



United States Department of the Interior

Water Resources Division
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Memorandum

To: Sula Jacobs, Superintendent, Delaware Water Gap (DEWA); Kara Deutsch, Chief of Resources, DEWA

Through: Alan C. Ellsworth, Chief, Aquatic Systems Branch, Water Resources Division (WRD)

From: Dr. Peter J. Sharpe, Hydrologist WRD/NERO
Michael Martin, Hydrologist WRD
Dr. Ellen Wohl, Professor, Colorado State University (CSU)

Subject: In-stream wood assessment for Dingmans Creek and other drainages, DEWA

Executive Summary

On June 26 and 27, 2018, staff from DEWA, WRD, and CSU participated in a reconnaissance-level assessment of five (5) stream reaches from the same number of watersheds to evaluate potential impacts of recently downed timber from Winter Storms Riley and Quinn (March 2018). The purpose of this assessment was to determine if large assemblages of instream and floodplain wood pose any immediate or ultimate threat to NPS infrastructure, functions or natural resources. From a resource management perspective, downed timber provides numerous ecosystem benefits and our general recommendation is to leave the instream/floodplain wood in place and allow natural processes to prevail. One important caveat to this “leave-it-alone” approach is when instream and/or floodplain wood presents an imminent or potential threat to infrastructure or park resources, then some form of treatment is appropriate. The body of this document presents observations and conclusions from the site visit, specifically related to several stream reaches along Dingmans Creek. Appendices A-C—contain specific hydrologic characteristics of each study watershed, a follow-up scientific research proposal, and general risk assessment and stability assessment guides along with some best management practices to consider should the park decide that some form of timber manipulation within the stream channel or riparian areas be necessary.

Project Overview

Winter Storms Riley and Quinn hit DEWA in March 2018 causing at least five local watersheds to experience substantial timber blow-down resulting in sizable collections of large wood in channels and floodplains (Figure 1). Subsequently, there was some local concern and suggestions that the park should consider removal operations. Before beginning this expensive and complicated process, park staff wanted to get input from professionals with relevant expertise to evaluate the risk to natural resources and infrastructure associated with instream and floodplain wood. Not only is large wood difficult, dangerous, and expensive to manage, but when allowed to remain and move naturally through the system, it provides numerous benefits to the instream and riparian ecosystems. Additionally, allowing wood to remain within the floodplain and stream systems is supported by 2006 NPS policy (4.6.6 Watershed and Stream Processes). Park, Region, and WRD staff collaborated with Dr. Ellen Wohl of CSU to complete an evaluation of the watersheds in question (Dingmans, Adams, Hornbecks, Mill, and Toms Creek).

The five watersheds assessed are high-gradient, hemlock dominated, headwater ravines that drain in an easterly direction directly into the Delaware River. All of these perennial streams form confluences with the Delaware River, where the ravines become relatively low-gradient drainages across the Delaware River floodplain. . The streams are high-to-exceptional quality cold water fisheries (PA Code Title 25, Chapter 93 Designations), and therefore; protection of habitat values is of great importance.

Development in these watersheds is minimal, especially in the riparian areas, and NPS infrastructure that could be affected by flow redirection is limited to a number of bridge crossings, both highway and footbridges. The storms of March 2018 resulted in the downing of many mature hemlock and white pines, some of which have, or will become part of the fluvial systems. Sizable collections of large wood can often create logjams capable of dramatically affecting flow. While these features are extremely beneficial to the riparian system, they can present a severe risk to nearby infrastructure. It is the goal of this document to inform management decisions regarding treatment of large wood in the riparian system. Unfortunately, predicting the mobility and potential threat of channel and floodplain wood to downstream infrastructure is not determinable, and the best approach to risk management is regular observation/monitoring following up with treatment when a likely or imminent hazard is identified.

The mobility of individual pieces of wood is mostly dependent on characteristics of the piece such as: length, diameter, and degree of burial (Wohl and Goode, 2008). Greater magnitude flows will access broader areas of the floodplain, possibly entraining and

transporting greater quantities of floodplain wood downstream and down-valley with successively higher flows. There are no general set of equations describing large wood transport in fluvial systems that could be realistically applied in this case and the discharge (flows) needed to move any large wood is not predictable.

Separate from mobility of individual pieces, there are a few characteristics of instream and floodplain wood that may suggest a likely or imminent threat. The proximity of infrastructure to collections of large wood, especially channel spanning trees, is one of those characteristics. Single pieces of wood generally do not present a threat. It is large collections of wood, logjams that can put infrastructure at risk by redirecting flow, such as around a bridge abutment, or raising a water surface and flooding nearby areas. These effects usually do not extend for great distances up or downstream, so if there is no infrastructure in the immediate vicinity of large wood collections, there is probably little associated hazard.

We suggest an adaptive management approach that includes observational monitoring of all stream crossings (including footbridges) or any other areas of concern, especially after the occurrence of large flow events (See Appendix C). The frequency of monitoring depends upon the level of effort that park staff can devote to this endeavor. Generally speaking, stream flows at DEWA tend to peak in early Spring/Summer and this should be the period of time where active monitoring of potential “at-risk” infrastructure should occur.

On the occasion when instream wood presents an imminent threat to infrastructure or park resources, such as the beginnings of a logjam against a bridge, then some form of wood manipulation may be needed. This type of circumstance has precedent in DEWA. In 2006, a large logjam blocked a portion of flow underneath the bridge at the crossing of US Hwy 209 and Dingmans Creek. This potentially destabilizing blockage was reportedly removed under an emergency action. Such conditions should be treated in accordance with the urgency of the threat, recognizing that the greatest risk will occur during high flow events, at the same time that removal operations in the stream or floodplain would be the most difficult and dangerous.

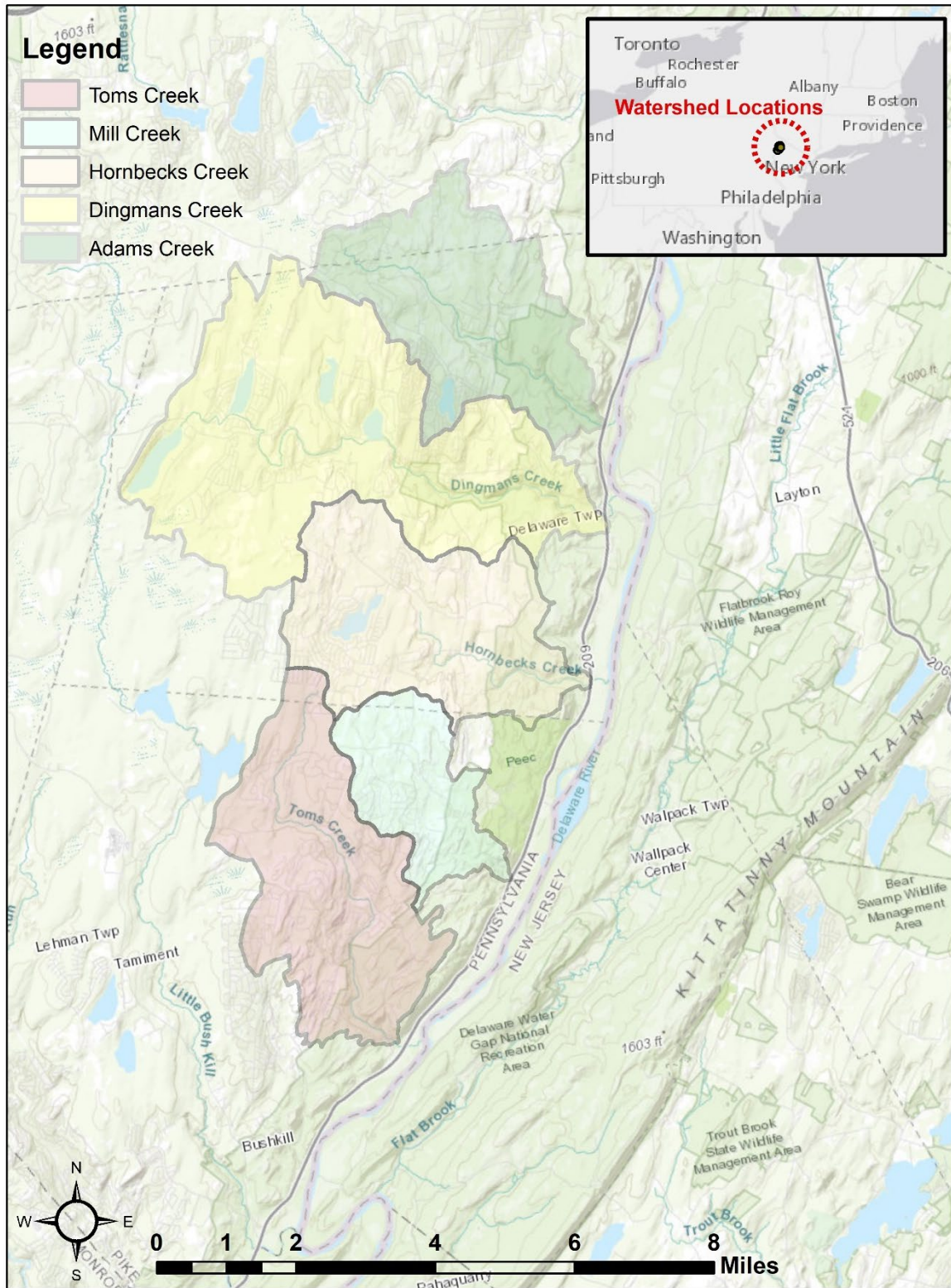


Figure 1. Watersheds of the instream wood assessment 26-27 June 2018. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

