Sediment Transport in the Patapsco River, Maryland following Bloede Dam Removal

Technical Memorandum

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Cover Photograph:

Bloede Dam on the Patapsco River, image from Maryland Department of Natural Resources (http://www.dnr.maryland.gov/).

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Table of Contents

List of Tables

List of Figures

1 Introduction

Bloede Dam is located approximately 18.6 km upstream from the mouth of the Patapsco River in Maryland (river km 18.6, or river mile [RM] 13.6). This 7.9 m (26 ft) tall dam is currently under investigation for potential removal (cover photograph and **Figure 1**). Preliminary modeling of the sediment transport dynamics following the proposed Bloede Dam removal was conducted in 2010 when Simkins Dam, located on the same river approximately 1.25 km (0.4 mile) upstream of Bloede Dam, was studied for removal (Stillwater Sciences 2010). This technical memorandum presents a refined modeling analysis based on updated information that became available after the 2010 preliminary study, including the grain size distributions of the impoundment deposit and the channel geometry along the river.

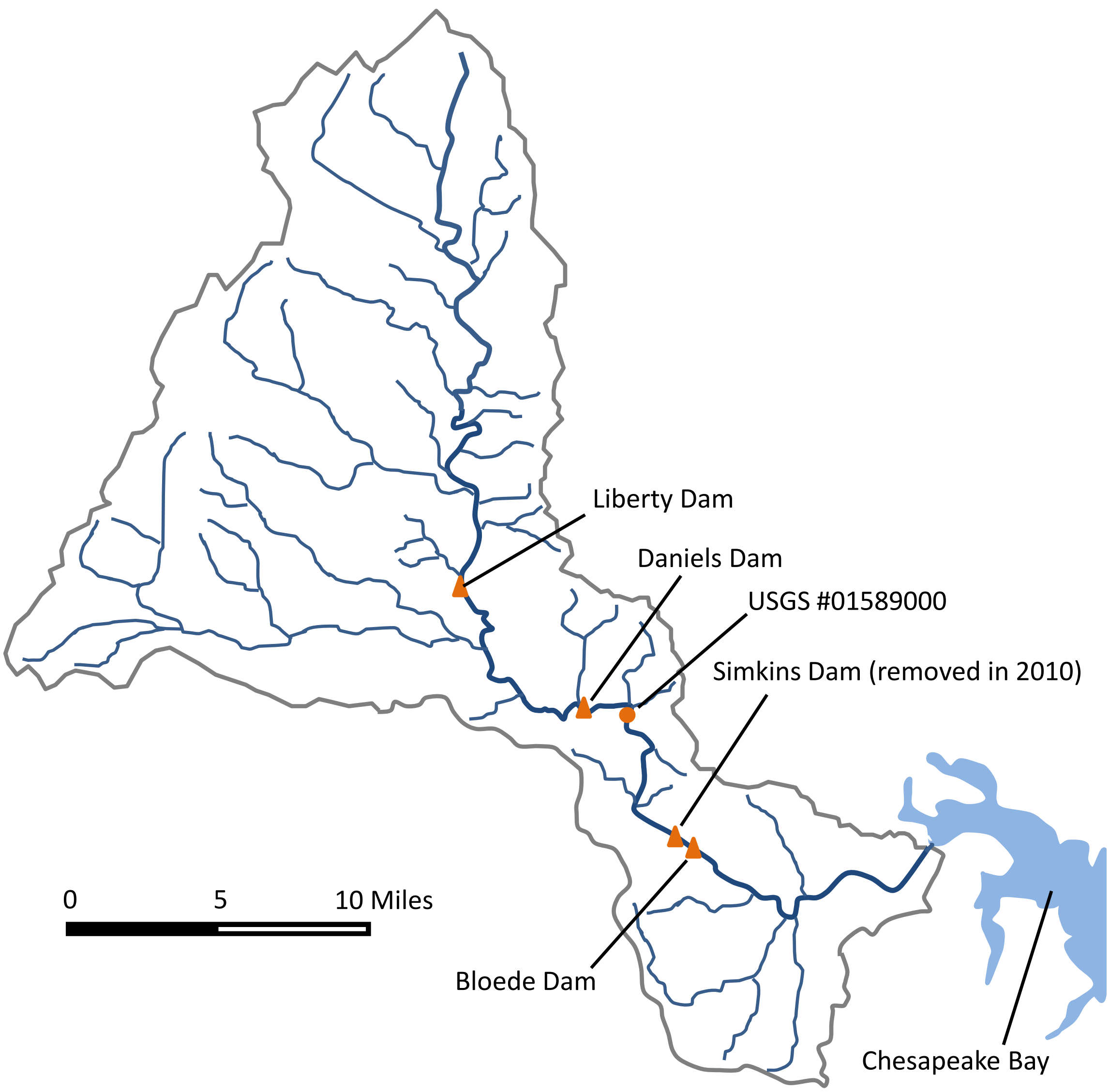

Figure 1. Patapsco River watershed, Maryland (derived from The National Elevation Dataset, Gesch, D.B. [2007]).

2 DREAM-1 Sediment Transport Model

We continue to use the DREAM-1 sediment transport model to simulate sediment transport dynamics in the Patapsco River following the proposed Bloede Dam removal. Details for the DREAM-1 model can be found in Cui et al. (2006a,b), and Stillwater Sciences (2010) also provided an overview of the model:

> *"DREAM-1 is one of the two Dam Removal Express Assessment Models developed for simulation of sediment transport following dam removal (Cui et al. 2006a, b). DREAM-1 was designed for simulations where the sediment deposit in the reservoir upstream of the dam under consideration for removal is composed primarily of non-cohesive fine sediment (i.e., sand and silt). It simulates the transport and deposition of fine sediment and is applicable to rivers with any combination of sand-bedded, gravel-bedded, and bedrock reaches downstream of the dam. Because DREAM-1 does not simulate the transport of gravel, it treats the gravel-beds downstream of the dam and the pre-dam historical gravel beds upstream of the dam as immobile — fine sediment either passes through or deposits onto the gravel-bedded surface and potentially transforms it into a sand-bedded reach if the sand deposit becomes sufficiently thick. For flow parameter calculations, the model applies a standard backwater equation (e.g., Chaudhry 1993) for low Froude number conditions (i.e., Froude numbers < 0.9, see Cui et al. 2006a for details) and applies a quasi-normal flow assumption (i.e., friction slope is identical to local bed slope; see Cui and Parker 2005) for high Froude number conditions. The model applies Brownlie's (1982) bed material equation for calculating sediment transport capacity and considers the transport of particles coarser than 0.0625 mm (i.e., sand and coarser) as one unit for mass conservation calculations, and considers particles finer than 0.0625 mm in diameter as wash load that is assumed unable to redeposit onto the channel bed once released into the water column following erosion of the reservoir deposit. Further, it is assumed that reservoir erosion is governed by the mobilization of sand-sized particles and coarser, and at any cross section, eroding the reservoir deposit down to a given elevation by mobilizing sand and coarser particles will also result in the release of all the finer particles (i.e., finer than 0.0625 mm) above that elevation. In addition to standard features briefly discussed above and detailed in Cui et al. (2006a,b), we also applied the roughness and partial sand coverage corrections to DREAM-1 detailed in Cui et al. (2008), which allows for a more accurate simulation of sand transport over the gravel bed when the sand deposit is too thin to completely cover the gravel bed."*
>
> *"The model requires the following input parameters: initial channel profile, initial thickness of fine sediment deposits in the reservoir and downstream reaches, channel cross-sections simplified as rectangles with widths equal to the bankfull channel width, daily average water discharge series, the rate and size of sediment supply, the downstream base-level control (i.e., either downstream water surface elevation or fixed bed elevation), and estimates of surface median bed material size along the river downstream of the dam. Model output includes the evolution of the thickness of sediment deposits within the reservoir and downstream reaches, coarse and fine sediment fluxes, and* ***daily-averaged*** *total suspended sediment concentrations (TSS) along the river in response to the specified water discharge and sediment supply conditions. In this particular case, because background TSS to discharge relation is not known*[1]*, we have assumed zero background TSS, and as a result, the simulated TSS represents* ***an increase in daily-averaged total suspended sediment***

[1] We now have suspended sediment record at USGS #01589000 for the period between 10/1/2010 and 9/30/2013.

***concentration**. Detailed model descriptions, model sensitivity tests and model examinations can be found in Cui et al. (2006a, 2006b, 2008) and Wooster (2003), and applications of DREAM-1 or its predecessors are included in Cui and Parker (1999), Cui et al. (2003), Cui and Parker (2005), Stillwater Sciences (1999), and Stillwater Sciences (2008)."*

3 Model Input Data

3.1 River Longitudinal Profile and Channel Width

The modeling in Stillwater Sciences (2010) relied primarily on the August and September 2009 Inter-Fluve water surface survey and the 2005 Baltimore County LiDAR survey to obtain a longitudinal profile of the river, and estimated active channel widths using a set of 1:5,350 scale aerial photographs. Subsequent to the 2009 Inter-Fluve water surface survey, more detailed cross section data were collected as part of the Simkins Dam removal monitoring program (McCormick Taylor 2011a, 2011b, 2011c, and 2012). Combining the available cross section surveys and the LiDAR data, DeTemple and Wilcock (2014) developed a hindcast HEC-RAS sediment transport model to simulate sediment transport dynamics following Simkins Dam removal, and Stillwater Sciences (2014) derived a longitudinal profile representing average bed elevation and active channel width based on DeTemple and Wilcock's (2014) HEC-RAS input file (**Figure 2** and **Figure 3**).

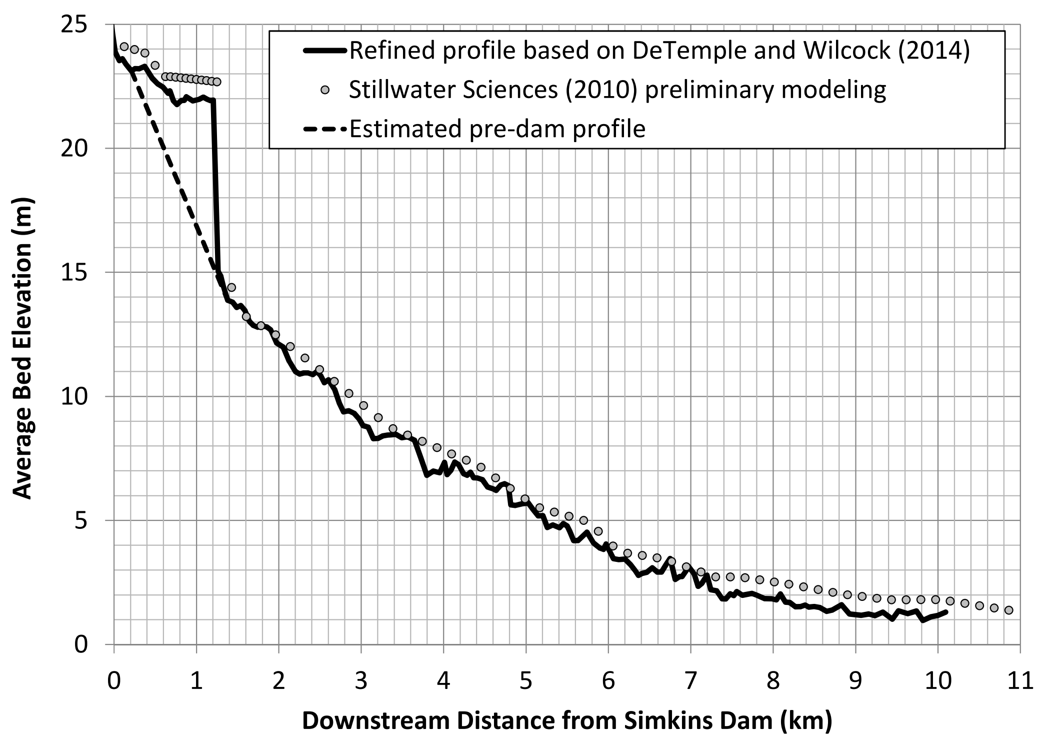

Figure 2. Comparison of the refined channel longitudinal profiles of the Patapsco River, Maryland.

For the Bloede Dam removal simulation presented in this technical memorandum, we use the refined active channel width presented in **Figure 3** for model input, and develop a numerically simulated quasi-equilibrium longitudinal profile based on the refined profile presented in **Figure 2**. In addition, we assume that all of the sediment eroded from the Simkins impoundment following the Simkins Dam removal will be evacuated out of the system, and that the river will regain its quasi-equilibrium condition at the time that the Bloede Dam is removed.

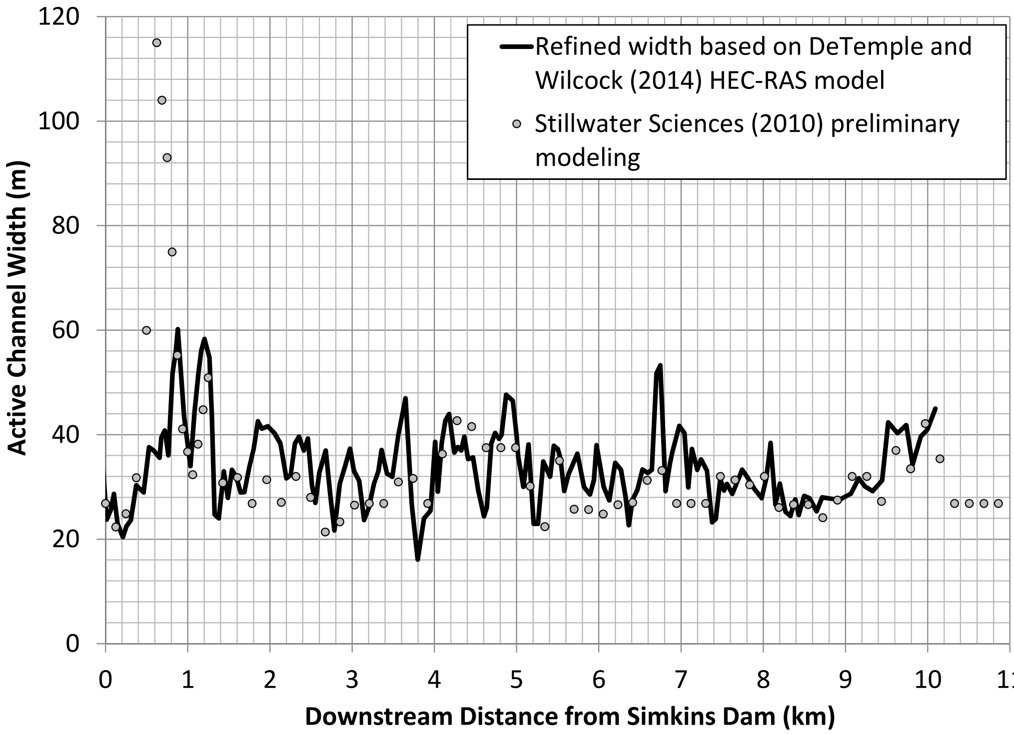

Figure 3. Comparison of the refined active channel width used for modeling in this technical memorandum and the active channel width used in Stillwater Sciences (2010) preliminary modeling.

3.2 Composition of Reservoir Deposit

Stillwater Sciences' (2010) preliminary modeling used a hypothetical grain size distribution to represent the Bloede Reservoir deposit. Below, we discuss the available information that has been incorporated into the refined modeling presented in this technical memorandum.

The sketch presented in **Figure 4** delineates the general composition of the Bloede Reservoir sediment deposit based on the coring logs of TRIAD Engineering during their September and December 2012 coring of the Bloede Reservoir deposit (TRIAD Engineering 2013). Because the reservoir is located at a sharp bend, high flows were concentrated near the right bank, while stagnant water or recirculating flow patterns formed near the left bank during the early days of reservoir operation. This resulted in a layer of silt deposits on the left side of the channel. As sediment accumulated in the reservoir area, flow velocity increased in the entire reservoir area, and as a result, sand started to deposit on top of the early silt deposit, forming approximately a 1.2 to 3 m (4 – 9 ft) thick sand layer on top of the silt layer (**Figure 4**).

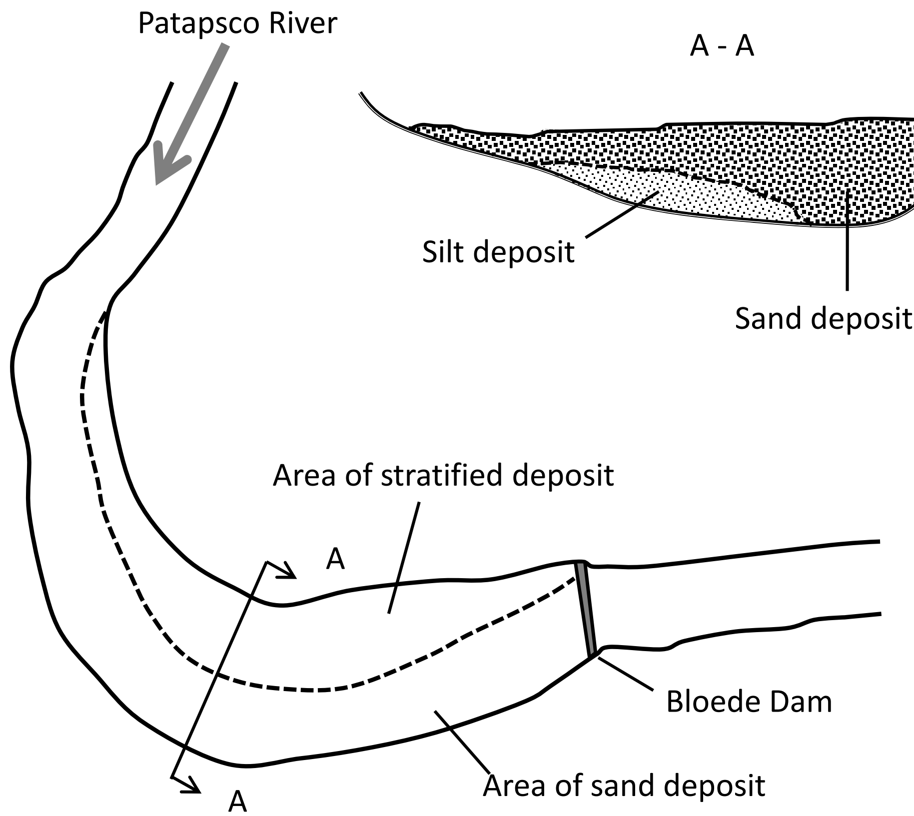

Figure 4. Schematic sketch, showing the interpreted general grain size of the Bloede Reservoir sediment deposit.

Norris (2013) used three different methods to estimate the volume of sediment stored in the Bloede Reservoir, the results of which are summarized in **Table 1**. The 3-D volume polygon method provided the most reliable estimates, with a total of 266,000 metric tons of sediment in Bloede Reservoir of which 189,000 metric tons is sand and 77,000 metric tons is silt. Note that the estimated sand deposit in Bloede Reservoir with the 3-Dimensional Volume Polygon method (189,000 metric tons) is only approximately 25 percent higher than the sand deposit in the Simkins Reservoir initially estimated prior to dam removal by Inter-Fluve (2009)[2], and approximately 73% more than the amount of sand eroded from the Simkins Dam impoundment by March 2014, approximately three years four months following Simkins Dam removal[3]. This indicates that the potential channel aggradation following Bloede Dam removal will likely be higher than that following Simkins Dam removal. However, because of the relatively small difference in the amount of sand releases, the channel aggradation differences between the two projects are expected to be small. Because of the higher silt and organic material content, the

[2] Inter-fluve's initial estimate of Simkins Reservoir deposit was 113,000 cubic yards, which translates to approximately 149,000 metric tons, assuming a porosity of 0.35 (i.e., specific density of approximately 1.7). The Simkins Reservoir deposit is denser than Bloede Reservoir deposit because there is significantly less silt and organic material in the deposit compared to the Bloede Reservoir deposit due to the smaller dam size.

