ROCKFALL HAZARD MITIGATION REPORT

ROUTE 29
ROCKFALL MITIGATION
MP 27.31 TO MP 30.43

TOWNSHIP OF KINGWOOD
HUNTERDON COUNTY

April 24, 2015

PREPARED FOR

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TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Project Description

HNTB Corporation (HNTB) has prepared this Route 29, Milepost 27.31 to 30.43, Rockfall Hazard Mitigation Report as part of the Concept Development (CD) phase for the New Jersey Department of Transportation (NJDOT). The rock slope is located in Kingwood Township, Hunterdon County, New Jersey, as shown on Figure 1-1, Project Location Map. This report summarizes findings of HNTB's literature search and field reconnaissance and concludes with recommendations. Although a preliminary cost estimate has been included in Appendix III, a detailed cost estimate has not be performed to date and will be included in the Final Engineering phase. Select photographs taken during the reconnaissance follow the report in Appendix I. For ease of reference, the areas under consideration are designated as follows (from south to north):

Table 1-1 – Project Limits and Slope Summary

Area	Southern Mile Post	Northern Mile Post	Measured Slope Length (ft.)	Approximate Slope Height At Tallest Location (ft.)	2004 Golder Report MP Limits	2003 Rockfall Hazard Rating
A	27.31	27.40	500	75	27.4 to 27.5	310
B	27.48	27.59	580	75	27.5 to 27.65	316
C	27.84	28.50	3450	50	27.78 to 28.48	628
D	29.86	30.43	3000	260	29.85 to 30.45	470

2.0 DESCRIPTION OF SITE RECONNAISSANCE

John Szturo, Senior Engineering Geologist HNTB; Brian Felber, Geotechnical Engineer, HNTB; and John Jamerson, NJDOT Engineering Geologist, conducted the field reconnaissance from Monday, October 20, 2014 to Wednesday, October 22, 2014. At the time of the reconnaissance, some trees remained partially leaf covered and no snow or ice was present on the slope. Climbing gear or specialized access equipment was not utilized for the inspection. In general, the slope was viewed from the shoulders of Route 29. However, the upland portion of Area D was accessed by foot.

The following describes the inspection procedures generally followed:

- Determined approximate slope lengths with a measuring wheel
- Estimated slope heights
- Measured dip and dip direction of bedding and persistent discontinuities with a compass
- Measured slope angles using a clinometer
- Assessed typical discontinuity characteristics
- Observed the location and quantity of rockfall debris at the toe of slope,
- Assessed and documented evidence of rockfall impact, or fresh faces indicative of recent rockfall
- Examined slopes for existing rockfall mitigation, as-built rock slope stabilization elements, or evidence of former line drilling or pre-splitting.
- Identified active rockfall-triggering mechanisms such as vegetation growth or seepage

Typed field notes from the reconnaissance are provided in Appendix I.

3.0 SITE GEOLOGY

A literature search and field reconnaissance were performed to review the geology and general conditions of the project area. The site is located along the Delaware River near the western boundary of New Jersey (Hunterdon County). The project site includes several miles along the east side of State Route 29 south of Frenchtown, NJ (Kingwood Station Road to Raven Rock Road). The study area is further divided into four areas from south to north, described as Areas A, B, C, and D (Devils Tea Table).

This project is located in the Piedmont Physiographic Province. The area is mostly underlain by slightly faulted and folded sedimentary rocks of Triassic and Jurassic Age (240 to 140 million years old) as well as intruded igneous rocks also of Jurassic Age.

One of the main elements of the Piedmont Province is the Hunterdon Plateau, which includes the area of the project. In addition, one of the features of the study area is a rather high and steep bluff composed of sandstone and siltstone. The bluffs rise approximately 300 feet above Route 29.

Of particular note is a rock feature locally known as Devils Tea Table. Geologically speaking, “tea tables” are formed when softer rock layers erode beneath tougher and more resistant upper layers. In this area, the softer layers have eroded to form large open joints and precarious large sandstone blocks and columns.

These precarious blocks form the basis for safety study in Area D. The basis for the study in the other areas is mainly due to discontinuities and weathering within the rock mass. The discontinuities can be described as joints, fractures, and bedding.

Below are generalized descriptions of the rock types present in the study area:

By geologic age:

Triassic Lockatong Formation – light to dark gray, greenish-gray, and black very fine-grained sandstone, silty argillite, and laminated mudstone, with bedding dipping northeast.

Triassic Passaic (Brunswick) Formation – Reddish-brown shale, siltstone, and mudstone with a few green and brown shale interbeds, red and dark gray interbedded argillites near the base. There are also conglomerate and sandstone beds near the base, with bedding dipping northeast

Diabase intrusives – Later in the Triassic, volcanic activity formed the diabase intrusives, which intersect the overlying formations. The diabase can be described as a dark, mafic, subvolcanic rock.

4.0 EXISTING SITE CONDITIONS

4.1 General

This section of Route 29 consists of two 12-foot lanes (one in each direction) with mostly 8-foot wide shoulders. The shoulders vary in width for short distances. Guiderail also protects various features and areas. Relevant site conditions were established through onsite discussions with John Jameson, performance of a site reconnaissance walkover, and review of previously published reports.

Four slope failure mechanisms were observed or inferred for the existing slopes, these include:

- Differential weathering
- Block toppling
- Root wedging
- Ice jacking

The prevalence of each of these mechanism varied by slope area.

4.2 Differential Weathering

The geologic setting described in Section3.0 indicate there is a general reduction in rock strength proceeding northward. This is due to the presence of a diabase intrusive rock mass in Area A which served to slightly metamorphose the proximal sedimentary units. Thus, the argillite and slate transitions to mudstone, siltstone, and shale progressing northward. Consequently, in Area D, the presence of interbedded "red" siltstone and more competent sandstone results in differential weathering and the formation of capped columns such as Devils Tea Table. An example of this process is shown in Photo 1 in Appendix I. The ongoing differential weathering process leads to the potential for rockfalls of tens to hundreds of cubic yards that could originate from the natural back slope.

4.3 Block Toppling

A second slope failure mechanism relates to the steeply east-dipping joint set, J1. This set strikes approximately parallel to the Route 29 alignment and dips into the slope at between 80 and 90 degrees. Because the joints in the set are relatively widely spaced, the slope is susceptible to block toppling (as opposed to flexural topping in thinly laminated rock masses). Multiple locations with incipient block toppling were observed during the reconnaissance. Block sizes were generally less than 10 CY. This mechanism is most prevalent in Areas B and C and could originate from either the cut slope or the back slope. Area A is less vulnerable because the joints related to the diabase intrusive appear to be randomly oriented.

4.4 Root Wedging

The rock slopes have extensive tree coverage consisting of both coniferous and deciduous species. The latter appears to be especially fast growing with roots that exploit fractures in the rock mass in search of water. This leads to long-term root wedging as shown in Photo 2, in Appendix I. During high winds, the more mature trees act as lever arms to pry rock blocks from the face. Thus, the third failure mechanism operative on both the existing cut slopes and back slopes in all four areas is the wedging action of roots, either long-term due to root expansion or transient due to wind loading.

4.5 Ice Jacking

The Delaware River Valley is deeply incised (±500 feet) into the regional topographic plateau. The lower slopes above the river therefore represent discharge zones for structurally controlled groundwater flowing toward the valley from the recharge areas on the adjacent uplands. John Jamerson confirmed this model by relaying that significant discharge is observed from joints and bedding planes just above highway grade during heavy rainfall events and snowmelt periods. Combined with freeze-thaw cycles that persist during the winter and spring months, this groundwater discharge leads to ice jacking as the fourth rockfall mechanism operative in all four areas and from both the cut slope and the back slope.

4.6 Rockfall History

The history of rockfall events has not been well recorded, but several rockfall events have been documented and are summarized in Table 4-1 below. This list was compiled from discussions with NJDOT Engineering Geologist, John Jamerson, and from a 12/15/14 telephone interview with Paul Dejong, from NJDOT's West Amwell, NJ Maintenance Yard. During the reconnaissance, HNTB looked for evidence of rockfall at the toe of slope, localized fresh rock faces, impact damage, and debris piles.

Table 4-1 – Rockfall History

Area	Location	Date	Weather Related	Description
A	604' South MP 27.43 Post	Dec. 2013	During Harsh Winter	1 CY Reached NB Lane
B	Throughout Area	-	-	Rock Blocks Close to Toe
C	100' N of MP 28.00 Post	April 2014	Spring Thaw after Harsh Winter	5'x4'x4' Rock Block reached SB Lane, several ± 2'x2'x2' Blocks in NB Lane, Source 25' above Highway Grade
D	MP 30.2	3/16/96	Extremely Harsh Winter	Covered Entire Roadway
	MP 27.9	3/21/96	Extremely Harsh Winter	Softball to Basketball Sized Rock Blocks
	Throughout Area	-	-	Piles of rockfall debris, generally particles smaller than 6", placed west of the SB shoulder during cleanup.

5.0 SLOPE EVALUATION

5.1 General

Remedial measures to mitigate rockfall instability must meet two broad geotechnical objectives:

1. Maintain or improve overall (global) slope stability
2. Provide face stability and/or control rockfall.

Other considerations of a non-geotechnical nature include constructability, aesthetic constraints, historic preservation, highway safety, and highway maintenance. The evaluations that follow concentrate on approaches that satisfy the geotechnical issues while highlighting non-geotechnical issues that stakeholder groups will have to reconcile in order to select an acceptable mitigation approach.

5.1.1 Overall Stability

A stereonet analysis of the limited-scale structural data set indicates the presence of two steep dipping joint sets along with northerly-dipping bedding (Figure 5-1). No features were found with intermediate dips toward the highway. This structural model is favorable for current global stability and indicates that steeper cut slopes could be achieved. Overall slope failure through the rock mass (non-structurally controlled) is improbable due to the strength of the rock and the limited slope heights.

5.1.2 Face Stability / Rockfall Control

Based on the discussion above (Section 1.0 Introduction) and the variation in slope height amongst the four design areas, it is recommended that areas A, B, and C be grouped for consideration of generic mitigation options, while area D is treated as a standalone site. For all sites, mitigation strategies involving rock removal, rock reinforcement, and rockfall control were considered.

5.2 Areas A, B, and C

Rock removal for these three areas would entail selective scaling, trim blasting of loose and overhanging blocks, and selective re-sloping to create a catchment ditch. Scaling would consist of hand scaling with pry bars and air pillows using rope access. Mechanical scaling, utilizing long reach excavators, is feasible for the lower slopes if sufficient workspace can be dedicated at the base of the slope and segregated from highway traffic. Scaling in isolation from other mitigation measures would only represent a temporary rockfall solution. In HNTB's experience, frost-prone rock slopes such as those in this project corridor would require scaling on a five to seven year interval to maintain effectiveness.

Rock reinforcement utilizing either tensioned rock bolts or untensioned steel dowels could be implemented for potentially unstable blocks. The holes for the bars would utilize hand-drilling methods (from ropes or wagon drills) thereby limiting the achievable hole lengths to about 30 feet and the maximum hole diameters to about three inches. Due to the difficulty of identifying all potentially unstable candidate blocks, this approach is considered impractical as the primary mitigation approach.

Alternatives for *rockfall control* include fences and slope drapes. The practicality of fences is dependent on being able to identify suitable mid-slope bench locations that are reasonably accessible. In some cases, the transition from the cut slope to the back slope provides a feasible location. Due to the lack of catchment between the shoulder of the highway and the toe of the slope, there are virtually no suitable locations at highway grade. Fences located upslope would suffer the drawback of inaccessibility for cleanout and maintenance. Consequently, the fence option could at best be partially effective at specific locations as a standalone mitigation approach.

An alternative rockfall control approach would be to utilize a robust slope drape consisting of cable net or ring net. Such systems are effective to control block sizes to about five feet (2 to 4 CY). This rockfall mitigation approach offers the advantages of being adaptable to variable slope geometry while being designed to meet site specific performance criteria. The aesthetic impact can be reduced through color matching the PVC coating of the drape to the background rock and by offering the opportunity to host secondary vegetative cover. A potential drawback for slope drape is the requirement to remove all tree growth from the areas to be covered. The slope drape can be either unsecured (free hanging), in which case dislodged blocks migrate beneath the drape, or secured to the face to prevent blocks from moving. Hybrid systems, in which the upper part of the drapery is elevated to intercept rockfalls originating from upslope, may also be applicable in specific areas.

5.3 Area D

Composite cut slopes and back slopes reach estimated heights of over 260 feet in Area D. Along the crest of the back slope, large, detached columns are present. Devils Tea Table represents such a column. Evidence of instability at the base of this landmark topographic feature was observed (Photo 3, Appendix I). Ongoing differential weathering will cause the eventual failure of this or other columns and will potentially result in rockfall events of hundreds of cubic yards that would likely reach Route 29.