On June 26, 2018, Dr. Peter Sharpe (WRD/NERO) hydrologist, along with Kara Deutsch (Chief of RM&S) and Mandi Stein (Biologist), conducted a reconnaissance level survey of instream and floodplain wood for the Adams, Mill, Hornbecks, and Toms Creek watersheds. On June 27, Dr. Sharpe, Kara Deutsch, and Mandi Stein were joined by Dr. Ellen Wohl and Michael Martin, WRD hydrologist, to complete a more detailed evaluation that focused on several sites in the Dingmans Creek drainage – with specific emphasis placed on areas with affected infrastructure (actual or potential). The sites evaluated were considered by the team to be representative of other local drainages affected by the winter storm blow-downs, so the conclusions and recommendations stated here should be applicable to similar stream types and watersheds within DEWA.

Large Wood in the Fluvial System - submitted by Dr. Wohl

Large wood is commonly defined as downed, dead wood that is at least 10 cm in diameter and 1 m in length. Studies from river corridors in diverse regions indicate that large wood in the channel and on the floodplain provides numerous physical and ecological benefits (Figure 2). River corridor here refers to the active channel(s), adjacent floodplain and riparian zones, and underlying hyporheic zone.

By creating frictional resistance and local obstructions to flow, large wood in the channel affects flow velocity, depth, and the transport of mineral sediment and particulate organic matter. Wood-induced alterations to the downstream movement of water, sediment, and organic matter typically result in greater abundance and diversity of instream habitat, as well as increasing the connectivity between the channel and hyporheic zone and the channel and adjacent floodplain. This greater connectivity facilitates the movement of organisms within the river corridor and enhances opportunity for at least temporary storage and biological uptake of organic carbon and nutrients such as nitrogen and phosphorus.

Large wood in the channel can also direct current toward or over the banks, affecting the rate of lateral channel movement and resulting in the formation of secondary channels that branch from the main channel before rejoining the main channel downstream. This also enhances the diversity of habitat within the river corridor.

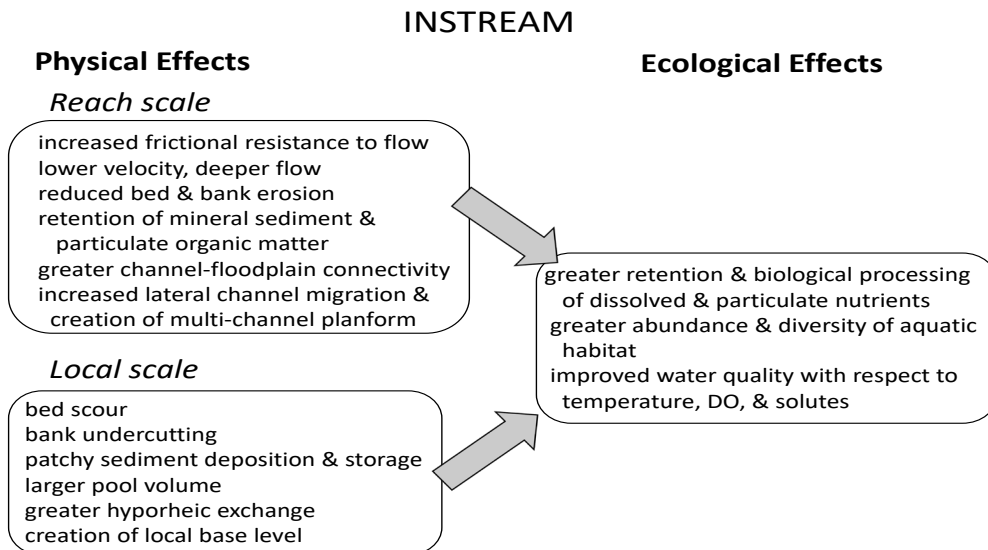
Large wood on the floodplain similarly slows down overbank flows, facilitating storage of material in transport, as well as increasing the abundance and diversity of riparian habitat, and biological uptake of nutrients. Floodplain large wood can also enhance the soil moisture and nutrient content of floodplain soils, and can provide habitat for terrestrial plants and animals.

In general, large wood increases the resilience of river corridors to natural and human-induced disturbances. Resilience includes resistance to change during disturbance and recovery after disturbance. Disturbances in river corridors include floods, droughts, wildfires, and spills of contaminants. Large wood increases resilience by attenuating flood peaks, increasing surface and subsurface water storage and sediment storage, and by

increasing habitat diversity and therefore providing refugia for fish and other organisms during disturbances.

Despite these numerous beneficial effects of large wood, rivers throughout the continental United States have a long history of wood removal. Wood removal has been motivated by attempts to limit flooding, enhance navigation or downstream conveyance of cut timber or pollutants, or by esthetic preferences. Consequently, most river corridors in the U.S. are wood-impooverished relative to natural conditions. However, surveys of river corridors in relatively unaltered watersheds indicate that large wood is not uniformly distributed along the length of a river. Longitudinal concentrations of wood can reflect uneven introduction of wood (e.g., point sources at tributary junctions or sites of hillslope failure) or uneven wood transport. In general, mobile wood tends to accumulate in relatively wide, low gradient river segments. These segments are sometimes referred to as beads because in aerial imagery they resemble beads along the 'string' of steeper, narrower lengths of river. Strings provide important migration and transport corridors and are necessary for longitudinal connectivity within a river network. Beads, however, commonly have greater aquatic and wetland habitat abundance and diversity, higher rates of biological uptake and processing of nutrients, and greater biomass and biodiversity. Beads are essentially the biological hot spots in a river network. Large wood naturally accumulates in beads as a result of lower gradient and reduced transport capacity for wood, and the presence of more abundant wood enhances the ecological importance of the river beads. In DEWA, bedrock-dominated river segments with waterfalls and gorges are unlikely to retain large wood for more than a few years. The intervening pool-riffle, cobble-bed river segments – the beads – are more likely to retain large wood in the channel and on the floodplain and it is in these river segments that large wood can provide the greatest geomorphic and ecological benefits.

A



B

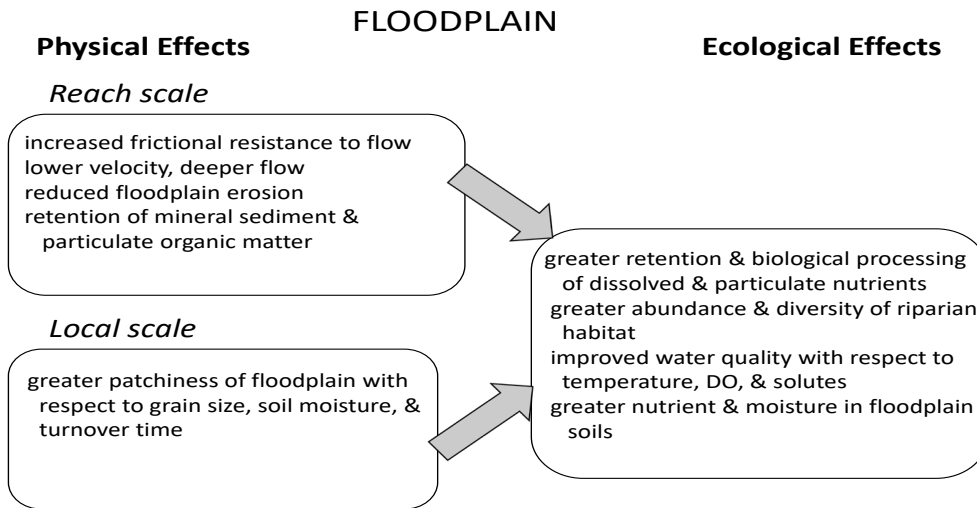


Figure 2. List of the physical and ecological benefits associated with the presence of wood in (A) the active channel and (B) the floodplain. Reach refers to a length of channel several times the average channel width. Local refers to the area around individual pieces of wood or logjams.