[3] The estimated Simkins impoundment erosion following Simkins Dam removal is 63,300 m^3 as of March 2014 (Mathias Collins, per. comm., August 2014), which translates to approximately 109,000 metric tons assuming a porosity of 0.35.

Bloede Dam removal will result in a higher suspended sediment concentration compared to the Simkins Dam removal. It should be noted, however, that the 77,000 metric tons of estimated silt deposit in Bloede Dam is only slightly higher than the maximum recorded daily suspended sediment discharge at USGS gage #1589000 (Patapsco River at Hollofield, MD) for the three year period between 1 October 2010 and 30 September 2013 when suspended sediment data was available (65,200 metric tons/day was recorded on 31 January 2013 when daily discharge at the station was 204 m^3/s [7,200 cfs], and peak flow was estimated to be approximately 450 m^3/s [16,000 cfs][4], or approximately an 8-year recurrence interval flow). This indicates that potential impacts to Chesapeake Bay are likely to be minimal as a result of receiving the silt-sized sediment following dam removal.

Table 1. Estimated gravel and sand deposits in Bloede Reservoir, converted to mass from the estimated volumes in Norris (2013) with the specific density of 1.3 estimated by Norris (2013).

Method	*Silt Estimate (metric tons)*	*Sand Estimate (metric tons)*	*Total (metric tons)*
Simple Volume Polygon Estimate	86,000	224,000	310,000
3-Dimensional Volume Polygon Estimate (most accurate estimate)	77,000	189,000	266,000
Average End Area Estimate	98,000	229,000	327,000

DREAM-1 modeling requires the grain size distribution for sand-sized sediment as model input. **Figure 5** below presents the available grain size distribution data from the Simkins and Bloede Reservoir deposits. Because Simkins Dam is only 1.25 km upstream of Bloede Dam with a small storage area that had been filled with sediment for many years, the Simkins Reservoir sand deposit should provide an excellent reference for the sand grain size distribution in the Bloede Reservoir deposit.

There are only two samples from the Bloede Reservoir that have a full grain size distribution, while the rest of the samples are truncated at 0.5 mm. Because of that, they are inadequate to derive an average grain size distribution without referencing the Simkins Reservoir deposit samples. As indicated in **Figure 5**, the grain size distributions of the sand deposit in Simkins Reservoir are similar to that of the Bloede Reservoir, and the average of the grain size distributions of the Simkins sand deposits is more or less in the middle of the scattered Bloede Reservoir sand deposit grain size distributions. As a result, we will continue to use the average of the Simkins Reservoir samples to represent the grain size distribution of the sand deposit in Bloede Reservoir. The implication of this assumption is discussed later in Section 6.

[4] Peak discharge on the day was not available at the time this technical memorandum was developed and was estimated based on the recorded gage height.

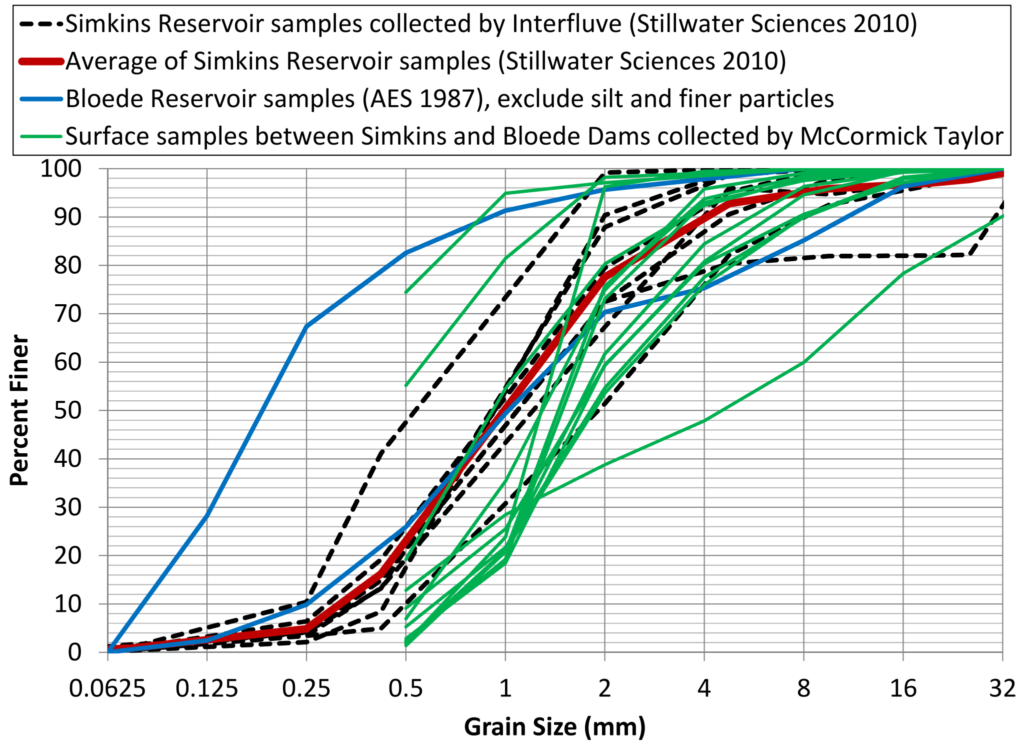

Figure 5. Grain size distribution of the sand deposit in Bloede and Simkins reservoirs. Silt is excluded in the grain size distributions presented in this diagram.

3.3 Hydrology

Similar to the preliminary modeling in Stillwater Sciences (2010), discharge records from USGS gage #01589000 (Patapsco River at Hollofield, MD) are used to establish input for the model, assuming that discharge is proportional to drainage area presented in **Figure 1**. The periods of discharge records selected to serve as model input and the reasons that they were selected are presented in **Table 2**. Note that the wet, average and dry years (**Figure 6**) were selected during the Simkins Dam removal study based on the criteria that a wet year has an exceedance probably of approximately 0.1, an average year 0.5, and a dry year 0.9 (Stillwater Sciences 2010). The exceedance probability is for both the annual runoff and annual peak flow because both are potentially important to the erosion and transport dynamics of the reservoir deposit.

3.4 Downstream Boundary

The modeling of the Simkins Dam removal in Stillwater Sciences (2010) used the recorded tidal level at NOAA tidal gauge #8574680 (located approximately 2 miles from the river mouth directly across the bay at Baltimore harbor) to serve as the downstream water surface level. Although the tidal effect is unlikely to affect modeling results, we elected to keep the tidal record as the downstream condition because it is already built into the model. Tidal levels are not presented in this technical memorandum because they are not considered to be an important factor.

Table 2. Discharge record to be used for Bloede Dam removal sediment transport modeling.

Modeling period	*Discharge record used for simulation*	*Note*
Year 1 after dam removal	WY 2004	A wet year, with an exceedance probability of approximately 0.1 for both annual run-off and annual peak flow
	WY 1983	An average year, with an exceedance probability of approximately 0.5 for both annual run-off and annual peak flow
	WY 1965	A dry year, with an exceedance probability of approximately 0.9 for both annual run-off and annual peak flow
Year 2 – Year 10 after dam removal	WY 1968 – 1976	Nine years of continuous record, with the first year (WY 1968) randomly selected from the available record

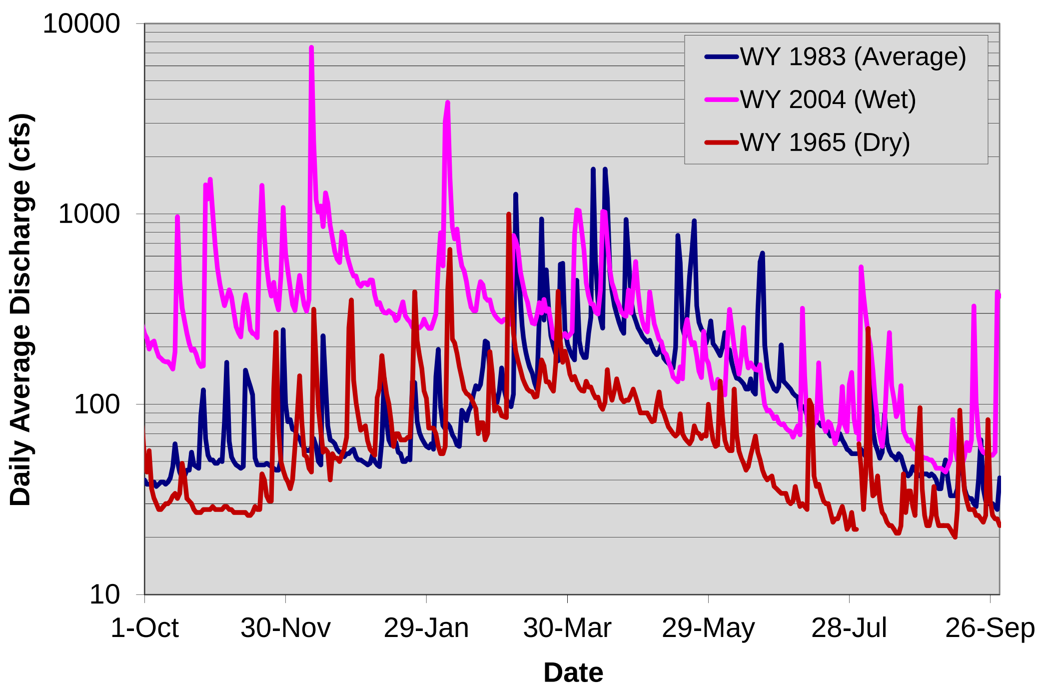

Figure 6. Patapsco River daily average discharge at USGS gauging station #01589000 for the average, wet, and dry years listed in **Table 2**.

3.5 Upstream Sand Supply

Through a model zeroing process, Stillwater Sciences (2010) estimated the long-term average sand supply in the Patapsco River near Bloede Dam to be approximately 6,900 metric tons per year (3,400 cubic yards per year, solid). We will continue to use this value for the Bloede Dam removal sediment transport modeling.

3.6 Surface Gravel Median size

A rough estimate of surface gravel median size in the Patapsco River was provided in Stillwater Sciences (2010). Because modeling results are relatively insensitive to this parameter, we will continue to use the estimated surface gravel median size in Stillwater Sciences (2010) as the input parameter for the Bloede Dam removal sediment transport modeling.

4 Hypothesis on the Erosion of Bloede Reservoir Deposit

Once the Bloede Dam is removed, the majority of the reservoir deposit will be available for transport (referred to as phase I erosion), while a small portion can be left behind, with potential erosion in the future only during very high flow events when the flow is able to access the sediment (referred to as phase II erosion) (**Figure 7**).

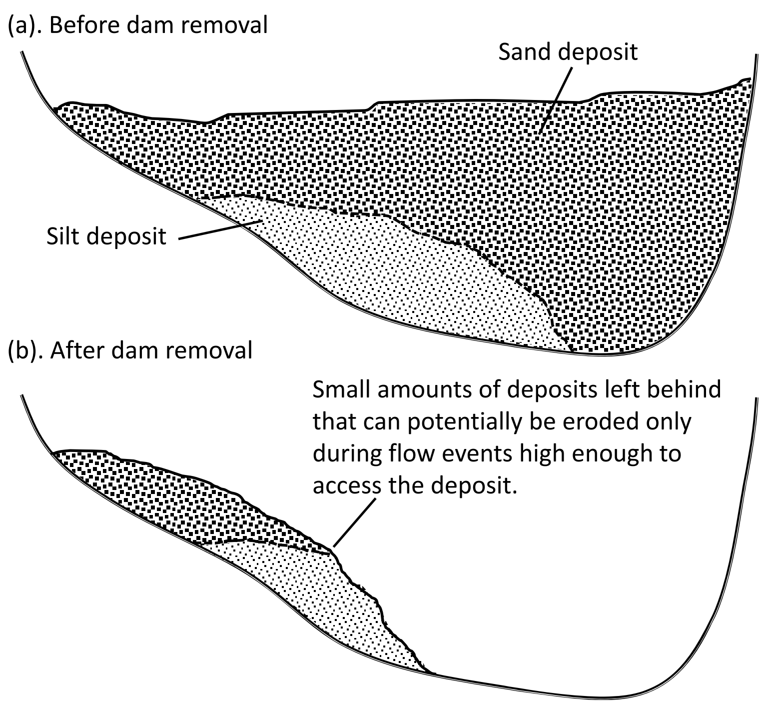

Figure 7. Sketch of the sediment deposit in Bloede Reservoir before and after dam removal, showing that a small amount of sediment deposit may be left behind in the former reservoir area following dam removal, with potential erosion occurring only during high flow events when the deposit is accessed by the flow.

Because of the one-dimensional nature of the DREAM-1 model, the process described above cannot be modeled directly in the simulation. Below we briefly describe how sediment erosion is represented in the DREAM-1 model and introduce assumptions so that we can reasonably approximate the erosion of sand and silt deposits with the model.

The DREAM-1 model assumes a stratified reservoir deposit, and in the case of Bloede Reservoir, we have assumed two layers: a bottom layer consisting of a substantial amount of silt, and a top layer consisting primarily of sand (**Figure 8**, **Figure 9**). In the pre-removal conditions, a trapezoidal channel exists with a user-defined width, depth, and bank angle (**Figure 8a**). Due to a lack of a better term, the depth of this trapezoidal channel is referred to as bankfull depth, which is not necessarily the depth of the river in the study area during bankfull flow. Similarly, the width of the top of the trapezoidal channel is referred to as bankfull width. Once the dam is removed, the model assumes that the channel will degrade, preserving the width at the bottom of the trapezoidal channel and the bank slope until the pre-dam historical channel bed is reached (**Figure 8b**). Once the erosion reaches the pre-dam historical channel bed, sediment will no longer be eroded from the reservoir area, hence the phase I erosion terminates. Thus, the model only simulates phase I erosion while neglecting phase II erosion. Phase II erosion is neglected due to the limitations of one-dimensional sediment transport models and is acceptable because the majority of the sediment erosion occurs during phase I erosion. Phase II erosion only occurs during very high flow events, making the small amount of sediment erosion from the former impoundment area relatively unimportant compared to the background sediment supply.

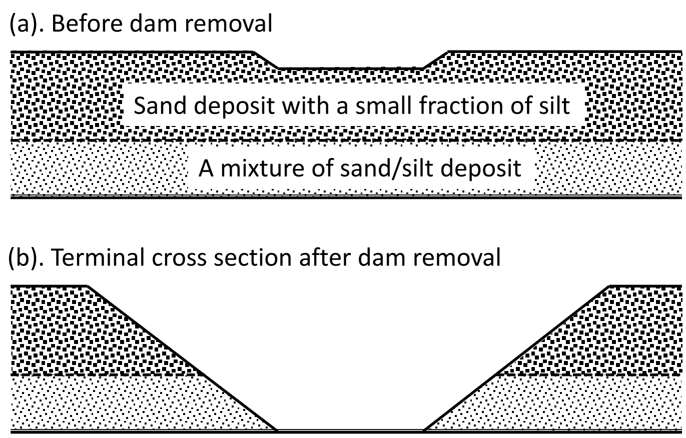

Figure 8. Sketch showing idealized sediment deposit and erosion following dam removal in the DREAM-1 model, in which sand and silt are combined as layers of sand/silt mixture.

To represent a range of possibilities for phase I erosion, we have chosen three options with different assumptions so that varying amounts of sand and silt erosion can be modeled (**Table 3**). In all three options, we have assumed a top sand layer that contains 5% silt with a thickness of 2.5 m in the reach where the sediment deposit is thicker than 2.5 m (**Figure 9**) based on interpretations of the TRIAD Engineering coring logs obtained on 5 – 6 September and 10 – 12 December 2012 (TRIAD Engineering 2013). Among the three modeling options, Option 1 is designed to release all of the sand and silt deposits from the impoundment area during phase I erosion; Option 2 is a more realistic estimate of channel width and bank angle but slightly on the conservative side (i.e., actual phase I erosion will likely be smaller than the simulated values); and Option 3 is also a more realistic estimate compared to Option 1 but slightly on the liberal side (i.e., actual phase I erosion will likely be more than the simulated values).

In combination with the three hydrologic conditions (**Table 2**), the three options listed in **Table 3** result in nine model runs as presented below in Section 5.

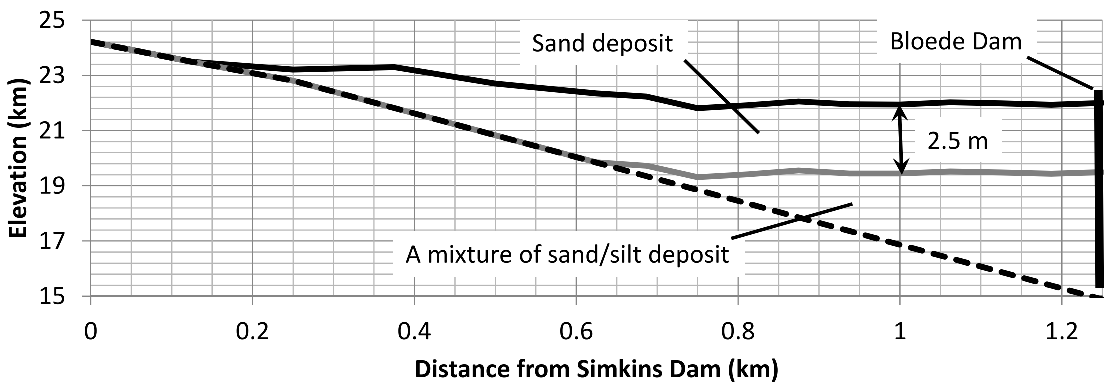

Figure 9. Longitudinal profiles of the river in Bloede Dam impoundment area, showing the assumed composition of the sediment deposit.

Table 3. List of the three options applied to sediment transport modeling with different assumptions that resulted in different amounts of potential sand and silt release following dam removal. The percentages in parentheses are sediment release as a percentage of the available deposit in Bloede Reservoir.

	Bankfull Width[a] (m)	*Bank Angle (degrees)*	*Silt Fraction in Upper/Lower Layers[b]*	*Potential Sand Erosion (metric tons)*	*Potential Silt Erosion (metric tons)*	*Potential Total Erosion (metric tons)*
Option 1: releasing all the deposit	49	30	0.05/0.72	189,000 (100%)	77,000 (100%)	266,000 (100%)
Option 2: More realistic estimate slightly conservative	38	30	0.05/0.5	166,000 (88%)	44,000 (75%)	210,000 (79%)
Option 3: More realistic estimate slightly liberal	30	35	0.05/0.4	138,000 (73%)	29,000 (38%)	167,000 (63%)

a. Assumed to be the width at 1 m above the base of the trapezoidal channel;

b. Variation in silt fraction in the lower layer represents different degrees of erosion of the silt-sized deposit, which is not deposited throughout the cross section (**Figure 7**). The values here are not physically based, but instead, they are assigned to obtain three pairs of representative sand/silt erosion volumes shown in the table.

5 Modeling Results

Nine runs were conducted, combining the three modeling options listed in **Table 3** and three hydrological conditions listed in **Table 2** using the following naming convention: each run is named with a digit of 1, 2 or 3 representing the three modeling options listed in **Table 3**, followed with a letter of "W", "A", or "D" representing the wet, average or dry conditions listed in **Table 2**. Run 2D, for example, applies the assumptions of Option 2 provided in **Table 3** for the erosion of reservoir deposit using the dry discharge series as outlined in **Table 2** for the model input. In addition to these nine runs, a tenth run, Run 2Af is conducted that serves as a sensitivity test run to examine whether the modeled sediment transport dynamics is significantly different if the sediment deposit in the impoundment is finer than assumed for the previous 9 runs. Run 2Af takes identical input compared to Run 2A, except the grain size distribution of the impoundment deposit is assumed to be the average of the two AES (1987) samples (i.e., average of the two blue lines in **Figure 5**) with a median size of approximately 0.5 mm, or approximately half of that used for the previous nine runs. Examination of modeling results indicate that: a) runs with the average and dry hydrologic conditions produced similar results; b) modeling results are relatively insensitive to the volume of sand and silt release for the three options examined other than minor differences in the magnitude of channel aggradation downstream of the dam and suspended sediment concentration; and c) assumed finer impoundment deposit (Run 2Af) produced only slightly reduced magnitude of downstream sediment deposition and moderately increased (within approximately a factor of 3) suspended sediment concentration. As a result, only the results from **Runs 2A** and **2W** are presented and discussed in detail below. Results for the additional runs are summarized briefly after the discussions of **Runs 2A** and **2W**, with diagrams provided in Appendix A without discussion. Presentations of modeling results below and in Appendix A employ the same reach delineation we used during Simkins Dam removal study (Stillwater Sciences 2014):

- **Reach 1**: Former Simkins Dam impoundment area, which is outside of the current study reach;
- **Reach 2**: Bloede Dam impoundment area;
- **Reach 3**: Bloede Dam to Vineyard Springs Road in Patapsco Valley Park approximately 4.5 km downstream of Simkins Dam;
- **Reach 4**: Vineyard Springs Road to I-195 Bridge approximately 9 km downstream of Simkins Dam;
- **Reach 5**: I-195 Bridge to Hammonds Ferry Road approximately 12.8 km downstream of Simkins Dam; and
- **Reach 6**: Hammonds Ferry Road to river mouth.

