	0.63	53.59	22,610	46.70	19,704	14.07	5,937	16.17	6,823
252	0.82	59.83	25,246	46.26	19,520	12.36	5,214	15.66	6,609
325	1.06	63.51	26,797	43.83	18,494	11.28	4,761	14.53	6,130
420	1.37	64.81	27,345	40.90	17,255	10.47	4,418	13.62	5,746
543	1.77	63.42	26,758	37.05	15,632	9.92	4,184	12.59	5,311
701	2.28	61.46	25,932	29.70	12,533	10.67	4,503	10.80	4,557
905	2.95	59.83	25,246	25.91	10,932	10.06	4,243	9.56	4,032
1,169	3.81	54.71	23,084	22.72	9,585	6.90	2,909	8.50	3,585
1,511	4.92	46.97	19,817	19.54	8,245	4.09	1,724	7.90	3,335
1,951	6.36	38.52	16,253	17.22	7,264	2.37	1,000	7.44	3,141
2,859	9.31	29.61	12,492	15.25	6,434	3.04	1,282	6.54	2,760

¹Constrained by 5-m shoreline buffer.

Table 3-16. Habitat versus discharge relations for segment 2 Neversink River (NVR2) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft ³ /s)	Q (ft ³ /s/mi ²)	Ha	m ² /km	Ha	m ² /km
70	0.23	47.33	16,503	10.92	3,809
90	0.29	51.06	17,806	14.99	5,228
117	0.38	54.92	19,152	21.20	7,394
151	0.49	57.37	20,006	28.22	9,839
195	0.63	56.31	19,638	33.73	11,761
252	0.82	56.90	19,842	40.90	14,263
325	1.06	55.24	19,262	44.48	15,509
420	1.37	52.47	18,295	48.10	16,773
543	1.77	44.21	15,416	47.18	16,453
701	2.28	39.70	13,844	40.89	14,258
905	2.95	34.32	11,969	37.20	12,971
1,169	3.81	29.06	10,134	31.38	10,942
1,511	4.92	24.89	8,681	22.66	7,902
1,951	6.36	22.85	7,969	17.61	6,142
2,859	9.31	21.30	7,427	13.57	4,733

**Appendix 4. Habitat Persistence Tables for Brown Trout (*Salmo trutta*)
Spawning – Incubation and Dwarf Wedgemussels (*Alasmidonta
heterodon*).**

Table 4-1. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site WB0. Units of habitat are m²/km.

		Incubation flow															
		(ft ³ /mi ²)	0.02	0.03	0.05	0.07	0.12	0.18	0.27	0.42	0.65	1.02	1.58	2.45	3.81	5.92	9.19
Spawning flow	(ft ³ /s)	9	14	21	32	53	82	124	192	298	465	721	1,118	1,740	2,698	4,189	
	0.02	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.03	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.05	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.07	32	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0
	0.12	53	2	26	39	51	126	126	124	126	126	126	126	123	89	82	2
	0.18	82	2	30	40	74	173	327	324	328	328	328	328	320	266	226	4
	0.27	124	2	29	40	81	210	488	748	748	749	748	748	738	672	476	5
	0.42	192	2	21	29	82	277	599	1,113	2,205	2,206	2,206	2,206	2,194	2,033	1,494	0
	0.65	298	1	12	22	72	295	724	1,605	3,160	4,105	4,103	4,094	4,092	3,932	2,619	826
	1.02	465	0	2	11	51	232	581	1,529	3,221	4,375	4,748	4,702	4,742	4,635	3,272	696
	1.58	721	0	0	3	31	151	425	1,280	2,756	3,848	4,225	4,634	4,629	4,604	3,321	649
	2.45	1,118	0	0	0	3	8	12	50	485	1,144	1,527	1,883	2,273	2,273	2,099	617
	3.81	1,740	0	0	0	0	0	0	0	0	47	119	211	406	486	486	266
5.92	2,698	0	0	0	0	0	0	0	0	2	5	15	39	75	107	94	
9.19	4,189	0	0	0	0	0	0	0	0	0	0	0	0	0	8	17	

Table 4-2. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site WB1. Units of habitat are m²/km.

		Incubation flow															
		(ft ³ /mi ²)	0.08	0.11	0.15	0.21	0.30	0.42	0.59	0.83	1.19	1.60	2.25	3.20	4.51	6.35	8.96
Spawning flow	(ft ³ /s)	46	64	88	125	177	247	353	494	706	953	1,341	1,906	2,683	3,777	5,330	
	0.08	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.11	64	0	58	59	59	59	59	59	59	59	59	59	45	23	23	13
	0.15	88	0	233	482	483	483	483	483	483	483	483	483	405	107	80	39
	0.21	125	0	493	862	1,153	1,152	1,153	1,152	1,153	1,153	1,153	1,152	933	280	192	92
	0.30	177	0	1,077	1,606	2,095	2,530	2,530	2,530	2,532	2,531	2,531	2,530	2,242	844	420	173
	0.42	247	0	1,505	2,661	3,403	3,979	4,603	4,600	4,602	4,602	4,601	4,598	4,300	2,063	695	307
	0.59	353	0	1,422	2,647	3,952	4,838	5,705	6,645	6,643	6,645	6,642	6,632	6,338	3,851	1,381	436
	0.83	494	0	1,266	2,421	3,767	5,381	6,888	8,172	9,044	9,043	9,041	9,028	8,742	6,143	3,329	824
	1.19	706	0	849	1,844	2,978	4,550	6,127	7,791	8,939	9,644	9,640	9,625	9,506	7,002	4,438	1,495
	1.60	953	0	411	932	1,521	2,614	3,758	5,195	6,413	7,276	7,608	7,593	7,590	6,481	4,515	1,808
	2.25	1,341	0	120	263	410	686	1,217	2,114	2,992	3,834	4,260	4,298	4,295	4,275	3,483	1,661
	3.20	1,906	0	0	0	1	21	71	212	512	1,020	1,336	1,405	1,429	1,429	1,369	850
	4.51	2,683	0	0	0	0	0	0	0	1	76	191	236	257	262	260	234
6.35	3,777	0	0	0	0	0	0	0	0	0	2	3	8	12	13	13	
8.96	5,330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4-3. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB0. Units of habitat are m²/km.

		Incubation flow															
		(ft ³ /s/mi ²)	0.02	0.03	0.05	0.07	0.10	0.15	0.24	0.35	0.54	0.82	1.25	1.90	2.89	4.40	6.68
Spawning flow	(ft ³ /s)	7	11	18	25	39	57	89	131	202	305	465	706	1,076	1,637	2,485	
	0.02	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.03	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.05	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.07	25	0	3	6	6	6	6	6	6	6	6	6	6	4	0	0
	0.10	39	0	13	27	30	32	32	32	32	32	32	32	31	26	10	0
	0.15	57	0	28	108	150	186	190	190	190	190	190	190	179	125	84	0
	0.24	89	0	35	211	481	797	840	849	849	849	849	849	838	702	535	0
	0.35	131	0	35	210	524	1,412	2,134	2,891	2,940	2,940	2,940	2,940	2,928	2,785	2,509	0
	0.54	202	0	25	155	368	1,217	2,339	3,621	3,873	3,949	3,949	3,949	3,949	3,899	3,511	0
	0.82	305	0	0	63	183	871	1,933	3,213	3,668	3,963	3,991	3,991	3,991	3,965	3,618	0
	1.25	465	0	0	0	18	523	1,393	2,406	2,776	3,096	3,210	3,215	3,215	3,207	3,008	0
	1.90	706	0	0	0	0	0	0	0	86	223	312	327	338	338	322	0
	2.89	1,076	0	0	0	0	0	0	0	0	0	0	1	6	9	9	0
4.40	1,637	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	
6.68	2,485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4-4. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB1. Units of habitat are m²/km.

		Incubation flow															
		(ft ³ /s/mi ²)	0.08	0.12	0.15	0.22	0.31	0.43	0.60	0.84	1.17	1.61	2.23	3.14	4.38	6.07	8.45
Spawning flow	(ft ³ /s)	35	53	70	102	141	197	275	384	535	739	1,021	1,440	2,006	2,781	3,872	
	0.08	35	91	91	91	91	91	91	91	91	82	50	40	26	17	11	5
	0.12	53	176	289	289	289	289	289	289	289	265	206	186	160	112	102	57
	0.15	70	333	474	599	600	600	600	600	600	571	478	447	408	265	228	98
	0.22	102	525	709	893	1,003	1,003	1,003	1,003	1,003	975	866	825	763	487	382	141
	0.31	141	629	906	1,148	1,324	1,439	1,440	1,439	1,440	1,413	1,295	1,211	1,121	791	581	266
	0.43	197	670	1,009	1,303	1,560	1,725	1,862	1,859	1,862	1,857	1,741	1,619	1,501	1,119	878	482
	0.60	275	598	938	1,328	1,635	1,868	2,087	2,194	2,194	2,193	2,120	2,010	1,869	1,453	1,168	715
	0.84	384	269	496	831	1,149	1,455	1,751	1,966	2,014	2,015	1,991	1,936	1,804	1,457	1,248	846
	1.17	535	59	139	257	478	815	1,158	1,435	1,570	1,642	1,626	1,631	1,569	1,342	1,215	905
	1.61	739	0	0	2	28	73	151	359	488	637	813	802	802	740	616	412
	2.23	1,021	0	0	0	0	0	15	103	186	341	539	701	701	686	607	468
	3.14	1,440	0	0	0	0	0	0	0	2	33	184	374	815	813	777	630
	4.38	2,006	0	0	0	0	0	0	0	0	0	45	117	537	740	739	693
6.07	2,781	0	0	0	0	0	0	0	0	0	0	0	144	253	262	261	
8.45	3,872	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	

Table 4-5. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB2. Units of habitat are m²/km.

Spawning flow	Incubation flow																
	(ft ³ /s/mi ²)	0.13	0.19	0.25	0.38	0.57	0.89	1.28	1.78	1.96	2.68	4.08	5.87	8.54	12.62	27.03	
	(ft ³ /s)	100	150	200	300	450	700	1,000	1,399	1,539	2,099	3,199	4,598	6,697	9,896	21,191	
0.13	100	543	543	543	543	543	543	543	543	543	475	166	121	7	0	0	
0.19	150	1,185	1,437	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,292	362	249	42	0	0	
0.25	200	1,919	2,244	2,408	2,409	2,409	2,409	2,409	2,409	2,409	2,234	753	342	92	2	0	
0.38	300	2,499	3,089	3,319	3,546	3,547	3,547	3,547	3,547	3,547	3,363	1,689	514	157	14	0	
0.57	450	1,868	2,872	3,538	4,200	4,666	4,667	4,667	4,667	4,667	4,487	2,899	1,238	435	30	0	
0.89	700	1,068	1,882	2,599	3,935	4,977	5,675	5,676	5,676	5,676	5,546	4,069	2,533	713	63	0	
1.28	1,000	124	422	790	1,813	3,130	4,192	4,375	4,375	4,375	4,375	3,664	2,533	793	111	0	
1.78	1,399	0	20	54	422	1,312	2,518	2,810	2,859	2,859	2,859	2,678	1,982	784	122	0	
1.96	1,539	0	5	18	242	990	2,146	2,431	2,473	2,473	2,474	2,294	1,698	663	89	0	
2.68	2,099	0	0	0	0	10	328	489	571	573	606	604	572	263	57	0	
4.08	3,199	0	0	0	0	0	0	0	1	1	16	22	22	20	0	0	
5.87	4,598	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8.54	6,697	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12.62	9,896	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27.03	21,191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4-6. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL1. Units of habitat are m²/km.