Site-Specific Observations

A stream by stream assessment was performed, however for brevity this report details only two specific areas within Dingmans Creek watershed (Figure 3), sites that all three report authors discussed with DEWA staff. The general recommendation and conclusions made for Dingmans Creek are applicable across all five assessed watersheds. Appendix A of this report presents watershed metrics and design flow estimates from the USGS StreamStats web application, as well as photo documentation for each stream reach assessed as part of this effort.

Childs Park

In the Childs Park area, there were extensive zones of the timber affected by the blow-down events. Much of this potentially mobile, large wood occurred in the upland areas as well as the riparian corridor, and will likely provide recruitment to the stream system for years to come. Likewise, much of the riparian system had substantial collections of both instream and floodplain wood, including channel spanning trees, that can often serve as “key pieces” in logjams. There were three specific areas evaluated in Childs Park; Factory Falls, Fulmer Falls, and Deer Leap Falls (Figs. 3, 4, 5 and 6). These three reaches are predominantly steep, transport reaches where large wood is not likely to collect and remain over the long-term. Instream wood will provide ecological benefits in these reaches while present, but high flows will have a tendency to move large wood downstream to lower gradient, collection reaches. Given the relatively short residence times of large wood in transport reaches, timber manipulation is not as likely to impact ecosystem services in these

areas, and may be considered if there are compelling reasons such as visitor safety or access to trails and across bridges. However, in reference to visitor access, the presence of large wood in the channel may discourage swimming, which is prohibited in many areas of the park.

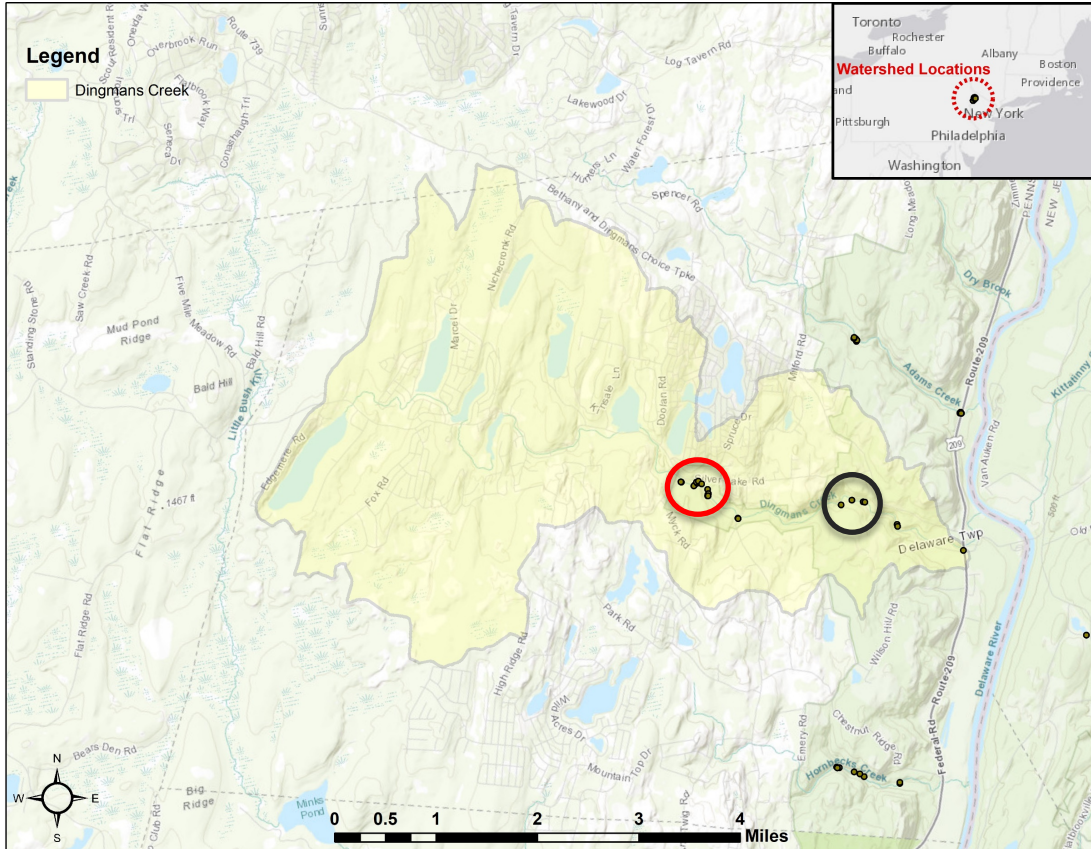


Figure 3. Dingmans Creek watershed showing the location of Childs Park (red circle) that contains Factory Falls, Fulmer Falls, and Deer Leap Falls among other locations, and the Visitor Center road crossings (black circle), both locations are described in the report.

A quick note on what is meant by timber manipulation in this report. Timber manipulation can mean a variety of things ranging from complete removal of the large wood to simply anchoring the wood in place to inhibit downstream movement. Any effort to remove/anchor large wood within the stream system or riparian zone is an expensive and time intensive action. As stated previously – the removal of large wood also removes ecological benefits to the waterway and floodplain, as such – timber removal should be considered a last resort action, necessary only when evidence exists that visitor safety is at clear risk or permanent damage to park infrastructure resulting from large wood transport is likely. Appendix C contains a general list of best management practices to be considered should it be determined that the removal of large wood is warranted.



Figure 4. Looking downstream at Factory Falls in the Childs Park area. Note the large collection of instream wood, including channel spanning trees. NPS – 2018.



Figure 5. Looking upstream at Dingmans Creek in the Childs Park area. Note the large collection of instream wood in the area of the footbridge (circled in yellow). NPS – 2018.



Figure 6. Looking upstream at Dingmans Creek in the Childs Park area. Note the collection of instream wood in the area of the footbridge. NPS – 2018.

Dingmans Falls Visitor Center

Along Dingmans Falls Visitor Center (DFVC) road and trail, we evaluated two road crossings as well as the stream reach between the DFVC and Dingmans Falls (Figure 3). Immediately upstream of the upper road crossing, a number of large logs had been mobilized by a slope failure, and were poised to move into the creek, possibly blocking flow under the bridge (Figure 7). This site serves as an example of a potential threat that could be considered for treatment. Besides the upper crossing shown in Figure 7, we saw no other conditions that appeared to pose a threat in this area. Most of the stream reach between the DFVC and Dingmans Falls had very little instream wood, even in the low gradient, collection areas.



Figure 7. Slope failure immediately upstream of the upper bridge crossing on DFVC road. View is looking upstream. Several large logs that have been mobilized will wind up in the channel, and could block flow under the bridge.

Conclusions/Recommendations

For the most part, instream and floodplain wood should be left in place and allowed to move and collect naturally in accordance with river flows and other surficial processes. As outlined throughout this document, naturally occurring wood in the fluvial system has numerous ecological and geomorphic benefits. Downed trees spanning the streams serve an important purpose in providing shade and cover to the streams while canopies recover, and can serve as “key pieces” in log jams. In-stream wood can help reduce bed load movement and reduce flow velocities, maintaining and creating geomorphic and habitat diversity.

However, there are cases where in-stream wood can present a threat to existing infrastructure, and therefore; monitoring of large wood that could create detrimental conditions, is well warranted. While it is not possible to conclusively identify which collections of large wood will become a hazard, as a general rule, large wood in the immediate vicinity of infrastructure, park resources, or other sensitive areas, may present potential threats and warrant consideration for treatment. This is especially true if there are steep slopes or high stream gradients that could facilitate transport of large wood. If

any large wood should become an imminent threat, such as a logjam at a bridge crossing, immediate treatment should be undertaken.