Run 2A: Following Bloede Dam removal, it takes approximately 26 weeks (roughly half a year) for the bed profile within the impoundment area to reach the pre-dam conditions (**Figure 10**), during which suspended sediment concentration downstream of the dam increases by up to 7,000 mg/l (**Figure 11**). Note that in **Figure 6**, the highest daily average discharge occurring during the first 26 weeks following Bloede Dam removal for **Run 2A** is only slightly higher than 1,000 cfs. The relatively low discharge in the river is responsible for the relatively long period of impoundment erosion. The erosion of the reservoir deposit following dam removal results in downstream channel aggradation, which is limited to approximately 15 km downstream of Bloede Dam (i.e., roughly between 1.25 km and 16.25 km downstream of Simkins Dam) (**Figure 12**). Immediately downstream of Bloede Dam (the upstream end of Reach 3), the channel aggrades rapidly, reaching a maximum channel aggradation of approximately 1.7 m (5.6 ft) after 4 weeks following dam removal, then degrades over time to recover the pre-removal condition (**Figure 13**). Channel aggradation in the rest of Reach 3 would last for approximately one year with the magnitude of channel aggradation on the order of approximately 1.5 m (5 ft). Farther downstream in Reach 4, channel aggradation would occur roughly 6 months after dam removal that would continue for approximately five years, with maximum channel aggradation on the order of 1 m (3.3 ft) (**Figure 13** and **Figure 14**). Channel aggradation would also occur in the upstream half of Reach 5 and the upstream half of Reach 6, with maximum magnitude of channel aggradation on the order of 0.9 m (3 ft) and 0.6 m (2 ft), repectively. Approximately 6 years after dam removal, the channel bed recovers to its pre-dam-removal profile (**Figure 14**).

Run 2W: Following Bloede Dam removal, it takes approximately 4 weeks (roughly 1 month) for the bed profile within the impoundment area to reach the pre-dam condition (**Figure 15**), during which suspended sediment concentration downstream of the dam increases by up to 6,000 mg/l (**Figure 16**). Note that in **Figure 6**, the highest daily average discharge occurring during the first 4 weeks reached almost 8,000 cfs for **Run 2W**. The high discharge in the river is responsible for the quick erosion of the impoundment deposit. Channel aggradation patterns downstream of Bloede Dam for **Run 2W** is similar to that of **Run 2A** (**Figure 17**, **Figure 18**, and **Figure 19**), with shorter impact durations in Reach 3 (approximately 18 weeks) and Reach 4 (approximately 1 year) due to the higher discharge in the river soon after dam removal.

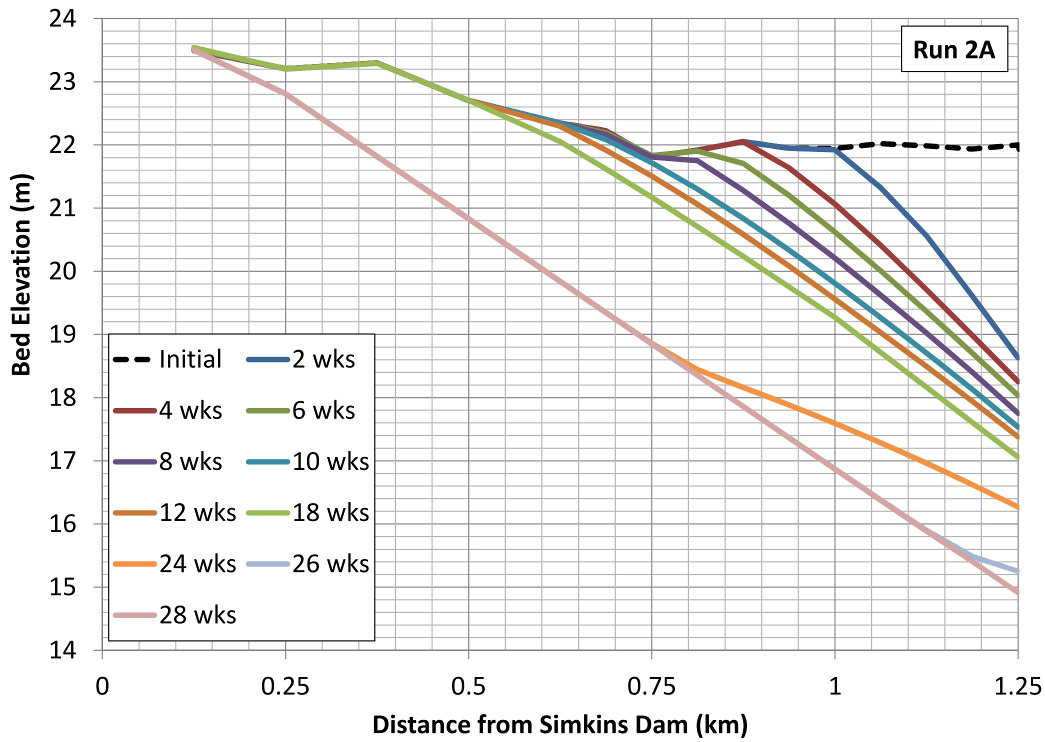

Figure 10. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 2A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

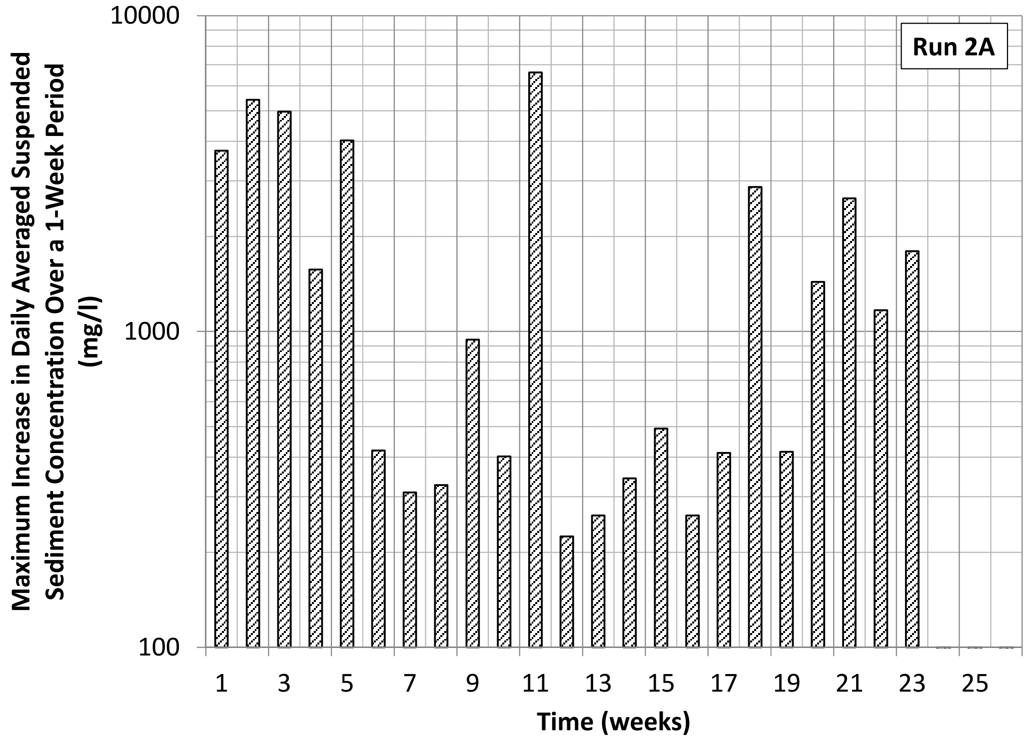

Figure 11. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 2A**.

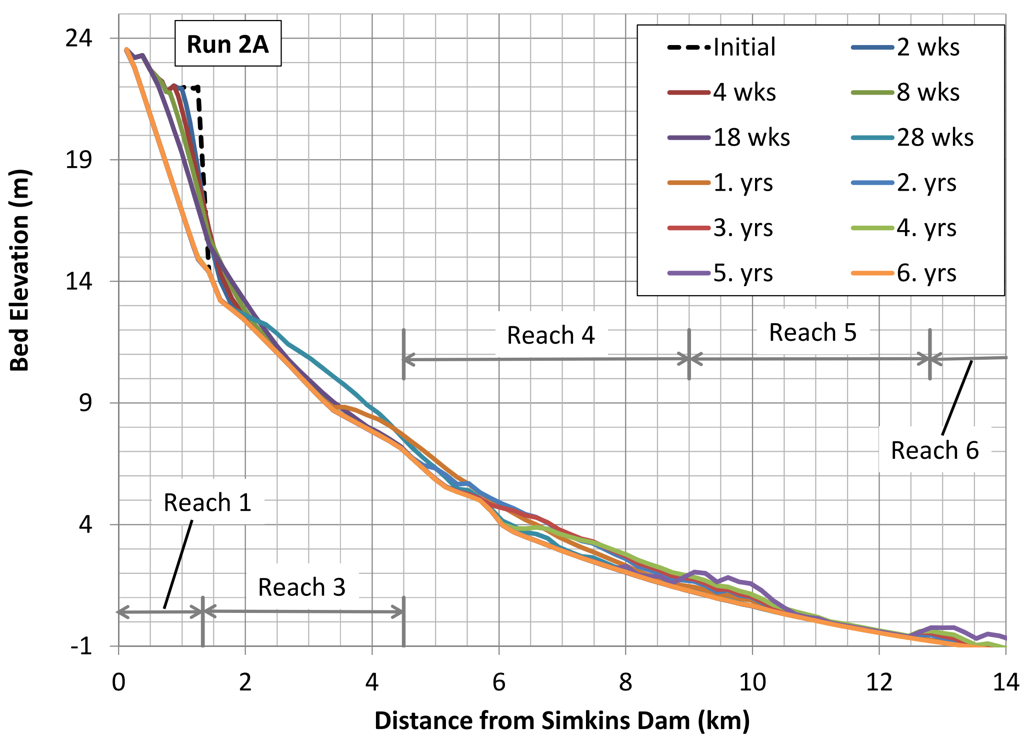

Figure 12. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 2A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

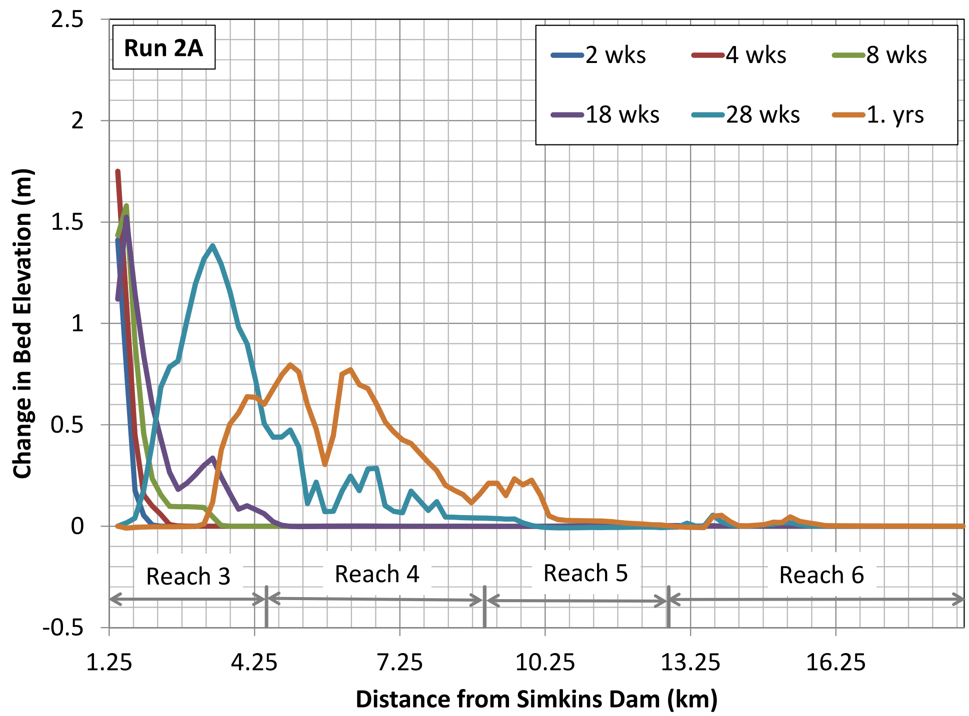

Figure 13. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 2A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

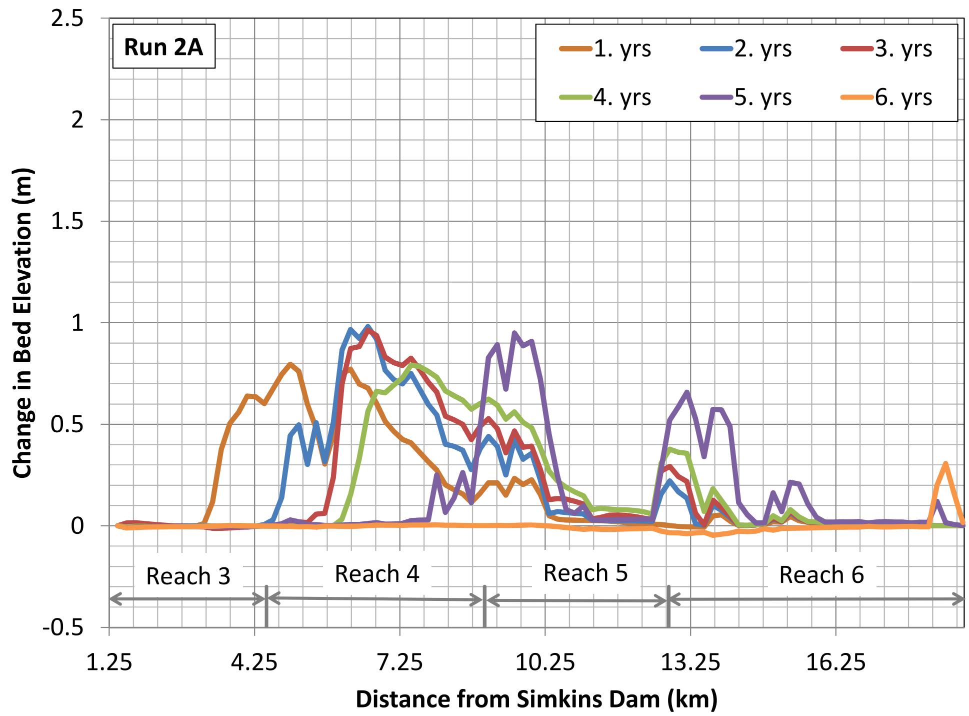

Figure 14. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 2A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

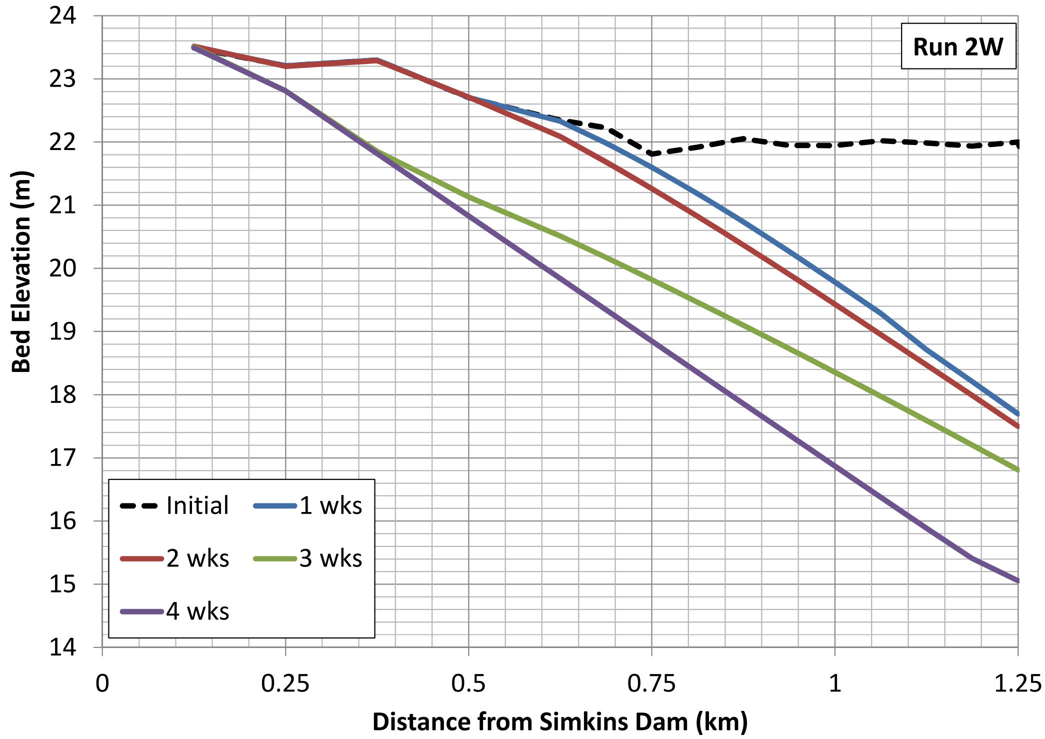

Figure 15. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 2W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

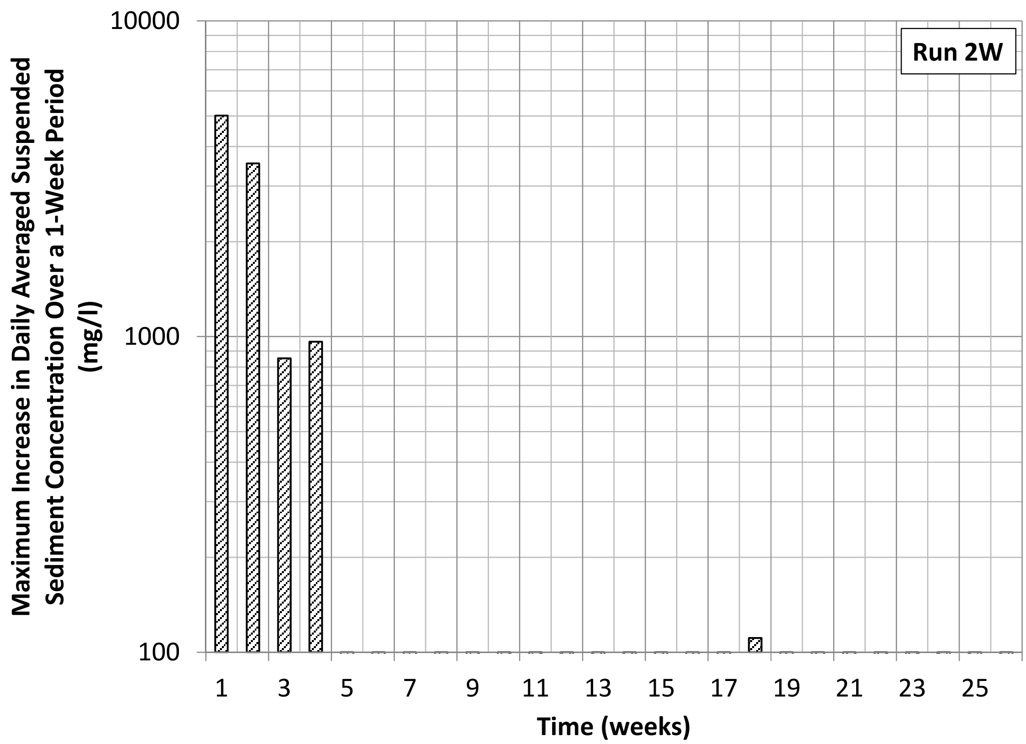

Figure 16. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 2W**.