Given the scope of the Concept Development phase, it is not feasible to recommend a single primary mitigation approach. Rather, detailed geologic and engineering analyses will be required to develop a hybrid mitigation solution that encompasses:

- Rock removal (trim blasting combined with intense scaling)
- Rock reinforcement (rock bolts / rock dowels bars, shotcrete or concrete grade beams, and shotcrete or concrete post-tensioned buttresses)
- Rockfall control (cable net, ring net, hybrid drape)

Table 5-1 – Comparison Matrix for Area A Mitigation Alternatives

Option	Description	Risk Reduction	Outside Right-of-Way	Required Ongoing Maintenance	Anticipated Service Life (Years)	Construction Impact	Construction Difficulty	Construction Duration (days)		Cost ($1,000)		Aesthetic Impact
								Low	High	Low	High	
I	No Action	None	No	Status Quo – Periodic Rock Removal	N/A	None	N/A	0	0	0	0	Low
II	**Removal** – Re-grade with Catchment Ditch	Moderate	No	Low – Periodic Ditch Cleaning, Good for Snow Removal	> 50	High – At Least 1 Lane Required	Low	90	180	150	449	Moderate
III	**Removal** – Remove Vegetation and Scale	Moderate	No	Moderate – Continual Vegetation Removal and Scaling	5 - 10	Moderate – 1 Lane	Low	30	60	186	557	Moderate
IV	**Removal / Protection** - Remove Vegetation, Scale, and Install Draped Mesh	High	No	Low – Periodic Cleanup Below Mesh	20	Moderate – 1 Lane	Moderate	60	120	520	1,560	High
V Fig. 6-1	**Removal / Protection** – Re-slope and Construct Catchment Ditch, Install Draped Mesh on Upper Portion of Lower Cut Slope	High	No	Low – Periodic Cleaning, Beneficial for Snow Removal & Storage	20	High – At Least 1 Lane Required	Moderate	90	180	421	1,262	High
VI	**Reinforcement** – Install Grouted Dowels and Shotcrete Facing	High	No	None	20	High – At Least 1 Lane Required	High	90	180	847	2,540	High
VII	**Reinforcement** – Install Anchored Mesh, spot dowels/rock bolts	High	No	Low – Infrequently Repair Mesh / Remove Significant Rock Accumulation	20	Moderate – 1 Lane	High	60	120	832	2,496	High

Color Key: Desirable | Neutral | Undesirable

Notes:

1. **Risk Reduction –** Subjectively compares the amount of risk that can be mitigated with each proposed alternative.
2. **Right-of-Way –** “No” means work remains within the NJDOT Right-of-Way, “yes” means work is required outside of the NJDOT Right-of-Way.
3. **Required Maintenance** is a subjective assessment of the degree to which the proposed mitigation requires ongoing periodic maintenance by highway operations personnel.
4. **Anticipated Service Life** is an estimate of how long the proposed mitigation will function before needing additional alteration or replacement of elements.
5. **Construction Impact** relates to the degree to which traffic will be impacted by the specific construction option.
6. **Construction Difficulty** relates to how difficult the proposed mitigation would be to construct, considering access, environmental impact, working conditions, and type of equipment and skills needed.
7. **Construction Duration** is an estimate of the days required for actual work assuming 10-hour work days.
8. **Costs** were developed from recent unit prices modified for the site-specific conditions.
9. **Aesthetic Impact** is a subjective assessment of the degree to which the mitigation measures will be noticeable by park users and by the traveling public.

Table 5-2 – Comparison Matrix for Areas B and C Mitigation Alternatives

Option	Description	Risk Reduction	Outside Right-of-Way	Required Ongoing Maintenance	Anticipated Service Life (Years)	Construction Impact	Construction Difficulty	Construction Duration (days)		Cost ($1,000)		Aesthetic Impact
								Low	High	Low	High	
I	No Action	None	No	Status Quo – Periodic Rock Removal	N/A	None	N/A	0	0	0	0	None
II Fig. 6-2	**Protection** – Re-slope, Construct Catchment Ditch, and Fence at Crest of Lower Slope	High	No	Low – Periodic Ditch Cleaning, Beneficial for Snow Removal & Storage	> 50	High – At Least 1 Lane Required	Low	60 B 180 C	90 B 270 C	5,350	16,049	High
III	**Protection** – Hybrid System - Barrier at Crest of Lower Slope and Draped Mesh on Lower Face	High	No	Moderate – Periodic Cleanup Below Mesh	20	High – At Least 1 Lane Required	Moderate	45 B 135 C	68 C 200 C	6,626	19,878	High
IV	**Protection** – Improved Catchment with Hybrid System (Combination of Options II and III)	High	No	Low – Periodic Ditch Cleaning, Good for Snow Removal	20	High – At Least 1 Lane Required	Moderate	60 B 180 C	90 B 270 C	8,621	25,864	High

Color Key: Desirable | Neutral | Undesirable

Notes:

1. **Risk Reduction –** Subjectively compares the amount of risk that can be mitigated with each proposed alternative.
2. **Right-of-Way –** "No" means work remains within the NJDOT Right-of-Way, "yes" means work is required outside of the NJDOT Right-of-Way.
3. **Required Maintenance** is a subjective assessment of the degree to which the proposed mitigation requires ongoing periodic maintenance by highway operations personnel.
4. **Anticipated Service Life** is an estimate of how long the proposed mitigation will function before needing additional alteration or replacement of elements.
5. **Construction Impact** relates to the degree to which traffic will be impacted by the specific construction option.
6. **Construction Difficulty** relates to how difficult the proposed mitigation would be to construct, considering access, environmental impact, working conditions, and type of equipment and skills needed.
7. **Construction Duration** is an estimate of the days required for actual work assuming 10-hour work days.
8. **Costs** were developed from recent unit prices modified for the site-specific conditions.
9. **Aesthetic Impact** is a subjective assessment of the degree to which the mitigation measures will be noticeable by park users and by the traveling public.

Table 5-3 – Comparison Matrix for Area D Mitigation Alternatives

Option	Description	Risk Reduction	Outside Right-of-Way	Required Ongoing Maintenance	Anticipated Service Life (Years)	Construction Impact	Construction Difficulty	Construction Duration (days)		Cost ($1,000)		Aesthetic Impact
								Low	High	Low	High	
I	No Action	None	No	Status Quo – Periodic Rock Removal	N/A	None	N/A	0	0	0	0	Low
II	**Warning** - Install Rockfall Warning Fence	Low	May Require TCE	Status Quo + Periodically Repair Fence	20	Low – Shoulder Closing	Moderate	30	60	1,373	4,118	Moderate
III	**Monitoring** – Inclinometer, Tiltmeters, and/or Routinely Scheduled LiDAR Survey	Low	May Require TCE	Status Quo + Maintain Monitoring Equipment	20	None	Moderate	30	60	1,290	3,869	Low
IV	**Removal** - Trim blasting and Rock Removal Using Airbags and Scaling	Moderate	May Require TCE	Moderate – Periodic Rock Removal	20	Low – Local Detour Required	High	30	60	3,131	9,392	Moderate
V	**Reinforcement** – Install Tensioned Rock Bolts, Dental Concrete, and Anchored Mesh	Moderate	May Require TCE	Moderate – Periodic Rock Removal	20	Moderate – 1 Lane	High	150	300	4,513	13,538	High
VI	**Protection** – Install Hybrid System Barrier at Crest of Lower Slope and Draped Mesh below, or Draped Mesh with Sacrificial Fences	Moderate	No	Moderate– Periodic Rock Removal	20	Moderate –1 Lane Required	Moderate	150	300	5,043	15,129	High
VII	**Protection** – Raise Roadway Elevation or Shift Roadway West to Create Catchment	High	No	None	75	Moderate – Lane Shift	High	150	300	5,396	16,188	Moderate
VIII	**Protection** – Rock Shed over Road	High	No	None	75	Moderate – Lane Shift	High	180	360	8,564	25,692	High
IX Fig. 6-3	**Combination** – Localized Trim Blasting, Reinforcement of the Devil's Tea Table and Shotcrete or Dental Concrete.	High	May Require TCE	Low – Periodic Rock Removal	20	Low – Local Detour Required	High	150	300	6,178	18,534	High

Color Key:	Desirable	Neutral	Undesirable

Notes:

1. **Typical notes from Table 5-2 are applicable for Table 5-3.**
2. **TCE = Temporary Construction Easement**

5.4 Constructability Review

On December 18, 2014, HNTB geotechnical staff visited the site with Todd Reccord (Ameritech Slope Constructors, Inc.). The intent of the visit was to identify logistical issues that may be encountered during the construction of rock slope stabilization or rockfall mitigation measures. These issues may include access, occupancy of the roadway, and equipment capabilities. The constructability review visit was also conducted to reach general agreement on the overall feasibility and constructability of the Preliminary Preferred Alternatives from a rockfall specialty contractor's perspective.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 General

For each of the four areas, concept-level mitigation alternatives were developed. In most cases, these alternatives incorporated combinations of re-grading, rock removal, rock reinforcement, and rockfall control as discussed in Section 5.0. For each area, a comparison matrix was developed that utilized both subjective and quantitative criteria to evaluate the mitigation alternatives for that particular area. In all cases, a "No Action" alternative was included as a benchmark for comparison.

6.2 Area A

Table 5-1 summarizes seven mitigation options for Area A. Option II requires that the slope be re-graded at a stable inclination to create an effective catchment ditch. Option III incorporates removal of vegetation and intense scaling. Option IV adds a draped mesh to the Option III elements. Option V includes a sub-vertical cut at the toe of the slope to create a ditch in combination with draped mesh for the slope above (after removal of vegetation). Excavation would be via a combination of mechanical and drill & blast methods. Option VI also removes all vegetation, with mitigation provided by a combination of grouted dowels or rock bolts and shotcrete facing ("rock nailing"). Option VII requires removal of vegetation and installation of a secured mesh to provide an active face pressure.

From a geotechnical perspective, HNTB recommends that **Option V** be progressed to the design stage for the following reasons:

- High degree of risk reduction
- Applicable to variable slope geometry
- Improves sight distance
- Collateral benefit for snow removal/storage
- Nearby rock disposal site
- Provides opportunity for minimization of aesthetic impact through color-coating of mesh and introduction of vegetative cover

Figure 6-1 is a conceptual figure of the recommended design. Activities required to finalize the design include:

- Detailed topographic mapping utilizing LiDAR

- Rockfall simulations to optimize the height of the sub-vertical cut and the achievable ditch width
- Engineering analysis to select mesh type (cable, ring), anchor spacing, requirement for supplemental reinforcement, and the desirability of elevating the upper mesh (hybrid system)

6.3 Areas B and C

Areas B and C have been grouped due to the commonality of topographic and geologic conditions as well as the mitigation alternatives. Table 5-2 summarizes four mitigation options for Areas B and C. Many of the slopes throughout these areas are composite back slopes with a moderately inclined lower slope and a steep upper slope. Options II and IV include a sub-vertical cut at the toe of the slope to create a catchment ditch. Option II supplements the ditch with a draped mesh and an intermediate rockfall control fence located at the crest of the lower slope. Option IV supplements the ditch with a hybrid drape system elevated at the upper limit of the mesh. Option III does not improve the ditch catchment, but utilizes slope drape for the lower slope combined with a mid-slope barrier to intercept rockfall from the upper slope.

From a geotechnical perspective, HNTB recommends that **Option II** be progressed to the design stage for the following reasons (same as Option V for Area A):

- High degree of risk reduction
- Applicable to variable slope geometry
- Improves sight distance
- Collateral benefit for snow removal/storage
- Nearby rock disposal site
- Provides opportunity for minimization of aesthetic impact through color-coating of mesh and introduction of vegetative cover

Figure 6-2 is a conceptual figure of the recommended design. Activities required to finalize the design include:

- Detailed topographic mapping utilizing LiDAR
- Geologic mapping to identify rockfall source areas from the steep upper slopes
- Rockfall simulations to optimize the height of the sub-vertical cut and the achievable ditch width
- Engineering analysis to select mesh type (cable, ring), anchor spacing, requirement for supplemental reinforcement, and the desirability of elevating the upper mesh (hybrid)

6.4 Area D

Table 5-3 summarizes eight mitigation options for Area D. Of the four areas, this area is the most complex in terms of potential rockfall hazards. Options II and III would not reduce the rockfall hazard but would reduce the risk through the installation of warning fences or other monitoring instruments to protect the safety of the travelling public. Such approaches do not mitigate potential damage to infrastructure. Option IV removes potentially unstable columns and blocks through a combination of trim blasting and intensive scaling. Option V seeks to minimize rock removal while reinforcing unstable rock masses with tensioned rock bolts (or untensioned dowels), dental shotcrete (e.g. buttresses beneath overhangs), and secured mesh. Option VI would control rockfall from the lower slope with draped mesh and rockfall originating from the steep upper slopes using either an elevated mesh (hybrid) or interceptor fences. Options IV, V, and VI all require extensive tree removal from the existing slopes. Options VII and VIII protect the highway by raising the grade, shifting the alignment to the west, or constructing a rock shed over the highway.

Option IX combines several options to include stabilizing Devils Tea Table with a roughly four-inch-thick fiber reinforced color matched sculpted shotcrete to slow the differential weathering with minimal aesthetic impact. In addition, this option would stabilize the Tea Table with rock bolts or rock dowels. Trim blasting would remove unstable columns, evident by dilated joints, to create a new localized upper cut slope. A hybrid barrier system on the mid slope bench in conjunction with improved catchment by pre-split blasting of the lower slope will require extensive tree removal and a local detour, as well as impacts to pedestrian, bike, and river traffic during blasting, but would also result in significant risk reduction with minimal maintenance. **Option IX** is the Preliminary Preferred Alternative for Slope D, from a geotechnical perspective.

Option IX is a combination of mitigation strategies, including selective rock removal, rock reinforcement, and possibly protection (ditch catchment). This multi-faceted approach is required to best reduce the risks associated with the following complexities:

- Significant rockfall impact energy due to size of rock blocks and height of source
- Variable availability of natural benches
- Limited catchment
- Difficult access limiting the viability of individual mitigation strategies at some locations
- Overall goal to minimize cost and esthetic impact

Figure 6-3 is a conceptual figure of the recommended design. To achieve the level of geologic and engineering understanding necessary to select and design feasible mitigation alternatives, the following activities will be required:

- Development of base plans using a combination of terrestrial LiDAR, airborne LiDAR, and aerial photography (helicopter or drone supported)
- Geologic mapping using rope access
- Virtual structural mapping using Sirovison and/or LiDAR techniques
- Rockfall analyses (possibly supplemented with test rolls of scaled blocks to calibrate the simulation models)
- Structural analyses followed by limit equilibrium analyses

7.0 PRELIMINARY COST ESTIMATES

Although Final Design has not been performed, HNTB was tasked to develop preliminary construction cost estimates for the preliminary concepts contained herein. Mitigation alternatives for Areas A, B, C, and D were specified in the conclusions above. Estimated costs are summarized in Tables 5-1, 5-2, and 5-3 above. Detailed assumptions for all cost estimates are included in Appendix III.

The trim blasting proposed and construction equipment anticipated to perform the Preliminary Preferred Alternatives has the potential to significantly damage the pavement, particularly in Area D. The use of blasting mats may reduce the extents of the damage, but the asphalt surface course has been assumed to be sacrificial and will be repaired as needed.

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13. Wyllie, D.C., Mah, C.W. *Rock Slope Engineering Civil and Mining*. 4th Edition. 2004.