A transport assessment may be conducted following the Federal Highways Administration, Hydraulic Engineering Circular No. 20 (April 2012); see Chapter 5 for resources that can be consulted to form the basis of a more detailed and quantitative analysis to assess large wood transport/damage risk to a given structure. Should removal operations proceed the park should consider removal following the BMPs outlined in Appendix C. Ideally any large wood risk assessment/analysis should be made by a park ecologist and civil engineer so that the decision to remove or not remove any wood will take into account the ecology of the aquatic system, as well as, the anticipated risks to a given park structure.

Future Research

WRD staff will be available to provide continued support and consultation regarding any aspect of this issue. Additionally, Dr. Wohl has also written and provided the park with a research proposal for a short-term (1-2 year) instream/floodplain Large Wood (LW) monitoring and Stage-Discharge modelling to estimate channel-floodplain connectivity for a subset of wood-rich and wood-impooverished stream reaches (see Appendix B). The supporting theory is that the presence of LW and associated increases in pool volume, spawning gravel, macroinvertebrate abundance and diversity, and overhead cover, will beneficially affect brook trout and other aquatic organisms. The proposed study would be of direct benefit to increasing our collective knowledge of the freshwater ecosystems at DEWA, and will provide a useful case study for other streams in the eastern US for which this type of research is very limited. The study would also importantly provide science-based management recommendations to park staff.

References

- Bellmore JR, Baxter CV. 2014. Effects of geomorphic process domains on river ecosystems: a comparison of floodplain and confined valley segments. *River Research and Applications* 30: 617–630.
- Benke AC, Wallace JB. 2003. Influence of wood on invertebrate communities in streams and rivers. In: Gregory SV, Boyer KL, Gurnell AM (Eds.), *The Ecology and Management of Wood in World Rivers*. American Fisheries Society Symposium 37, pp. 149–177, Bethesda, MD.
- Bureau of Reclamation and U.S. Army Engineer Research and Development Center (USBR and ERDC). 2016. National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure. 628 pages + Appendix. Available: www.usbr.gov/pn/ and <http://cw-environment.usace.army.mil/restoration.cfm> (click on “River Restoration,” then “Techniques”).
- Curran, J.C. (2010). Mobility of large woody debris (LWD) jams in a low gradient channel. *Geomorphology* 116 (2010) 320–329.
- Dolloff CA, Warren ML. 2003. Fish relationships with large wood in small streams. In: Gregory SV, Boyer KL, Gurnell AM (Eds.), *The Ecology and Management of Wood in World Rivers*. American Fisheries Society Symposium 37, pp. 179–193, Bethesda, MD.
- Gurnell AM. 2003. Wood storage and mobility. In: Gregory SV, Boyer KL, Gurnell AM (Eds.), *The Ecology and Management of Wood in World Rivers*. American Fisheries Society Symposium 37, pp. 75-91, Bethesda, MD.
- Wohl, E., and J. R. Goode (2008), Wood dynamics in headwater streams of the Colorado Rocky Mountains, *Water Resour. Res.*, 44, W09429, doi:10.1029/2007WR006522.
- Schiff, R., J. S. Clark, G. Alexander, and M. Kline 2008a. *The Vermont Agency of Natural Resources Reach Habitat Assessment (RHA)*. Prepared by Milone & MacBroom, Inc. with the Vermont Agency of Natural Resources, Departments of Environmental Conservation and Fish and Wildlife, Waterbury, VT.
- Schiff, R., E. Fitzgerald, J. MacBroom, M. Kline, and S. Jaquith, 2014. Vermont Standard River Management Principles and Practices (Vermont SRMPP): Guidance for Managing Vermont's Rivers Based on Channel and Floodplain Function. Prepared by Milone & MacBroom, Inc. and Fitzgerald Environmental Associates, LLC for and in collaboration with Vermont Rivers Program, Montpelier, Vermont.

Sear DA, Millington CE, Kitts DR, Jeffries R. 2010. Logjam controls on channel: floodplain interactions in wooded catchments and their role in the formation of multichannel patterns. *Geomorphology* 116: 305–319.

U.S. Department of Transportation Federal Highway Administration. April 2012. Stream Stability at Highway Structures Fourth Edition. Pub. No. FHWA-HIF-12-004, Hydraulic Engineering Circular No. 20.

Wohl E. 2013. Floodplains and wood. *Earth-Science Reviews* 123: 194–212.

Wohl E. 2017. Bridging the gaps: an overview of wood across time and space in diverse rivers. *Geomorphology* 279: 3-26.

CC: DEWA – R. McKenna, R. Evans
WRD – A. Ellsworth, K. Noon, P. Mangan
NERO – J. Meade

Appendix A

Detailed Watershed Characteristics and DEWA Instream Wood Examples

Adams Creek

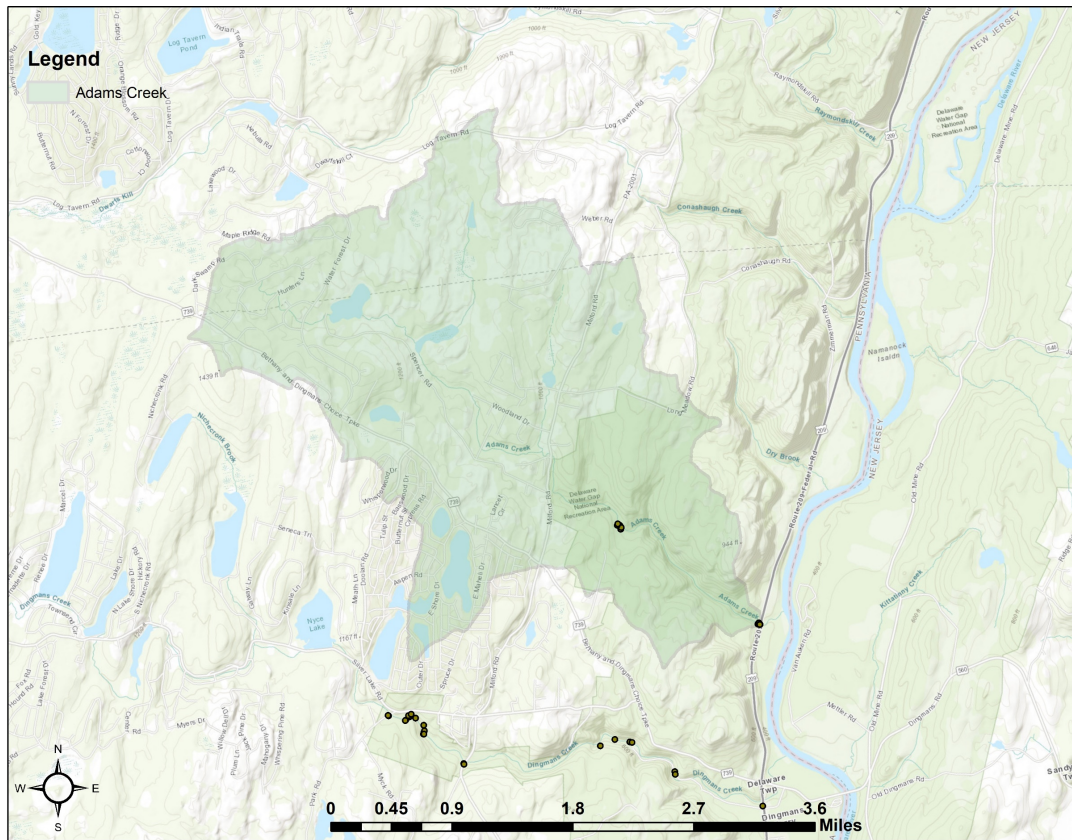


Figure A1. Adams Creek Watershed, individual points on the map show the specific locations of instream/floodplain wood that was assessed. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

Table A1. Adams Creek Watershed – Key Basin Characteristics (USGS StreamStats)

Characteristic	Value(Units)	Characteristic	Value(Units)
% in Forest Cover	84 %	2-Year Peak Flood	344 ft ³ /s
Mean Impervious Area	1.13%	10-year Peak Flood	815 ft ³ /s
Mean Annual Precip	43 inches	100-year Peak Flood	1680 ft ³ /s
Watershed Size	8.01 miles ²	500-year Peak Flood	2500 ft ³ /s

*Flood flows and basin stats derived from USGS StreamStats. Peak Floods were estimated using the following regression citation: Roland, M.A., and Stuckey, M.H.,2008, Regression equations for estimating Flood Flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57p. (<http://pubs.usgs.gov/sir/2008/5102/>)



Photograph A1. Adams Creek looking upstream 339⁰N from the location of the historic water wheel (41.252117, -74.882109). Much of the instream and floodplain wood shown in the photograph was recently deposited as a result of the winter Nor-Easters that came through the park in [March](#), 2018. This site is indicative of similar blow down areas within the survey watersheds and our recommendation is to leave the instream and floodplain wood in place and allow it to move and collect naturally. Some of the ecosystem services that are exemplified in this image are: providing energy dissipation, adding structure and diversity to the channel morphology, providing instream nutrient source and refugia, etc.