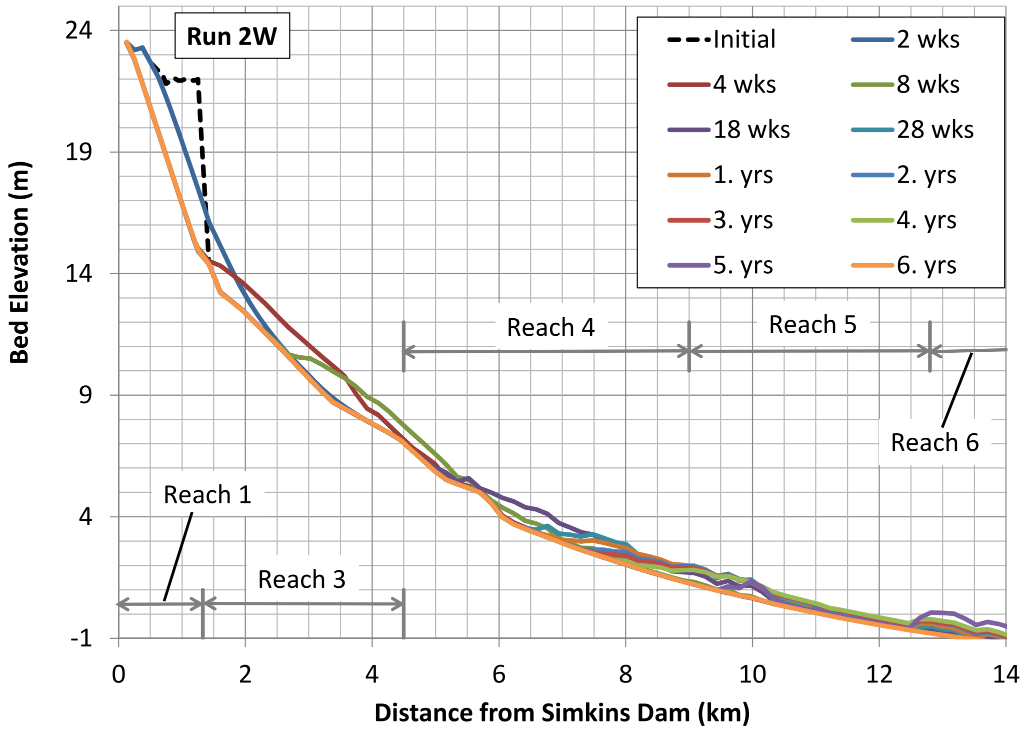

Figure 17. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 2W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

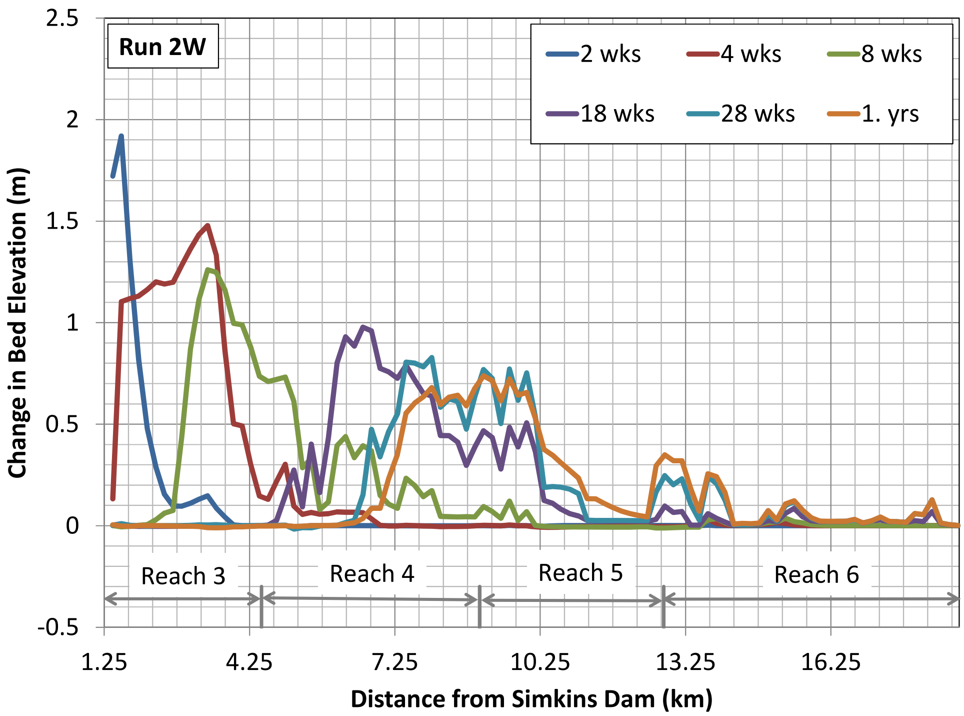

Figure 18. Simulated change in bed elevation downstream of Bloede Dam within the first year following Dam removal for **Run 2W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

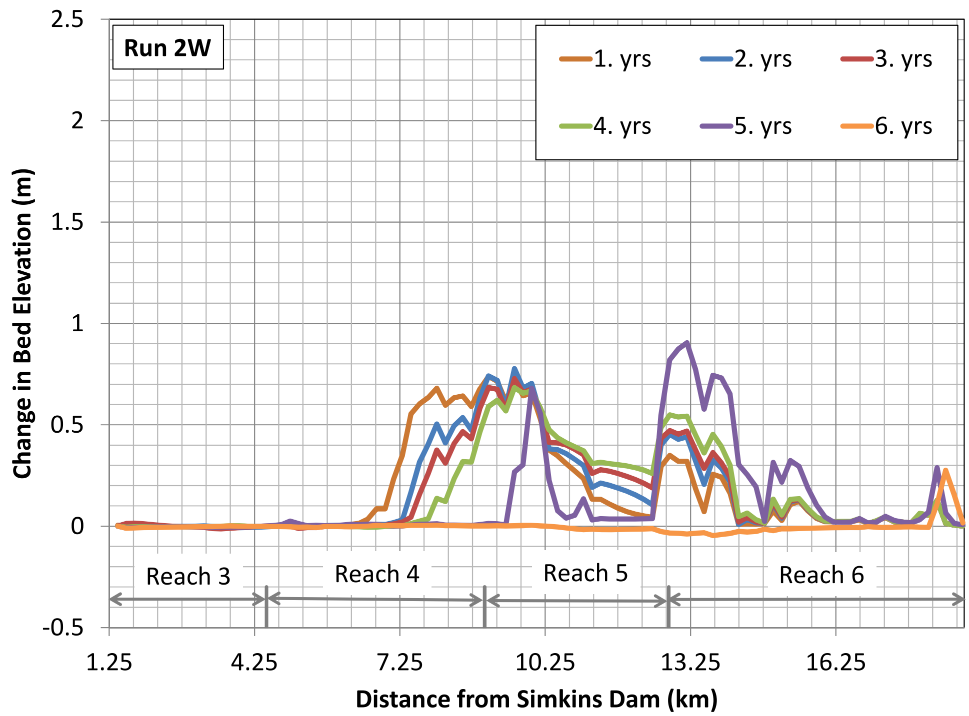

Figure 19. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 2W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

Below we briefly summarize the general range for all model runs. Diagrams for the runs other than **Runs 1A** and **2W** are provided in Appendix A.

Impoundment (Reach 2) erosion: Predicted duration for sediment erosion from the reservoir impoundment is between 4 weeks and 28 weeks, with the controlling factor being water discharge after dam removal.

Increase in suspended sediment concentration: The duration for increased suspended sediment concentration is identical to the duration of impoundment erosion (i.e., 4 to 28 weeks). Predicted maximum increases in suspended sediment concentration ranges between 5,000 and 20,000 mg/l.

Reach 3 sediment deposition: Predicted maximum magnitude of sediment deposition ranges between 1.2 and 1.5 m (4 – 5 ft) (1.7 – 2.0 m at the upstream end of the reach, or 5.6 – 6.6 ft) that lasts for 18 weeks to 3 years. The primary factor affecting the duration of impact is water discharge after dam removal.

Reach 4 sediment deposition: Predicted maximum magnitude of sediment deposition for all runs are on the order of 1 m (3.3 ft) that lasts for 1 – 5 years. The primary factor affecting the duration of impact is water discharge after dam removal.

Reach 5 sediment deposition: Predicted maximum magnitude of sediment deposition ranges between 0.7 and 0.9 m (2.3 – 3 ft) that lasts for approximately 6 years.

Reach 6 sediment deposition: Predicted maximum magnitude of sediment deposition ranges between 0.6 and 0.9 m (2 – 3 ft) that lasts for approximately 6 years.

6 Conclusion and Discussion

We have come to the following realizations based on the available information and modeling results with regard to the sediment transport dynamics following Bloede Dam removal.

1. The estimated maximum potential sand release following the Bloede Dam removal is approximately 25 percent higher than that estimated for the Simkins Dam removal and less than twice as much as the amount of sand erosion from the Simkins impoundment as of March 2014, approximately three and a half years after Simkins Dam removal. This comparison indicates that the amount of channel aggradation downstream of Bloede Dam following dam removal will be higher than the observed channel aggradation following Simkins Dam removal. However, because of the relatively small differences in the amount of sand that can potentially be eroded from the two reservoir deposits, the differences in the magnitude and duration of channel aggradation between the two projects are not expected to be substantial.
2. The estimated maximum potential silt release following Bloede Dam removal is equivalent to the amount of suspended sediment transported in the river over a one day period under the background conditions during an 8-year recurrence flow event. The implication of this comparison is that the impact from the release of silt deposit can be reduced to negligible levels if the dam can be removed just before a high flow event of similar magnitude. Due to the engineering logistics, however, dam removal will likely start and finish during the low flow season, implying that the impact of increased suspended sediment concentration following dam removal will be limited to the period between the dam removal and the first high flow event or between dam removal and the time at which most of the sediment in the impoundment has eroded downstream, whichever is sooner.
3. Modeling results indicated that it may take up to 28 weeks (approximately 6.5 months) for most of the reservoir deposit to be eroded downstream and to reduce the suspended sediment concentration to the background levels if there are no high flow events following dam removal. The duration of impoundment erosion and high suspended sediment concentration is reduced to about 4 weeks (approximately 1 month) if high flow occurs soon after dam removal. The potential increase in average daily suspended sediment concentration during the period of impoundment deposit erosion is up to 5,000 to 20,000 mg/l, depending on water discharge in the river following dam removal. Higher discharge following dam removal generally result in reduced suspended sediment concentration and shortened period of increased suspended sediment concentration.
4. Predicted maximum channel aggradation immediately downstream of the dam is between 1.7 and 2 m (5.6 - 6.6 ft). The thickness of sediment deposition generally decreases in the downstream direction. Predicted maximum thickness of sediment deposition for Reach 3 away from the dam, for example, decreases to 1.2 – 1.5 m (4 – 5 ft), then to approximately

1 m (3.3 ft) in Reach 4, 0.7 – 0.9 m (2.3 – 3 ft) in Reach 5, and 0.6 – 0.9 m (2 – 3 ft) in Reach 6. The channel recovers to the pre-dam-removal condition within 6 years following dam removal.

5. Predicted duration of sediment deposition for Reach 3 (18 weeks to 3 years) and Reach 4 (1 to 5 years) is strongly influenced by water discharge. Predicted duration of sediment deposition for Reaches 5 and 6 is approximately 6 years under the hydrologic conditions simulated. It should be noted, however, the persistent sediment deposition in a reach does not mean the bed will be ubiquitously covered with sand deposit (Downs et al. 2009). Instead, a deep base-flow channel will likely persist, while the deposition will primarily be in the form of expanded sand bars (including formation of new bars), primarily in the area above the low water marks. Sand deposition will also partially fill deep pools, if any, reducing the size and depth of the pool habitats.

Because of the relatively small amount of silt to be released following dam removal (equivalent to one day of suspended sediment load during an 8-year recurrence flow event), dam removal is unlikely to have a significant impact on the Chesapeake Bay ecosystem. Channel aggradation downstream of Bloede Dam following dam removal will result in elevated water surface elevations during flood flows. The increase in water surface elevations, however, should be substantially smaller than the predicted amount of channel aggradation as demonstrated in other similar studies (i.e., most likely by a few inches instead of a few feet during high flow events) (e.g., Stillwater Sciences 2013). If there are low lying high value properties in an impacted reach that is of concern for increased flooding risks, new HEC-RAS modeling can be conducted easily using the existing Patapsco River HEC-RAS model in combination with the channel aggradation predicted by the DREAM-1 model presented in this memorandum.

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Appendix A: Modeling Results for Runs 1A, 1D, 1W, 2Af, 2D, 3A, 3D, and 3W

Results for these runs are presented below without further discussions. Results for **Runs 1A**, **1D**, **2Af**, **3A**, and **3D** are similar to that of **Run 2A** discussed earlier; and results for **Runs 1W** and **3W** are similar to that of **Run 2W** discussed earlier. Please refer to **Runs 2A** and **2W** figures and discussions presented earlier in this memorandum for implications of the following results.

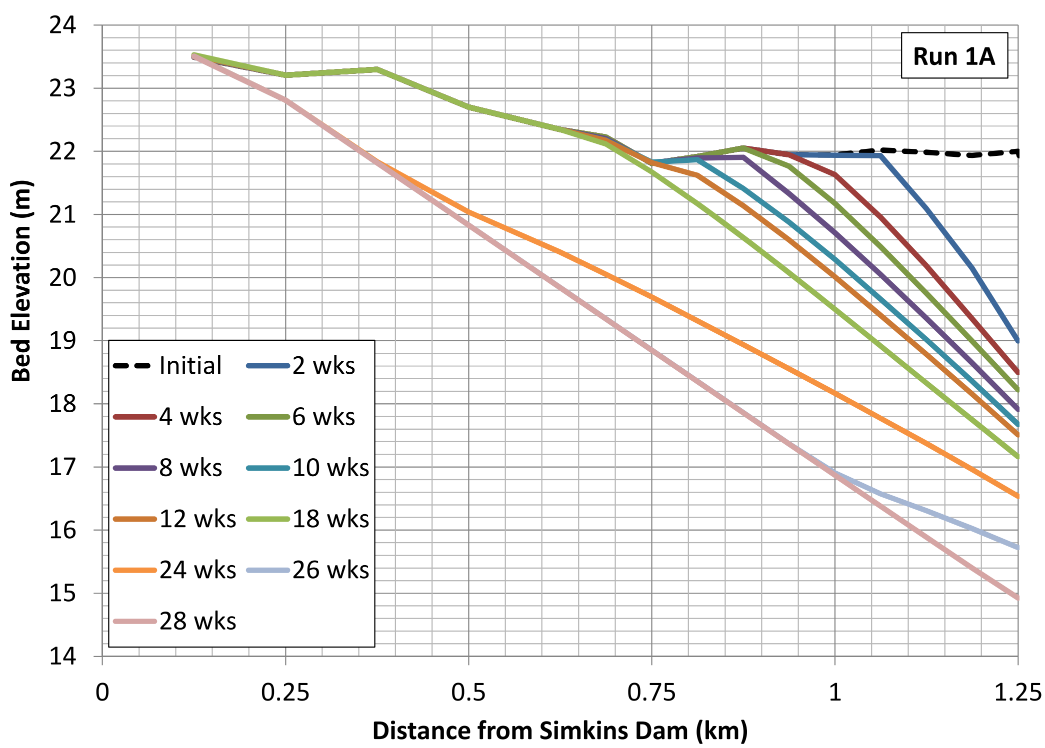

Figure 20. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 1A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

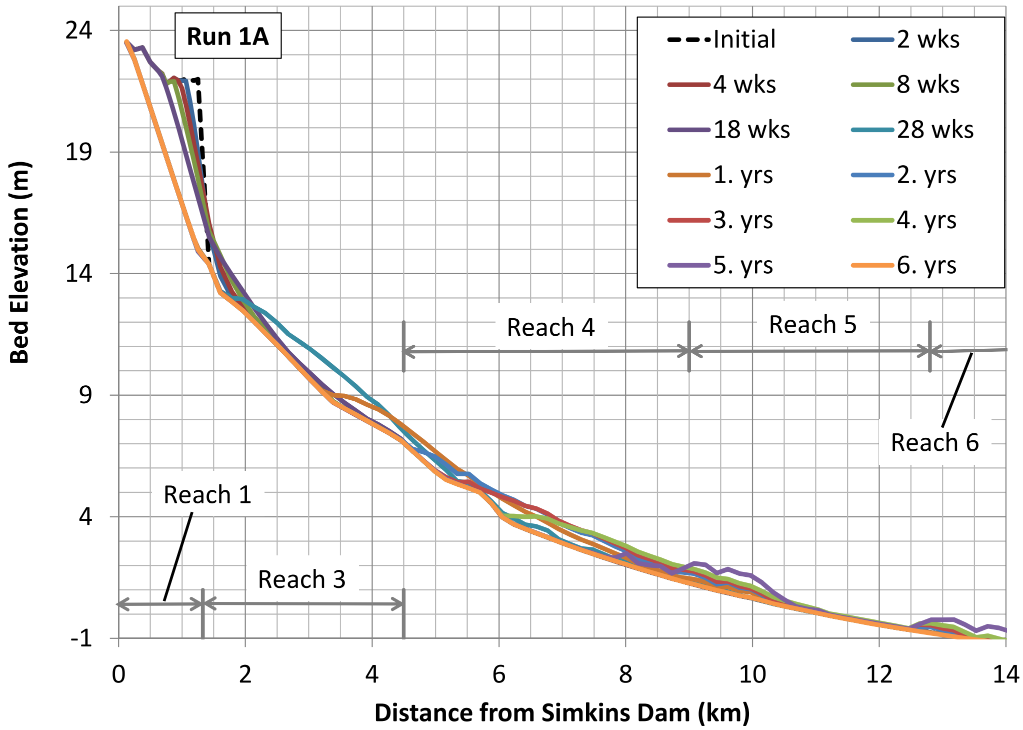

Figure 21. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 1A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

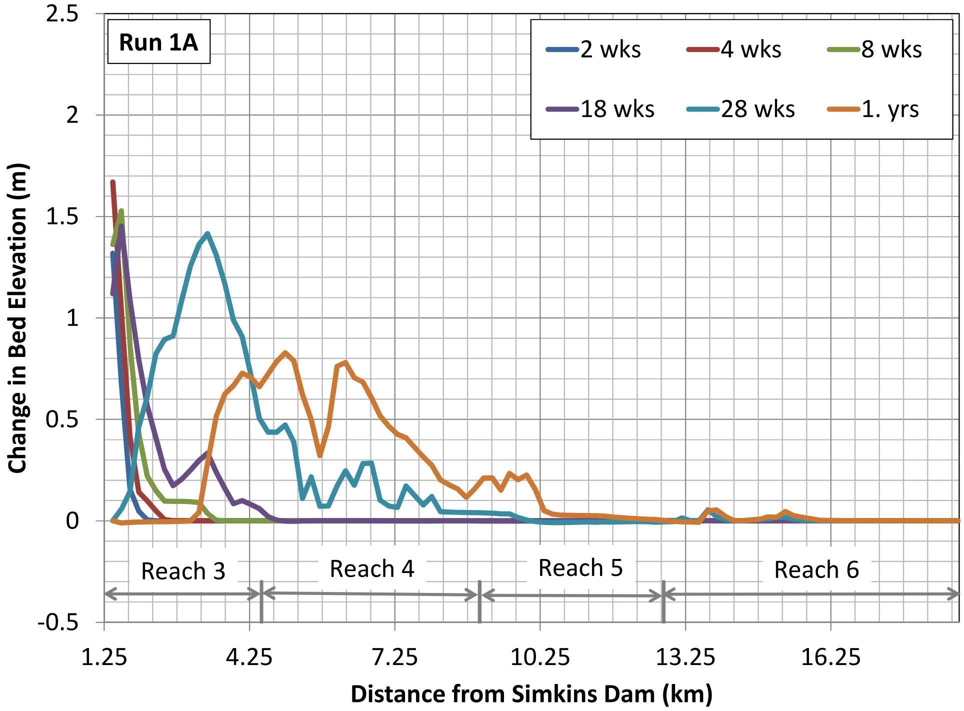

Figure 22. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 1A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