		Incubation flow															
		(ft ³ /s/mi ²)	0.22	0.27	0.36	0.47	0.60	0.78	1.00	1.31	1.69	2.20	2.84	3.69	4.75	6.17	7.99
Spawning flow	(ft ³ /s)	342	424	565	741	953	1,236	1,589	2,083	2,683	3,495	4,518	5,860	7,554	9,813	12,708	
	0.22	342	431	1,831	1,833	1,833	1,833	1,832	1,832	1,831	1,832	1,832	1,833	1,820	1,818	1,597	1,314
	0.27	424	2,603	2,643	2,644	2,644	2,644	2,643	2,642	2,641	2,642	2,642	2,643	2,630	2,625	2,397	2,057
	0.36	565	3,710	3,803	3,841	3,841	3,842	3,841	3,840	3,838	3,839	3,838	3,840	3,828	3,813	3,612	3,210
	0.47	741	4,886	5,092	5,188	5,227	5,227	5,226	5,225	5,223	5,223	5,222	5,224	5,214	5,188	5,015	4,451
	0.60	953	4,859	5,357	5,565	5,643	5,662	5,660	5,660	5,658	5,657	5,655	5,658	5,651	5,625	5,414	4,666
	0.78	1,236	4,199	5,062	5,722	5,949	6,018	6,028	6,026	6,024	6,025	6,022	6,025	6,018	5,994	5,611	4,456
	1.00	1,589	2,912	3,699	4,484	4,952	5,086	5,151	5,169	5,165	5,167	5,163	5,166	5,164	5,144	4,831	3,510
	1.31	2,083	1,318	1,768	2,279	2,600	2,786	2,908	3,006	3,040	3,040	3,039	3,039	3,038	3,030	2,857	2,089
	1.69	2,683	314	435	605	772	880	992	1,125	1,250	1,270	1,270	1,270	1,270	1,266	1,223	1,060
	2.20	3,495	0	9	64	132	192	244	335	509	589	613	613	612	611	602	556
	2.84	4,518	0	0	0	0	0	5	20	120	193	241	253	253	253	251	220
3.69	5,860	0	0	0	0	0	0	5	47	84	117	126	126	126	126	119	
4.75	7,554	0	0	0	0	0	0	0	2	12	20	22	22	22	22	22	
6.17	9,813	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7.99	12,708	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4-7. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL2. Units of habitat are m²/km.

		Incubation flow															
(ft³/s/mi²)		0.28	0.36	0.46	0.58	0.74	0.95	1.21	1.54	1.98	2.52	3.22	4.11	5.25	6.70	8.55	
(ft³/s)		466	597	762	974	1,243	1,585	2,023	2,577	3,297	4,208	5,373	6,855	8,751	11,172	14,261	
Spawning flow	0.28	466	2,219	2,220	2,220	2,220	2,219	2,214	2,201	2,147	1,801	1,195	457	361	239	82	29
	0.36	597	2,216	2,380	2,381	2,381	2,380	2,380	2,375	2,330	1,985	1,355	629	500	335	124	63
	0.46	762	2,009	2,478	2,716	2,716	2,716	2,716	2,715	2,687	2,380	1,785	1,097	852	539	139	88
	0.58	974	1,625	2,294	2,661	2,836	2,836	2,836	2,835	2,835	2,617	2,101	1,467	1,126	690	133	94
	0.74	1,243	1,114	1,771	2,297	2,727	3,117	3,118	3,117	3,118	3,100	2,682	2,065	1,566	929	114	85
	0.95	1,585	531	1,091	1,549	2,032	2,480	3,215	3,214	3,215	3,214	3,123	2,587	1,951	1,139	101	75
	1.21	2,023	95	287	655	1,044	1,487	2,246	2,428	2,428	2,427	2,428	2,175	1,635	944	62	57
	1.54	2,577	0	6	72	319	694	1,421	1,609	1,798	1,798	1,797	1,779	1,327	748	9	9
	1.98	3,297	0	0	0	10	143	561	743	986	1,219	1,219	1,219	922	433	45	23
	2.52	4,208	0	0	0	0	0	8	86	307	668	833	833	821	607	272	162
	3.22	5,373	0	0	0	0	0	0	0	57	330	790	844	844	975	678	245
	4.11	6,855	0	0	0	0	0	0	0	0	33	275	592	867	867	695	91
	5.25	8,751	0	0	0	0	0	0	0	0	0	10	137	480	727	687	123
	6.70	11,172	0	0	0	0	0	0	0	0	0	0	4	32	183	345	304
8.55	14,261	0	0	0	0	0	0	0	0	0	0	0	0	0	17	34	

Table 4-8. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL3. Units of habitat are m²/km.

		Incubation flow															
(ft³/s/mi²)		0.28	0.36	0.46	0.58	0.76	0.98	1.26	1.62	2.09	2.69	3.46	4.45	5.73	7.38	9.50	
Spawning flow	(ft³/s)	505	650	833	1,059	1,377	1,779	2,291	2,951	3,798	4,889	6,294	8,105	10,435	13,435	17,297	
	0.28	505	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,670	8,224	5,091	840	79	0
	0.36	650	10,362	10,546	10,546	10,546	10,546	10,546	10,546	10,546	10,546	10,538	10,153	6,691	1,501	273	33
	0.46	833	10,604	11,079	11,270	11,270	11,270	11,270	11,270	11,270	11,270	11,262	11,023	7,980	2,599	687	212
	0.58	1,059	9,535	10,381	10,889	11,338	11,669	11,729	11,729	11,729	11,729	11,724	11,532	8,377	3,978	1,169	380
	0.76	1,377	7,111	8,806	9,819	11,433	12,231	12,376	12,376	12,376	12,376	12,373	12,247	8,818	5,804	1,942	599
	0.98	1,779	4,006	5,665	9,796	11,554	12,943	13,195	13,195	13,195	13,195	13,195	13,153	12,114	10,209	4,566	832
	1.26	2,291	591	1,400	3,163	6,015	8,729	9,230	9,357	9,342	9,348	9,355	9,357	9,130	8,589	5,008	1,203
	1.62	2,951	73	309	710	2,141	5,455	6,377	6,598	6,746	6,747	6,747	6,747	6,722	6,534	4,443	1,508
	2.09	3,798	0	0	38	244	1,095	1,821	2,237	2,485	2,586	2,586	2,584	2,577	2,499	1,560	560
	2.69	4,889	0	0	0	1	69	400	686	1,051	1,283	1,364	1,358	1,358	1,313	1,000	402
	3.46	6,294	0	0	0	0	0	0	32	215	418	564	668	663	664	642	293
	4.45	8,105	0	0	0	0	0	0	0	0	19	102	211	365	353	365	237
5.73	10,435	0	0	0	0	0	0	0	0	0	2	32	134	199	198	156	
7.38	13,435	0	0	0	0	0	0	0	0	0	0	0	8	34	61	47	
9.50	17,297	0	0	0	0	0	0	0	0	0	0	0	0	2	7	9	

Table 4-9. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR0. Units of habitat are m²/km.

		Incubation flow															
(ft ³ /s/mi ²)		0.12	0.16	0.22	0.28	0.37	0.50	0.66	0.87	1.19	1.56	2.06	2.72	3.59	4.78	6.31	
Spawning flow	(ft ³ /s)	14	18	25	32	42	56	74	99	134	177	233	307	406	540	713	
	0.12	14	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	0.16	18	5	10	11	11	11	11	11	11	11	11	10	3	2	1	1
	0.22	25	39	55	81	81	81	81	81	81	81	80	75	64	49	41	34
	0.28	32	82	104	142	170	171	171	172	172	172	170	162	150	96	70	63
	0.37	42	88	128	177	230	273	273	273	273	273	271	263	245	180	112	92
	0.50	56	89	133	209	542	628	721	720	721	720	719	710	688	606	445	391
	0.66	74	89	138	323	873	1,121	1,243	1,559	1,549	1,552	1,534	1,553	1,529	1,436	977	796
	0.87	99	79	125	373	1,134	1,530	1,670	1,964	2,109	2,109	2,084	2,107	2,094	1,992	1,473	1,210
	1.19	134	55	92	362	1,145	1,628	1,934	2,338	2,550	2,604	2,554	2,585	2,602	2,551	2,031	1,764
	1.56	177	28	63	346	1,134	1,650	2,015	2,578	2,818	2,972	3,069	3,070	3,070	3,047	2,553	2,279
	2.06	233	6	27	212	936	1,382	1,663	2,076	2,308	2,558	2,708	2,884	2,884	2,882	2,849	2,659
	2.72	307	0	18	185	815	1,194	1,430	1,769	1,978	2,259	2,496	2,707	2,788	2,789	2,785	2,744
3.59	406	0	0	1	9	148	286	492	618	847	1,087	1,329	1,463	1,526	1,526	1,525	
4.78	540	0	0	0	0	1	1	27	104	241	411	619	774	897	960	959	
6.31	713	0	0	0	0	0	0	0	1	10	55	176	263	354	433	457	

Table 4-10. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR1. Units of habitat are m²/km.

Spawning flow	Incubation flow																
	(ft ³ /s/mi ²)	0.17	0.23	0.32	0.44	0.62	0.85	1.19	1.65	2.30	3.19	4.43	6.16	8.55	11.88	16.51	
	(ft ³ /s)	28	39	54	76	105	146	203	282	393	545	758	1,053	1,463	2,032	2,824	
0.17	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.23	39	31	95	95	95	95	95	95	95	95	95	95	95	95	95	74	41
0.32	54	51	131	161	162	162	162	162	162	162	162	162	158	158	117	51	
0.44	76	191	340	400	425	425	425	425	425	425	425	425	237	217	158	58	
0.62	105	321	734	817	860	896	896	896	896	896	896	896	521	348	262	74	
0.85	146	339	855	1,067	1,166	1,260	1,322	1,322	1,321	1,322	1,322	1,322	943	698	514	133	
1.19	203	304	824	1,221	1,932	2,211	2,322	2,343	2,344	2,344	2,344	2,344	1,995	1,729	1,464	222	
1.65	282	209	713	1,094	1,919	2,424	2,623	2,663	2,670	2,670	2,670	2,670	2,373	2,129	1,881	381	
2.30	393	62	328	558	979	1,451	1,706	1,790	1,827	1,841	1,841	1,841	1,738	1,630	1,397	368	
3.19	545	0	0	2	53	365	591	676	751	789	791	791	792	760	583	230	
4.43	758	0	0	0	0	0	15	61	104	143	162	165	165	164	136	66	
6.16	1,053	0	0	0	0	0	0	0	0	3	5	8	8	8	8	6	
8.55	1,463	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11.88	2,032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
16.51	2,824	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4-11. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR2. Units of habitat are m²/km.