Dingmans Creek

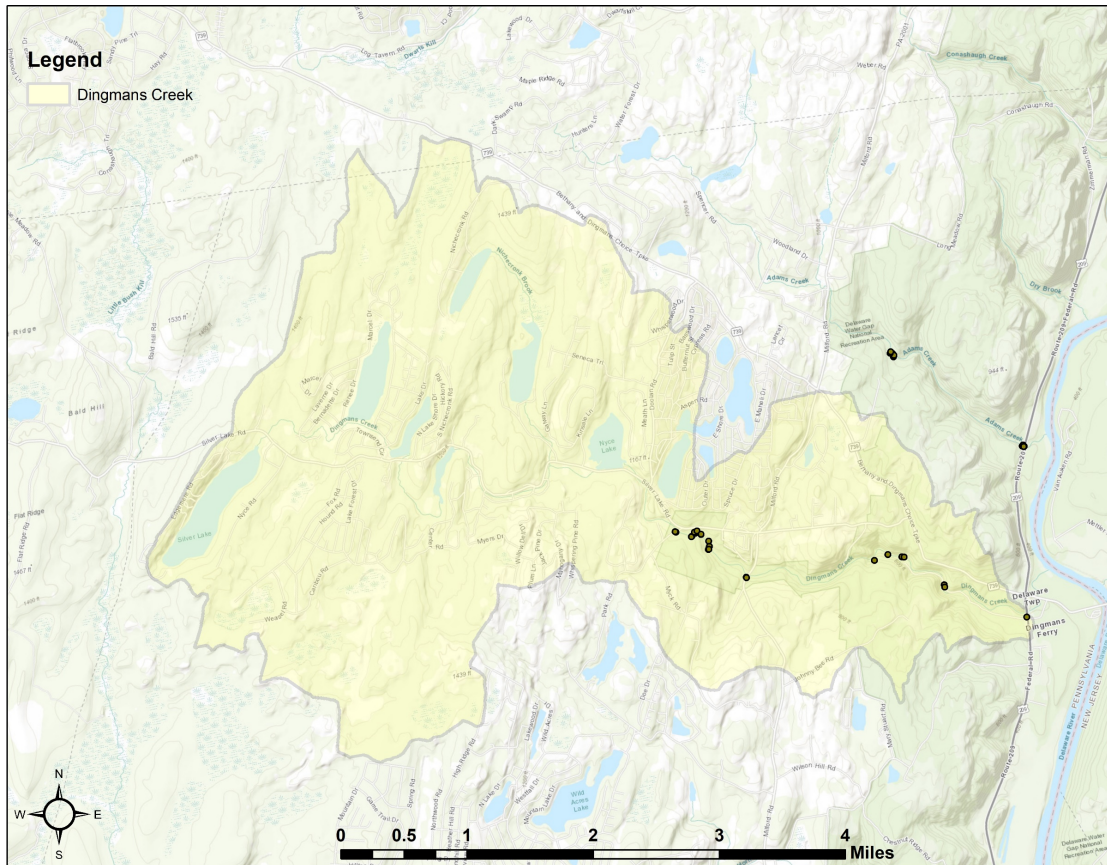


Figure A2. Dingmans Creek Watershed, individual points on the map show the specific locations of instream/floodplain wood that was assessed. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

Table A2. Dingmans Creek Watershed – Key Basin Characteristics (USGS StreamStats)

Characteristic	Value(Units)	Characteristic	Value(Units)
% in Forest Cover	81 %	2-Year Peak Flood	555 ft ³ /s
Mean Impervious Area	1.56%	10-year Peak Flood	1290 ft ³ /s
Mean Annual Precip	43 inches	100-year Peak Flood	2680 ft ³ /s
Watershed Size	16.4 miles ²	500-year Peak Flood	4010 ft ³ /s

*Flood flows and basin stats derived from USGS StreamStats. Peak Floods were estimated using the following regression citation: Roland, M.A., and Stuckey, M.H.,2008, Regression equations for estimating Flood Flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57p. (<http://pubs.usgs.gov/sir/2008/5102/>)



Photograph A2. Dingmans Creek looking downstream 185°S looking at the stream as it flows underneath the SR 2001 Bridge (41.232312, -74.910356). This bridge is indicative of the type of structures that would be vulnerable to instream wood movement within our assessment watersheds. As can be seen here, the bridge is single-span with no piers, which minimizes the chance of instream wood captures. This is the type of structure present at every major bridge crossing we examined as part of this study. Nevertheless, under certain conditions, a logjam could form at this type of bridge crossing leading to redirected flows and possibly damaging resources and infrastructure. A reconnaissance level survey of all bridge crossing after any large flow should be considered.

Hornbecks Creek

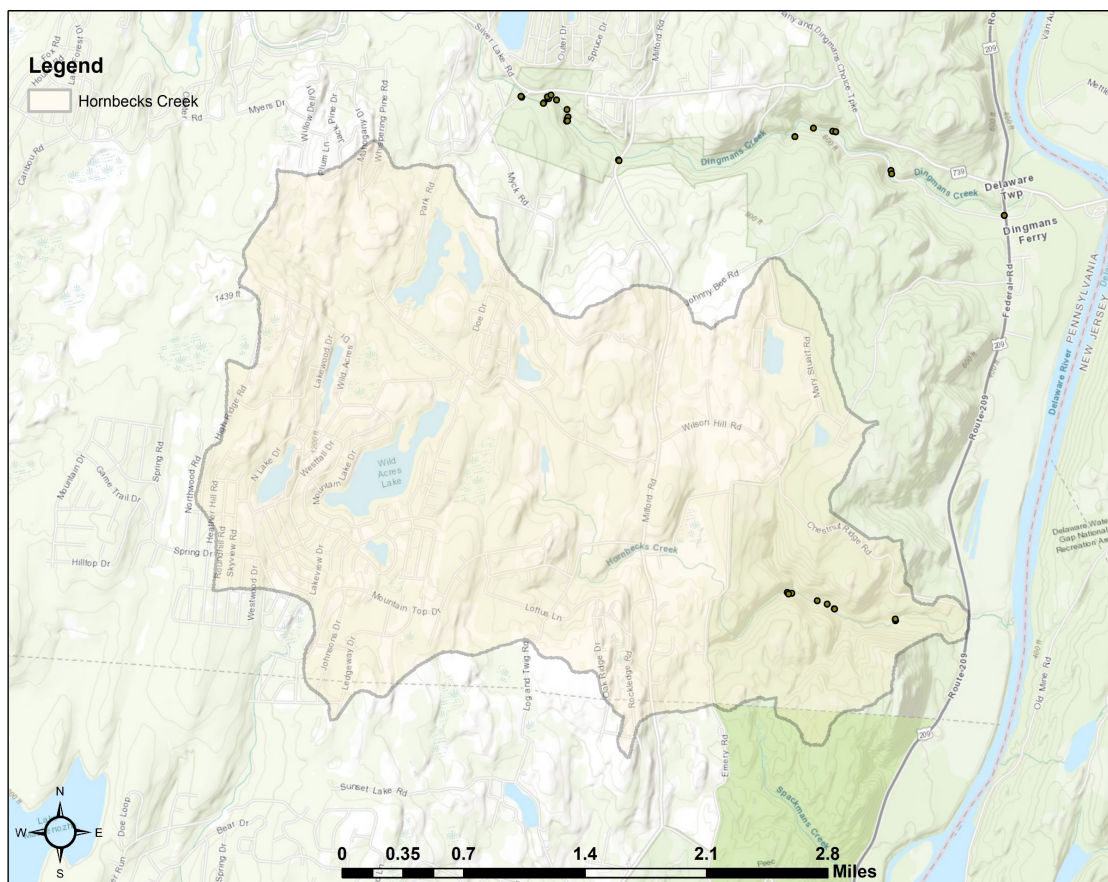


Figure A3. Hornbecks Creek Watershed, individual points on the map show the specific locations of instream/floodplain wood that was assessed. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