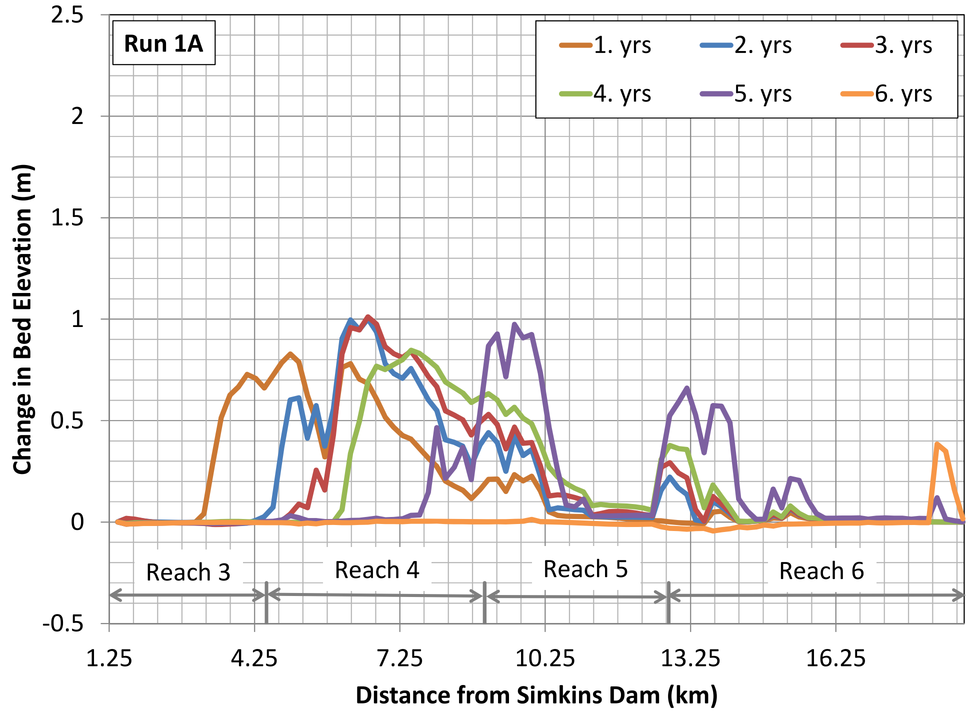

Figure 23. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 1A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

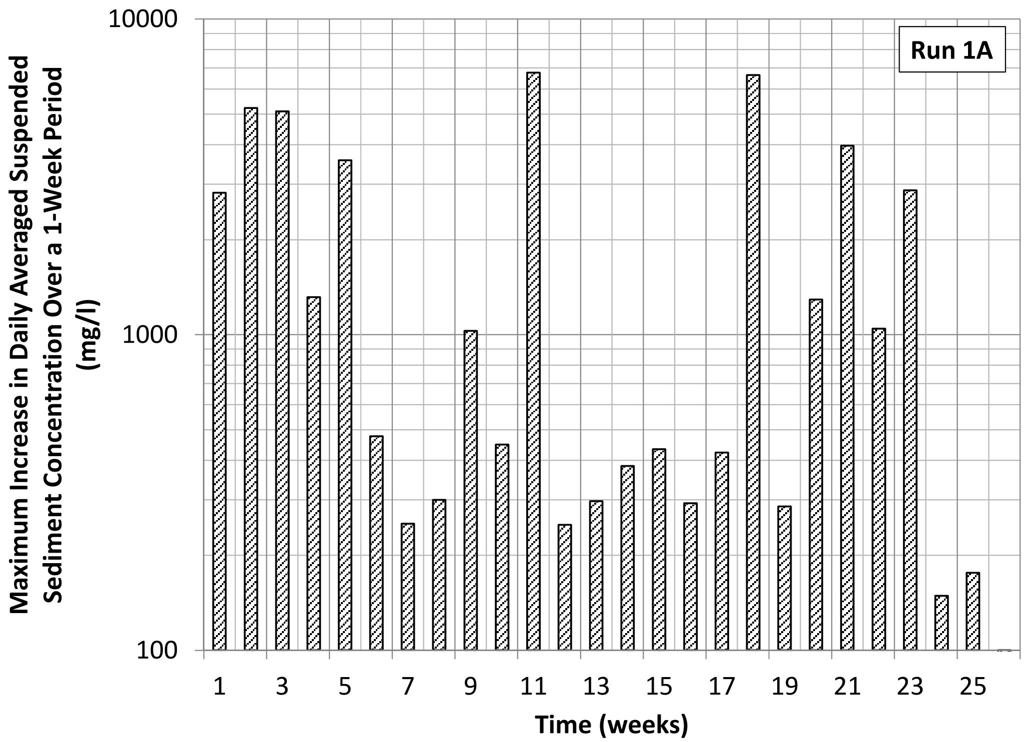

Figure 24. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 1A**.

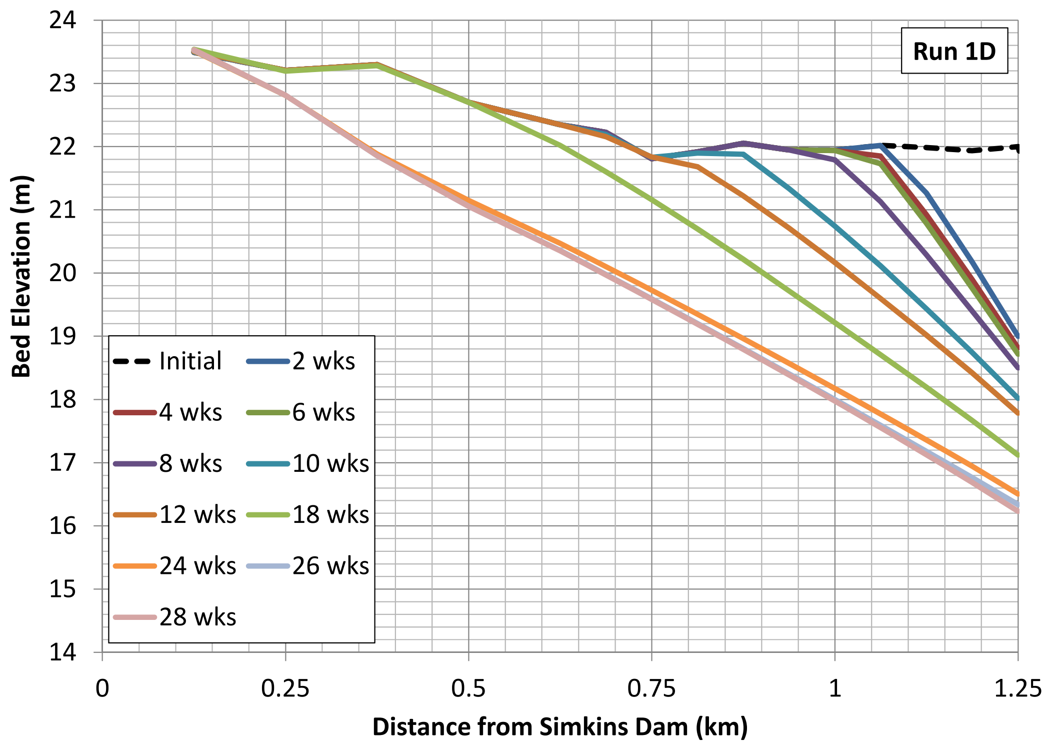

Figure 25. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 1D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

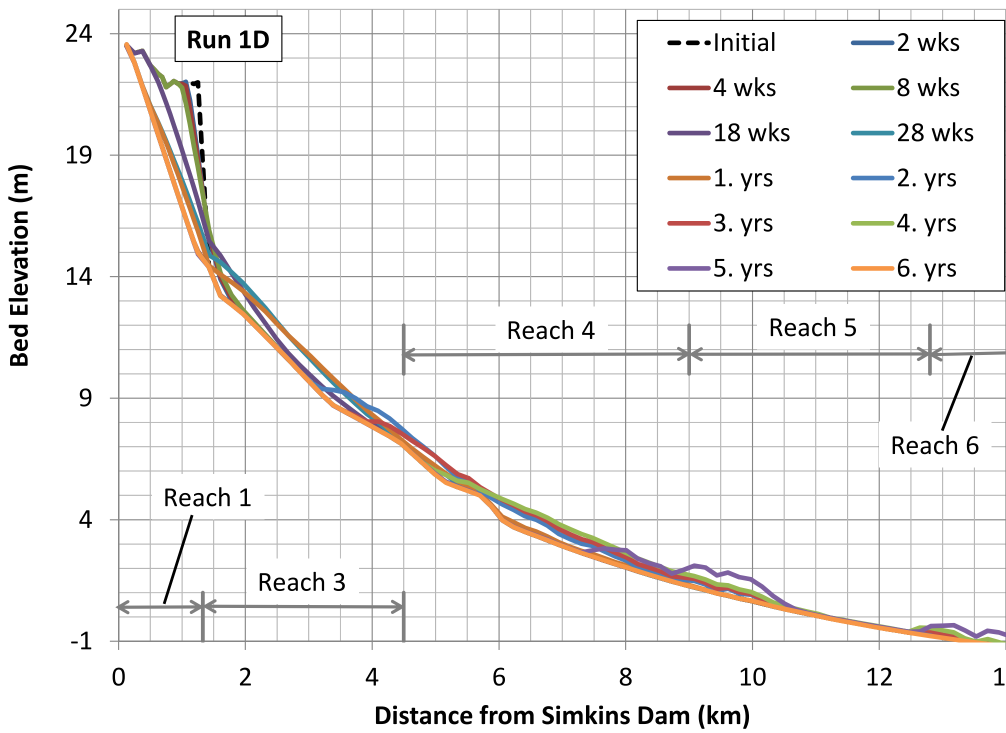

Figure 26. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 1D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

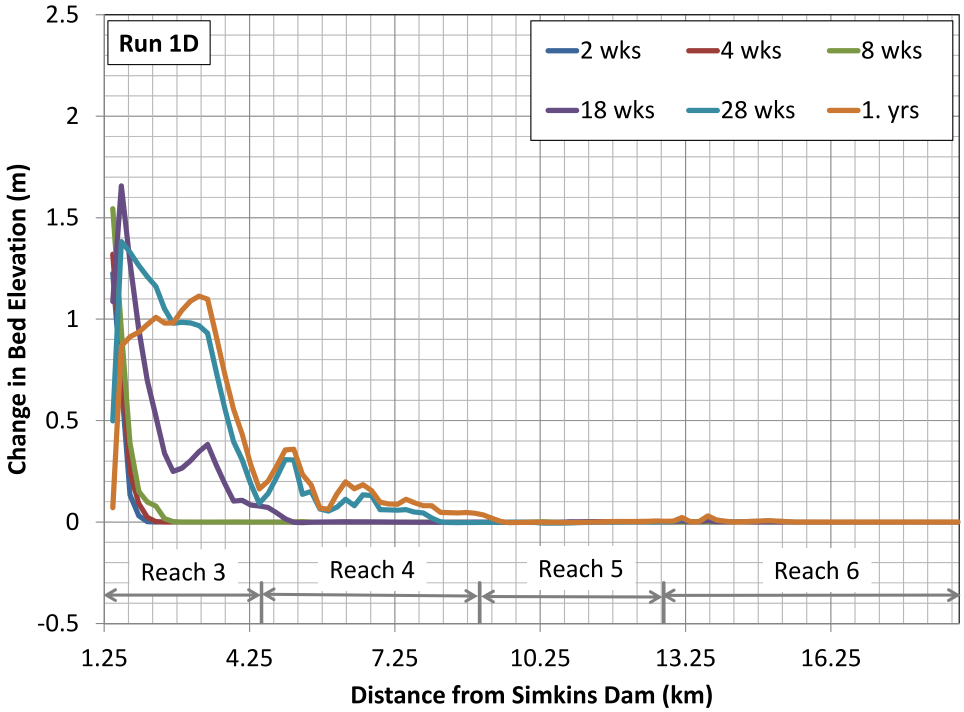

Figure 27. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 1D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

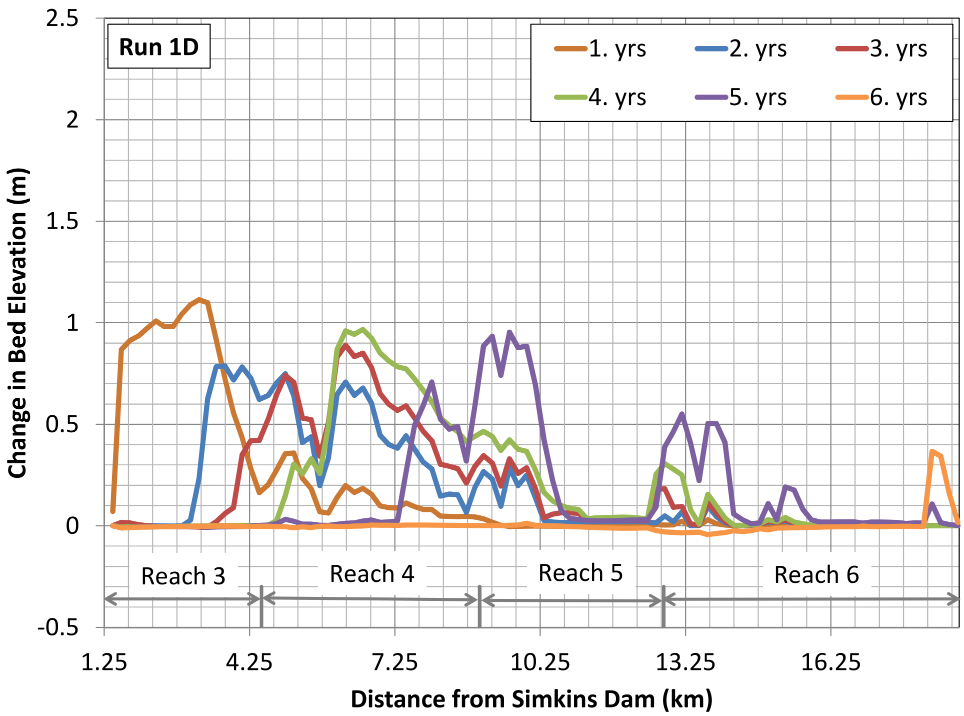

Figure 28. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 1D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

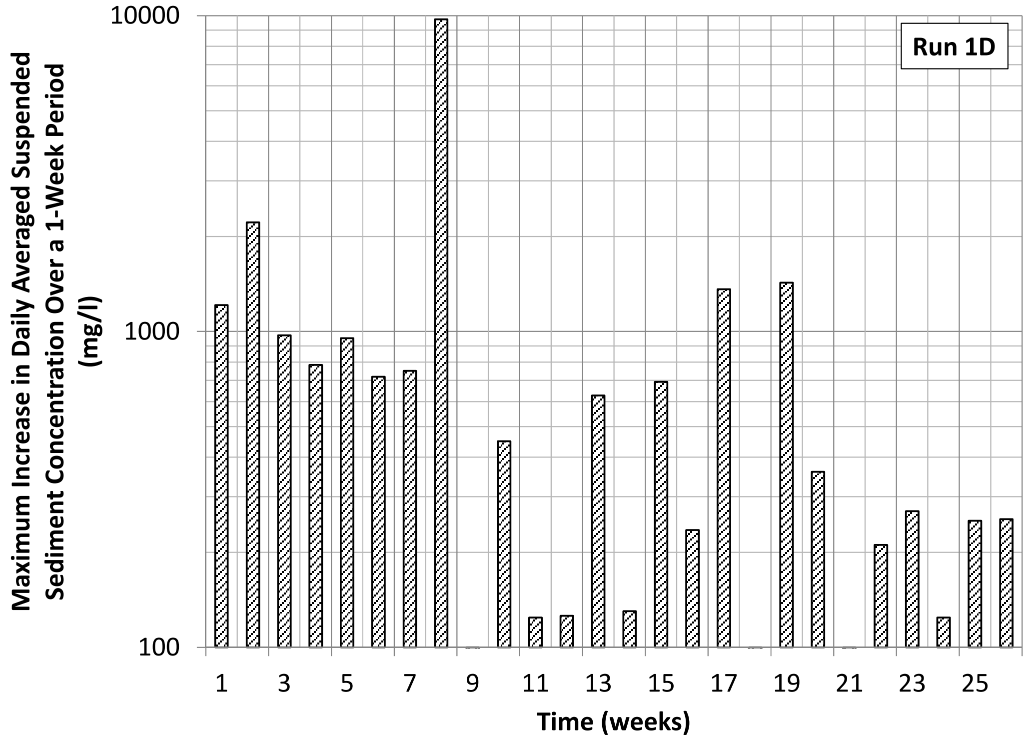

Figure 29. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 1D**.