Spawning flow	Incubation flow																
	(ft ³ /s/mi ²)	0.23	0.30	0.38	0.49	0.64	0.82	1.07	1.38	1.78	2.30	2.97	3.83	4.95	6.39	9.37	
	(ft ³ /s)	70	90	117	151	195	252	325	420	543	701	905	1,169	1,511	1,951	2,859	
0.23	70	995	993	996	996	988	984	970	941	747	483	331	224	34	1	0	
0.30	90	1,280	1,370	1,371	1,371	1,371	1,371	1,361	1,333	1,140	757	545	396	60	1	0	
0.38	117	1,571	1,708	1,839	1,841	1,841	1,841	1,836	1,809	1,621	1,207	870	669	188	10	0	
0.49	151	1,993	2,284	2,507	2,718	2,721	2,721	2,720	2,702	2,518	2,111	1,663	1,393	500	75	6	
0.64	195	2,932	3,624	4,094	4,477	4,785	4,788	4,788	4,785	4,624	4,226	3,726	3,358	1,931	159	33	
0.82	252	2,717	3,823	4,472	4,982	5,366	5,718	5,720	5,720	5,682	5,347	4,867	4,393	2,673	440	64	
1.07	325	2,262	3,314	4,125	4,864	5,407	5,878	6,174	6,177	6,177	6,078	5,694	5,159	3,152	811	120	
1.38	420	1,891	2,821	3,531	4,300	4,974	5,542	5,920	6,169	6,171	6,171	5,971	5,494	3,329	968	199	
1.78	543	1,617	2,397	2,963	3,574	4,174	4,718	5,182	5,514	5,777	5,778	5,776	5,488	3,310	996	253	
2.30	701	858	1,389	1,769	2,125	2,563	3,007	3,409	3,725	3,968	4,185	4,187	4,138	2,652	949	293	
2.97	905	1	23	67	117	186	310	495	701	890	1,103	1,248	1,250	1,114	751	368	
3.83	1,169	0	1	5	15	33	76	133	223	329	486	633	685	685	624	359	
4.95	1,511	0	0	0	2	6	21	39	64	109	203	312	398	412	411	321	
6.39	1,951	0	0	0	0	1	1	5	15	28	62	118	180	206	209	203	
9.37	2,859	0	0	0	0	0	0	0	0	0	4	22	44	56	64	171	

Table 4-12. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL1. Units of habitat are hectares.

		Discharge # 2															
		(ft ³ /s/mi ²)	0.22	0.27	0.36	0.47	0.60	0.78	1.00	1.31	1.69	2.20	2.84	3.69	4.75	6.17	7.99
Discharge # 1	(ft ³ /s)	342	424	565	741	953	1,236	1,589	2,083	2,683	3,495	4,518	5,860	7,554	9,813	12,708	
	0.22	342	2.83	2.82	2.82	2.82	2.82	2.79	2.79	2.82	2.72	2.50	2.03	1.73	1.44	0.99	0.79
	0.27	424	2.82	3.04	3.04	3.03	3.03	3.00	3.00	3.03	2.92	2.70	2.22	1.91	1.59	1.11	0.88
	0.36	565	2.82	3.04	3.18	3.18	3.17	3.14	3.14	3.17	3.07	2.84	2.35	2.02	1.69	1.19	0.94
	0.47	741	2.82	3.03	3.18	3.30	3.29	3.27	3.27	3.29	3.18	2.95	2.44	2.11	1.77	1.26	0.99
	0.60	953	2.82	3.03	3.17	3.29	3.39	3.36	3.36	3.38	3.27	3.04	2.52	2.19	1.85	1.32	1.04
	0.78	1,236	2.79	3.00	3.14	3.27	3.36	3.56	3.55	3.56	3.46	3.22	2.70	2.35	2.00	1.46	1.16
	1.00	1,589	2.79	3.00	3.14	3.27	3.36	3.55	3.67	3.67	3.56	3.32	2.79	2.44	2.09	1.54	1.22
	1.31	2,083	2.82	3.03	3.17	3.29	3.38	3.56	3.67	3.82	3.69	3.44	2.91	2.55	2.19	1.63	1.31
	1.69	2,683	2.72	2.92	3.07	3.18	3.27	3.46	3.56	3.69	3.82	3.57	3.02	2.66	2.30	1.74	1.40
	2.20	3,495	2.50	2.70	2.84	2.95	3.04	3.22	3.32	3.44	3.57	3.70	3.12	2.76	2.39	1.82	1.47
	2.84	4,518	2.03	2.22	2.35	2.44	2.52	2.70	2.79	2.91	3.02	3.12	3.29	2.88	2.47	1.86	1.53
	3.69	5,860	1.73	1.91	2.02	2.11	2.19	2.35	2.44	2.55	2.66	2.76	2.88	2.95	2.53	1.89	1.55
	4.75	7,554	1.44	1.59	1.69	1.77	1.85	2.00	2.09	2.19	2.30	2.39	2.47	2.53	2.60	1.91	1.57
6.17	9,813	0.99	1.11	1.19	1.26	1.32	1.46	1.54	1.63	1.74	1.82	1.86	1.89	1.91	2.03	1.60	
7.99	12,708	0.79	0.88	0.94	0.99	1.04	1.16	1.22	1.31	1.40	1.47	1.53	1.55	1.57	1.60	1.69	

Table 4-13. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL2. Units of habitat are hectares.

		Discharge # 2															
(ft³/s/mi²)		0.28	0.36	0.46	0.58	0.74	0.95	1.21	1.54	1.98	2.52	3.22	4.11	5.25	6.70	8.55	
Discharge # 1	(ft³/s)	466	597	762	974	1,243	1,585	2,023	2,577	3,297	4,208	5,373	6,855	8,751	11,172	14,261	
	0.28	466	5.56	5.56	5.56	5.56	5.56	5.55	5.54	5.33	4.85	4.11	3.23	2.73	2.23	1.51	0.91
	0.36	597	5.56	5.71	5.71	5.71	5.71	5.70	5.69	5.47	4.98	4.22	3.32	2.81	2.30	1.56	0.94
	0.46	762	5.56	5.71	5.86	5.86	5.86	5.85	5.84	5.62	5.12	4.34	3.42	2.90	2.38	1.62	0.98
	0.58	974	5.56	5.71	5.86	6.06	6.06	6.05	6.03	5.81	5.30	4.50	3.55	3.02	2.48	1.69	1.04
	0.74	1,243	5.56	5.71	5.86	6.06	6.25	6.25	6.23	5.99	5.47	4.66	3.67	3.13	2.58	1.77	1.09
	0.95	1,585	5.55	5.70	5.85	6.05	6.25	6.36	6.34	6.11	5.57	4.75	3.75	3.20	2.64	1.80	1.12
	1.21	2,023	5.54	5.69	5.84	6.03	6.23	6.34	6.47	6.23	5.68	4.85	3.83	3.26	2.70	1.84	1.15
	1.54	2,577	5.33	5.47	5.62	5.81	5.99	6.11	6.23	6.35	5.78	4.93	3.90	3.33	2.75	1.89	1.19
	1.98	3,297	4.85	4.98	5.12	5.30	5.47	5.57	5.68	5.78	5.94	5.06	4.02	3.43	2.84	1.93	1.23
	2.52	4,208	4.11	4.22	4.34	4.50	4.66	4.75	4.85	4.93	5.06	5.19	4.10	3.50	2.91	1.95	1.25
	3.22	5,373	3.23	3.32	3.42	3.55	3.67	3.75	3.83	3.90	4.02	4.10	4.23	3.60	2.98	1.88	1.23
	4.11	6,855	2.73	2.81	2.90	3.02	3.13	3.20	3.26	3.33	3.43	3.50	3.60	3.67	3.05	1.79	1.18
	5.25	8,751	2.23	2.30	2.38	2.48	2.58	2.64	2.70	2.75	2.84	2.91	2.98	3.05	3.11	1.70	1.14
	6.70	11,172	1.51	1.56	1.62	1.69	1.77	1.80	1.84	1.89	1.93	1.95	1.88	1.79	1.70	2.25	1.28
	8.55	14,261	0.91	0.94	0.98	1.04	1.09	1.12	1.15	1.19	1.23	1.25	1.23	1.18	1.14	1.28	1.52

Table 4-14. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL3. Units of habitat are hectares.

		Discharge # 2															
		(ft ³ /s/mi ²)	0.28	0.36	0.46	0.58	0.76	0.98	1.26	1.62	2.09	2.69	3.46	4.45	5.73	7.38	9.50
Discharge # 1	(ft ³ /s)	505	650	833	1,059	1,377	1,779	2,291	2,951	3,798	4,889	6,294	8,105	10,435	13,435	17,297	
	0.28	505	3.53	3.48	3.39	3.27	3.15	2.97	2.74	2.44	2.06	1.76	1.36	0.90	0.31	0.21	0.24
	0.36	650	3.48	3.91	3.80	3.68	3.55	3.14	2.96	2.71	2.36	2.03	1.57	1.04	0.39	0.26	0.28
	0.46	833	3.39	3.80	4.29	4.16	4.02	3.49	3.13	2.95	2.68	2.29	1.78	1.16	0.46	0.31	0.32
	0.58	1,059	3.27	3.68	4.16	4.59	4.44	3.90	3.40	3.11	2.93	2.48	1.92	1.26	0.50	0.33	0.35
	0.76	1,377	3.15	3.55	4.02	4.44	4.72	4.25	3.74	3.29	3.09	2.61	2.01	1.32	0.52	0.35	0.37
	0.98	1,779	2.97	3.14	3.49	3.90	4.25	4.52	4.02	3.53	3.15	2.38	1.84	1.19	0.45	0.31	0.34
	1.26	2,291	2.74	2.96	3.13	3.40	3.74	4.02	4.14	3.72	3.27	2.26	1.77	1.16	0.46	0.32	0.34
	1.62	2,951	2.44	2.71	2.95	3.11	3.29	3.53	3.72	3.95	3.33	2.78	2.11	1.33	0.52	0.35	0.37
	2.09	3,798	2.06	2.36	2.68	2.93	3.09	3.15	3.27	3.33	3.49	2.85	2.11	1.31	0.50	0.33	0.36
	2.69	4,889	1.76	2.03	2.29	2.48	2.61	2.38	2.26	2.78	2.85	3.02	2.07	1.25	0.49	0.32	0.35
	3.46	6,294	1.36	1.57	1.78	1.92	2.01	1.84	1.77	2.11	2.11	2.07	2.39	1.15	0.46	0.32	0.32
	4.45	8,105	0.90	1.04	1.16	1.26	1.32	1.19	1.16	1.33	1.31	1.25	1.15	1.59	0.33	0.24	0.24
	5.73	10,435	0.31	0.39	0.46	0.50	0.52	0.45	0.46	0.52	0.50	0.49	0.46	0.33	0.76	0.18	0.12
7.38	13,435	0.21	0.26	0.31	0.33	0.35	0.31	0.32	0.35	0.33	0.32	0.32	0.24	0.18	0.58	0.12	
9.50	17,297	0.24	0.28	0.32	0.35	0.37	0.34	0.34	0.37	0.36	0.35	0.32	0.24	0.12	0.12	0.64	