Table A3. Hornbecks Creek Watershed – Key Basin Characteristics (USGS StreamStats)

Characteristic	Value(Units)	Characteristic	Value(Units)
% in Forest Cover	78 %	2-Year Peak Flood	326 ft ³ /s
Mean Impervious Area	1.01%	10-year Peak Flood	773 ft ³ /s
Mean Annual Precip	43 inches	100-year Peak Flood	1620 ft ³ /s
Watershed Size	8.61 miles ²	500-year Peak Flood	2420 ft ³ /s

*Flood flows and basin stats derived from USGS StreamStats. Peak Floods were estimated using the following regression citation: Roland, M.A., and Stuckey, M.H.,2008, Regression equations for estimating Flood Flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57p. (<http://pubs.usgs.gov/sir/2008/5102/>)



Photograph A3. Hornbecks Creek looking upstream 243°SW as it flows underneath a trail bridge (41.190812, -74.891804). The instream and floodplain wood shown here is not currently threatening any park infrastructure and resources and is unlikely to readily move under normal flow conditions. Many of the trees span the entire width of the channel with some still partially rooted or anchored into the bank. Much of the wood exhibits high degrees of branching that tends to inhibit mobility. Some redistribution during floodflows should be expected, but it is unlikely that the trail bridge or any other park infrastructure or resources will be impacted by the resulting conditions.

Mill Creek

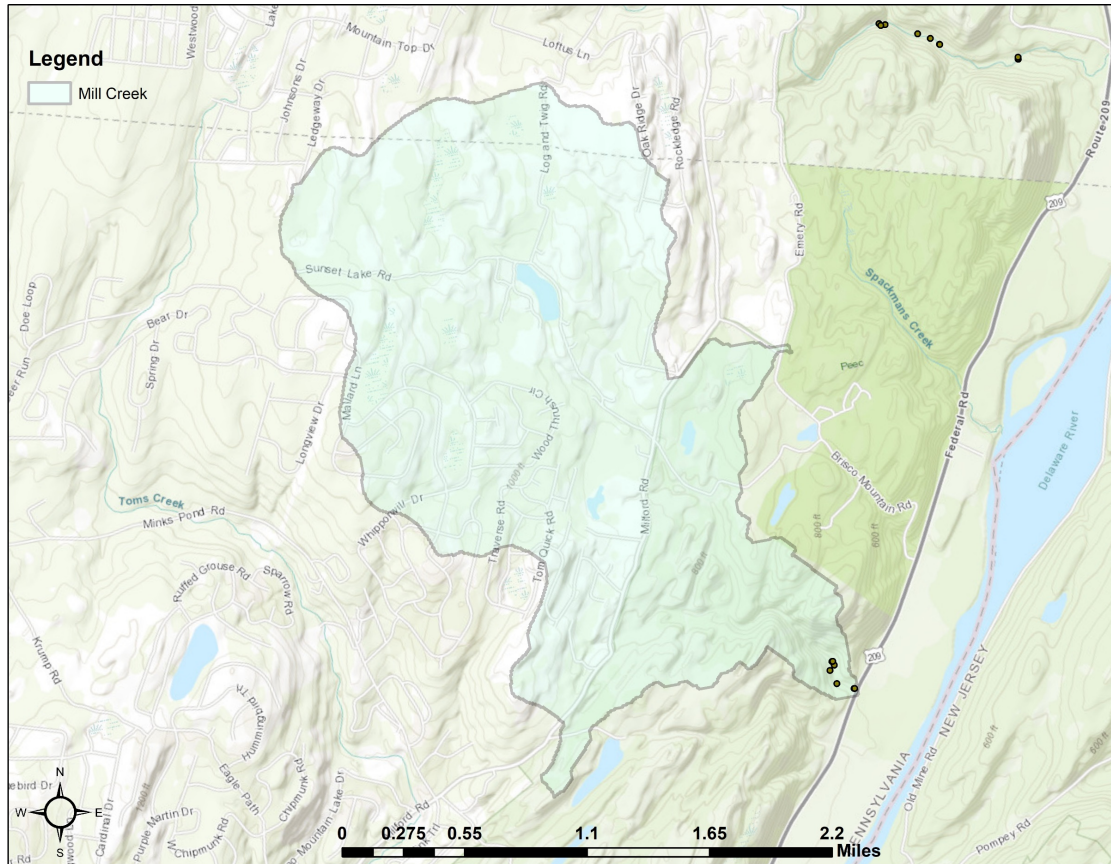


Figure A4. Mill Creek Watershed, individual points on the map show the specific locations of instream/floodplain wood that was assessed. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

Table A4. Mill Creek Watershed – Key Basin Characteristics (USGS StreamStats)

Characteristic	Value(Units)	Characteristic	Value(Units)
% in Forest Cover	74 %	2-Year Peak Flood	179 ft ³ /s
Mean Impervious Area	0.64%	10-year Peak Flood	435 ft ³ /s
Mean Annual Precip	43 inches	100-year Peak Flood	912 ft ³ /s
Watershed Size	3.91 miles ²	500-year Peak Flood	1360 ft ³ /s

*Flood flows and basin stats derived from USGS StreamStats. Peak Floods were estimated using the following regression citation: Roland, M.A., and Stuckey, M.H.,2008, Regression equations for estimating Flood Flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57p. (<http://pubs.usgs.gov/sir/2008/5102/>)



Photograph A4. Mill Creek looking upstream 2°N at a large deposit of instream wood (41.154668, -74.917715). This reach of the stream appears to be heavily impacted by downed timber, yet ecosystem services identified in Figure A1 are provided here by the instream and floodplain wood. The wood shown here is unlikely to move downstream during normal flow conditions, but some redistribution during flood flows should be expected. Given the setting, it is unlikely that this instream and floodplain wood could impact either park infrastructure or resources.

Toms Creek

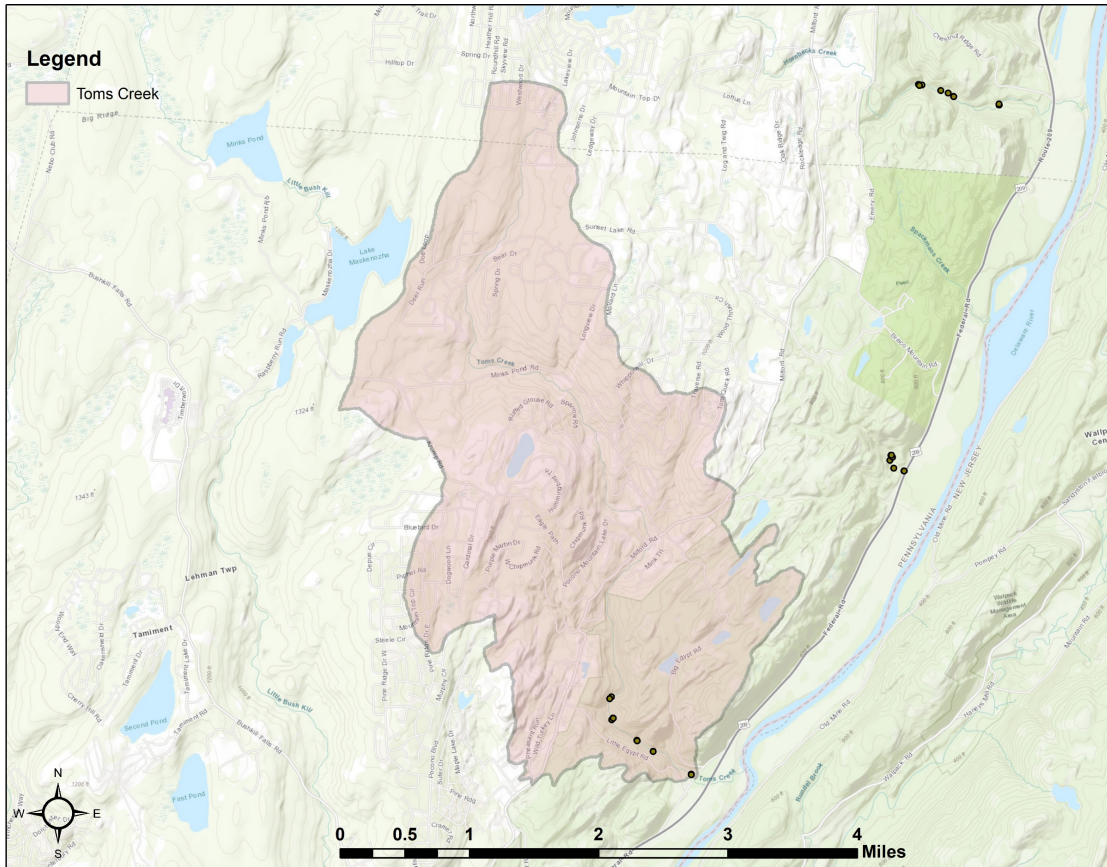


Figure A5. Toms Creek Watershed, individual points on the map show the specific locations of instream/floodplain wood that was assessed. Watershed boundaries were delineated using the USGS StreamStats web application and imported into ArcMap 10.5.