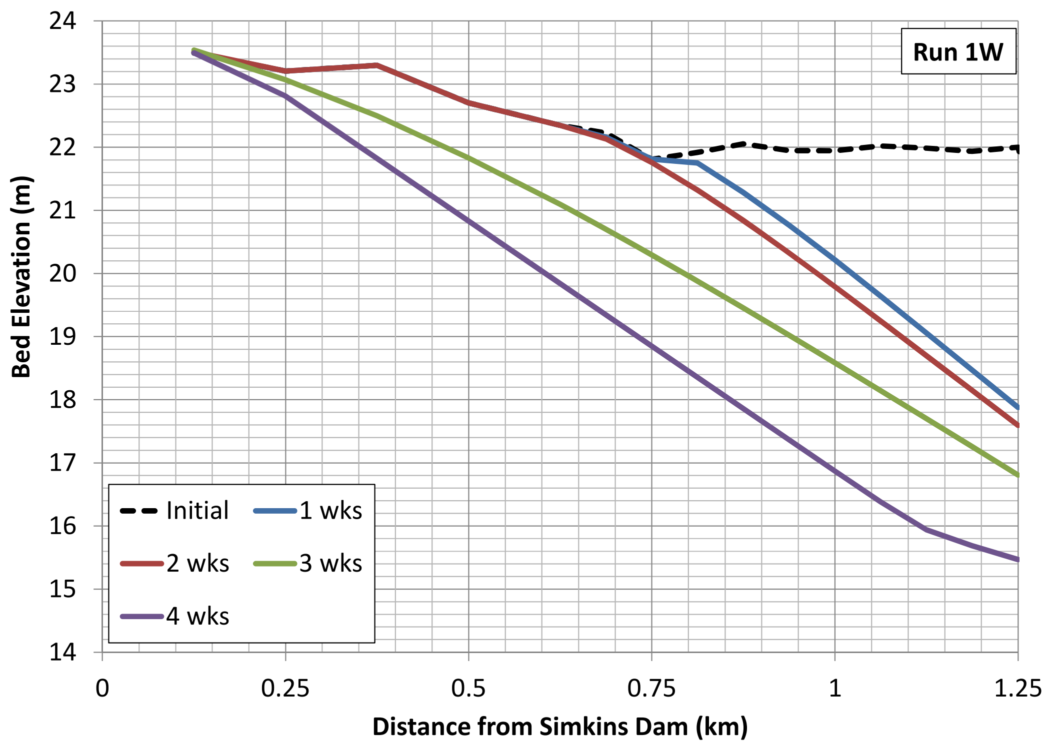

Figure 30. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 1W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

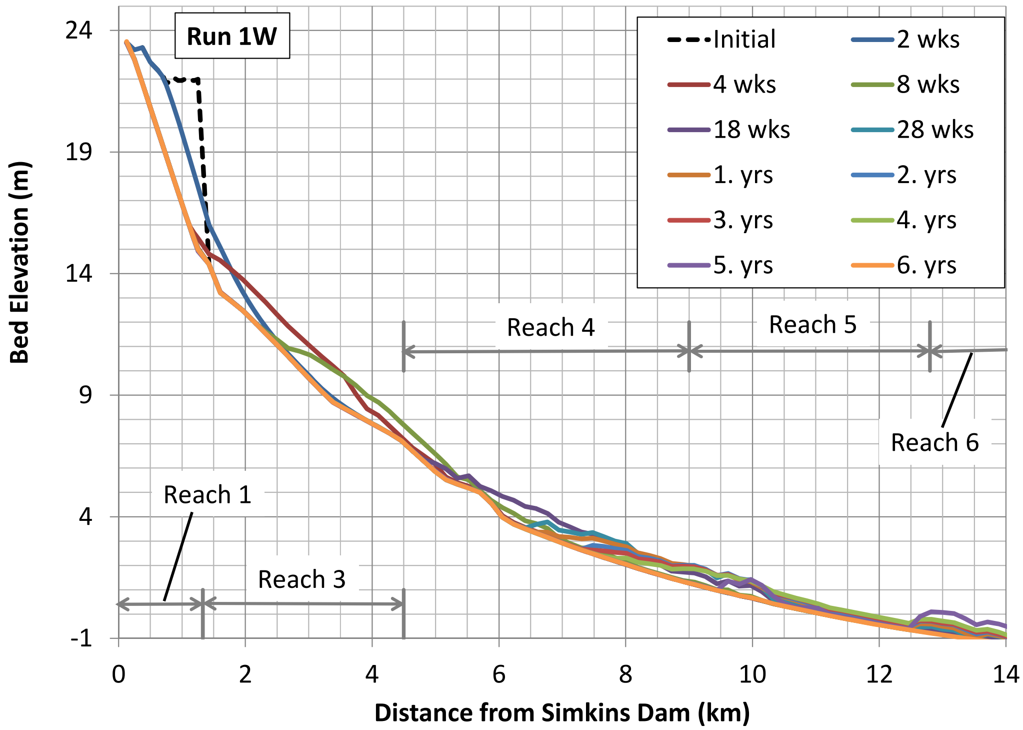

Figure 31. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 1W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

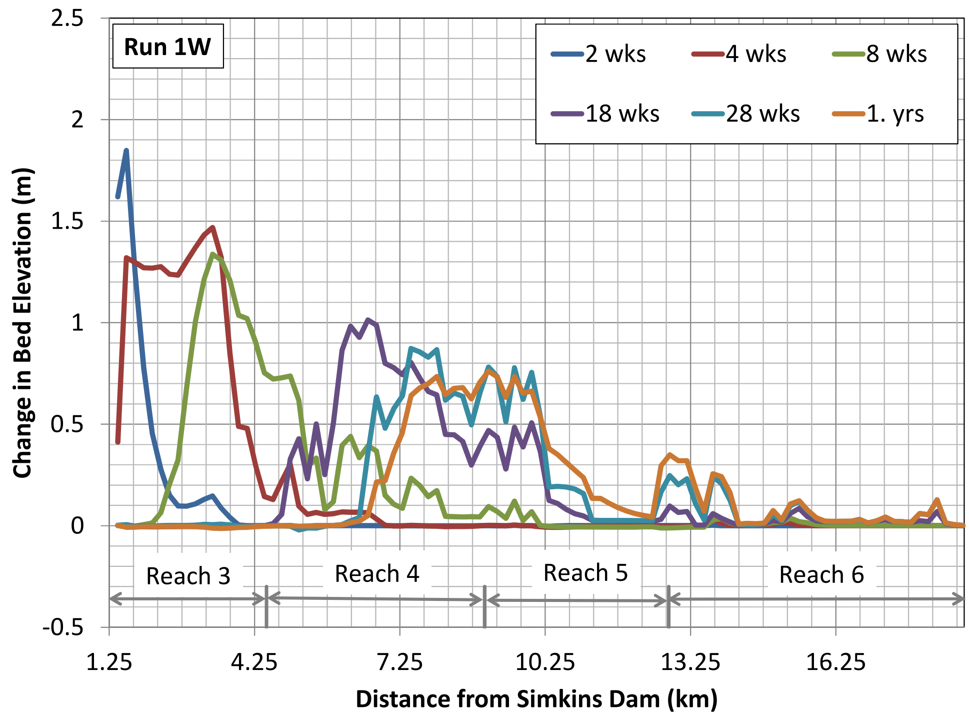

Figure 32. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 1W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

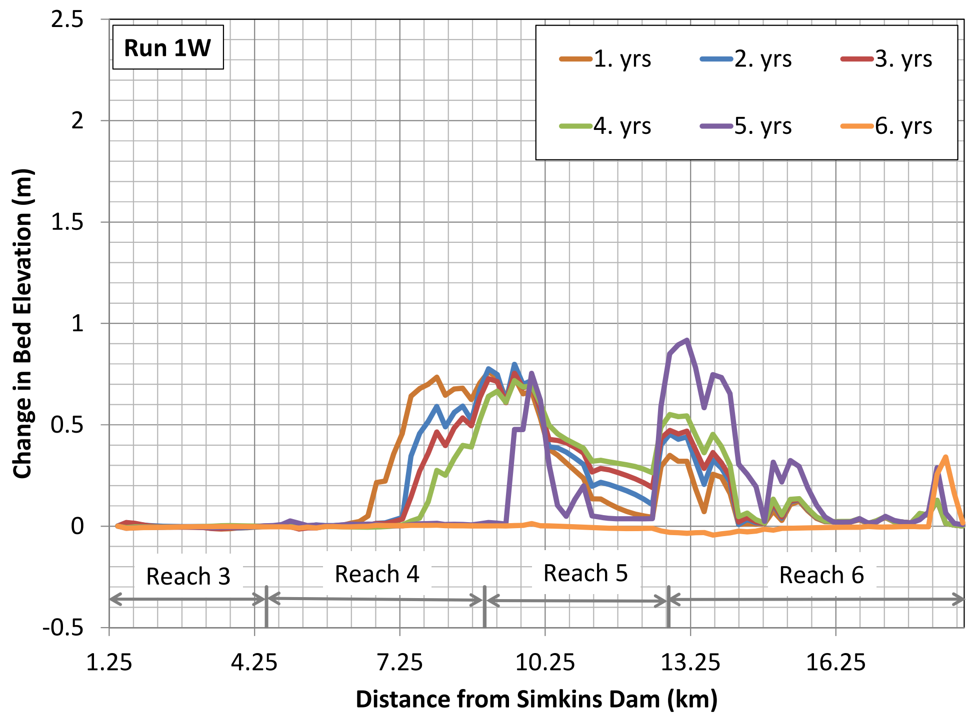

Figure 33. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 1W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

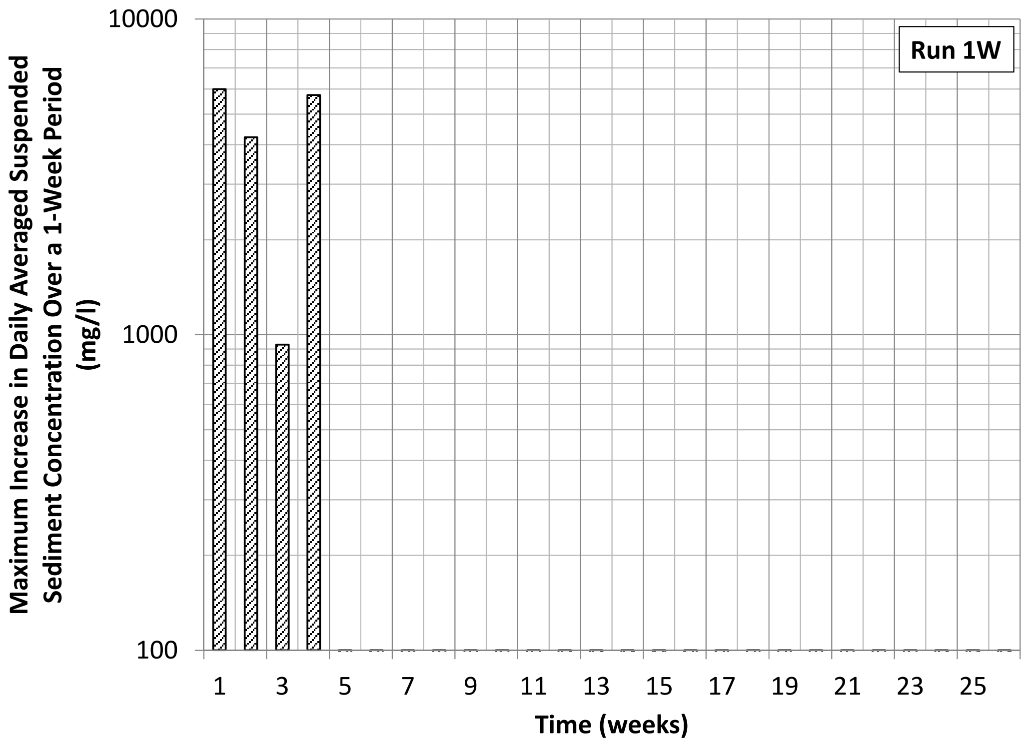

Figure 34. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 1W**.

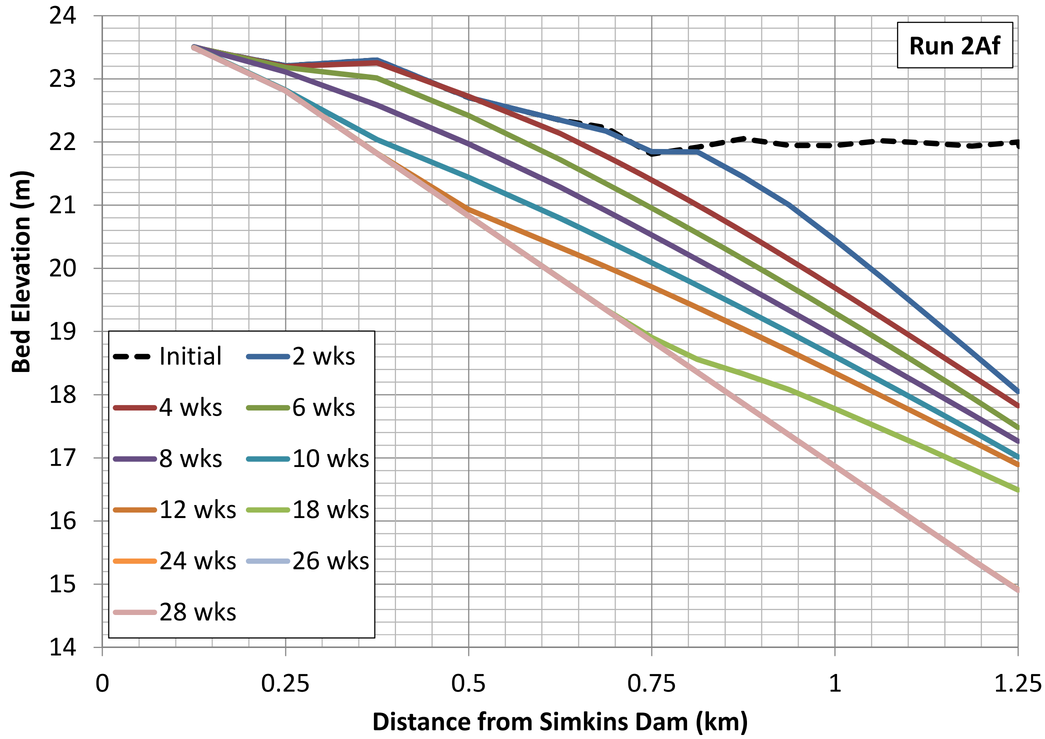

Figure 35. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 2Af**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

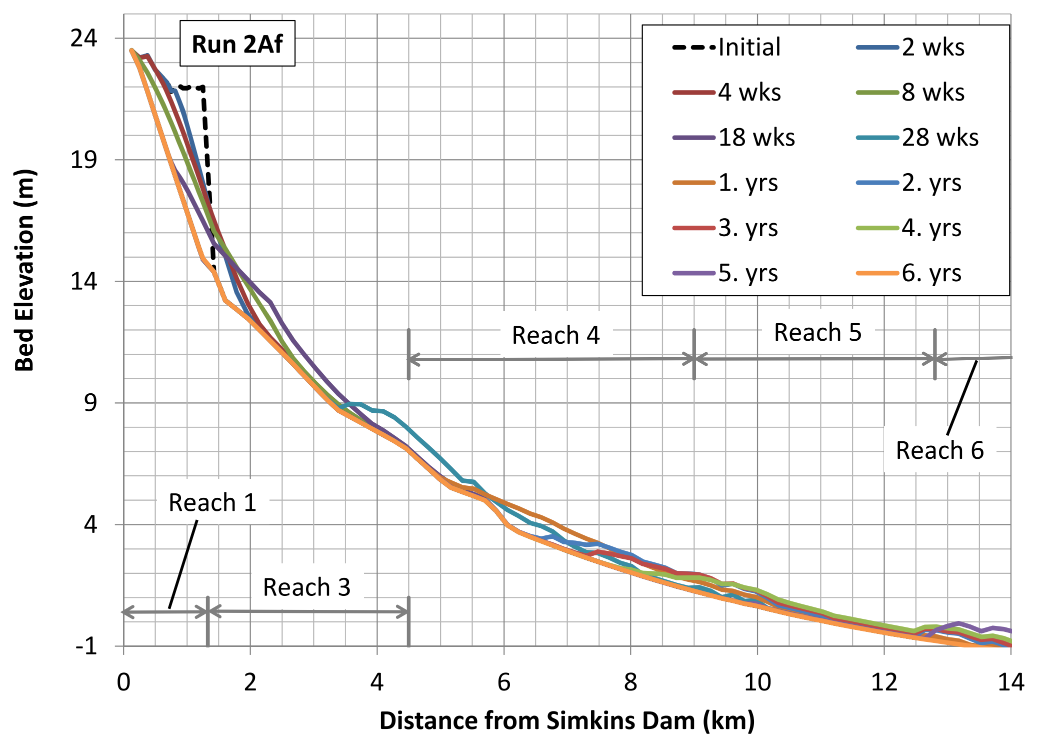

Figure 36. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 2Af**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

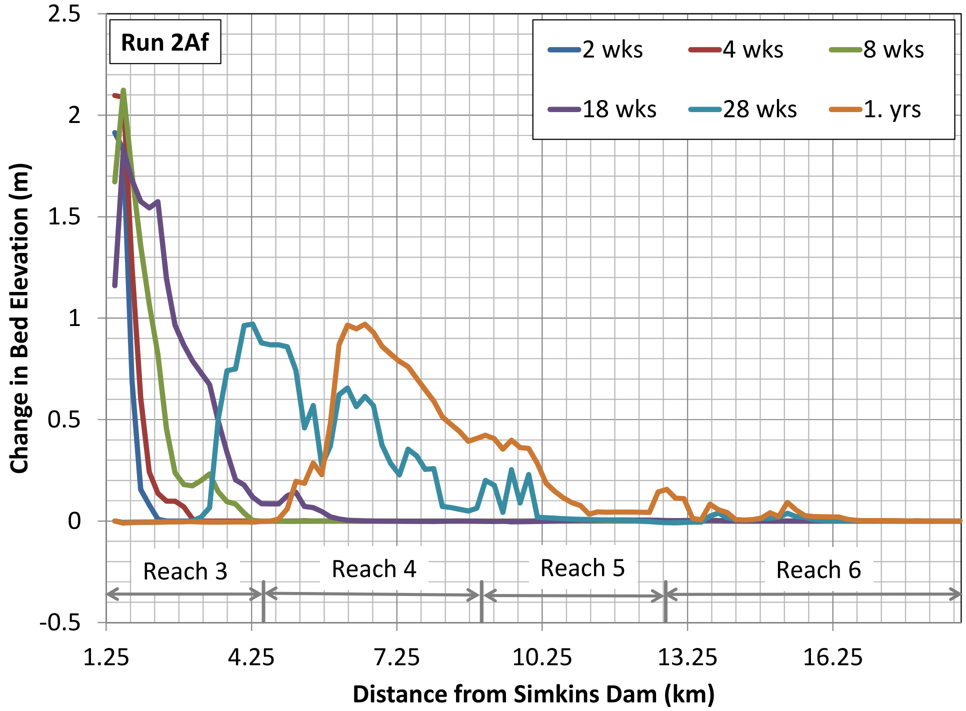

Figure 37. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 2Af**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

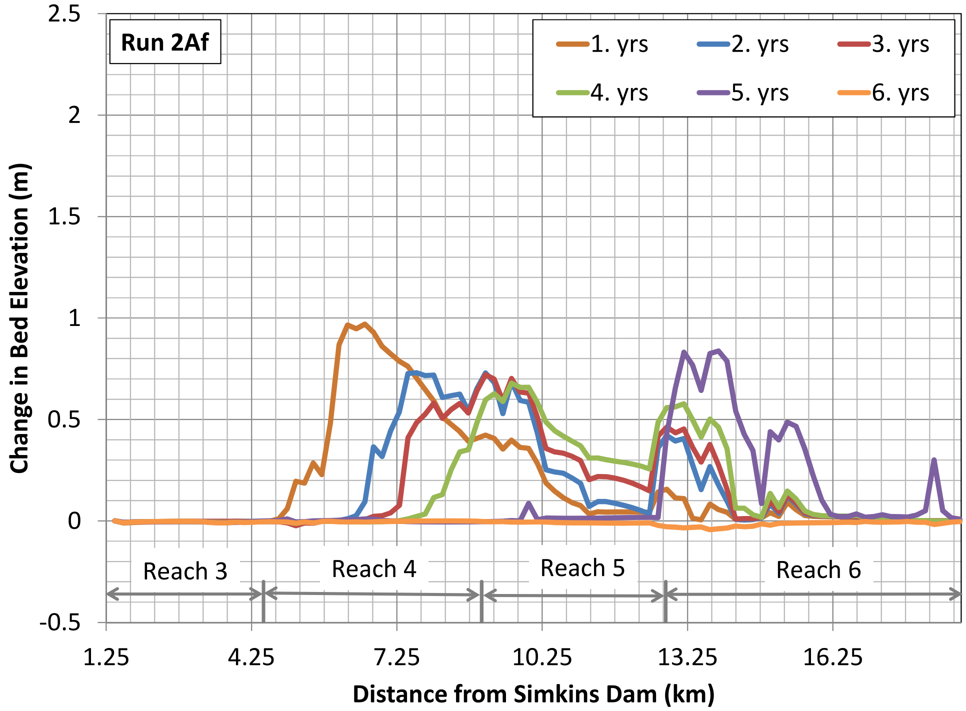

Figure 38. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 2Af**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

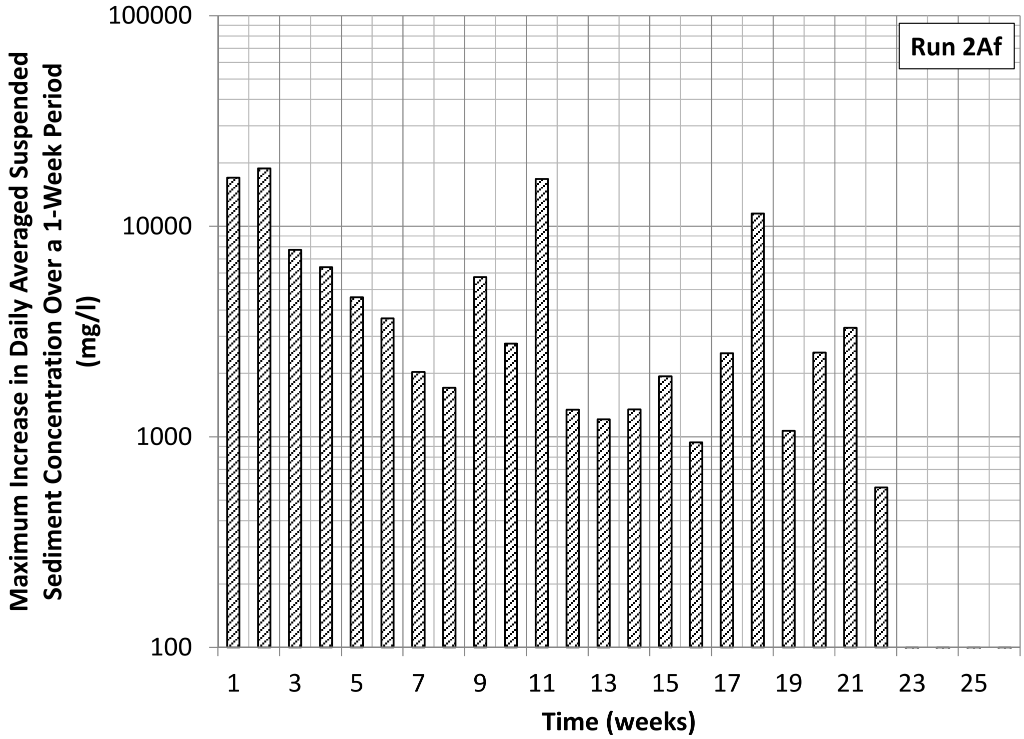

Figure 39. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 1W**.