Appendix 5. User Documentation for the Delaware River Decision Support System

Getting Started

The very first step in using the Delaware River Decision Support System (DRDSS) is to make sure that the computational infrastructure is up to the task. The system appears to run adequately on computers having a 3 GHz processor and at least 1 GB of RAM. In addition, we have found that the DRDSS requires Excel 2003 in order to load all the required spreadsheets. Excel 2002 will open some of them, but not all. Each run of the DRDSS requires a separate directory containing all the spreadsheets and any supporting files. Consequently, the volume of hard drive space consumed by DRDSS directories can accumulate rapidly. A convenient and economical solution to this problem is to store DRDSS directories on an external hard drive. External hard drives provide good system backup as well as ease of transport from one computer to another (especially useful for public hearings or meetings where multiple runs are to be displayed). Although the most of the graphics displays in the DRDSS are formatted to be distinguishable in black and white, a color printer capable of handling tabloid-sized paper (11 x 17 in) or larger will provide greater definition of graphs and charts. In some cases, access to a large-format plotter capable of generating poster-sized printouts may be desirable.

The DRDSS consists of five linked spreadsheets titled DSS_AGG.XLS, DSS_WB.XLS, DSS_EB.XLS, DSS_DEL.XLS, and DSS_NVR.XLS. In addition, there are two utility spreadsheets, "met_data.xls" and "OASIS reformatterV2_1.xls" that are integral components to the DRDSS. "Met_data.xls" contains the meteorological data (historical, normal, and worst-case) needed to perform temperature simulations. The OASIS reformatter converts hydrologic information from OASIS into the format required as input to the DRDSS.

None of these spreadsheets is adequately protected to prevent inadvertent damage caused by keystroke errors or information pasted into the wrong places. Even minor modifications to the code can render the entire system useless, so users are advised to work on copies of the DRDSS master files instead of working on the original version. Before doing anything else, the user should create a directory named according to the alternatives to be tested (for example, REV1_REV7 as a directory name). The DSS_AGG worksheet, all four of the SUBS (DSS_WB.XLS, DSS_EB.XLS, DSS_DEL.XLS, and DSS_NVR.XLS), and the two utility files should be copied into this directory. The DRDSS cannot be run from the native medium (in this case, a CD) and must be copied to a hard drive. It is helpful to include a small "README" file to this directory that describes the OASIS modifications performed for the comparisons embodied in the particular DRDSS run. These two steps will provide backup in the event that the DRDSS files are compromised and will assist the user in recalling the changes made to test an alternative. Describing the characteristics of the run is especially important if multiple runs are made because some of the changes may be subtle. It can be extremely frustrating to arrive at a promising solution and not remember how it was derived.

Preparing Input Data

Importing Data from OASIS to DRDSS

There are several critical details to keep in mind before starting. First, order is critical, both temporally and spatially. If data are not entered in the order expected by the DSS, the results will

be incorrect; in such a case, the only way to gain correct results would be to start over. Incorrect or erroneous applications of the DRDSS may be virtually indistinguishable from correct applications. Finding mistakes can be traumatic, especially if they are found during a public hearing or negotiations setting. Fixing them can be time-consuming and frustrating.

An example of this type of mix-up occurred during the beta-testing of version 2.0, where a user entered OASIS output for the baseline period 1990 – 2000, but used the record from 1960 – 1970 for the alternative. The mistake was detected by the decisionmakers, who realized that the outcome displayed on the summary scoring page was counterintuitive. In this case, the intuition of the decisionmakers was correct and the model results were wrong.

The DRDSS operates on a 10-year period of water years, which begin on October 1 (October 1, 1995, is the first day of water year 1996). Any 10-year period between 1953 and 2000 can be used, so long as it starts on October 1, ends on September 30, and has 10 years of data between the two. Note that OASIS output extends back to 1928. The usable period in the DRDSS extends only to 1953 because of limitations of the meteorological database.

Output derived from OASIS consists of at least two individual text files containing daily flow data, reservoir storage and release data, system-wide drought trigger data, Montague flows, and export data for New York City and the Delaware and Raritan canal diversion in New Jersey. One file contains data for the baseline and the other contains data for the alternative. The spatial order of the data from left to right is the same in the OASIS text files as it is in the DRDSS with one major exception: OASIS does not produce flow statistics for the Beaverkill, but there is a column in the DRDSS “FLOWS” sheet for the Beaverkill. The historical discharges of the Beaverkill have been incorporated in the “OASIS reformatter.xls” spreadsheet, provided to convert OASIS output to the correct spatial order required to the DRDSS.

Preparing Data for Import from OASIS

1. Open the “OASIS formatter.xls” spreadsheet and click on the page labeled “From_OASIS” (Fig. 5-1).
2. Open the first (baseline) OASIS text file in a new Excel workbook as a space delimited file.
3. Go to the first data value (the first Stilesville flow) in the newly opened OASIS workbook. Select and copy all the data values. Do not copy dates or column headers.
4. Open the “From_OASIS” page in the OASIS_formatter spreadsheet and paste the OASIS data to cell B15 (Fig 5-1).
5. As soon as the OASIS data are pasted into the “From_OASIS” sheet, the “To_DSS” sheet is automatically updated.

Exporting Data to the DRDSS

6. Click on the tab “To_DSS” in the OASIS formatter spreadsheet (fig. 5-2).
7. Move the cursor to the first day of the first water year to be processed in the DRDSS (for example, October 1, 1959, for water year 1960).
8. Select and copy the entire block of data (including the date) from this point to the last data column for the last day of the tenth water year from the start date (in this example, September 30, 1969; fig. 5-2).

Microsoft Excel - OASIS reformatter.xls

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B15 45

DATE	Stilesville flow cfs	Hale Eddy flow cfs	Downsvill flow cfs	Harvard flow cfs	Fishes Edd flow cfs	Callicoon flow cfs	Woodbourn flow cfs	Bridgeville flow cfs	Oakland V flow cfs	Montague Flow cfs	Cannonsv Storage bg	Cannonsv release cfs	Pepacton Storage bg	Pepacton release cfs
1/1/1928	45	499.5	35	804.4	3178.3	2531	154.3	431.1	726.8	7040	69.1	45	103	35
1/2/1928	45	389.6	35	329.5	1691.4	3759	48.1	159.7	250.3	9573	69.7	45	103.4	35
1/3/1928	45	389.6	35	253.4	1127.5	2289	66.1	171.9	270.8	6578	70.2	45	103.6	35
1/4/1928	45	360.5	35	239.3	1021.5	1949	66.1	179.4	283.6	5274	70.7	45	103.6	35
1/5/1928	45	315.5	35	247.4	1045.3	1924	64.1	173.2	273	4929	71	45	103.7	35
1/6/1928	45	282.5	35	236.3	1008	1869	66.1	178.5	282	5381	71.3	45	103.7	35
1/7/1928	45	252.4	35	241.3	1021.3	1818	70.1	194.7	309.5	5171	71.5	45	103.7	35
1/8/1928	45	276.4	35	241.3	1024.7	1869	72.1	200.8	320	5917	71.8	45	103.8	35
1/9/1928	45	332.5	35	212.3	900.6	1873	74.1	208.4	333	6524	72.1	45	103.9	35
1/10/1928	45	252.4	35	207.4	864.6	1669	69	194	306.3	4838	72.3	45	103.9	35
1/11/1928	45	248.4	35	184.3	763.5	1499	63.1	173.1	272.9	4186	72.5	45	103.9	35
1/12/1928	45	236.3	35	181.3	735.1	1416	64.1	173.1	272.8	3718	72.6	45	103.9	35
1/13/1928	45	247.4	35	160.2	648	1342	63.1	171.5	270.1	3904	72.8	45	103.8	35
1/14/1928	45	247.4	35	205.3	819.6	1483	78.2	218	349.5	3207	72.9	45	103.8	35
1/15/1928	45	210.2	35	168.3	699	1391	69	195.7	311.3	3310	73	45	103.8	35
1/16/1928	45	263.4	35	152.2	604.4	1308	58	155.2	242.6	3410	73.2	45	103.7	35
1/17/1928	45	199.2	35	160.2	626.7	1210	62	164	257.4	3273	73.3	45	103.6	35
1/18/1928	45	184.2	35	148.2	584.9	1119	59.1	154.6	241.6	3129	73.3	45	103.5	35
1/19/1928	45	203.3	35	140.2	545.2	1097	53.1	132.5	204.8	2811	73.4	45	103.4	35

Figure 5-1. The “From_OASIS” page of “OASIS_formatter.xls.” Outlined box in figure shows where the data copied from the OASIS text file are to be pasted.