FIGURES

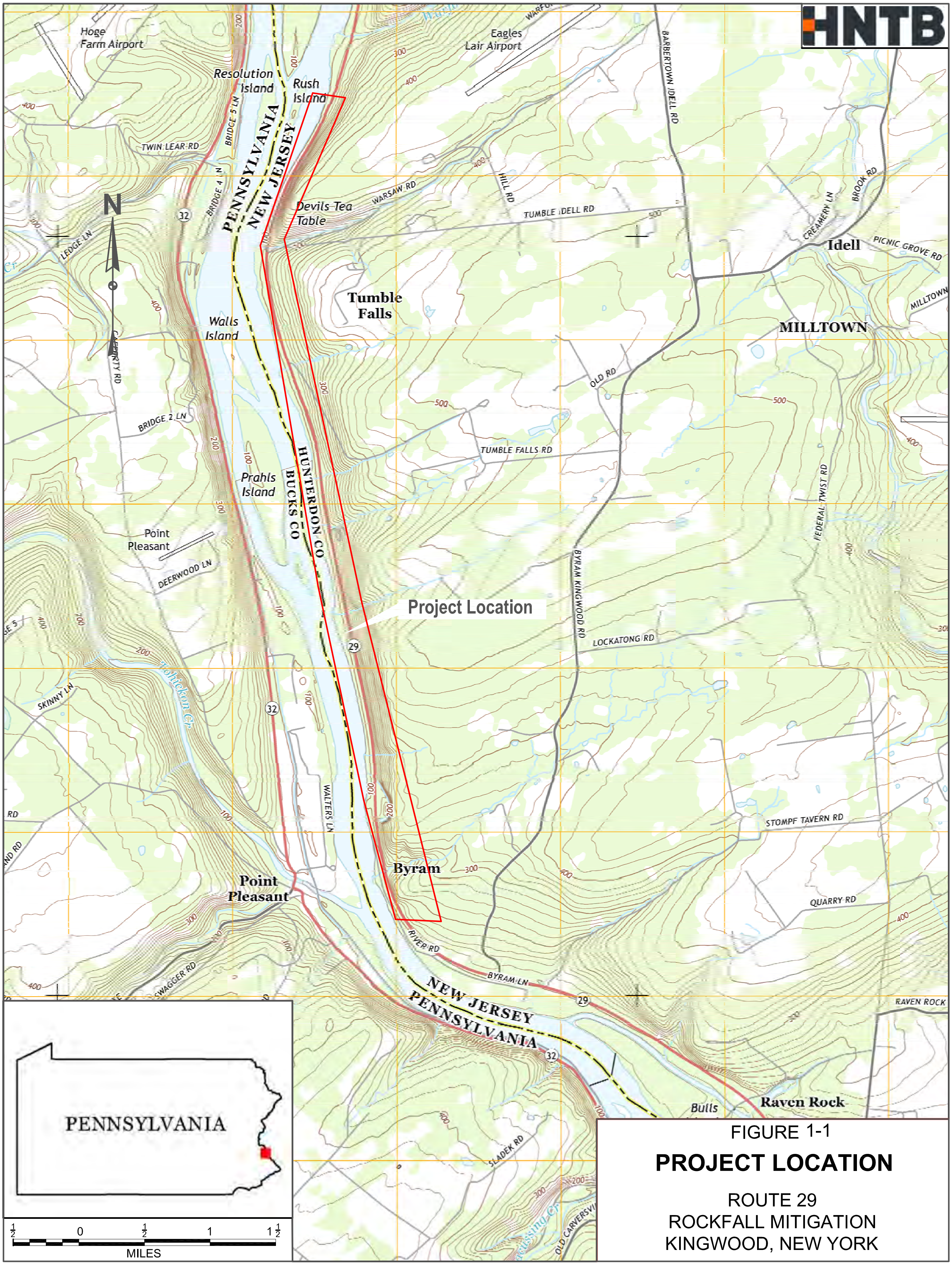


FIGURE 1-1

PROJECT LOCATION

ROUTE 29
ROCKFALL MITIGATION
KINGWOOD, NEW YORK

Basemap: U.S.G.S. Lumberville, PA-NJ Quadrangle, US Topo, 2013.

RT 29 ROCKFALL MITIGATION

TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-2a

DESIGN INFLUENCE PLAN

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 1 OF 6

RT 29 ROCKFALL MITIGATION

TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-2b

DESIGN INFLUENCE PLAN

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 2 OF 6

RT 29 ROCKFALL MITIGATION

TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-2c

DESIGN INFLUENCE PLAN

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 3 OF 6

RT 29 ROCKFALL MITIGATION

TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-2d

DESIGN INFLUENCE PLAN

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 4 OF 6

RT 29 ROCKFALL MITIGATION

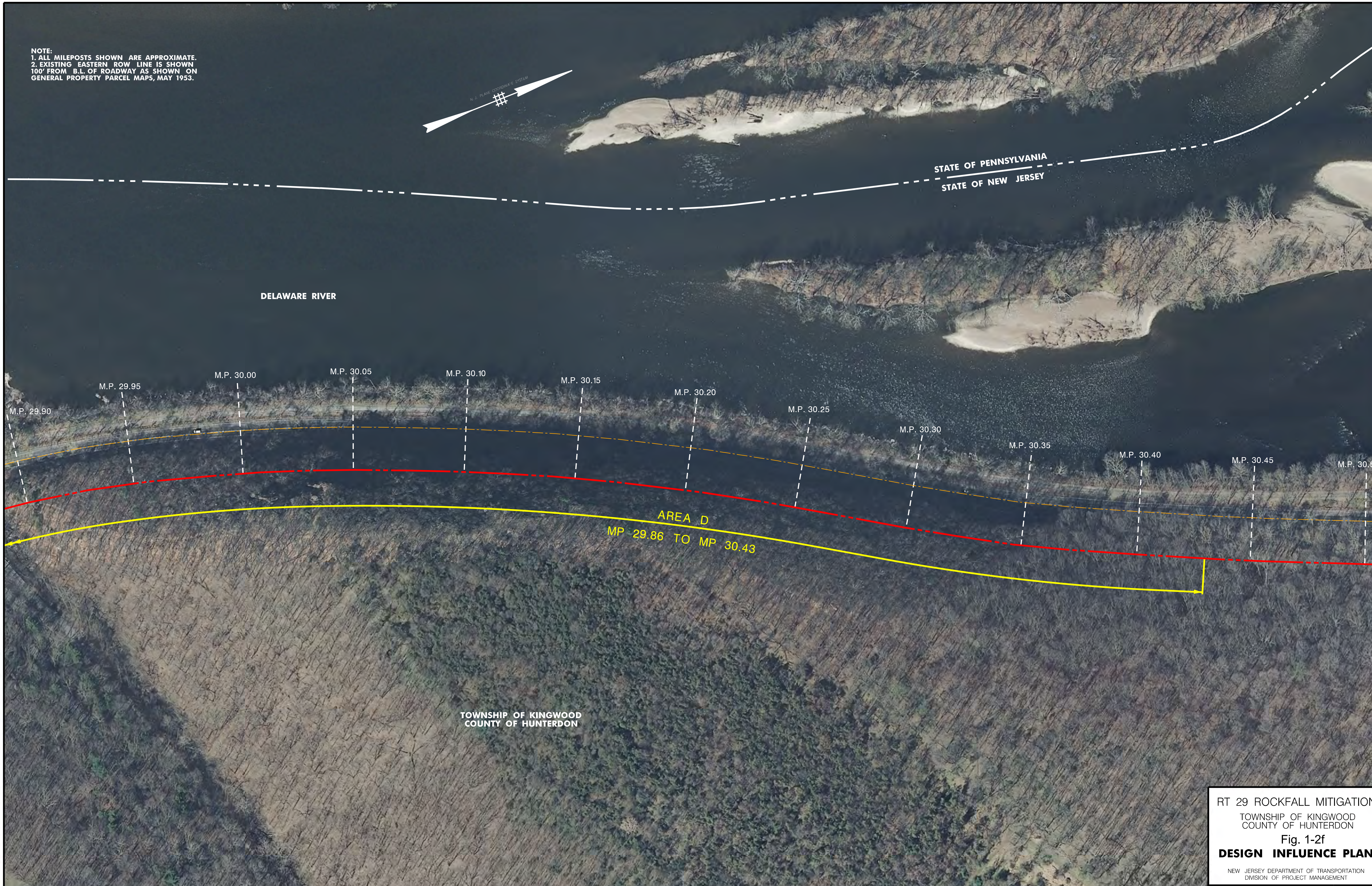
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

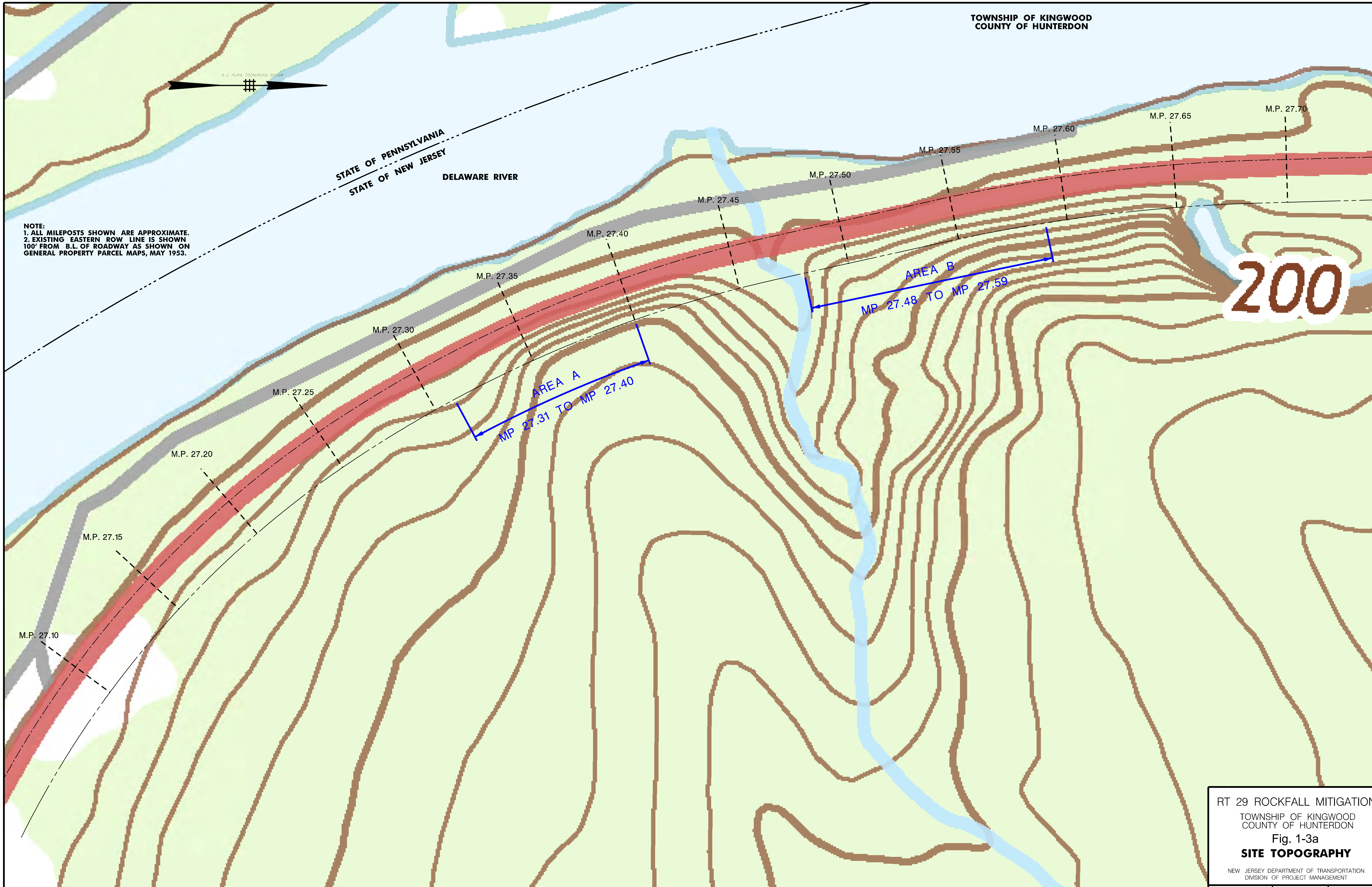
Fig. 1-2e

DESIGN INFLUENCE PLAN

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 5 OF 6


NOTE:
1. ALL MILEPOSTS SHOWN ARE APPROXIMATE.
2. EXISTING EASTERN ROW LINE IS SHOWN 100' FROM B.L. OF ROADWAY AS SHOWN ON GENERAL PROPERTY PARCEL MAPS, MAY 1953.
STATE OF PENNSYLVANIA
STATE OF NEW JERSEY
DELAWARE RIVER
M.P. 29.90
M.P. 29.95
M.P. 30.00
M.P. 30.05
M.P. 30.10
M.P. 30.15
M.P. 30.20
M.P. 30.25
M.P. 30.30
M.P. 30.35
M.P. 30.40
M.P. 30.45
M.P. 30.50
AREA D
MP 29.86 TO MP 30.43
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
RT 29 ROCKFALL MITIGATION
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
Fig. 1-2f
DESIGN INFLUENCE PLAN
NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT
SCALE: 1" = 200'
FEBRUARY 2015
SHEET 6 OF 6