Table A5. Toms Creek Watershed – Key Basin Characteristics (USGS StreamStats)

Characteristic	Value(Units)	Characteristic	Value(Units)
% in Forest Cover	72 %	2-Year Peak Flood	418 ft ³ /s
Mean Impervious Area	0.93%	10-year Peak Flood	984 ft ³ /s
Mean Annual Precip	43 inches	100-year Peak Flood	2010 ft ³ /s
Watershed Size	9.26 miles ²	500-year Peak Flood	2970 ft ³ /s

*Flood flows and basin stats derived from USGS StreamStats. Peak Floods were estimated using the following regression citation: Roland, M.A., and Stuckey, M.H.,2008, Regression equations for estimating Flood Flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102, 57p. (<http://pubs.usgs.gov/sir/2008/5102/>)



Photograph A5. Toms Creek looking upstream 297°NW at a large collection of instream wood (41.129811, -74.960302). Note the length and diameter of the downed timber. Deposits of instream wood like this tend to be relatively stable, even during high flows due to the difficulty of moving large trees through a fluvial system. These types of large (long) pieces of wood often times serve as structural elements in logjams and form bed steps by trapping sediment.

Appendix B

Dr. Ellen Wohl (CSU) Draft (July 2018) Proposal for Additional work

Proposal for wood-related research at DEWA

Ellen Wohl, Department of Geosciences, Colorado State University

Following a June 2018 visit to the Delaware Water Gap National Recreation Area (DEWA) to examine downed wood in tributaries to the Delaware River, I outline below a research project to document the effects of this wood on stream corridors in DEWA. In this context, stream corridor refers to the active channel(s), floodplain, and underlying hyporheic zone. In this proposal, large wood (LW) describes downed, dead wood pieces greater than 10 cm in diameter and 1 m in length.

Background

Previous studies of LW in diverse stream corridors indicate that the continued presence of LW can result in numerous geomorphic and ecological effects that cumulatively increase the habitat abundance and diversity, connectivity, retention, resilience, and biomass and biodiversity of a stream corridor. The tributary streams within DEWA have a history of timber harvest, milldams, and other human modifications and appear to be simplified and homogenized relative to expected characteristics. Specifically, these stream corridors appear to lack LW and to have reduced pool volume, spawning gravel, and habitat for macroinvertebrates and salmonids, as well as having high bed mobility relative to the grain size (cobble to small boulders) of the channel substrate. Floodplains are in places compacted and trampled by visitors and lack LW that, while decaying, provides habitat for diverse organisms as well as nutrients to the soil. The toppling of numerous trees during a storm in March 2018 provides a unique opportunity to document changes in streams affected by tree topple and to compare geomorphic changes in these stream corridors to streams that did not receive fallen trees. The great majority of studies of the effects of LW in streams come from the Pacific Northwest region of the United States, and we are not aware of any studies from the eastern U.S. documenting the response of streams to abrupt LW additions of the type that occurred in DEWA during March 2018. Documentation of stream response to this LW addition could provide useful management guidelines regarding the magnitude of stream corridor response in relation to different levels of wood load and characteristics of the stream corridor. Specifically, I hypothesize that stream corridors with channel gradient between 0.5% and 2%, floodplain width $\geq 2X$ active channel width, and intermediate wood loads (with wood load expressed as m^3 of wood per hectare of stream corridor surface) will show the greatest response to storm-related LW inputs.

Objectives

- document geomorphic changes in the river corridor associated with the presence of LW, including
 - local erosion & deposition
 - changes in substrate grain size
 - changes in channel bedforms and planform
 - storage of particulate organic matter (POM)
 - channel-floodplain connectivity and surface-hyporheic connectivity

- develop recommendations for sustaining beneficial effects associated with the presence of LW

Plan of Work

The primary research would be performed by an MS student from Colorado State University, overseen by myself and assisted by an undergraduate student.

- choose 20 stream segments (10 with increased LW inputs and 10 with minimal to no LW) within DEWA
- each stream segment will be $\geq 10X$ average bankfull channel width
- at each stream segment,
 - survey channel geometry (average bankfull width and depth, gradient)
 - measure substrate grain size in channel
 - measure bedform type and dimensions and pool volume in channel
 - measure wood volume, characterize wood (decay category, piece complexity, and survey wood location (dispersed vs jams, orientation) in channel and on floodplain
 - measure POM storage in channel and on floodplain
 - use hydraulic modeling (HEC-RAS) to quantitatively estimate channel-floodplain connectivity for a subset of wood-rich and wood-impooverished reaches
 - use existing relations between LW and hyporheic exchange, or do salt tracer tests and/or water temperature measurements to quantitatively estimate hyporheic exchange at a subset of wood-rich and wood-impooverished reaches
- (if collaborators are available, this work could be supplemented with macroinvertebrate and/or fish sampling in study reaches, as well as riparian plant inventories)

Significance

Knowledge of LW-related geomorphic and ecological effects suggests that the presence of LW and associated increases in pool volume, spawning gravel, macroinvertebrate abundance and diversity, and overhead cover, will beneficially affect brook trout and other aquatic organisms. This will be of direct benefit to freshwater ecosystems at DEWA, but will also provide a useful case study and management guidelines for other streams in the eastern US for which LW-related research is currently very limited.

Estimated Budget

I anticipate that the entire budget for this project would be on the order of \$100,000. This would include 2 years of salary for an MS student, salary for an undergraduate field

assistant, travel and lodging during field work, tuition for the graduate student, and indirect costs for Colorado State University. Potential partners that might be interested in contributing funds for this research include Trout Unlimited.

Appendix C

General Risk Assessment Criteria and Best Management Practices for Timber Manipulation within the study Stream/Floodplains

Rapid Large Wood Risk Assessment Criteria – Taken from Chapter 5 of the FHWA (2012) Pub. No. FHWA-HIF-12-004 and National Large Wood Manual (2016) - Chapter 5 (Table 5-3 of the National Large Wood Manual, 2016).

Large Wood Removal Recommendations Risk Level	Risk Description	Recommendation
HIGH	Channel-spanning large wood jams with altered flow path and high risk of avulsion. Remobilization of large amounts of wood and downstream structure clogging likely. Structure completely or mostly clogged.	Remove large wood jam.
HIGH TO MODERATE	Large mid channel or bank accumulations of large wood. Flow path may be altered, but risk of avulsion is low. Remobilization of a large amount of large wood and downstream structure clogging likely. Structure partially clogged.	Remove large wood.
MODERATE	Large mid channel or bank accumulations of large wood. Flow path may be altered, but risk of avulsion is low. Remobilization of a large amount of wood is not likely.	Leave large wood in place.
LOW	Bank accumulations of large wood jam or individual embedded pieces of wood in channel. Flow path may be altered, but risk of avulsion is low. Remobilization of large wood not likely.	Leave large wood in place.

Source: Adapted from Homer et al. (2004) and Schiff et al. (2014). PJS copied from page 5-32 of the Large Wood Manual (2016)

Rapid Assessment Data can take the form of the following (PJS adapted from the National Large Wood Manual (2016) also see Schiff et al. (2008 and 2014) for more detail.