Microsoft Excel - OASIS reformatter.xls

File Edit View Insert Format Tools Data Window Help

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A11611 =From_OASIS!A11611

DATE	Stilesville WB0 Q	Hale Eddy WB1 Q	Downsvill EBO Q	Harvard EB1 Q	BeaverKill smoothed Q	Fishes Edd EB2 Q	Callicoon* Del 1 Q	Callicoon* Del 2 Q	Callicoon Del 3 Q	Woodbourn Nvr 0 Q	Bridgeville Nvr 1 Q	Oakland V Nvr 2 Q	Montague Flow Q	Cannonsv Storage Vol bg
9/29/1959	205.90	269.10	133.00	175.00	123.25	333.30	860.5	881.25	902.00	140.80	117.20	179.60	1922.00	31.30
9/30/1959	192.00	227.60	151.90	175.00	280	263.20	622.4	688.2	754.00	128.70	120.50	184.80	1735.00	30.90
10/1/1959	171.80	229.90	50.80	175.00	903.1	646.80	490.8	601.9	713.00	79.80	137.10	212.30	1676.00	30.80
10/2/1959	137.90	233.40	35.00	370.60	821.4	1509.40	876.7	1122.35	1368.00	53.10	141.70	220.10	2596.00	30.70
10/3/1959	440.60	430.50	45.00	193.30	554.45	874.60	1742.8	1849.4	1956.00	88.70	98.60	149.10	2728.00	30.50
10/4/1959	437.10	476.90	59.80	175.00	401.7	620.90	1305.1	1400.55	1496.00	107.80	106.40	161.70	2346.00	30.20
10/5/1959	203.00	282.00	80.80	175.00	493.4	532.50	1097.8	1165.4	1233.00	119.70	109.60	167.00	1759.00	30.10
10/6/1959	133.90	241.40	35.00	199.30	955.4	804.30	814.5	888.75	963.00	116.80	116.40	178.10	1566.00	30.00
10/7/1959	45.00	349.50	35.00	365.60	1489.15	1505.10	1045.7	1229.35	1413.00	64.70	138.50	214.70	2075.00	30.10
10/8/1959	45.00	226.30	35.00	507.90	3966.5	2204.40	1854.6	2335.8	2817.00	59.10	156.90	245.50	4143.00	30.30
10/9/1959	45.00	941.70	35.00	1583.80	4030.35	6744.40	2430.7	4363.85	6297.00	98.20	280.20	457.70	9364.00	31.40
10/10/1959	45.00	286.50	35.00	860.50	2742.55	4483.90	7686.1	8584.05	9482.00	76.20	227.10	365.20	13921.00	32.30
10/11/1959	172.90	193.10	35.00	560.00	1821.45	2722.20	4770.4	4816.7	4863.00	60.00	164.50	258.30	9419.00	32.70
10/12/1959	124.90	237.20	35.00	438.80	1365.1	2040.70	2915.3	3075.15	3235.00	53.10	133.60	206.60	5021.00	33.00
10/13/1959	144.90	220.00	35.00	342.50	1137	1567.10	2277.9	2407.95	2538.00	51.00	124.60	191.70	4014.00	33.20
10/14/1959	101.80	235.70	35.00	314.50	994.4	1391.90	1787.1	1955.05	2123.00	51.00	122.50	188.20	3284.00	33.40
10/15/1959	107.80	223.40	35.00	279.40	839.9	1225.90	1627.6	1793.8	1960.00	51.00	124.40	191.30	3563.00	33.60
10/16/1959	137.90	217.50	35.00	233.40	706.8	1012.70	1449.3	1577.65	1706.00	52.60	114.30	174.70	2936.00	33.70
10/17/1959	149.80	222.10	35.00	205.30	646.05	867.70	1230.2	1355.1	1480.00	51.70	115.40	176.60	2672.00	33.70

Figure 5-2. The “To_DSS” page of “OASIS_formatter.xls.” In the example, the first date of the first water year of interest is October 1, 1959, located at cell A11611.

9. In the DSS_AGG.xls workbook, click on the tab labeled “Flows” (fig. 5-3). This worksheet contains the flows, storage volumes, releases, and spills computed by OASIS. Flows are arrayed by date (row) and by study area (column) in two blocks (left and right). The first block pertains to the baseline, and starts at cell A11 (fig 5-3). The second block is for the alternative, and it starts in cell AB11. Do not forget to update the second block with the same period of record as the first one.
10. Having copied the 10-year data baseline block from “OASIS formatter.xls,” **SELECT** cell A11 on the “Flows” page of DSS_AGG.xls and **PASTE SPECIAL/VALUES**. The data must be pasted as values because the dates in the data block from “OASIS formatter.xls” are actually formulas.

Oasis 1 and 7 1990-2000, Norm met data														
				Start Year		End Year								
		dp_rev1_v2_feb06		1990 to		2000								
		dp_rev7_v2feb06		1990 to		2000								
Paste Data Below														
		dp_rev1_v2_feb06												
	Stilesville	Hale Eddy	Downsville	Harvard	BeaverKill	Fishes Eddy	Callicoon Del1	Callicoon Del2	Callicoon Del3	Woodbourn Nwr0	Bridgeville Nwr1	Godeffroy Nwr2	Montague	
	WB0	WB1	EB0	EB1	EB2	Q	Q	Q	Q	Q	Q	Q	Q	
	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	
10 Date	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	
11	10/1/1990	736.20	680.90	70.00	97.00	164.40	261.40	749.80	808.90	868.00	52.00	60.50	88.30	1702.0
12	10/2/1990	736.70	760.80	70.00	90.00	160.70	250.70	942.30	998.15	1054.00	51.00	58.90	85.80	1774.0
13	10/3/1990	520.10	590.90	70.00	89.00	146.60	235.60	1011.50	1064.75	1118.00	51.00	57.80	84.00	1809.0
14	10/4/1990	649.60	637.50	70.00	92.00	149.00	241.00	826.50	883.75	941.00	52.00	60.50	88.30	1796.0
15	10/5/1990	651.10	680.90	70.00	107.00	208.00	315.00	878.50	968.75	1059.00	56.00	75.60	112.00	1997.0
16	10/6/1990	777.80	775.30	70.00	98.00	200.00	298.00	995.90	1062.95	1130.00	53.00	65.60	96.30	1858.0
17	10/7/1990	844.40	853.90	70.00	94.00	170.60	264.60	1073.30	1146.65	1220.00	52.00	61.50	89.70	1884.0
18	10/8/1990	62.80	270.60	70.00	91.00	157.00	248.00	1118.50	1169.75	1221.00	51.00	59.60	86.70	1764.0
19	10/9/1990	258.50	229.10	70.00	91.00	149.00	240.00	518.60	604.80	691.00	51.00	59.10	86.00	1606.0
20	10/10/1990	298.70	328.50	70.00	100.00	152.00	252.00	469.10	543.05	617.00	51.00	58.40	85.00	2469.0
21	10/11/1990	45.00	150.50	70.00	107.00	170.40	277.40	590.50	644.25	708.00	54.00	67.20	98.80	1466.0
22	10/12/1990	45.00	102.80	70.00	155.00	378.20	533.20	427.90	508.45	589.00	62.00	97.90	148.00	1614.0
23	10/13/1990	45.00	143.00	70.00	212.00	702.50	914.50	636.00	750.50	865.00	75.00	146.00	227.30	1866.0
24	10/14/1990	45.00	188.00	70.00	279.00	2151.10	2430.10	1057.50	1347.75	1638.00	88.00	195.10	310.30	2107.0
25	10/15/1990	45.00	143.00	70.00	221.00	1079.70	1300.70	2618.10	2645.55	2673.00	67.00	129.50	199.70	4030.0
26	10/16/1990	45.00	123.00	70.00	189.00	758.80	947.80	1443.70	1530.85	1618.00	62.00	102.70	155.70	2988.0
27	10/17/1990	45.00	111.00	70.00	170.00	618.40	788.40	1070.80	1166.40	1262.00	59.00	92.50	139.20	2303.0
28	10/18/1990	45.00	231.00	70.00	339.00	668.00	1007.00	899.40	993.70	1088.00	68.00	118.90	182.30	2119.0
29	10/19/1990	45.00	727.00	70.00	1070.00	2249.20	3319.20	1238.00	2212.50	3187.00	114.00	275.60	449.60	4421.0

Figure 5-3. The “Flows” page of “DSS_AGG.xls,” with outlined cell indicating where to paste baseline data from “OASIS formatter.xls.”

11. Open the second OASIS text file, containing information for the alternative and repeat steps 1 – 10, but pasting the data from “OASIS_reformatter.xls” in cell AE11 on the “Flows” page of “DSS_AGG.xls” (fig. 5-4). Note that the dates for the baseline and the alternative are copied and pasted into their respective locations independently from each “OASIS_reformatter.xls” scenario. The DRDSS compares the ranges of dates to confirm that the same period of record was used for both cases. The DRDSS will run successfully if mismatched data sets are used, but the user is alerted to the disparity on the scoring pages.

Alternative Date	Stilesville V/B0	Hake Eddy V/B1	Downsville E/B0	Harvard E/B1	BeaverKill	Fisht Eddy E/B2	Callicoon Del1	Callicoon Del2	Callicoon Del3	Woodbour Nvr0	Bridgeville Nvr1	Godet Nvr2
10/1/1990	538.20	522.20	148.00	175.00	171	346.00	614	673.5	733.00	138.90	115.90	11
10/2/1990	587.80	614.90	155.00	175.00	156	321.00	888.2	824.1	980.00	141.90	113.60	12
10/3/1990	368.20	440.10	156.00	175.00	146	321.00	945.9	998.95	1052.00	142.90	114.60	13
10/4/1990	432.20	436.40	153.00	175.00	151	326.00	761.1	818.05	875.00	138.90	116.80	14
10/5/1990	474.70	493.80	138.00	175.00	218	393.00	762.4	852.2	942.00	116.90	124.90	15
10/6/1990	641.70	629.40	147.00	175.00	194	369.00	886.8	953.9	1021.00	134.90	106.70	16
10/7/1990	702.10	713.10	151.00	175.00	168	343.00	996.4	1071.7	1145.00	138.90	113.20	17
10/8/1990	204.00	345.10	154.00	175.00	155	330.00	1056.1	1100.05	1184.00	140.90	114.10	18
10/9/1990	205.00	223.30	154.00	175.00	149	324.00	675.1	761.55	848.00	140.90	115.00	19
10/10/1990	186.00	229.70	145.00	175.00	158	333.00	547.3	621.15	695.00	141.90	114.50	20
10/11/1990	182.00	225.90	138.00	175.00	175	350.00	562.7	626.85	691.00	128.90	120.90	21
10/12/1990	167.00	228.70	90.00	175.00	410	595.00	675.9	656.95	738.00	83.90	135.30	22
10/13/1990	127.00	234.90	95.00	177.00	738.7	916.70	812.7	927.85	1042.00	95.00	152.70	23
10/14/1990	82.00	236.10	95.00	244.00	2150.7	2394.70	1150.6	1446.3	1730.00	98.00	163.40	24
10/15/1990	127.00	213.70	95.00	186.00	1079.7	1265.70	2630.8	2857.4	2684.00	58.90	119.20	25
10/16/1990	147.00	220.10	95.00	175.00	745	920.00	1479.4	1567.2	1655.00	85.90	102.60	26
10/17/1990	159.00	222.10	75.00	175.00	605.9	780.90	1140.1	1236.05	1322.00	97.90	109.60	27
10/18/1990	45.00	263.30	95.00	304.00	694.6	998.60	1003	1097.5	1192.00	54.90	134.50	28
10/19/1990	45.00	726.90	95.00	1035.00	2248	3283.00	1257.9	2231.95	3206.00	84.00	267.10	29
10/20/1990	45.00	370.00	95.00	543.00	1500.9	2043.90	4009.9	4261.95	4514.00	95.00	157.90	30
10/21/1990	45.00	282.00	95.00	382.00	1050.5	1459.50	2413.9	2593.45	2752.00	49.00	118.40	31
10/22/1990	45.00	239.00	95.00	282.00	930.7	1212.70	1740.5	1911.25	2082.00	63.90	108.20	32
10/23/1990	45.00	299.00	95.00	342.00	1150.8	1492.80	1451.7	1671.35	1891.00	84.00	239.70	33
10/24/1990	45.00	1176.00	95.00	984.00	4311.7	5295.70	1791.8	4002.4	6213.00	254.00	770.50	34
10/25/1990	45.00	700.00	95.00	759.00	2797.5	3596.50	6471.7	7121.85	7772.00	97.00	362.20	35
10/26/1990	45.00	535.00	95.00	534.00	2009.5	2543.50	4256.5	4557.25	4898.00	72.00	213.10	36
10/27/1990	45.00	430.00	95.00	382.00	1540.2	1932.20	3078.5	3339.25	3600.00	61.00	165.60	37
10/28/1990	45.00	368.00	95.00	312.00	1260.9	1672.90	2362.2	2602.1	2842.00	55.00	142.50	38
10/29/1990	45.00	326.00	95.00	262.00	1071.2	1332.20	1938.9	2170.95	2403.00	51.00	126.60	39
10/30/1990	45.00	282.00	95.00	215.00	908.8	1123.80	1653.2	1862.1	2065.00	50.90	115.10	40

Figure 5-4. The “Flows” page of “DSS_AGG.xls,” with outlined cell indicating where to paste data for an alternative from “OASIS formatter.xls.”