RT 29 ROCKFALL MITIGATION

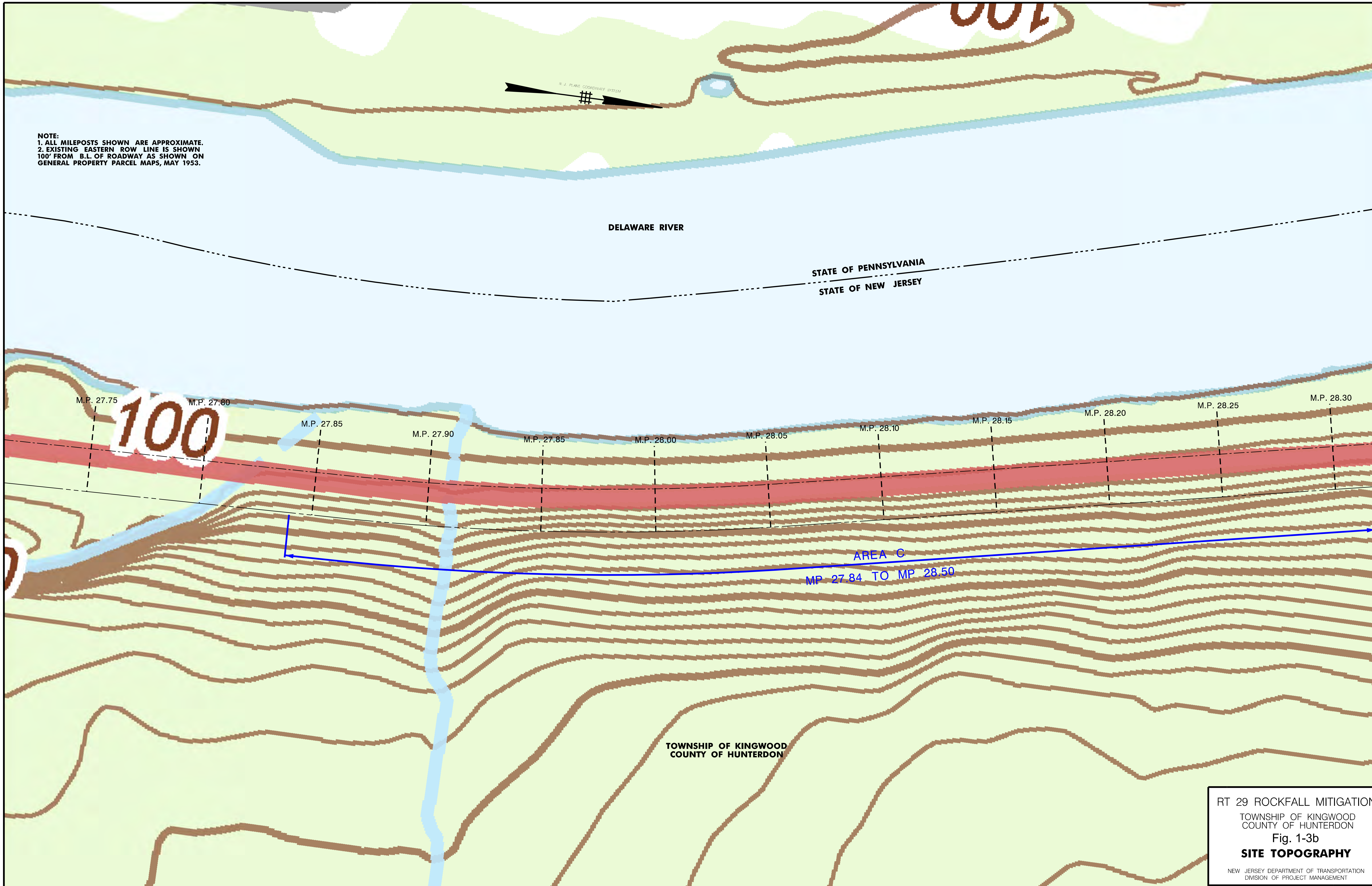
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-3a

SITE TOPOGRAPHY

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 1 OF 6



RT 29 ROCKFALL MITIGATION

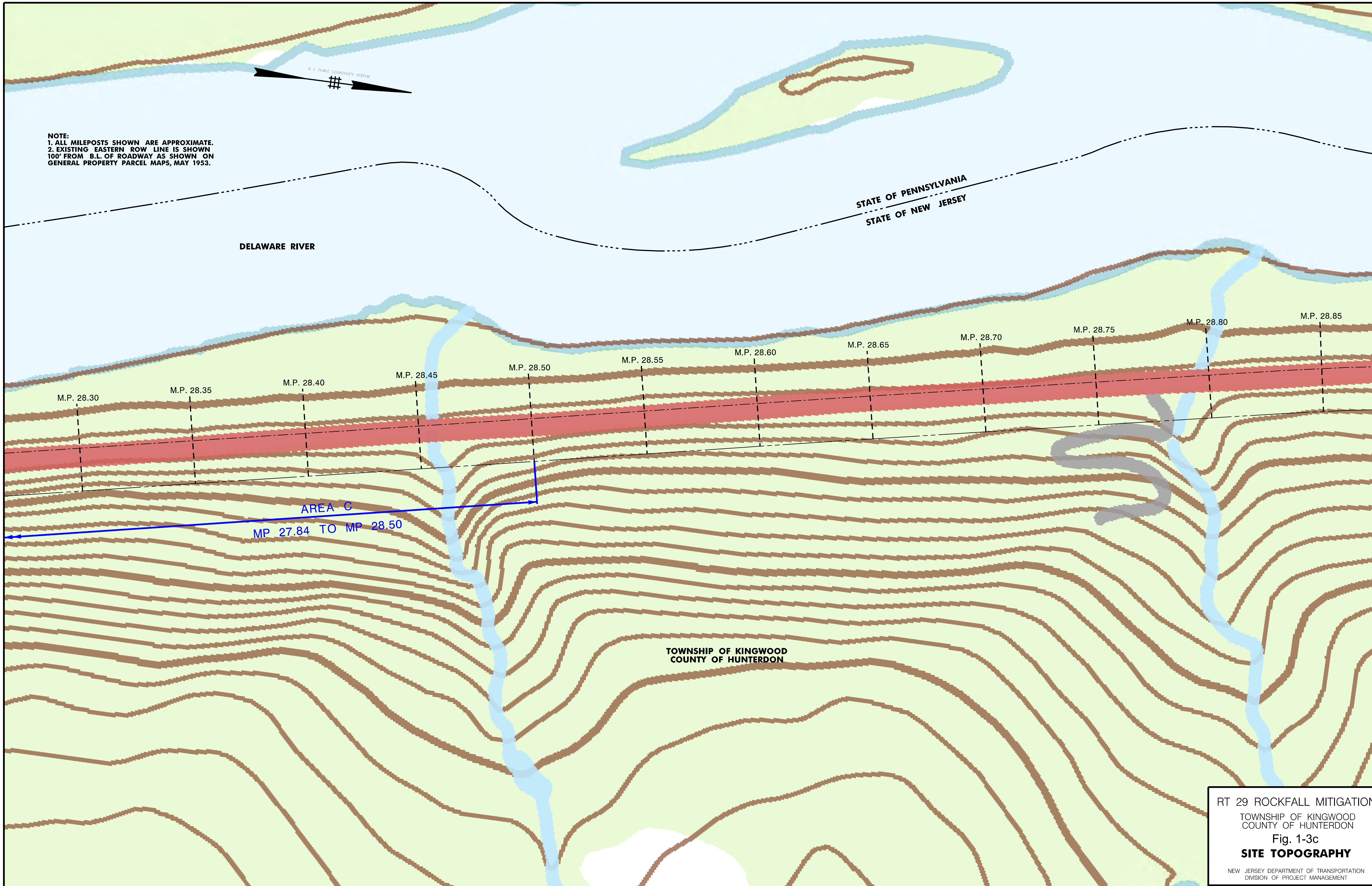
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-3b

SITE TOPOGRAPHY

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 2 OF 6



RT 29 ROCKFALL MITIGATION

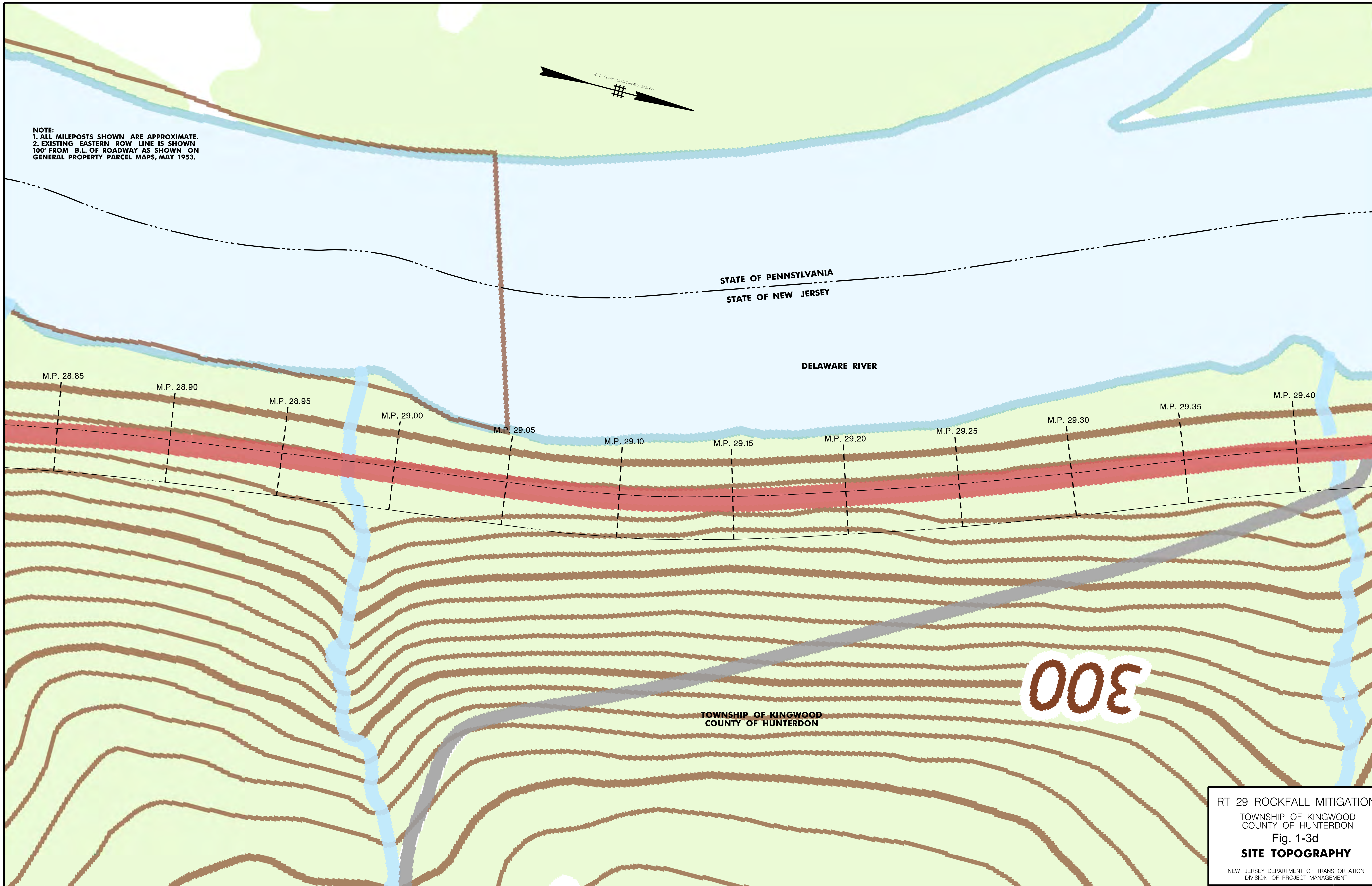
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-3c

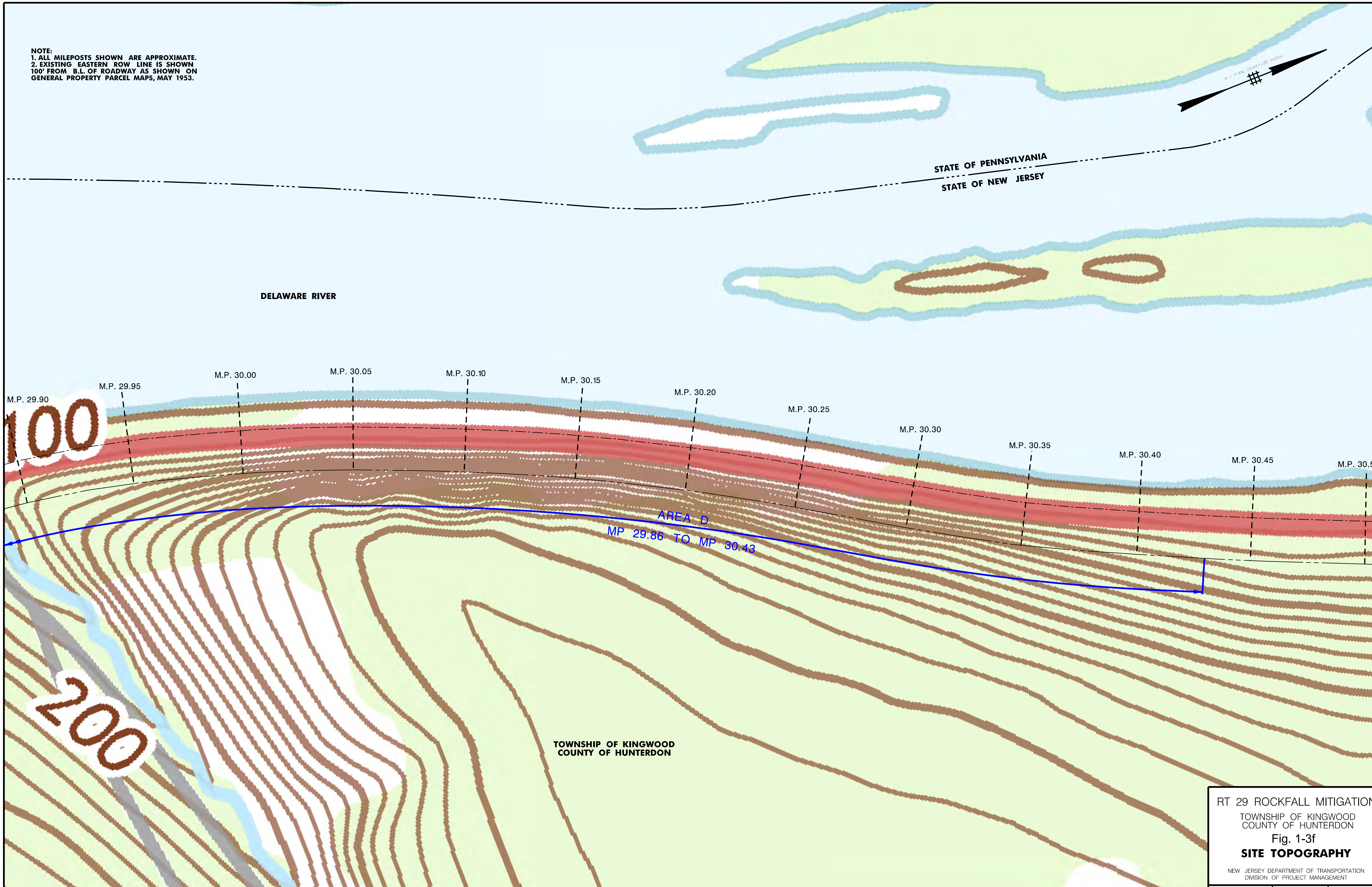
SITE TOPOGRAPHY

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1" = 200'	FEBRUARY 2015	SHEET 3 OF 6