General Assessment (Modified From National Large Wood Manual (2016)):

1. Location in or near structure, channel, or floodplain (GPS if possible) Recreation grade is suitable, though a mapping grade GPS unit is preferable.
2. Photo-documentation – preferably geo-located and field marked for repeatability.
3. Species of tree (see reproduced Table 6-2, below – generally species with lower decay rates are less likely to break apart and travel downstream).
4. Number of pieces and lengths wood.
5. Dimensions, area, and volume (small, medium, or large)
6. Degree of Embeddedness, (i.e. are the trees/logs branched, are they partially rooted in the stream bank)
7. Prediction of stability (Does the tree span the entire bankfull depth of the waterway, does it appear anchored in place?)
8. Distance and proximity of large wood to nearby property and infrastructure. If greater than 150 feet – rate as low risk, between 66-150 feet – medium risk, between 0-66 feet high risk – modified from Table 5.5 FHWA handbook page 5.28.
9. Assessment of structure of concern – Is it a single span bridge (y/n), Is it already free of debris/obstructions (y/n). Is the bridge well aligned with stream flow (y/n)

More Detailed - Channel/Floodplain Assessment (from Schiff et al. 2014)

Channel

1. Determine Geomorphic stream type
2. Determine/measure bankfull width and depth (and removal volume)
3. Assess channel alignment
4. Assess any slope transitions
5. Determine the equilibrium sediment slope
6. Determine stream geomorphic pattern (i.e., meandering, braided, wandering)
7. Assess/document stream roughness elements
8. Determine existence/extent of an intact natural bed armor layer
9. Determine channel incision ratio
10. Evaluate the channels geomorphic evolution

General Tree decay Information: Copied from the National Large Wood Manual (2016) Table 6.-2 “Comparison of Desirability of Various Tree Species for Stream Structures”

Species	Durability (assuming wetting and drying)	Source ¹
Cottonwood (<i>Populus</i> spp.)	Poor	Johnson and Stypula (1993)
Alder (<i>Alnus</i> spp.)	Poor	Johnson and Stypula (1993) Cederholm et al. (1997a, 1997b, 1997c)
Maple (<i>Acer</i> spp.)	Fair (will survive 5 to 10 years)	Johnson and Stypula (1993)
Hemlock (<i>Tsuga</i> spp.)	Least of conifers	Johnson and Stypula (1993)
Sitka spruce (<i>Picea sitchensis</i>)	Excellent	Johnson and Stypula (1993)
Douglas-fir (<i>Pseudotsuga</i> spp.)	Excellent, will survive 25–50 years 32–56	Johnson and Stypula (1993) Harmon et al. (1986)
Western red cedar (<i>Thuja plicata</i>)	Most desirable, will survive 50 to 100 years	Johnson and Stypula (1993)
Yellow-poplar (<i>Liriodendron tulipifera</i>)	0.4 year	Harmon et al. (1986)
Aspen (<i>P. tremuloides</i>)	5 years	Harmon et al. (1986)
White fir (<i>A. concolor</i>)	4 years	Harmon et al. (1986)
Norway spruce (<i>Picea abies</i>)	~30 years	Kruys et al. (2002)
Conifers (<i>P. sitchensis</i> , <i>T. heterophylla</i> , <i>P. menziesii</i> , <i>T. plicata</i>)	Half-life of ~20 years	Hyatt and Naiman (2001)
Black locust (<i>Robinia pseudoacacia</i>), red mulberry (<i>Morus rubra</i>), Osage orange (<i>Maclura pomifera</i>), Pacific yew (<i>Taxus brevifolia</i>)	Exceptionally high heartwood decay resistance	Simpson and TenWolde (1999)
Old growth bald cypress (<i>Taxodium distichum</i>), catalpa (<i>Catalpa</i> spp.), cedars (<i>Cedrus</i>), black cherry (<i>Prunus serotina</i>), chestnut (<i>Castanea</i> spp.), Arizona cypress (<i>Cupressus arizonica</i>), junipers (<i>Juniperus</i> spp.), honey locust (<i>Gleditsia triacanthos</i>), mesquite (<i>Prosopis glandulosa</i>), old growth redwood (<i>Sequoia sempervirens</i>), sassafras (<i>Sassafras albidum</i>), black walnut (<i>Juglans nigra</i>)	Resistant or very resistant to heartwood decay	Simpson and TenWolde (1999)
Young growth bald cypress (<i>Taxodium distichum</i>), western larch (<i>Larix occidentalis</i>), longleaf old growth pine (<i>Pinus palustris</i>), old growth slash pine (<i>Pinus elliotii</i>), young growth redwood (<i>Sequoia sempervirens</i>), tamarack (<i>Larix laricina</i>), old growth eastern white pine (<i>Pinus strobus</i>)	Moderately resistant to heartwood decay	Simpson and TenWolde (1999)
Species	Durability (assuming wetting and drying)	Source ¹

Red alder (<i>Alnus rubra</i>), ashes (<i>Fraxinus</i> spp.), aspens (<i>Populus tremuloides</i>), beech (<i>Fagus</i> spp.), birches (<i>Betula</i> spp.), buckeye (<i>Aesculus glabra</i>), butternut (<i>Juglans cinerea</i>), cottonwood (<i>Populus</i> spp.), elms (<i>Ulmus</i> spp.), basswood (<i>Tilia Americana</i>), true firs (<i>Abies</i> spp.), hackberry (<i>Celtis occidentalis</i>), hemlocks (<i>Tsuga</i> spp.), hickories (<i>Carya</i> spp.), magnolia (<i>Magnolia grandiflora</i>), maples (<i>Acer</i> spp.), pines (<i>Pinus</i> spp.), spruces (<i>Picea</i> spp.), sweetgum (<i>Liquidambar styraciflua</i>), sycamore (<i>Platanus occidentalis</i>), tanoak (<i>Notholithocarpus densiflorus</i>), willows (<i>Salix</i> spp.), yellow-poplar (<i>Liriodendron tulipifera</i>)	Slightly or nonresistant to heartwood decay	Simpson and TenWolde (1999)
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Information from Johnson and Stypula (1993) is qualitative and unsubstantiated. Evidently these comments pertain to the region of King County, Washington. Harmon et al. (1986) provide a review of scientific literature dealing with decomposition rates of snags and logs in forest ecosystems. The times from Harmon et al. (1986) represent the time required for 20% decomposition (mineralization) of a log based on exponential decay constants obtained from the literature. Fragmentation of logs in streams due to mechanical abrasion would accelerate the decay process, as would more frequent wetting and drying. Kruys et al. (2002) provide data on decay of fallen and standing dead trees in a forest in mid-northern Sweden. Hyatt and Naiman (2001) provide data on residence time of large wood in Queets River, Washington. Simpson and TenWolde (1999) provide data for evaluating wood products, not whole trees. Additional data on lumber (not large wood) are available from Forest Products Laboratory (2010).

Timber Manipulation BMPs

Prior to undertaking an timber manipulation a consultation with park engineers, PADEP, and Philly Army Corps/NJDEP, and NERO staff should be undertaken. This coordination will ensure that any and all potential compliance issues are highlighted and addressed, along with making sure that park staff adhere to best management practices while performing any timber manipulations within the stream bed and banks and associated floodplains.

1. Fallen trees and other debris in the floodplain should be removed, buried, or secured as soon as possible or at the earliest appropriate (**SAFE**) time. Standing trees should be left as they are. All removed instream wood should be secured within the floodplain whenever possible. Wood removal operations should be conducted only during low flow periods. Small wood can (and should be if it's deemed safe) be removed from the channel without any heavy gas powered equipment. Larger logs and trees across the channel will need to be cut into manageable pieces and dragged out of the stream. Downed trees still attached to streambanks should be cut off near their stumps. Do not grub (pull out) tree stumps from banks. Stumps keep streambanks from eroding.
2. Keep large equipment out of the stream bed and banks and to the greatest extent possible as far away from the top of banks of the waterways as is manageable. Logjam removal activities should never be attempted alone, and a crew leader should be appointed to keep visual contact with everyone on the crew. The utmost caution should be taken to protect the personal safety of all workers.
3. To the extent you can try and use a single ingress/egress road for any heavy machines within the floodplain to limit impacts and make restoration easier.
4. The following equipment is typically used for logjam removal projects: hand tools to facilitate removal of small debris; articulated log skidders with cable winches to remove larger logs; a chain saw or reciprocating saw to cut large logs and trees to manageable size; an adequate length of cable, chain, or rope to attach to the logs to facilitate their removal; a tractor, or truck on the top of the stream bank to pull the logs out of the stream; and a truck on which to load the debris for subsequent removal from the floodplain should securing the logs within the floodplain prove infeasible or unsafe to park visitors.
5. If you see areas of the stream banks that look as if they were degraded during the event and you have downed logs available you could consider securing them in place at the site of the bank erosion zone as a form of erosion control and debris management.
6. A basic (non-plastic) erosion control mulch blanket and native floodplain seed mix should be installed immediately after timber manipulation activities have ceased for all disturbed areas.