Importing Meteorological Data

To reiterate, there are three choices with regard to the meteorological data used in the DRDSS temperature calculations: (1) repetitive cycles of the 1993 – 2003 empirical data set from Monticello, (2) normal (average) meteorological values arranged by date, or (3) extreme daily values arranged by date. These data are contained in the file “met_data.xls.” Records in this spreadsheet match the period of record applicable to the DSS, extending from October 1, 1953, to September 30, 2003, with daily values filled in accordingly. As with the flow data, it is extremely important to match the dates from which the meteorological data are to be extracted with the dates used for the flow data. However, with the meteorological date, the copy/paste sequence is a little trickier because data are only recorded for the period May 1 – September 30. The rest of the dates have no data, but **MUST BE COPIED ANYWAY** in order to synchronize properly with the flow data. Furthermore, the dates for the meteorological data are not copied to the “Flows” page, so cross checking is not performed within the DRDSS to ensure synchronization.

1. If not previously done, make a copy of “met_data.xls” and work off the copy.
2. Continuing with our previous example, our period of record is from October 1, 1959, through September 30, 1969. Supposing that we are using “normal” meteorological conditions, the block from cell F2002 to I5854 would be copied (figs. 5-5 and 5-6).

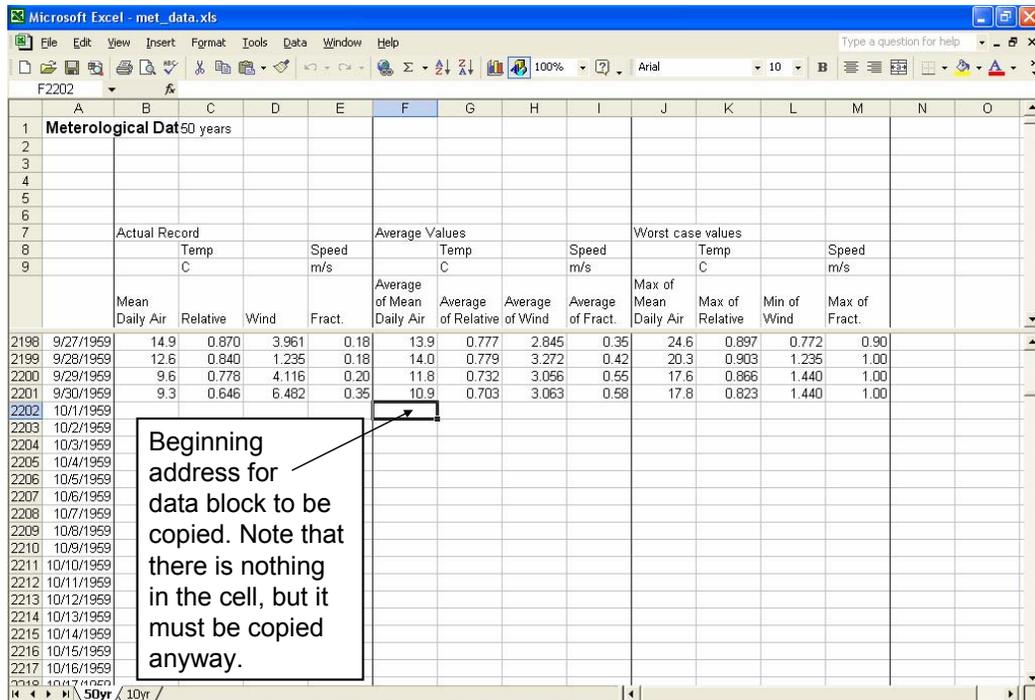


Figure 5-5. Cell F2202 in “met_data.xls,” the starting location for copying a ten-year block of “normal” meteorological data corresponding to the dates and flows previously imported to the “Flows” page of “DSS_AGG.xls.”

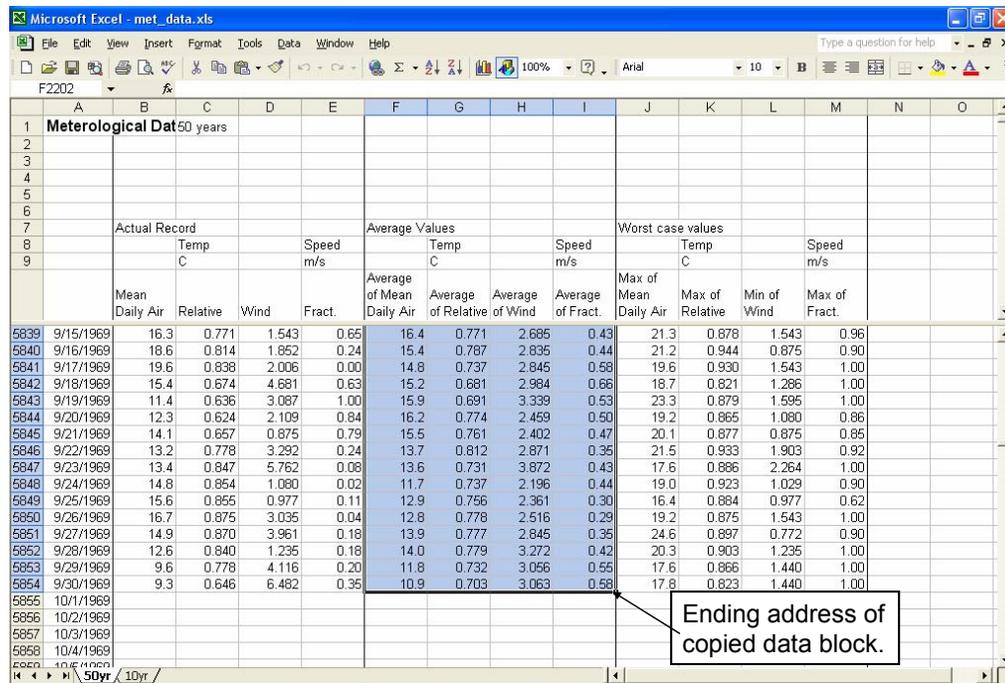


Figure 5-6. Selected block ending at cell I5854 in “met_data.xls,” the ending location for copying a ten-year block of “normal” meteorological data corresponding to the dates and flows previously imported to the “Flows” page of “DSS_AGG.xls.”

- Once the desired block of meteorological data has been copied, return to the “Flows” page of DSS_AGG.xls, and paste the data to cell B111 (fig. 5-7).

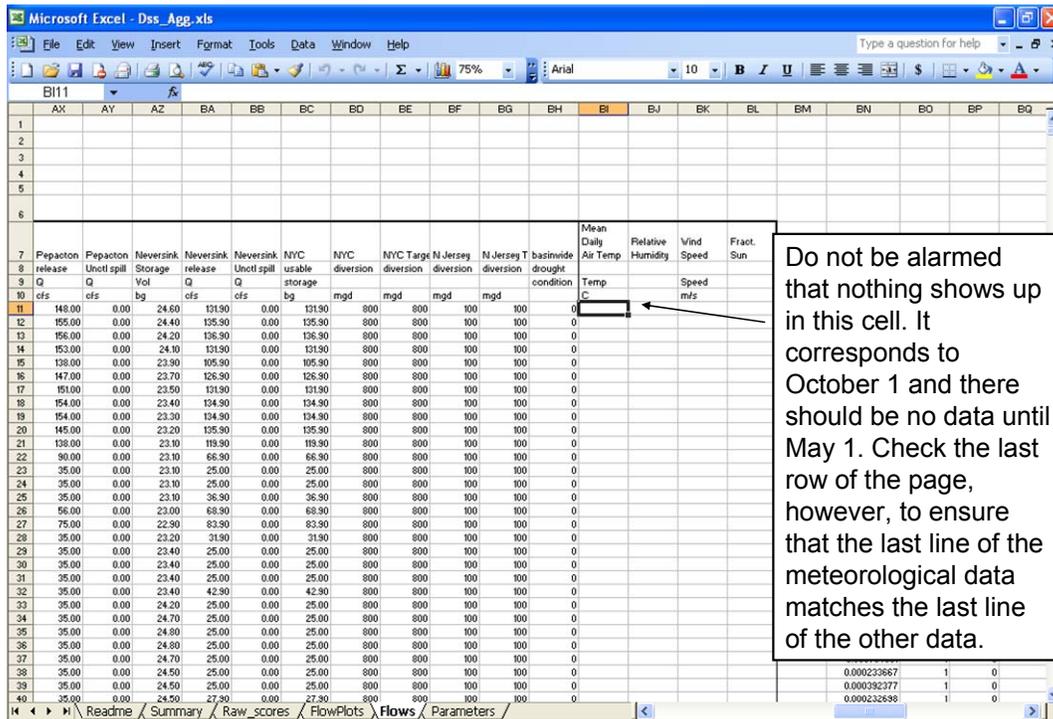


Figure 5-7. Cell B111 on the “Flows” page of “DSS_AGG.xls” is outlined. This is where the meteorological data originating from the met_data.xls database are pasted.

Setting the Scoring Parameters and Related Information on the “Parameters” Page.

- Open the DSS_AGG workbook and click on the tab labeled Parameters (fig. 5-8).
- Update parameters and scoring thresholds as desired. If no data are supplied, the values in the Default column (column C) will be used instead. Any value in column D (as well as E, F, or G in the case of temperature thresholds) will override the Default. User values must be in correct units or formatted as shown in the Units column (column B). Do not overwrite the values in column C as this will replace the defaults. If the default value is acceptable, no entry needs to be made in column D. Otherwise, modify the appropriate values as desired in column D. The exceptions are for entries 4, 5, and 6 (cells D17, D19, D20, and D22), which should be updated to keep track of the specifics of a scenario. The meteorological series entry (D39) is a documentation field only and DOES NOT import the meteorological data automatically. The DRDSS uses the meteorological data from the last run unless new data have been copied and pasted from “met_data.xls.” Run settings, labels for baseline and alternative scenarios, and the period of record are updated automatically on the “Summary” and “Raw Scores” pages of the DSS_AGG.xls spreadsheet as an aid to run documentation.