NOTE:
1. ALL MILEPOSTS SHOWN ARE APPROXIMATE.
2. EXISTING EASTERN ROW LINE IS SHOWN 100' FROM B.L. OF ROADWAY AS SHOWN ON GENERAL PROPERTY PARCEL MAPS, MAY 1953.
N.J. PLANE COORDINATE SYSTEM
STATE OF PENNSYLVANIA
STATE OF NEW JERSEY
DELAWARE RIVER
M.P. 28.85
M.P. 28.90
M.P. 28.95
M.P. 29.00
M.P. 29.05
M.P. 29.10
M.P. 29.15
M.P. 29.20
M.P. 29.25
M.P. 29.30
M.P. 29.35
M.P. 29.40
300
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
RT 29 ROCKFALL MITIGATION
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
Fig. 1-3d
SITE TOPOGRAPHY
NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT
SCALE: 1" = 200'
FEBRUARY 2015
SHEET 4 OF 6


NOTE:
1. ALL MILEPOSTS SHOWN ARE APPROXIMATE.
2. EXISTING EASTERN ROW LINE IS SHOWN 100' FROM B.L. OF ROADWAY AS SHOWN ON GENERAL PROPERTY PARCEL MAPS, MAY 1953.
STATE OF PENNSYLVANIA
STATE OF NEW JERSEY
DELAWARE RIVER
M.P. 29.35
M.P. 29.40
M.P. 29.45
M.P. 29.50
M.P. 29.55
M.P. 29.60
M.P. 29.65
M.P. 29.70
M.P. 29.75
M.P. 29.80
M.P. 29.85
M.P. 29.90
M.P. 29.95
100
200
AREA D
MP 29.86 TO MP 30.43
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
RT 29 ROCKFALL MITIGATION
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
Fig. 1-3e
SITE TOPOGRAPHY
NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT
SCALE: 1" = 200'
FEBRUARY 2015
SHEET 5 OF 6



RT 29 ROCKFALL MITIGATION

TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON

Fig. 1-3f

SITE TOPOGRAPHY

NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

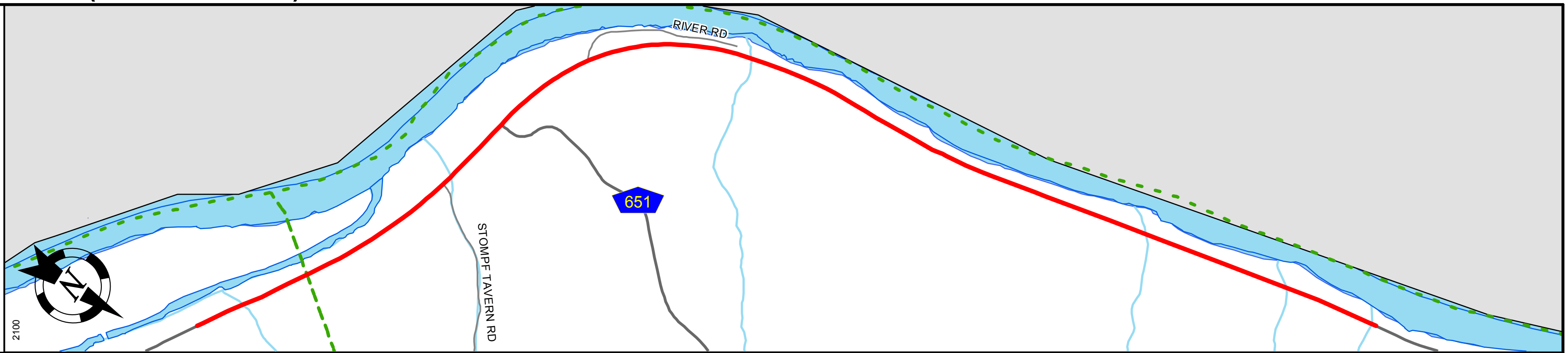
SCALE: 1" = 200'	FEBRUARY 2015	SHEET 6 OF 6

NJ 29 (South to North)

Mile Posts: 26.000 - 29.000

Secondary Direction

Primary Direction



Pavement	
Shoulder	
Number of Lanes	
Speed Limit	
Street Name	

Interstate Route 287

US Route 22

NJ Route 21

County Road 689

Interchange Number 2

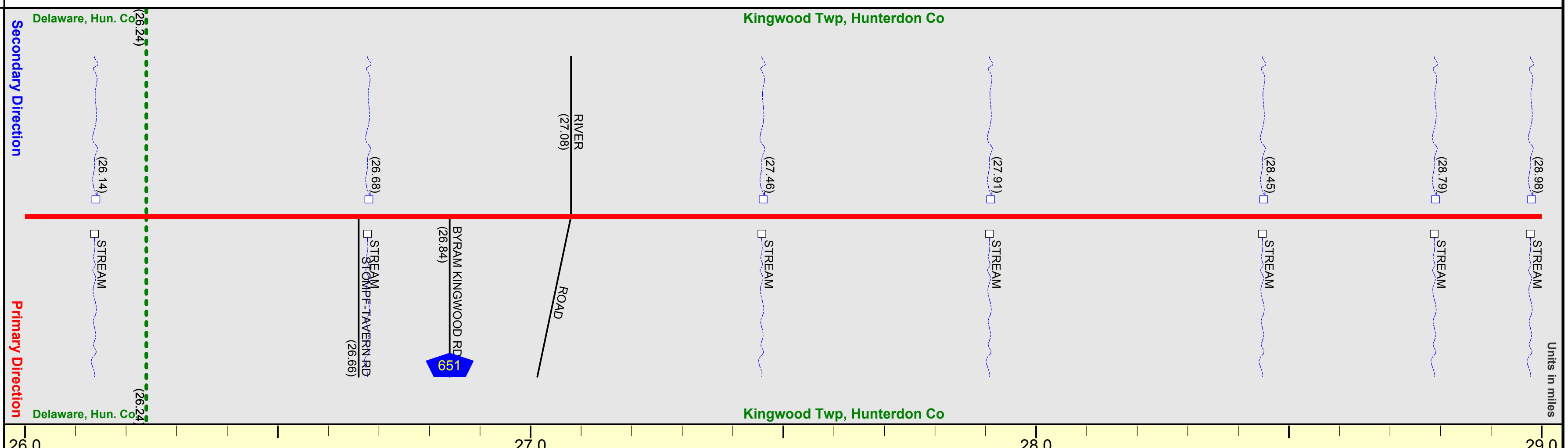
Grade Separated Interchange

Traffic Signal

Traffic Monitoring Sites WIM AVC VOL

Road Underpass

Road Overpass



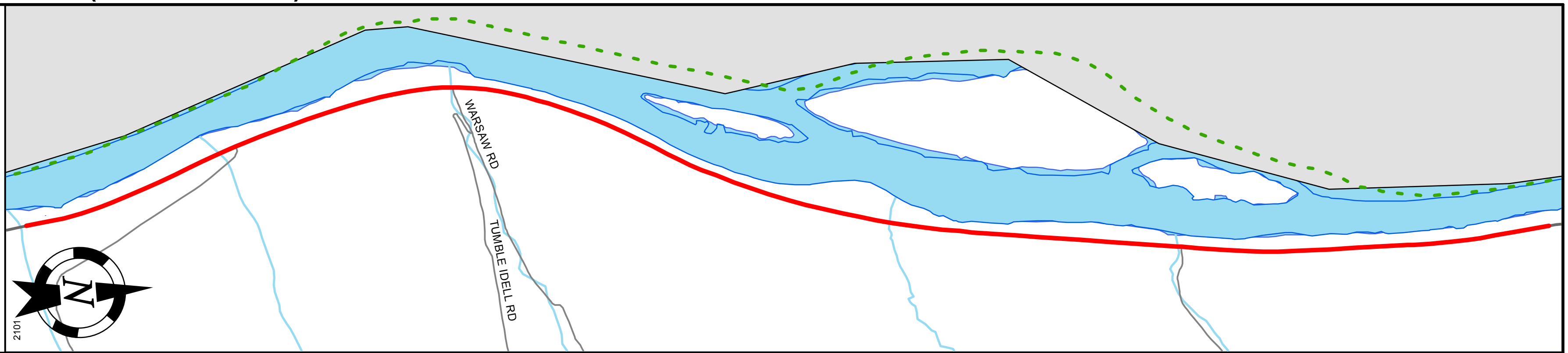
Street Name	Main Street; Daniel Bray Highway
Jurisdiction	N.J.D.O.T.
Functional Class	Rural Minor Arterial
Federal Aid - NHS Sy	STP
Control Section	1008
Speed Limit	50
Number of Lanes	2
Med. Type	None
Med. Width	0
Pavement	24
Shoulder	10
Traffic Volume	2,430 (2007); 1,864 (2008)
Traffic Sta. ID	5-4-309; 5-4-305
Structure No.	1008166; 1008152; 1008153; 1008154; 1008155; 1008156; 1008157
Enlarged Views	

Page Created: May 2010

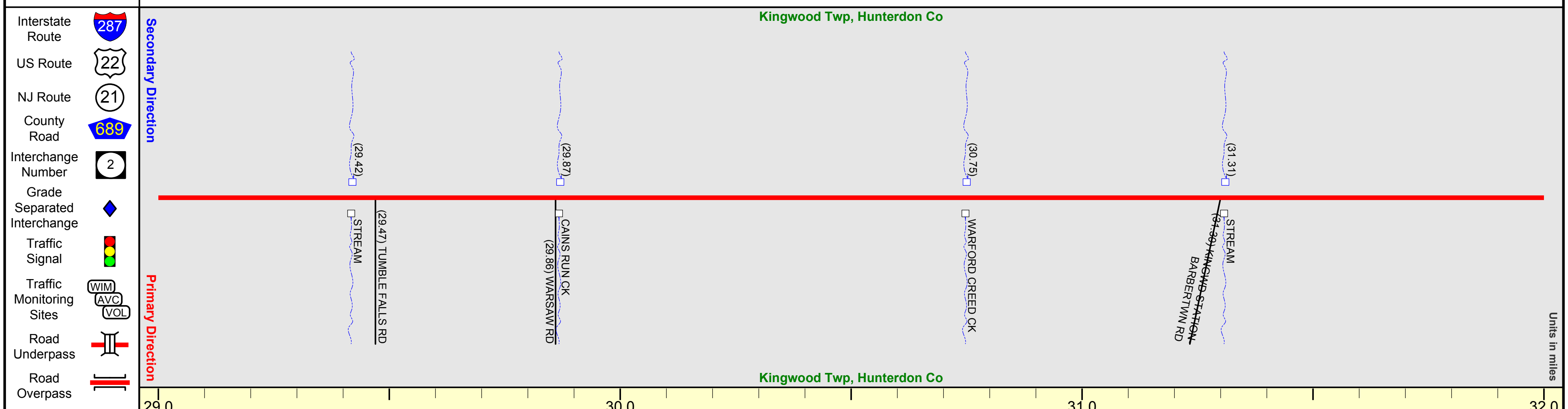
SRI = 00000029__

Date last inventoried: April 2009

FIGURE 1-4a



Pavement	
Shoulder	
Number of Lanes	
Speed Limit	
Street Name	



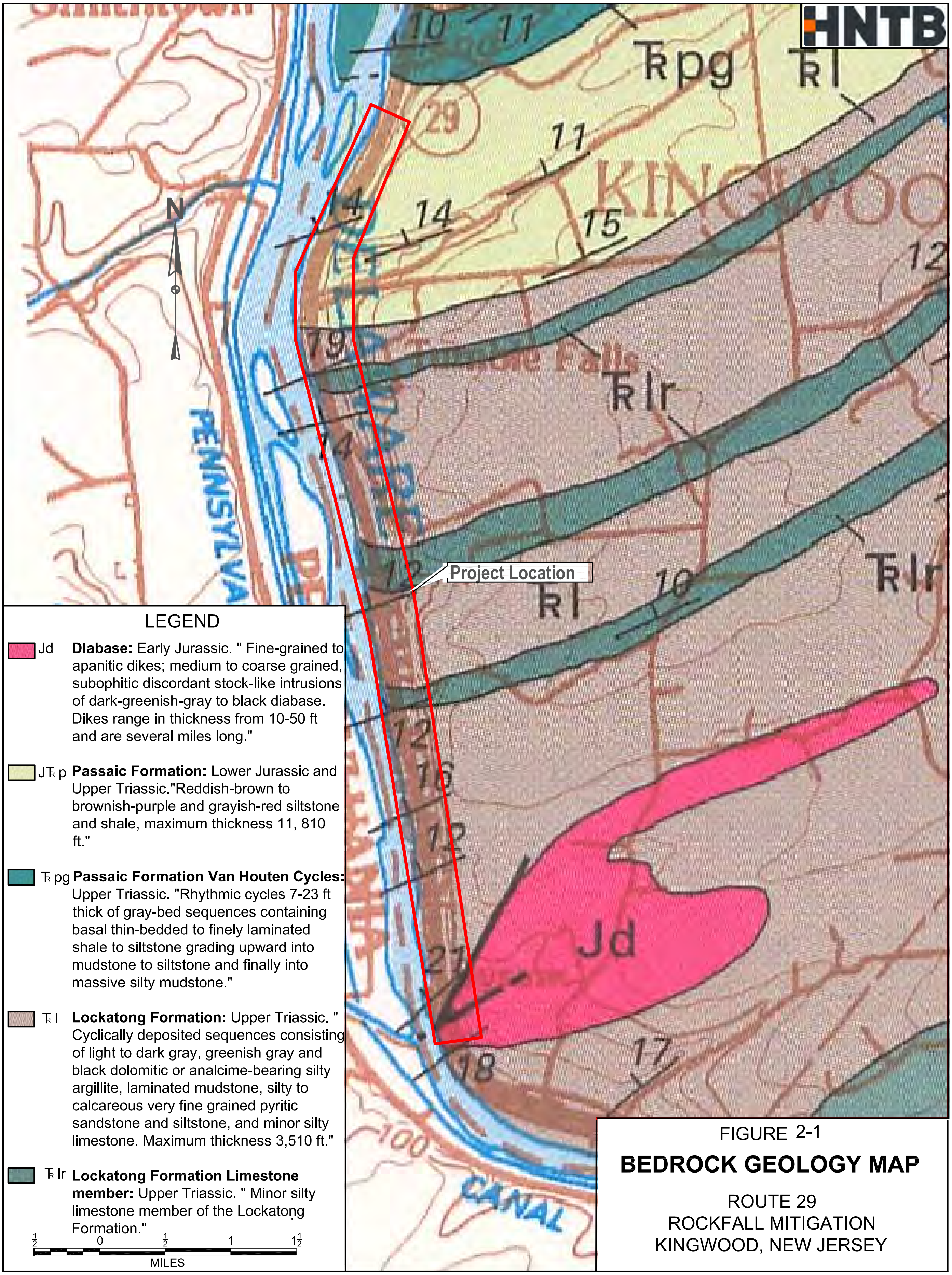
Street Name	Daniel Bray Highway			
Jurisdiction	N.J.D.O.T.			
Functional Class	Rural Minor Arterial			
Federal Aid - NHS Sy	STP			
Control Section	1008		1009	
Speed Limit	50			
Number of Lanes	2			
Med. Type	None			
Med. Width	0			
Pavement	24		22	
Shoulder	10	6	10	
Traffic Volume				
Traffic Sta. ID				
Structure No.	1008158	1008159	1008160	1009151
Enlarged Views				

Page Created: May 2010

SRI = 00000029__

Date last inventoried: April 2009

FIGURE 1-4b



LEGEND

Jd **Diabase:** Early Jurassic. " Fine-grained to apanitic dikes; medium to coarse grained, subophitic discordant stock-like intrusions of dark-greenish-gray to black diabase. Dikes range in thickness from 10-50 ft and are several miles long."