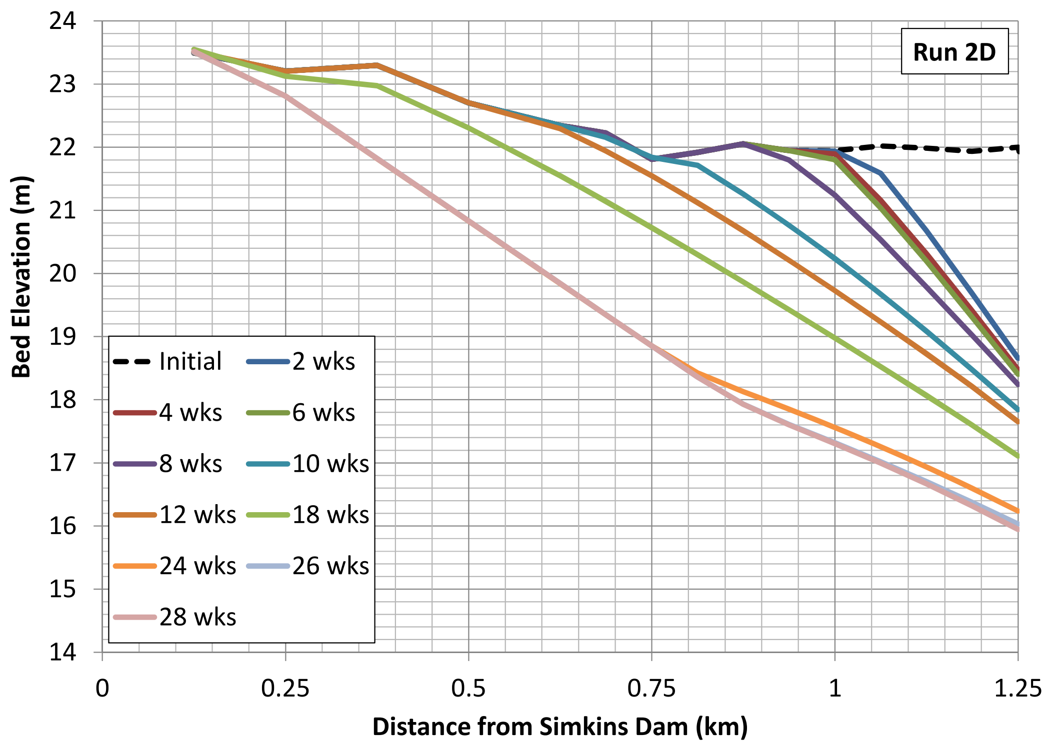

Figure 40. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 2D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

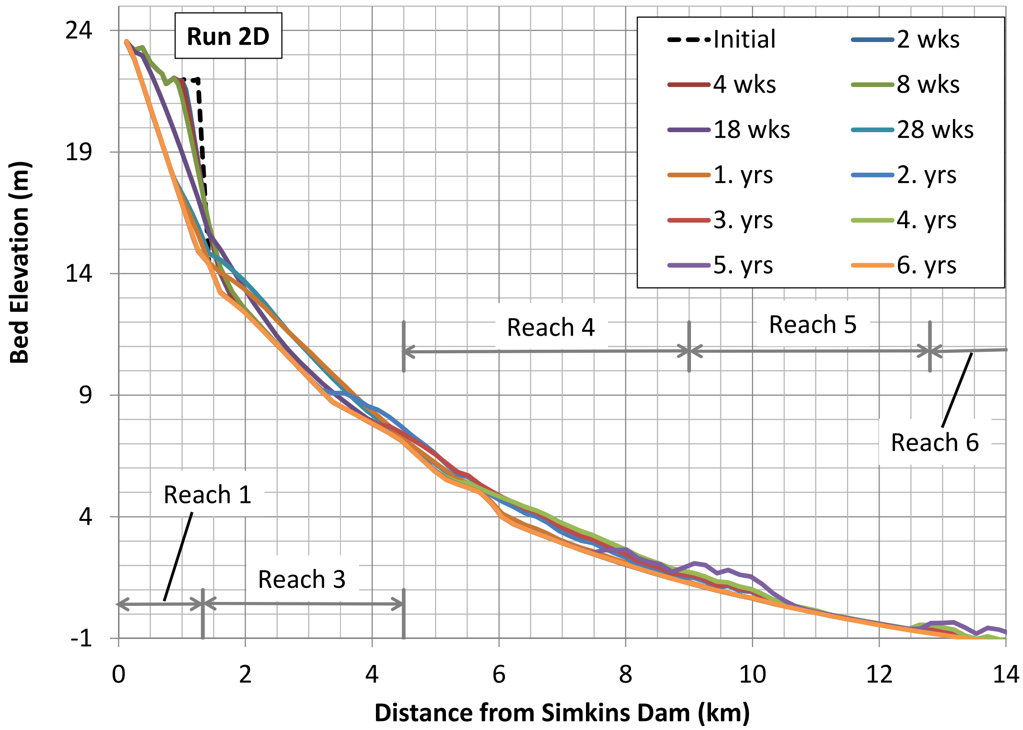

Figure 41. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 2D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

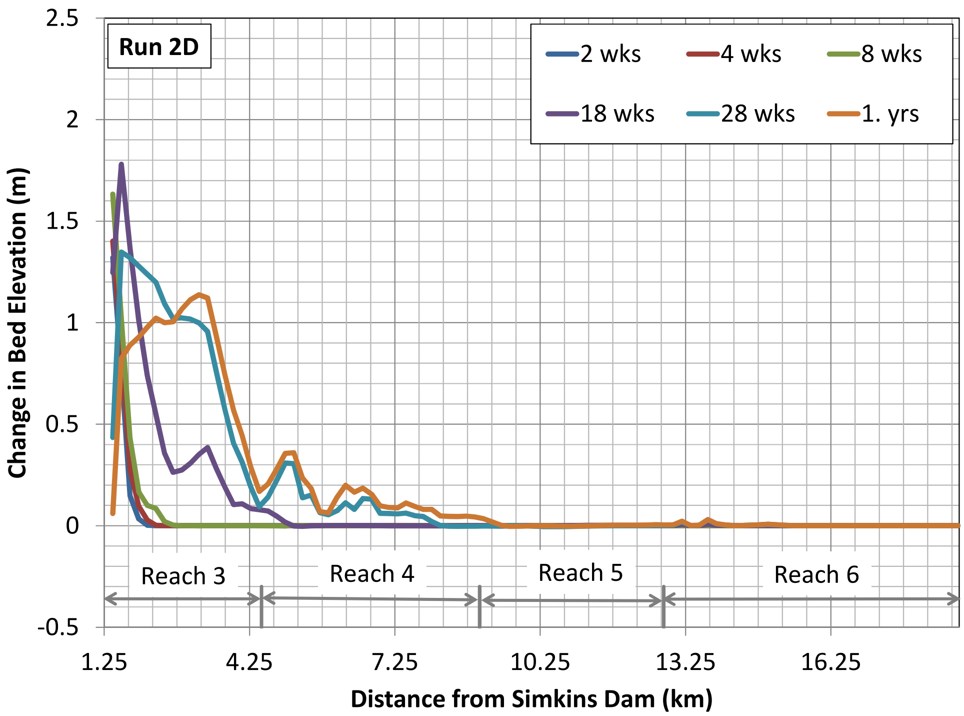

Figure 42. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 2D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

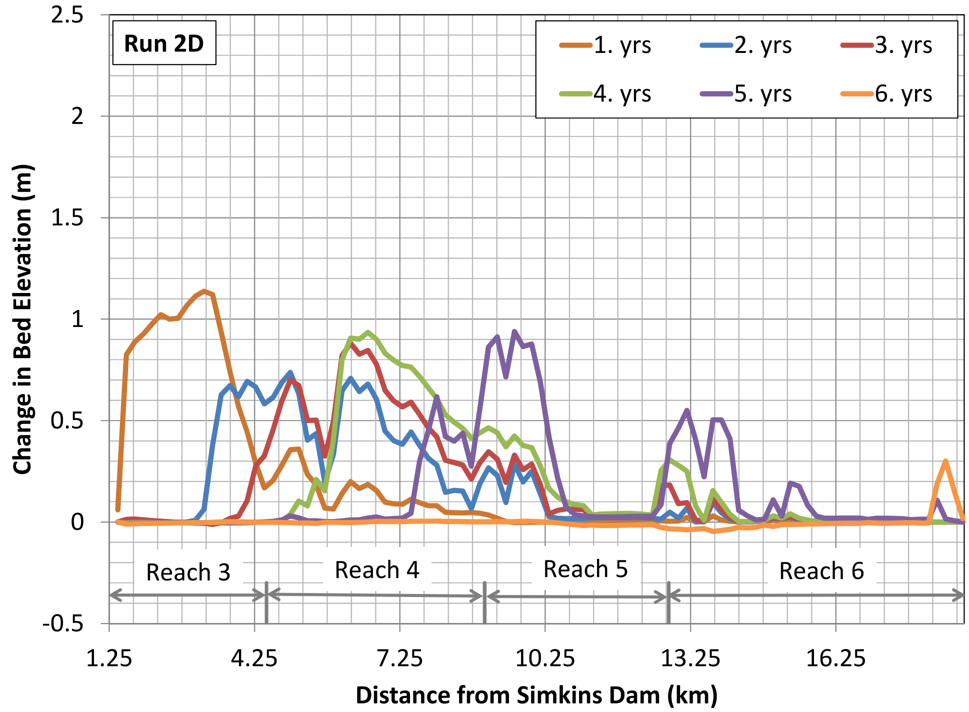

Figure 43. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 2D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

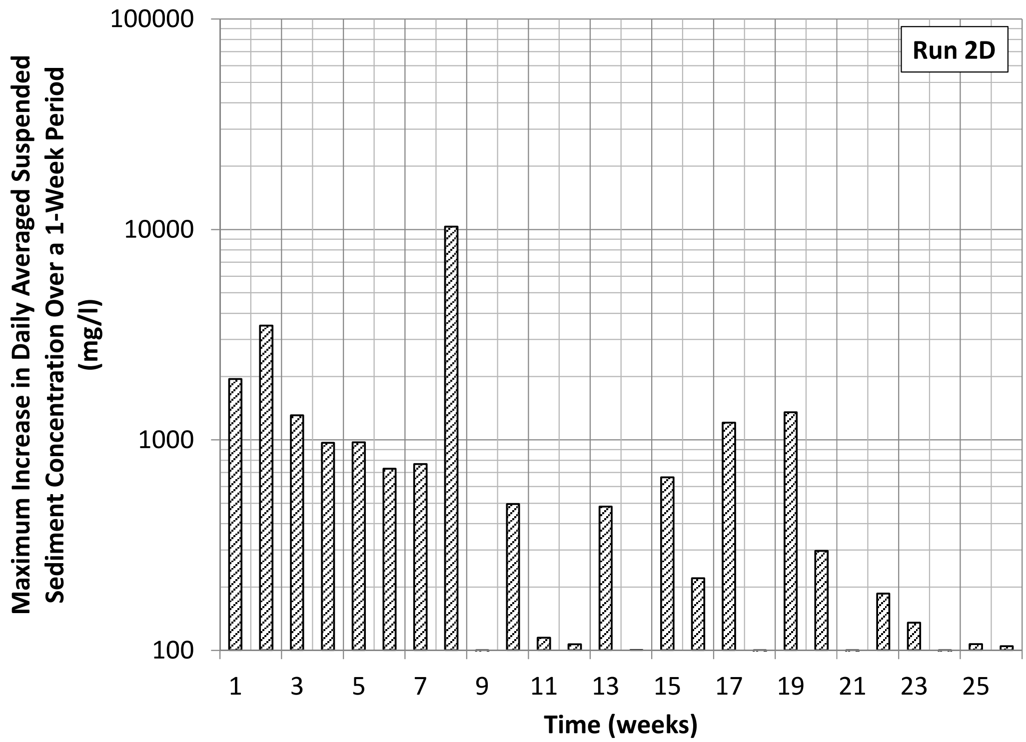

Figure 44. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 2D**.

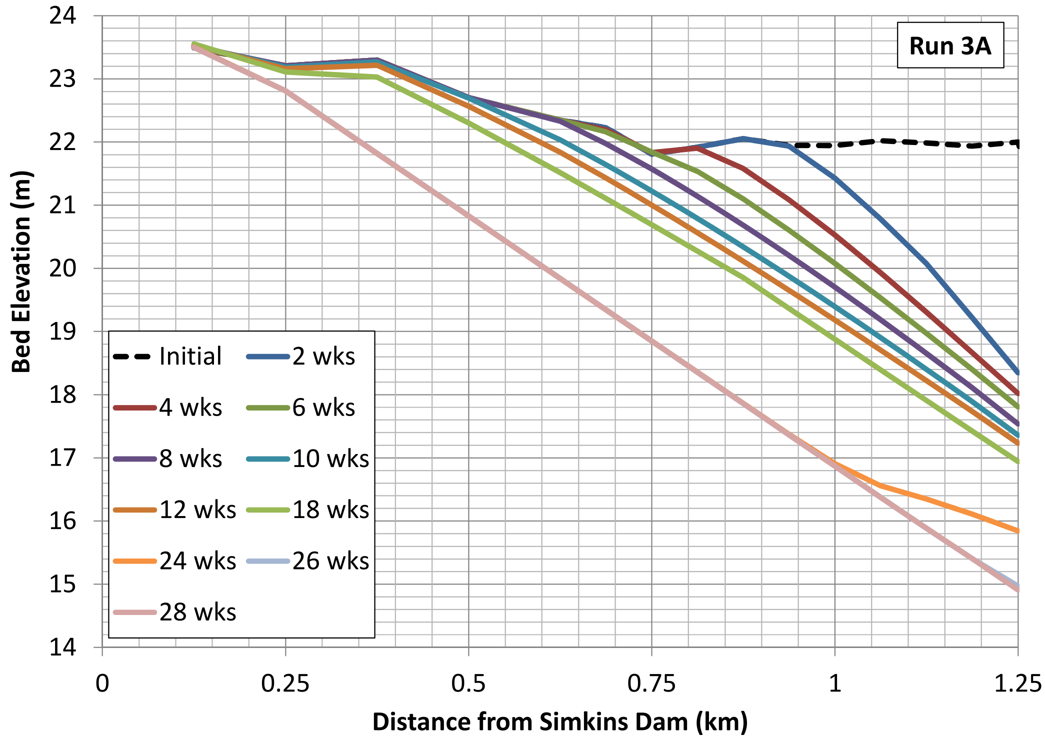

Figure 45. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 3A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

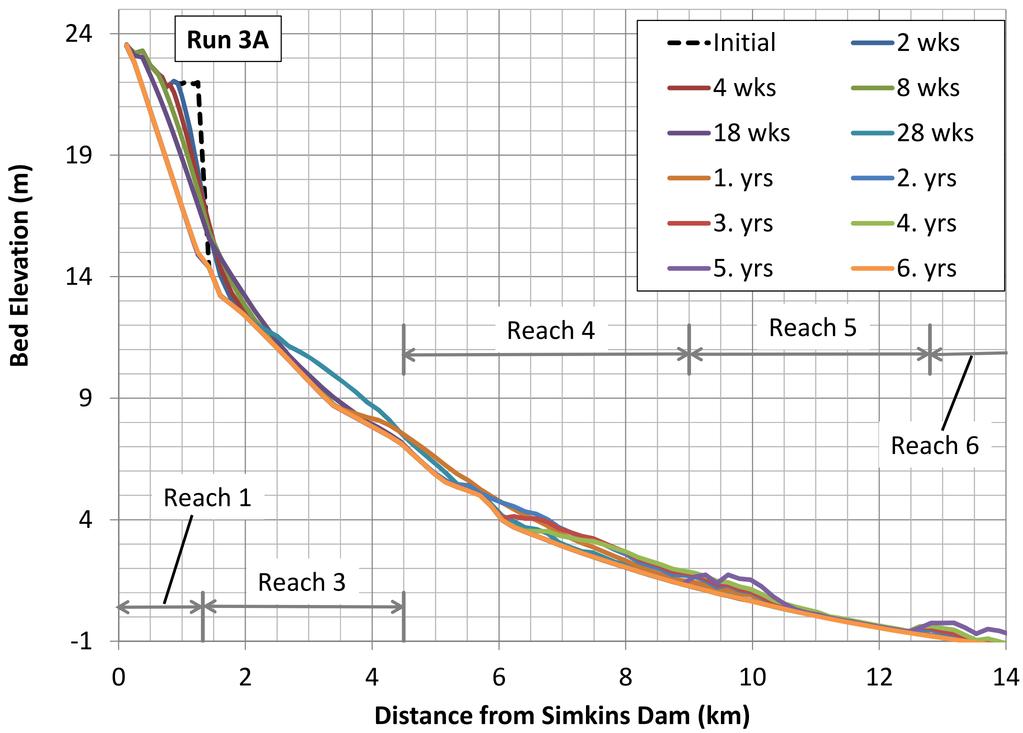

Figure 46. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 3A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

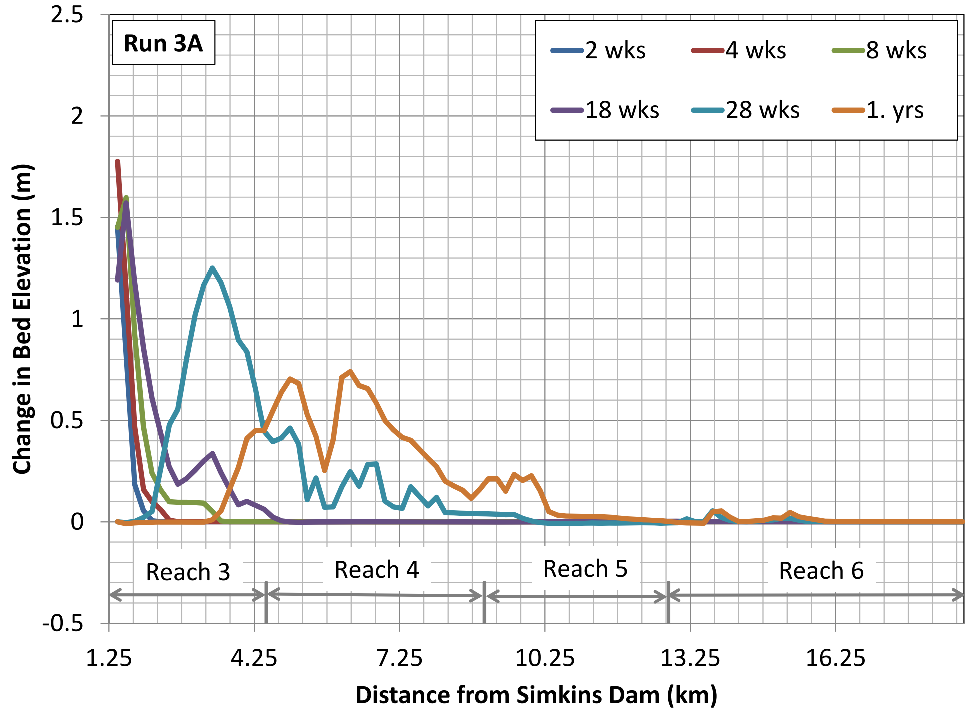

Figure 47. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 3A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