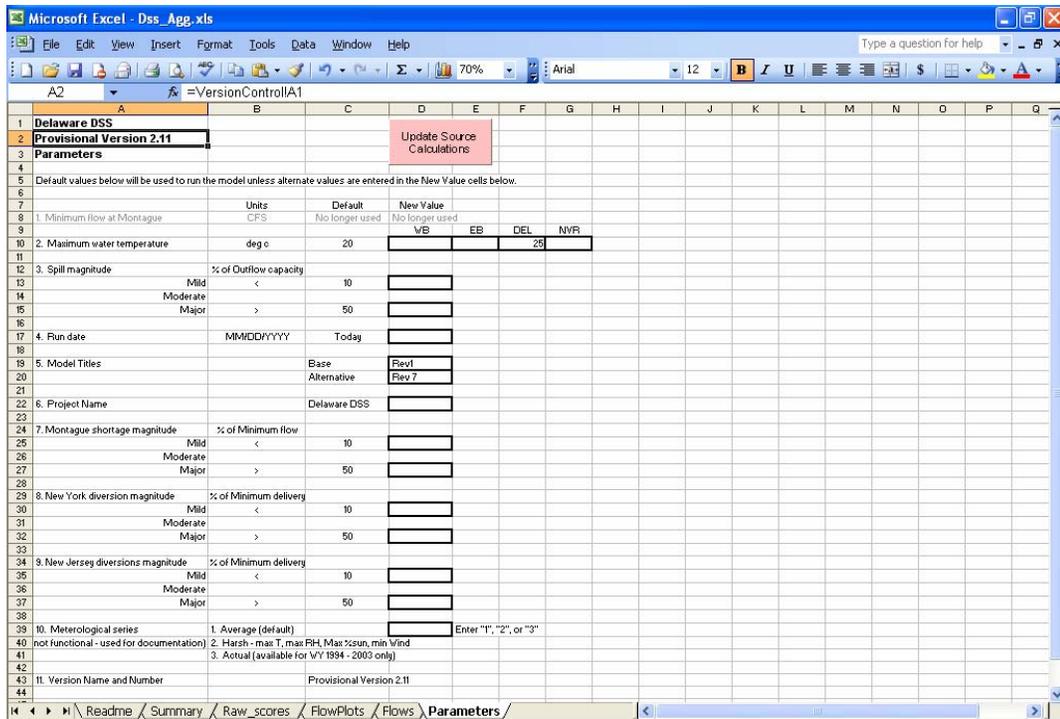


Figure 5-8. Parameters page from “DSS_AGG.xls.”

Making a DSS Run

1. Double check all imported data to make sure everything lines up correctly with respect to dates and locations.
2. Review the “Parameters” page to ensure that all the thresholds are correctly set and that the run identification data are entered correctly.
3. Press the pink button labeled “Update Source Calculations” (fig. 5-8). The Update Source Calculations button sequentially opens each of the subsidiary workbooks (DSS_WB.xls, DSS_EB.xls, DSS_DEL.xls, and DSS_NVR.xls); copies the flow, meteorology, and parameter data into them; and recalculates all the values for the stream segment. Links to the stream files are updated in the DSS_AGG.xls file. Typical run times vary from 20 to 40 minutes, depending on processor speed. Do not push this button until all pertinent changes have been made and checked.

Generating Graphics and Displays

The DRDSS can generate a wide variety of graphics, all of which can be useful at different stages of interpreting and evaluating the outcomes of a run. Some displays should be generated for every run, whereas others need only to be generated on a case-by-case basis. Some of the graphics generated by the DRDSS are not automatically saved and can be overwritten. Therefore, it is advisable to save any desired graphics as hard copy, in electronic format (JPEG, TIF, or BMP, for example), or both. In this section, we have arranged the types of graphics and the means of generating them as a hierarchy, starting with graphics that should always be generated.

Scoring Summary and Raw Scores Pages

These scoring pages are actually tables that appear as Excel spreadsheet pages. Neither is a self-contained graphical unit, but must be manipulated to look like one for export, either to a printer or to an electronic graphics file. These pages can be printed directly from Excel to a single sheet, using the page setup and print preview options. Clarity and legibility can be improved by printing on tabloid-sized paper (11 x17 in), or larger. To create an electronic graphics file:

1. Outline the block of cells to be included in the graphics file (cells A1 to Q64 for the summary page or cells B1 to BP103 for the raw scores page). **Copy** the block.
2. Open Microsoft Word or (preferably) Powerpoint, select a new page (Word) or slide (Powerpoint) and click **Edit/Paste Special/Picture**. When the table appears satisfactorily on the page or slide, save the file under a name that reflects the alternatives being compared (for example, Rev1_Rev7_norm_60, for Revision 1 versus Revision 7 using normal year meteorological data for the decade 1960–1970). The advantage of storing these graphics in Powerpoint is that individual slides can be saved as JPEGs or other electronic graphics files. They cannot be saved directly in this format from Word.

Flow, Storage, and Temperature Duration Curves

These graphics are grouped together because they are all generated the same way. Flow and storage curves should be generated for every location and scenario. Temperature curves are optional and the decision to generate them depends on site- or situation-specific circumstances.

1. Generate a duration curve for one of the sites. We will use flows at WB0 for this example. Generation of duration curves for other variables and sites will follow a parallel approach.
 - a. Open one of the SUBS spreadsheets (in this example, DSS_WB.xls) and move to the WBDurCurve tab (fig. 5-9).
 - b. Select “Flows” from the menu adjacent to the button labeled “Get Variable Plot” and “WB0” from the menu next to the button labeled “Get Study Site” (fig. 5-9).
 - c. Press the purple button labeled “Update Data.” The associated macros will proceed to sort the data and update the graph at the “DurCurveChart” page.
 - d. As soon as the chart has updated, Excel automatically tabs to the DurCurveChart page, accompanied by an information window stating that the update is complete. Click OK on the information box.
2. If desired, rescale the Y-axis to accentuate the low-flow portion of the curve. Set the cursor over the Y-axis, right click, and select “Format axis.” From the menu, select “Scale” and manually set the limit for the maximum value. Reset the increments between the maximum and minimum values if necessary by manually changing the number in the box labeled “Major Unit.” Click OK. Note that once the scale has been changed, the same scale will be used for all subsequent charts, sometimes with unintelligible results. To avoid such problems, the scale can be reset to automatically adjust after the graph has been printed or saved.

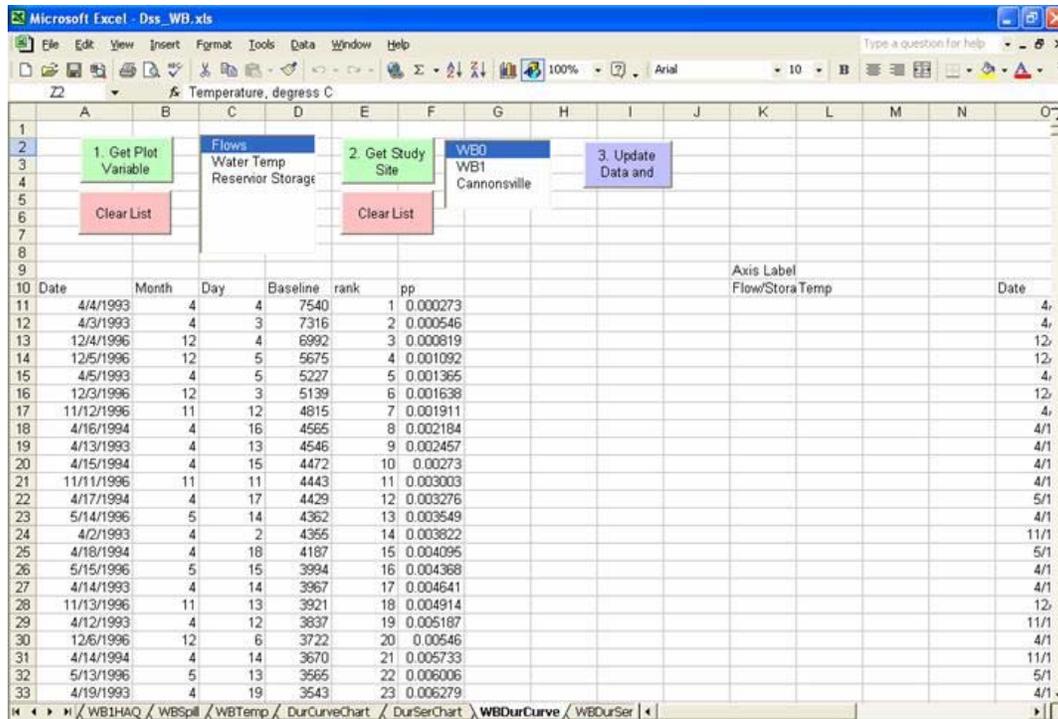


Figure 5-9. Setup to generate a flow duration curve for WB0 on the “WBDurCurve” page of “DSS_WB.xls.” Selected Page tab and variables are highlighted.

3. IMMEDIATELY print and/or save the chart.
 - a. Left click anywhere on the chart area. Black highlight dots should appear to outline the chart. To print, select **File/Print**. (The default print settings are for letter-sized paper and landscape orientation. Check to ensure that the printer paper matches the size specified in the print settings).
 - b. To save the chart electronically, select the chart area as above, and click Edit/Copy. Then open the electronic graphics file (the Word or Powerpoint file) created for the scenario, create a new page or slide, and **Paste Special/Picture** to paste the chart. Save the File and return to the WBDurCurve page in the DSS_WB.xls spreadsheet
4. Select the next site or variable, and repeat steps 1–3 as necessary until all appropriate duration curves have been generated, printed, and saved. When finished, close the DSS_WB.xls workbook **without** saving.
5. Open the next SUB workbook, such as DSS_EB.xls and repeat steps 1–4. Repeat for all the SUBS workbooks until the full complement of duration curves has been generated and saved.

Duration Series Curves

Duration series curves are generated by procedures almost identical to those used to produce the duration curves described in the previous section. The basic differences are that the variables and sites are selected on the <sitename>DurSer page of the SUB workbook (fig. 5-10), and the chart will be updated on the DurSerChart page of that site’s workbook. These charts may be considered optional, but should at least be reviewed and those showing “interesting” patterns of habitat availability should be saved or printed. The methods of printing or saving electronic

versions of these charts are identical to those described for duration curves in the previous section. Unlike the duration curves, however, it will probably never be necessary to rescale the Y-axis to accentuate a particular portion of the chart.