JTR p **Passaic Formation:** Lower Jurassic and Upper Triassic."Reddish-brown to brownish-purple and grayish-red siltstone and shale, maximum thickness 11, 810 ft."

TR pg **Passaic Formation Van Houten Cycles:** Upper Triassic. "Rhythmic cycles 7-23 ft thick of gray-bed sequences containing basal thin-bedded to finely laminated shale to siltstone grading upward into mudstone to siltstone and finally into massive silty mudstone."

TR l **Lockatong Formation:** Upper Triassic. " Cyclically deposited sequences consisting of light to dark gray, greenish gray and black dolomitic or analcime-bearing silty argillite, laminated mudstone, silty to calcareous very fine grained pyritic sandstone and siltstone, and minor silty limestone. Maximum thickness 3,510 ft."

TR lr **Lockatong Formation Limestone member:** Upper Triassic. " Minor silty limestone member of the Lockatong Formation."

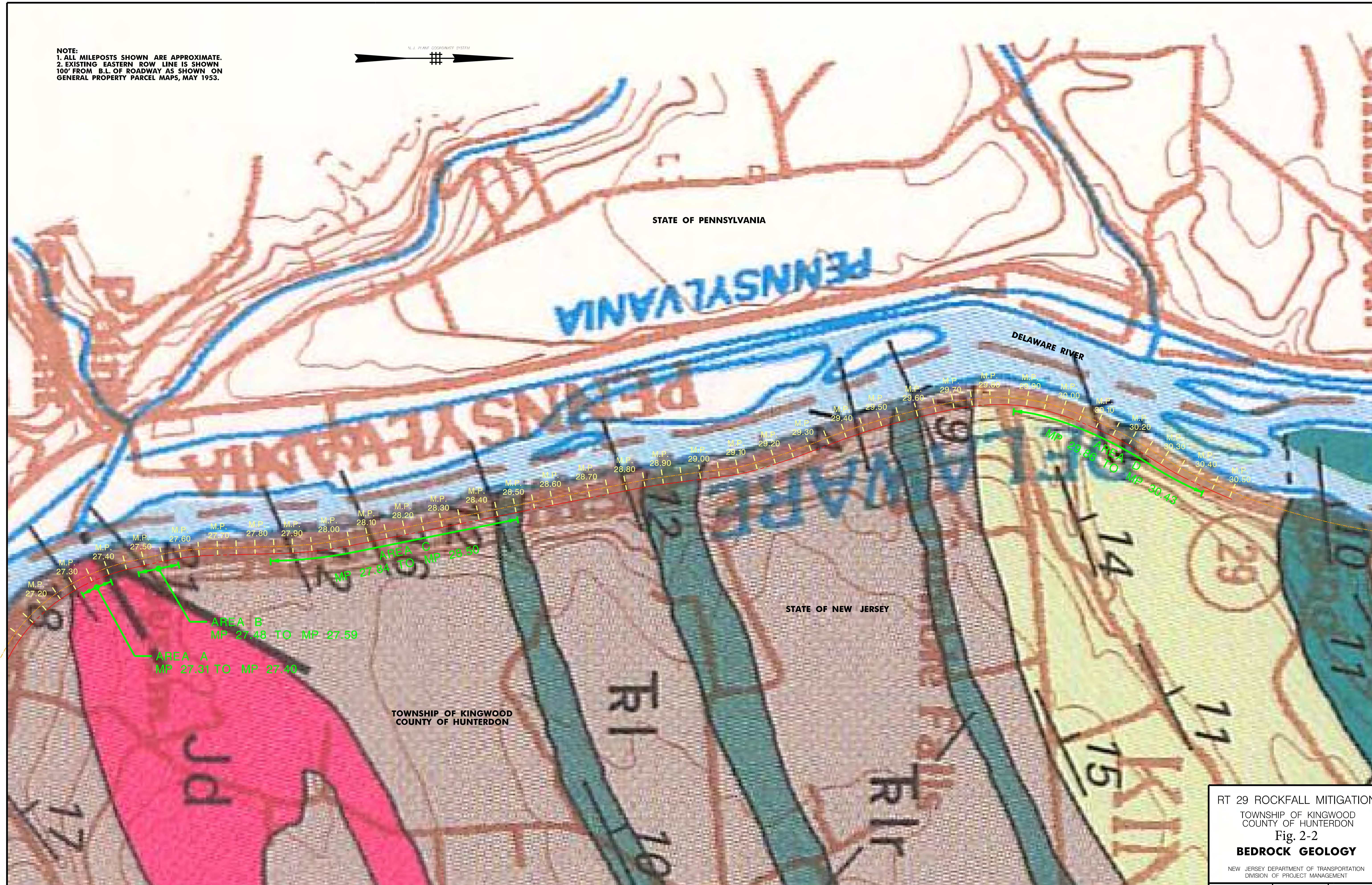
FIGURE 2-1

BEDROCK GEOLOGY MAP

ROUTE 29
ROCKFALL MITIGATION
KINGWOOD, NEW JERSEY

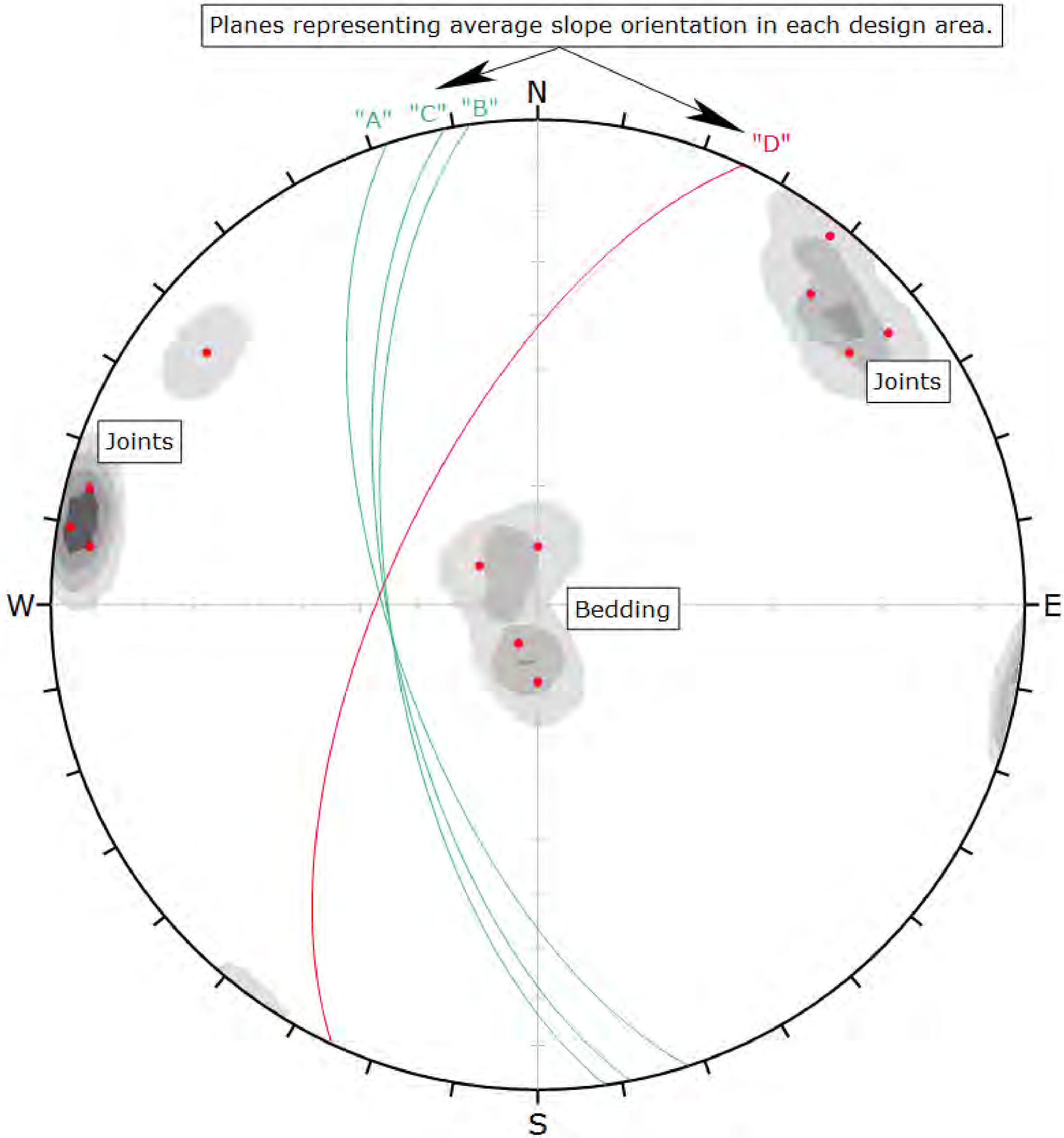
Basemap: Bedrock Geologic Map of Central and Southern New JerseyOwnes, J.P., and others, United States Geological Survey, 1998.

NOTE:
1. ALL MILEPOSTS SHOWN ARE APPROXIMATE.
2. EXISTING EASTERN ROW LINE IS SHOWN 100' FROM B.L. OF ROADWAY AS SHOWN ON GENERAL PROPERTY PARCEL MAPS, MAY 1953.



RT 29 ROCKFALL MITIGATION
TOWNSHIP OF KINGWOOD
COUNTY OF HUNTERDON
Fig. 2-2
BEDROCK GEOLOGY
NEW JERSEY DEPARTMENT OF TRANSPORTATION
DIVISION OF PROJECT MANAGEMENT

SCALE: 1"=1200'	FEBRUARY 2015	SHEET 1 OF 1



Symbol	Scatter
•	1 Pole Vectors

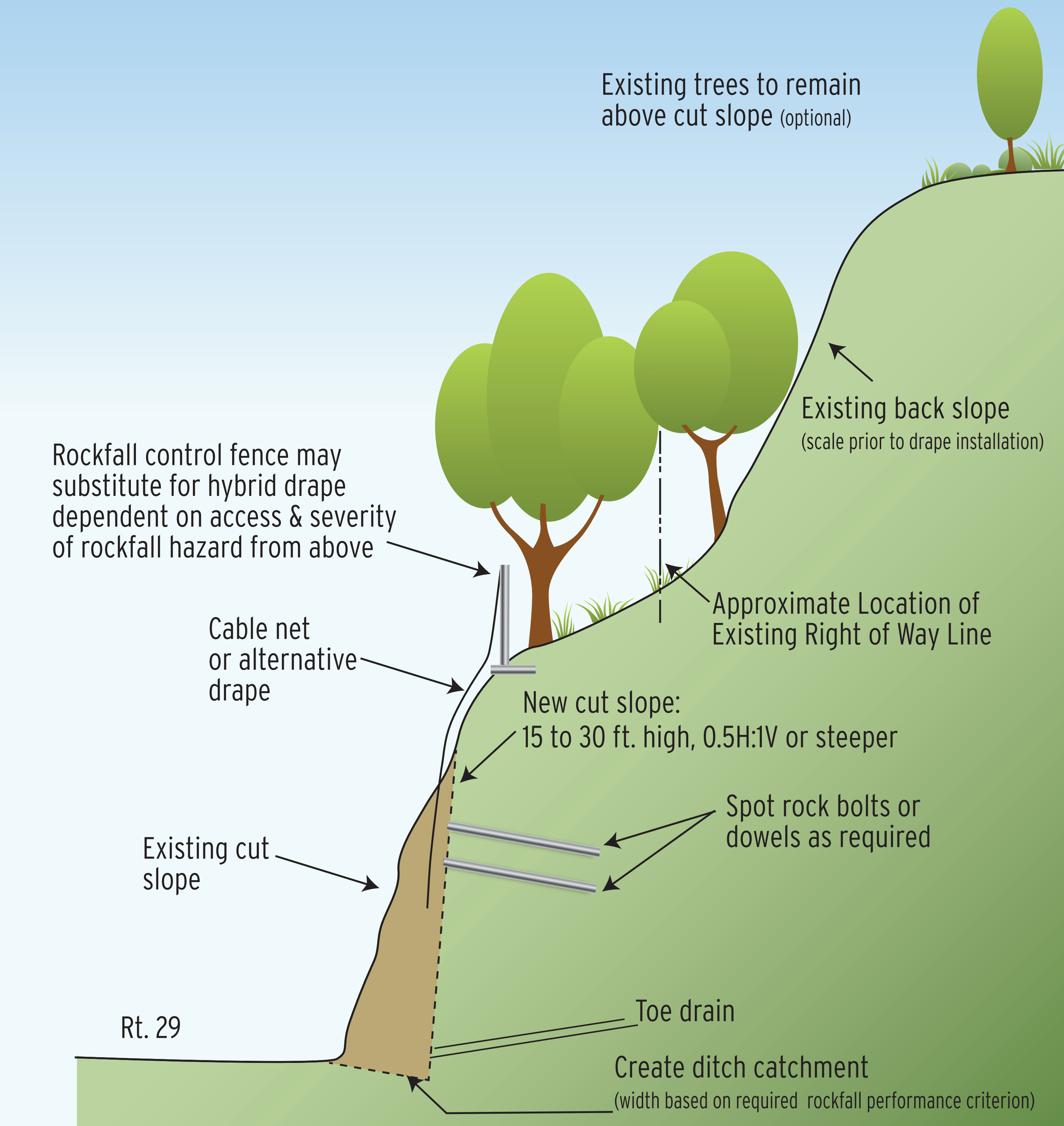
Color	Density Concentrations
	0.00 - 5.00
	5.00 - 10.00
	10.00 - 15.00
	15.00 - 20.00
	20.00 <
Maximum Density	23.41%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	12 (12 Entries)
Hemisphere	Lower
Projection	Equal Area

Figure 5-1 - Stereographic analysis of the limited structural geology indicates the presence of two-steeping dipping joint sets along with northerly-dipping flat-lying bedding.

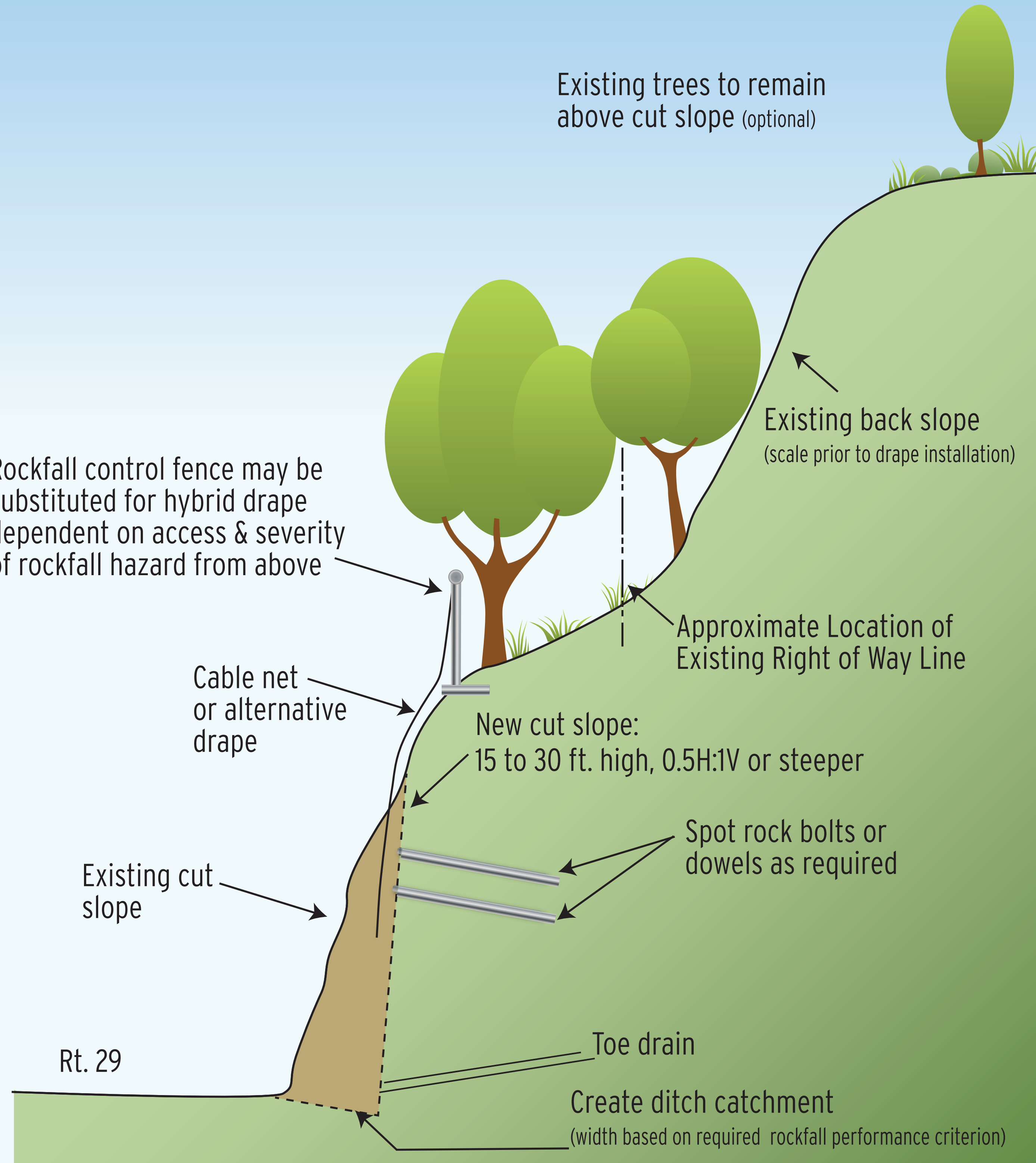
Figure 6-1
(NTS)

Preliminary Preferred Conceptual Mitigation Option (Area "A" = Option V)



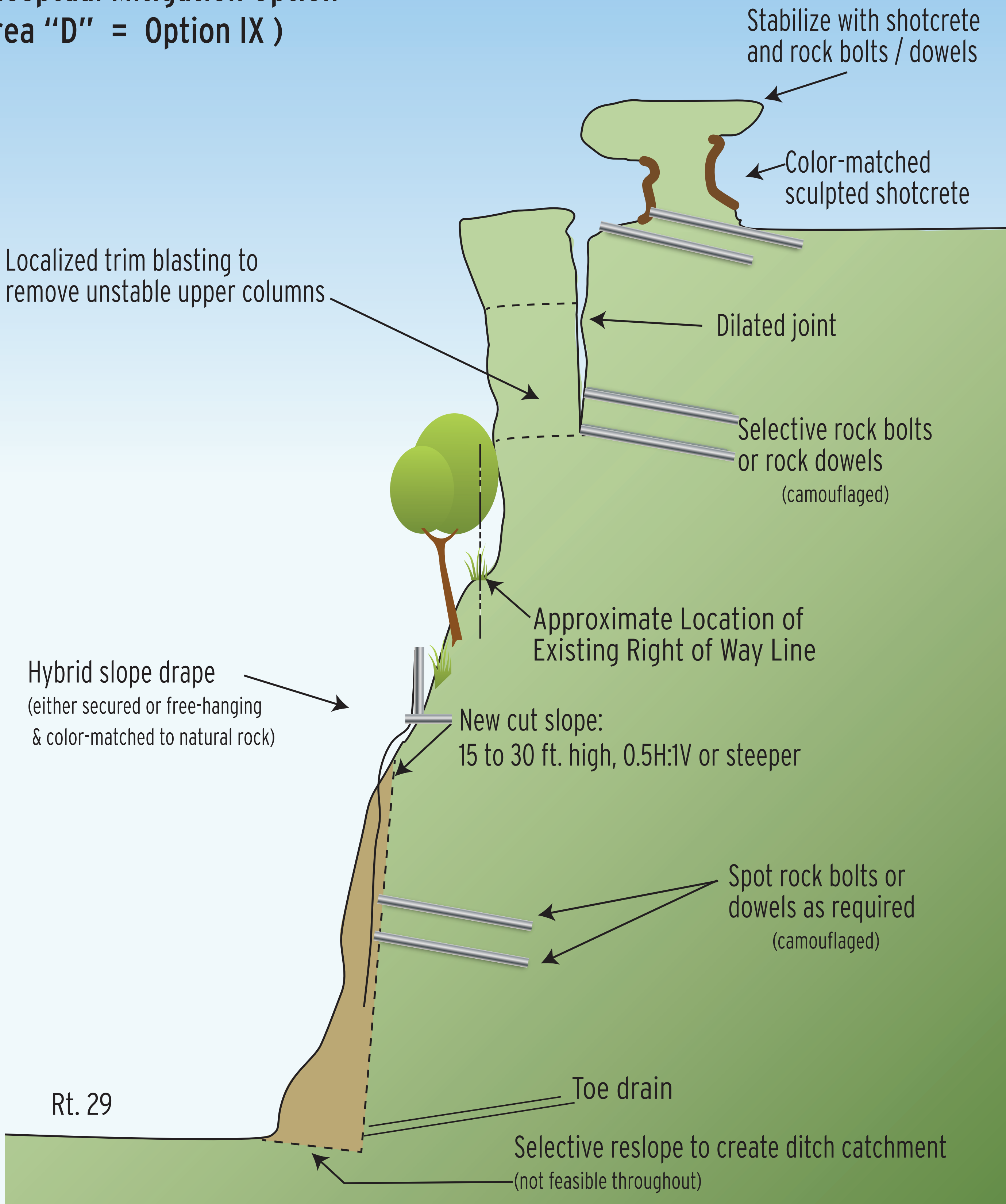
Preliminary Preferred Conceptual Mitigation Option (Areas "B"+"C" = Option II)

Figure 6-2
(NTS)



Preliminary Preferred Conceptual Mitigation Option (Area “D” = Option IX)

Figure 6-3
(NTS)



APPENDIX I

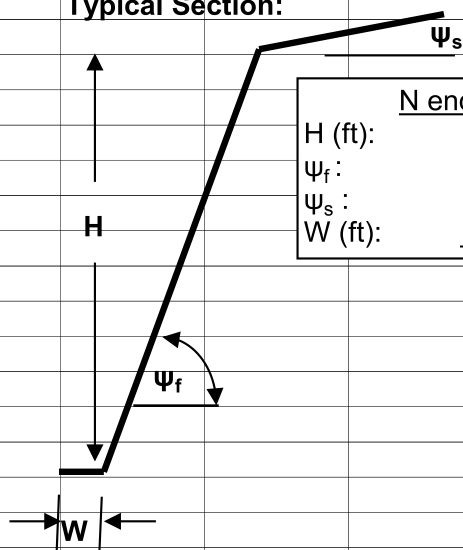
Typed Field Notes and Field Reconnaissance Photos

FIELD NOTES
REGION: Hwy: Route 29
MP: BEG **27.31** END **27.40**
Slope Designation: Area "**A**"

Prepared by: NN/JS/BF
Date: 10/21/2014

Site Measurements:
Impact of Failure: 500 ft slope length
Sight Distance: ~400' - 450'
Highway Trend: 252° average

Typical Section:



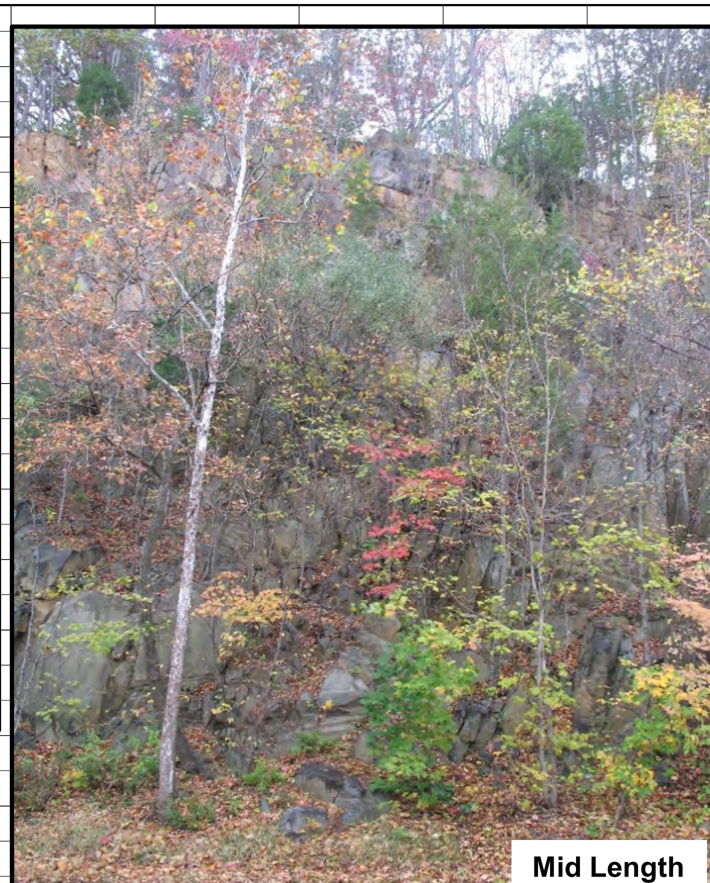
	N end	Mid	S end
H (ft):		75'	60'
ψ_f:		65-70°	51-65°
ψ_s:		20°	20°
W (ft):		___Nil____	

Rock Mass Characterization:
Rock Type: Fresh, strong diabase, closely jointed and fresh medium strong siltstone, slightly metamorphosed.

Structures: Joints are sub vertical with random orientations defining equidimensional blocks with typical block size 2CY

Site Photographs: Oct 21, 2014


South End


Mid Length

Types of Instability:

1. Loose rockmass with evidence of root and frost jacking.
2. Localized block toppling.

Special Notes:
1. Dec 2013 rockfall ~ 1CY reached N bound travel lane.
2. Location of maximum cut slope height which is approximate mid-length.

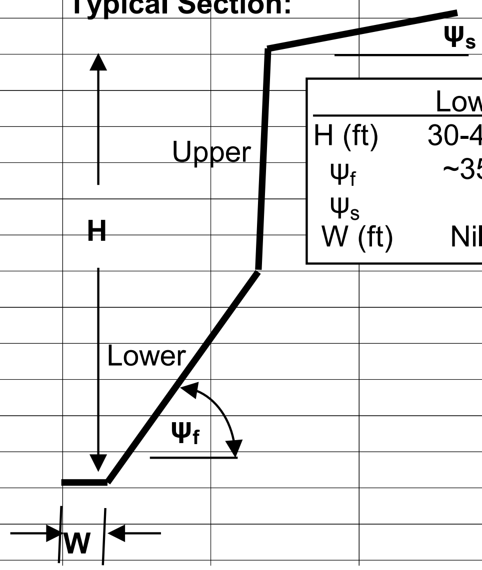
Mitigation Alternatives:
1. Protection measures to control rockfall and provide ditch catchment (see report for details).