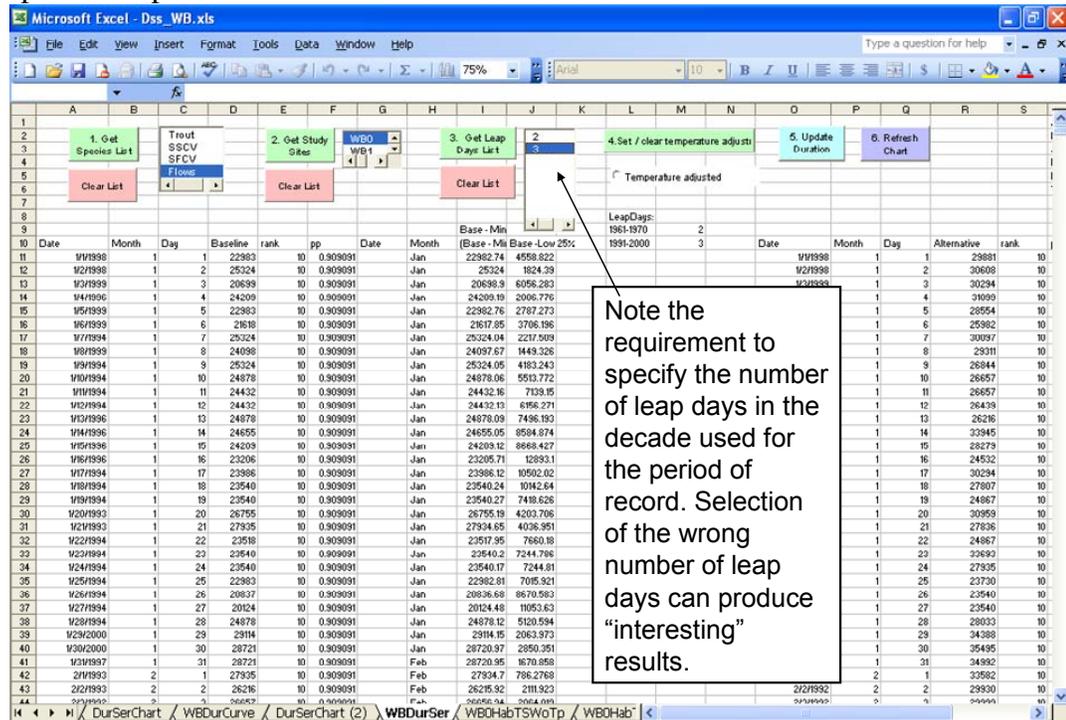


Figure 5-10. Setup to generate a flow duration series curve for WB0 on the "WBDurSer" page of "DSS_WB.xls." Selected Page tab and variables are highlighted.

Flow Plots

The time series plots of flows in each segment and storage volumes in the three reservoirs are found on the "Flow Plots" page of the DSS_AGG workbook. The original intent of incorporating these plots into the DRDSS was to provide a quick on-screen review of the sequence of flows and storage volumes. The charts are set up to lock the window for the Y-axis, allowing the user to scroll back and forth through the sequence. Unfortunately, the sequence is so long that plotting the whole thing compresses the scale so much that the plot is virtually unreadable.

There are several options available, however, in the event that a legible plot is needed. If the user has access to a large format color plotter, such as those used to produce poster presentations, the entire time series can be copied and pasted to a custom-sized (for example, 36 x 48 in) Powerpoint slide and printed in its entirety. Otherwise portions of the series can be copied to a more commonly-used size (either letter or tabloid) in a Powerpoint presentation file. The easiest way to copy a portion of the series is to scroll to the desired part of the sequence and use the "Print Screen" function on the computer. The contents of the clipboard can then be pasted to a Powerpoint slide and trimmed up to make presentable.

The Raw Scores Page

On occasion, it may be desirable to generate the Raw Scores page of the DSS_AGG workbook, especially if there are substantial spatial differences in the habitat responses to a change

in operations. For example, the same operating rules might result in an increase of habitat metrics at WB0 and a decrease at WB1. Such a result could be masked on the Summary Scores page, which might indicate little or no change for the West Branch as a whole.

The Raw Scores page is organized in exactly the same format as the Summary Scores page. The difference between the two scoring pages is that the Raw Scores page contains information for each study segment instead of a compilation of scores for each stream. Because the Raw Scores page is so much larger than the Summary Scores page, we encounter the same problem discussed previously for the Flow Plots. The entire Raw Scores page can be copied to a letter-sized slide or document, but no one will be able to read it. Tabloid size is marginally better, but still hard to read.

The best overall option is the use of a custom sized Powerpoint slide that can be printed on a large format color plotter, or viewed as a projected image on a screen. To be as legible as a tabloid-sized version of the Summary Scores page, the page size for Raw Scores should be about three times as large (approximately 36 x 48 in). The same general procedures described for generating the Summary Scores page apply to copying and pasting the Raw Scores page, except that the block to be copied is much larger.

Information Management

The purpose of the DRDSS is to compare operations and results for numerous runs, so data management and organization of tabular and graphical output is of paramount importance. Each run has the potential of generating 89 different graphs and figures:

1. One (1) Summary Scores page,
2. Eleven (11) flow duration plots,
3. Three (3) storage duration plots,
4. Eight (8) temperature duration plots (none for the Neversink),
5. Forty-eight (48) duration series curves (85 if curves including both temperature conditioned and unconditioned habitat are generated),
6. Eleven or more (11+) flow series plots, depending on whether a series of partial plots must be generated,
7. Three or more (3+) storage series plots, with the same caveat as above, and
8. Four (4) Raw Scores pages.

Recall that a DRDSS run represents the outcome for a single OASIS alternative for one decade. If the analyst were only to produce the minimum number of routinely-generated graphics (items 1–3 above) for all five decades in the period of record, there would be at least 45 graphs for each alternative. The need for organization should be obvious to even the most casual of observers.

We have already discussed some of the basics regarding information management, such as setting up individual computer directories for each run. A parallel approach can be followed to organize the results from each run:

1. Create a single directory for each run, named according to the alternative tested and the time period represented by the run (for example, Rev1_Rev7_1960s). The directory can consist of a file folder if all the results are to consist of hard copy. If the directory is to be created electronically, a backup folder should be created on an independent medium such as a CD-ROM or external hard drive.
2. Write a README file containing the specifics of the objectives of the alternative and the operating rules defining the baseline and the alternative in the OASIS run, and put it in the

folder. Over the years, we have witnessed a widespread failure to do this. Universally, everyone who has not documented the alternatives has regretted it later.

3. Generate and save the necessary graphics. It may be convenient to save electronic graphics as a series of slides in an appropriately named Powerpoint presentation file. For hardcopy, it may be worthwhile to segregate graphics of a particular type, such as all the flow duration curves, into a subfolder.
4. To the extent possible, conduct a cause-and-effect analysis of the run and write a brief synopsis of the mechanics leading to particular outcomes. For example, "Spawning-incubation habitat was decreased under the alternative. The probable cause was that streamflow was increased during October and November and remained the same as the baseline from December through April. The net result was that the differential between spawning flows and incubation flows increased, thereby causing a reduction in persistent spawning-incubation habitat." Although this step might be considered optional, documenting the cause-effect mechanisms for both positive and negative outcomes will be extremely useful for developing the next scenario or a contingency plan.

One idea for organizing these materials with consistent format and content is to collect all the aforementioned products into a poster. A primary advantage of the poster format is that the results of multiple runs can be displayed side-by-side for comparison during public hearings or Commission-related meetings. The best information in the world is useless if no one can understand it. It is almost as useless if decisionmakers cannot find or readily identify the information they need to address a particular problem.

The poster option is available only for users having access to a large format color plotter, but it may be of sufficient utility to justify acquiring access to one by purchase, lease, or contract. Figure 5-11 illustrates a basic poster template that accommodates the summary scores page, multiple graphics (in this case, all the flow and storage duration curves), and text boxes describing the conditions and outcomes of a DRDSS run. A similar design can be used for displaying raw scores and additional graphics. The poster shown in figure 5-11 was generated in ArcMap and originally dimensioned to 36 x 74 inches. This seems to be a suitable size because the items on the poster are legible at distances of two to three meters, but the posters are small enough to display several of them side-by-side in a meeting room.

The poster format is a promising technique for consolidating, organizing, and displaying large amounts of information. The advantages of posters are that they can be fairly self-explanatory (not much text required or wanted) and visually stimulating, facilitating "big-picture" comparisons among alternatives. A disadvantage of posters is that it may difficult to anticipate what information the decisionmakers will find the most useful. This can lead the poster designer to try to include everything, at the risk of creating an illegible billboard overloaded with information. It may take several attempts before the most effective combination of design and content is accomplished, but the goal should always be to convey the most information to the most people in the most understandable way possible.

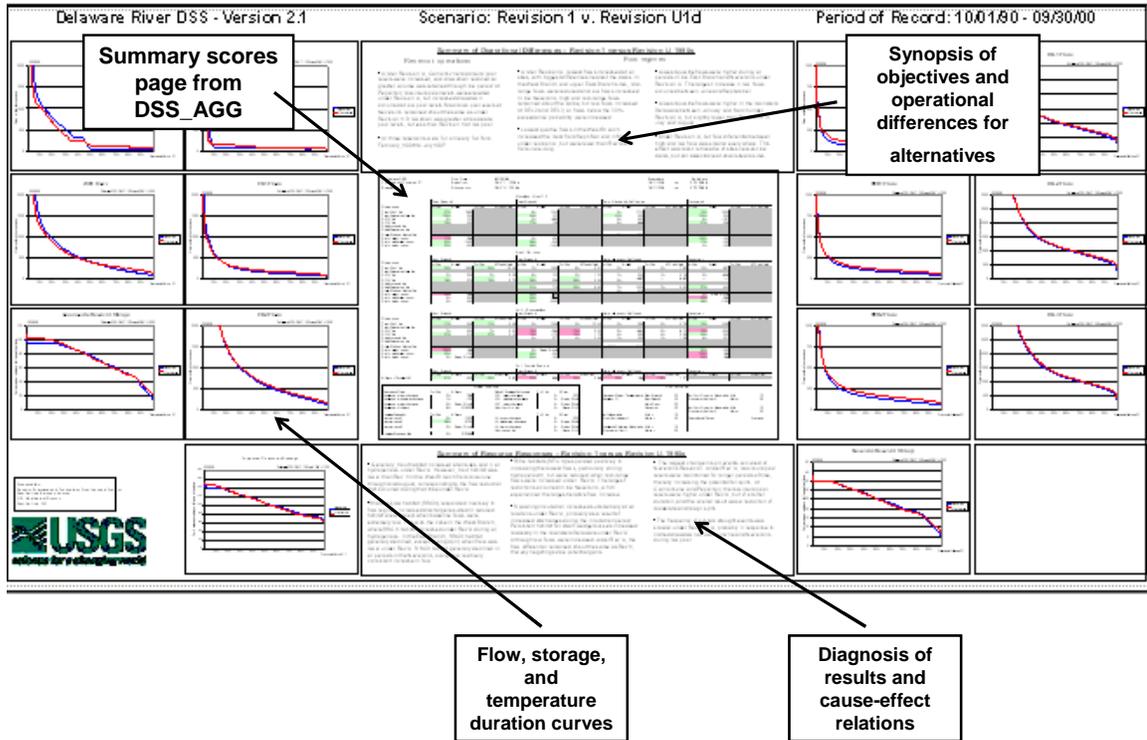


Figure 5-11. Poster template generated for 36 x 74 inch page size in ArcMap, showing locations and relative sizes of components.