FIELD NOTES
REGION: Hwy: Route 29
MP: BEG **27.48** END **27.59**
Slope Designation: Area "**B**"

Prepared by: NN/JS/BF
Date: 10/21/2014

Site Measurements:
Impact of Failure: 580 ft slope length
Sight Distance: ~800'
Highway Trend: 262° average

Typical Section:



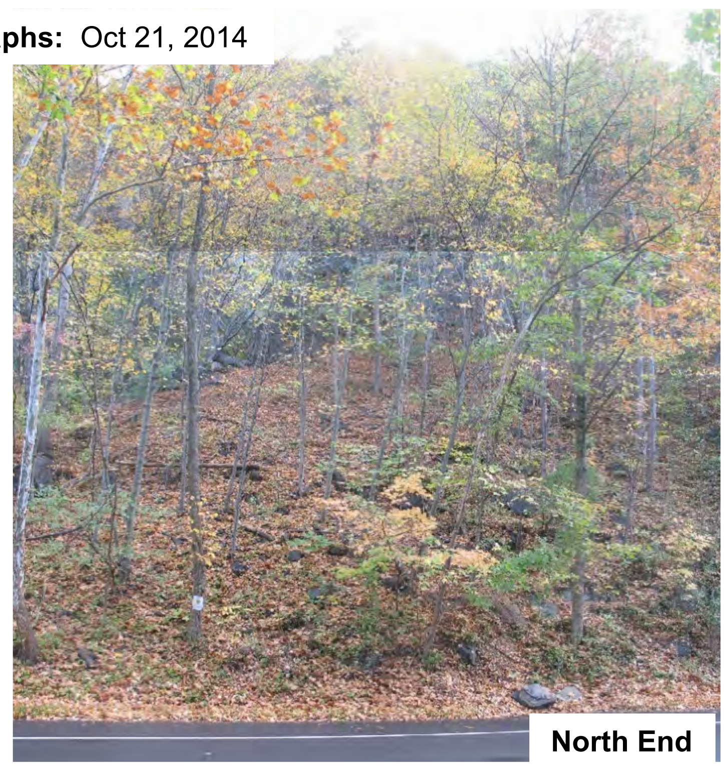
	Lower	Upper	Overall
H (ft)	30-40'	30-40'	75'
ψ_f	~35°	subvert	
ψ_s			35°
W (ft)	Nil		

Rock Mass Characterization:
Rock Type: Fresh medium strong siltstone, locally massive, slightly metamorphosed.

Structures: Joints typically smooth& planar, locally dilated with 3 to 4" apperture. Typical block size 2 - 3 CY.
Set 1: 84-90°/100° Set 2: 87°/217° Bedding: 07°/032°

Site Photographs: Oct 21, 2014

250 ft from South End



North End

Types of Instability:

1. Loose detached blocks with evidence of root and frost jacking.
2. Localized block toppling.

Special Notes:
1. Primarily a back slope not a cut slope.
2. Evidence of rockfall at toe but no significant reported/documented rockfalls by NJDOT.

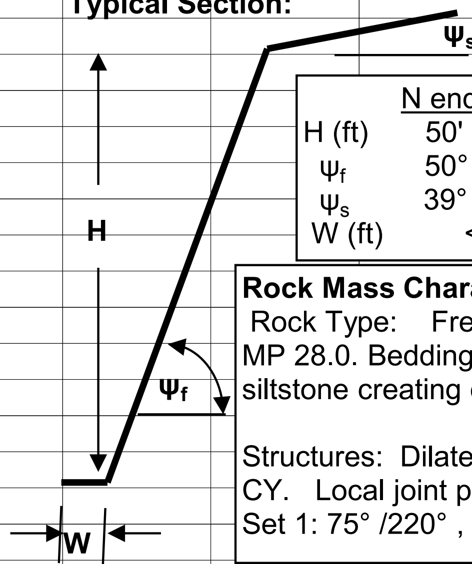
Mitigation Alternatives:
1. Protection measures to control rockfall and provide ditch catchment (see report for details).

FIELD NOTES
REGION: Hwy: Route 29
MP: BEG **27.84** END **28.50**
Slope Designation: Area "**C**"

Prepared by: NN/JS/BF
Date: 10/21/2014

Site Measurements:
Impact of Failure: 3450 ft slope length
Sight Distance: ~1000'
Highway Trend: 259° average

Typical Section:



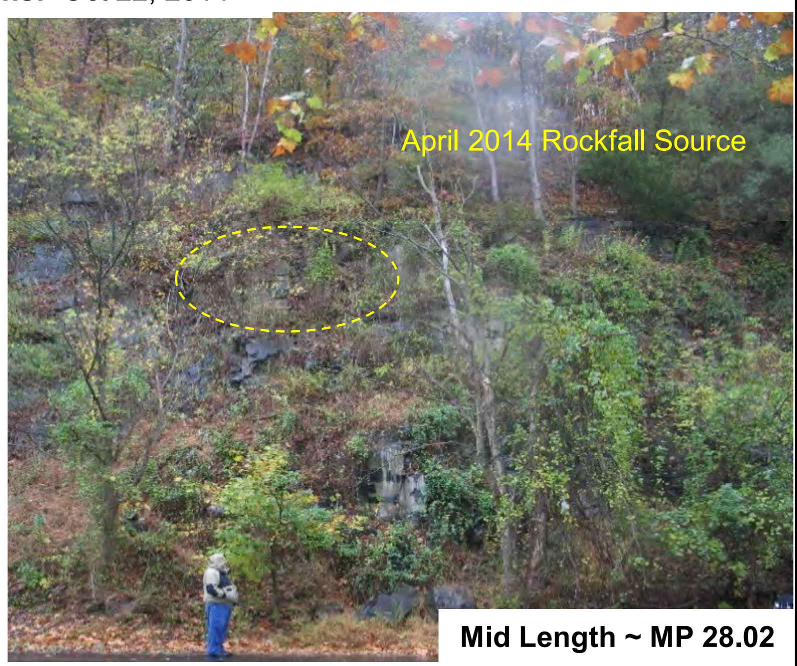
	N end	Mid	S end
H (ft)	50'	40'	25'
ψ_f	50°	68°	70-80°
ψ_s	39°	40°	35°
W (ft)	<5'		

Rock Mass Characterization:
Rock Type: Fresh, strong argillite transitioning to moderatly strong siltstone at approx MP 28.0. Bedding is massive to thinly laminated. Localized differential weathering in siltstone creating overhangs.

Structures: Dilated joints with 1 to 2" aperture, argillite blocks have typical size 3 to 4 CY. Local joint persistence greater than 50 ft.
Set 1: 75° /220° , 70°/230°, Set 2: 83°/097°, 86°/104° , Bedding: 10°/182°, 13°/357°

Site Photographs: Oct 22, 2014

Mid Length ~ MP 28.05



Mid Length ~ MP 28.02

Types of Instability:

1. Loose rockmass with evidence of root and frost jacking.
2. Localized block toppling.
3. Differential erosion of siltstone.

Special Notes:
1. April 2014 rockfall located 100' N of MP 28.0
Intact block ~ 5'x4'x4' reached S bound lane,
Several ± 2'x2'x2' blocks in in N bound lane.
Source 25' above highway grade.

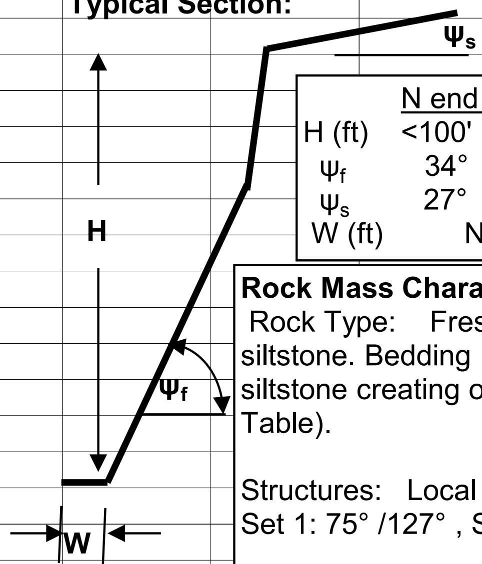
Mitigation Alternatives:
1. Protection measures to control rockfall and provide ditch catchment (see report for details).

FIELD NOTES
REGION: Hwy: Route 29
MP: BEG **29.86** END **30.43**
Slope Designation: Area "**D**"

Prepared by: NN/JS/BF
Date: 10/21/2014

Site Measurements:
Impact of Failure: 3000 ft slope length
Sight Distance: ~1500'
Highway Trend: 295° average

Typical Section:



	N end	Mid	S end
H (ft)	<100'	200'	30'
ψ_f	34°	65°	52°
ψ_s	27°	42°	13°
W (ft)		Nil	

Devil's Tea Table @ MP 30.05
Slopes north of this location taper from 260' height to zero at MP 30.43.

Rock Mass Characterization:
Rock Type: Fresh to moderately weathered , moderatley strong "red bed" sandstone / siltstone. Bedding is massive to thinly laminated. Localized differential weathering in siltstone creating overhangs and detached sub vertical columns along crest (Devil's Tea Table).

Structures: Local joint persistence greater than 50 ft.
Set 1: 75° /127° , Set 2 80°/232°, Bedding: 11°/123°

Site Photographs: Oct 21/22, 2014 (see also next page)

South end ~ MP 29.90

Mid Length ~ MP 30.08

Types of Instability:

1. Loose rockmass with evidence of root and frost jacking.
2. Localized block toppling.
3. Differential erosion of siltstone.

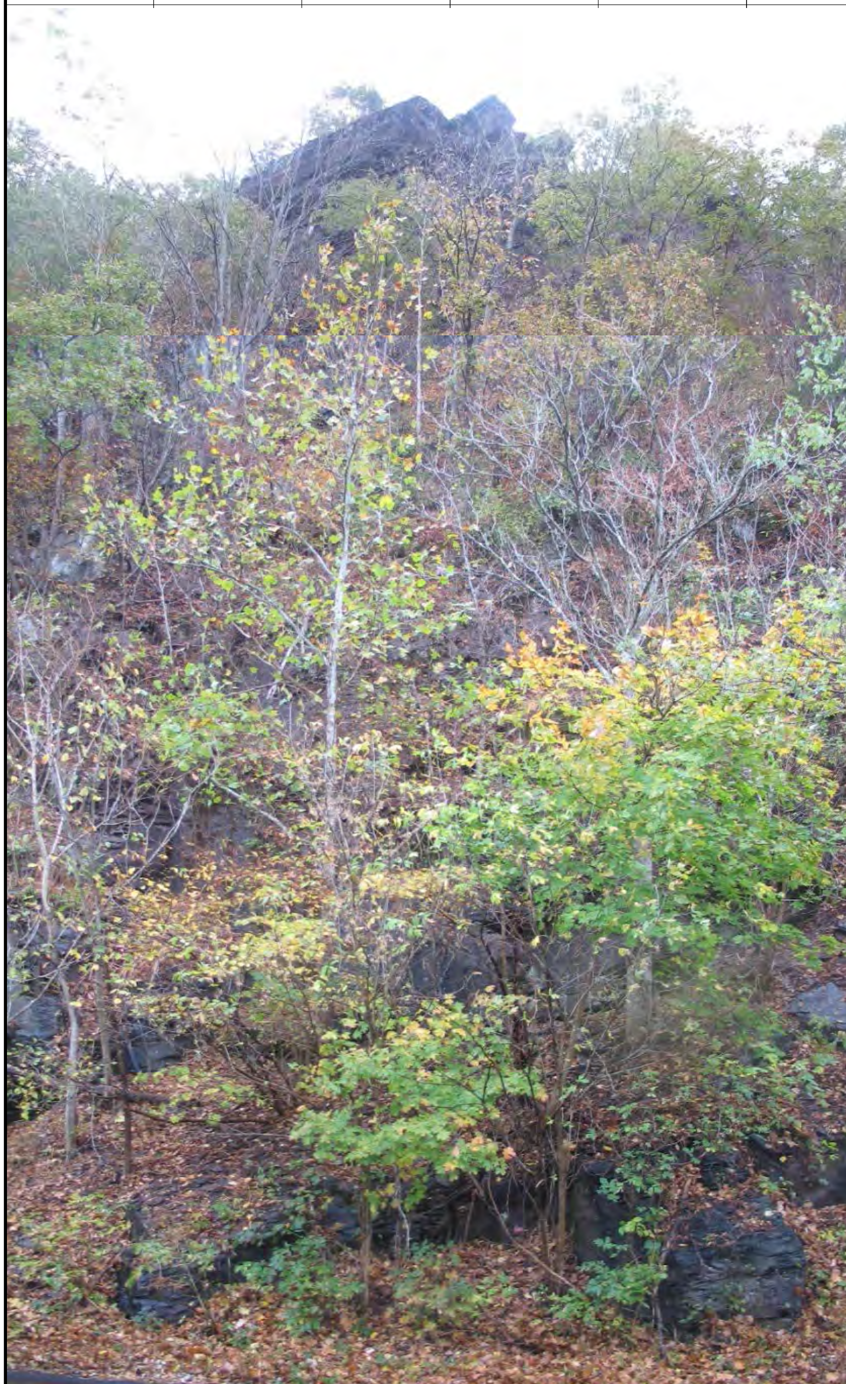
Special Notes:
1. Devil's Tea Table represents scenic landmark which . should be considered in slope mitigation.

Mitigation Alternatives:
1. Combination of rock removal, reinforcment and protection measures. Further study design required.

FIELD NOTES
REGION: Hwy: Route 29
MP: BEG **29.86** END **30.43**
Slope Designation: Area "**D**"

Prepared by: NN/JS/BF
Date: 10/21/2014

Site Photographs: Oct 21/22, 2014



Mid Length ~ MP 30.00

Devil's Tea Table @ MP 30.05

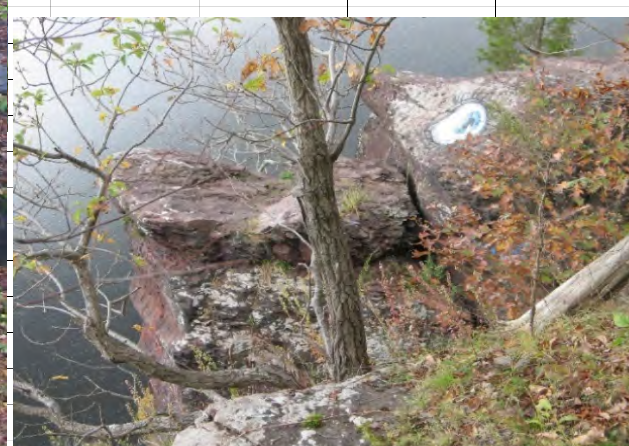


PHOTO 1 - Differential weathering above Devil's Tea Table (Top of Slope, Area D, Looking Northeast)

PHOTO 2 – Example of Root Wedging (Toe of Slope, Area D, Looking Northeast)

PHOTO 3 - S Shaped Crack in North Side of Block above Devil's Tea Table (Area D)

Photo 4 – Devil's Tea Table Looking Southwest from Top of Slope

Photo 5 – Devil’s Tea Table Looking Northeast and Up