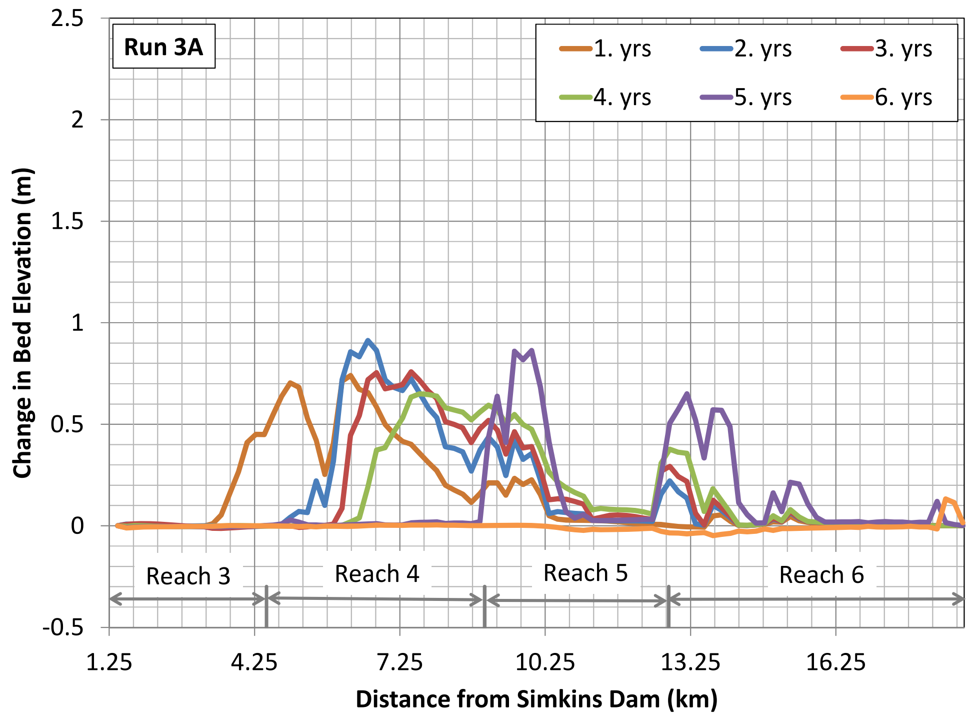

Figure 48. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 3A**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

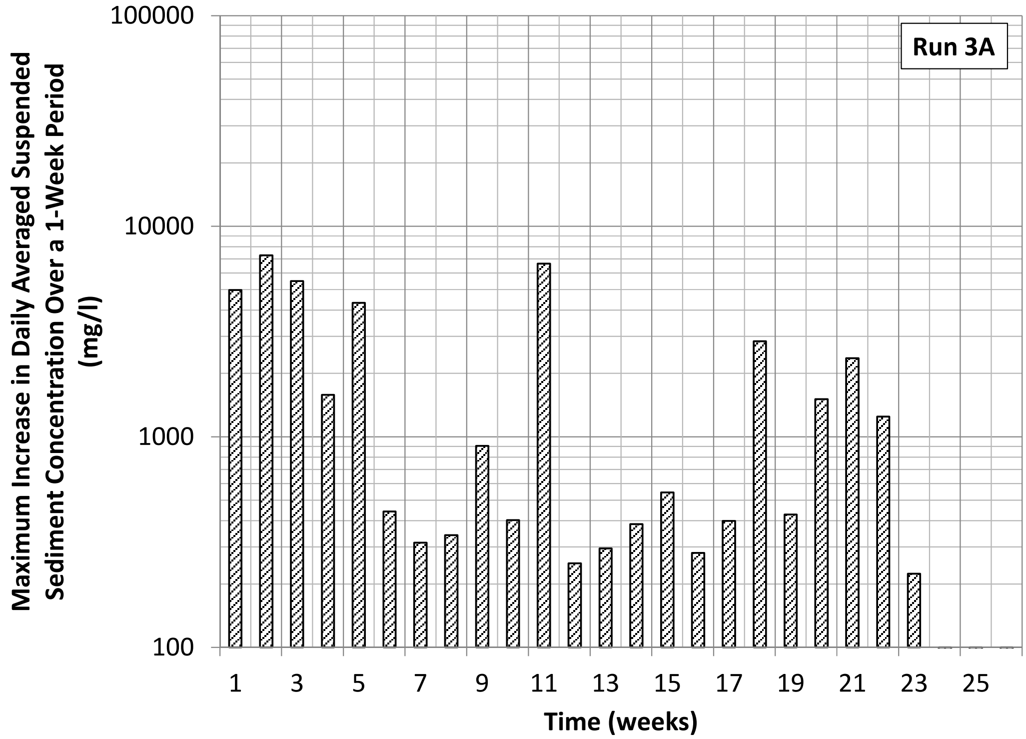

Figure 49. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 3A**.

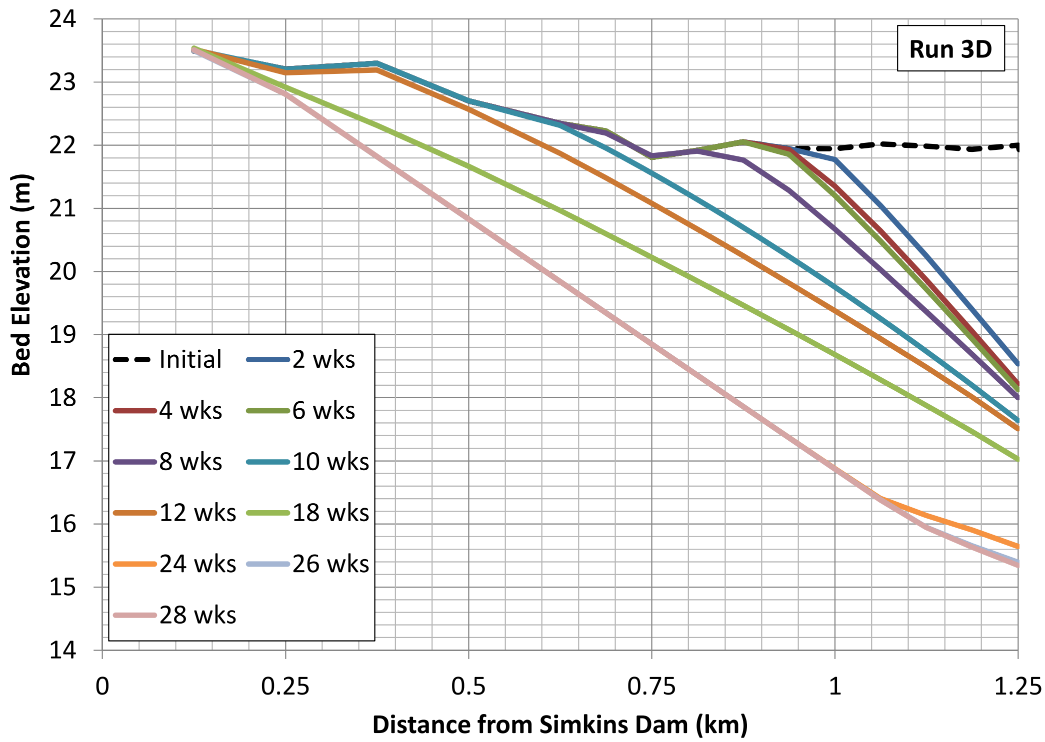

Figure 50. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 3D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

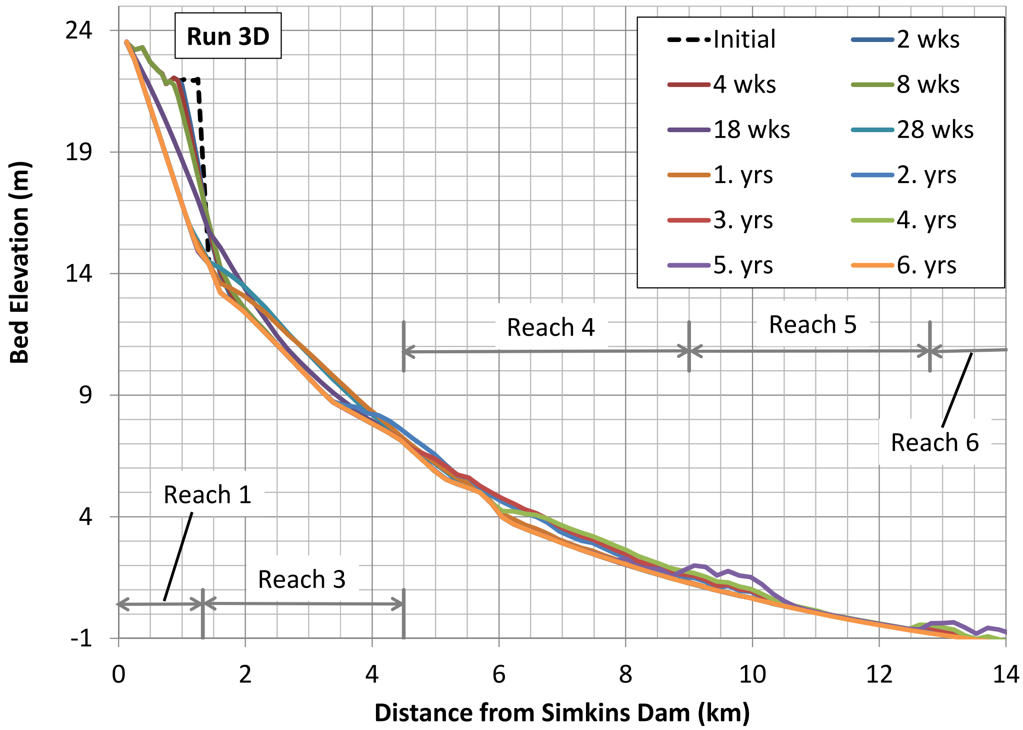

Figure 51. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 3D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

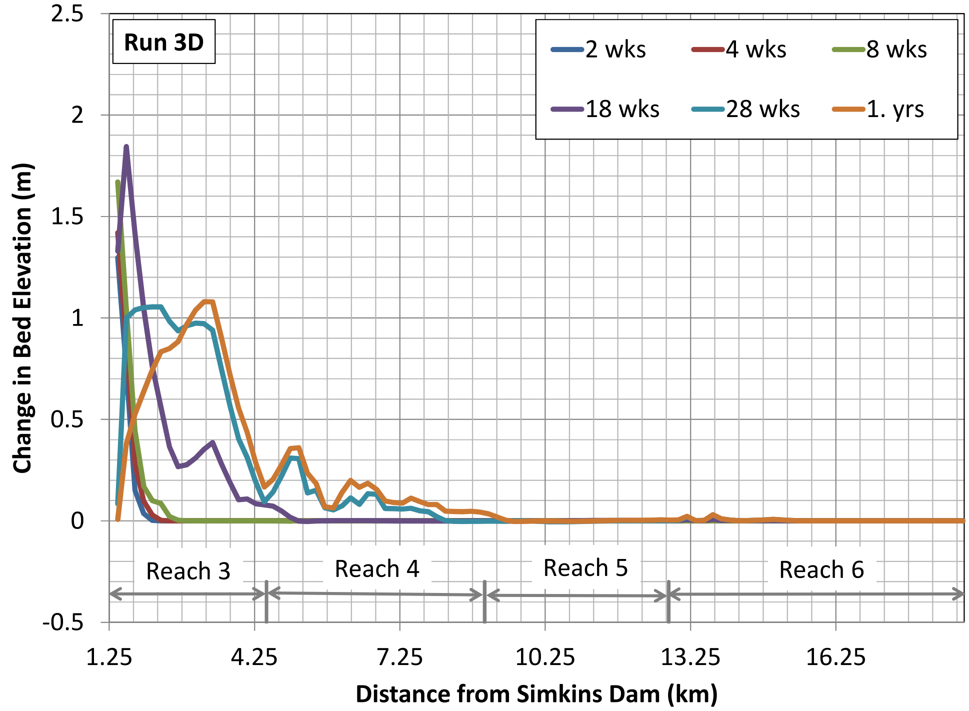

Figure 52. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 3D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

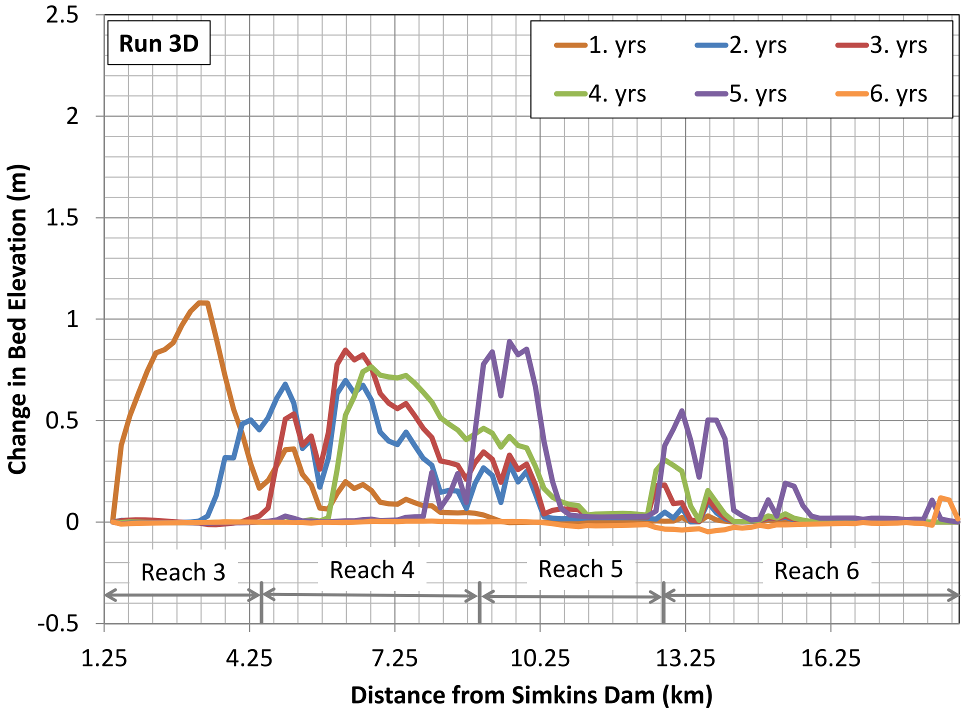

Figure 53. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 3D**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

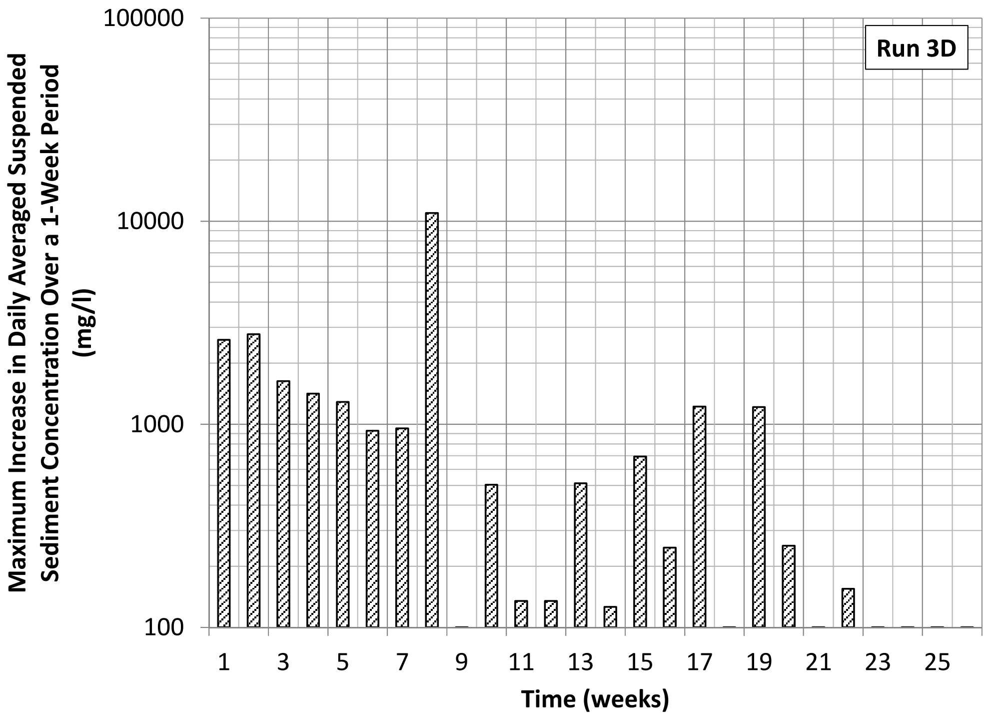

Figure 54. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 3D**.

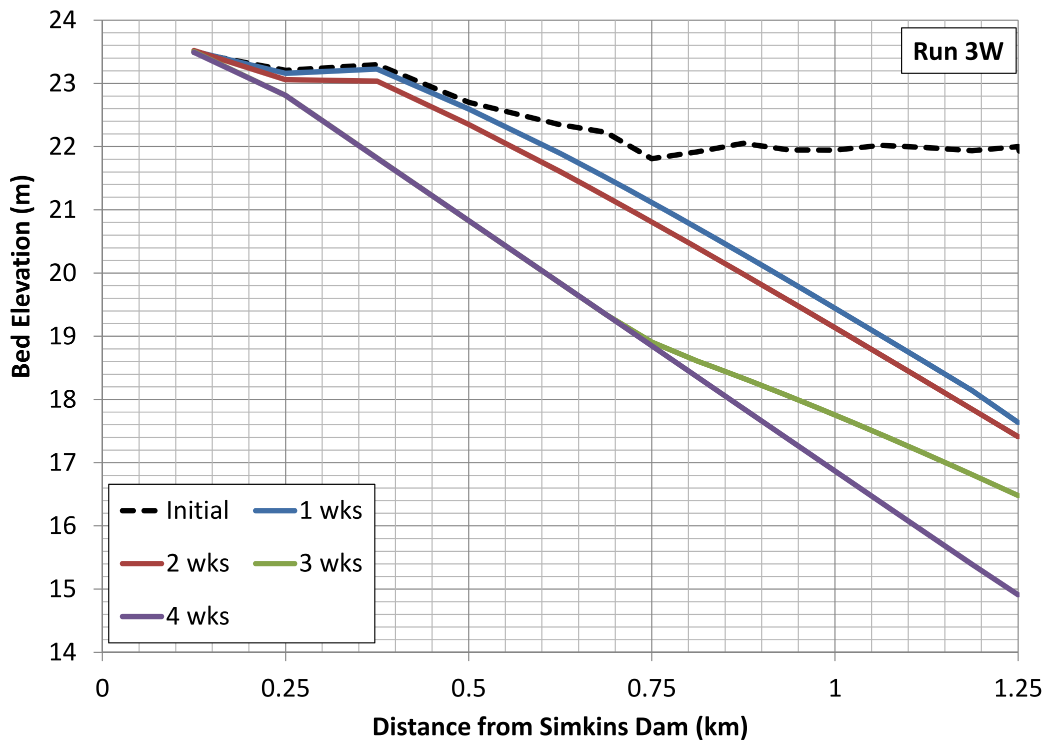

Figure 55. Simulated bed profile in Bloede Dam impoundment following dam removal for **Run 3W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

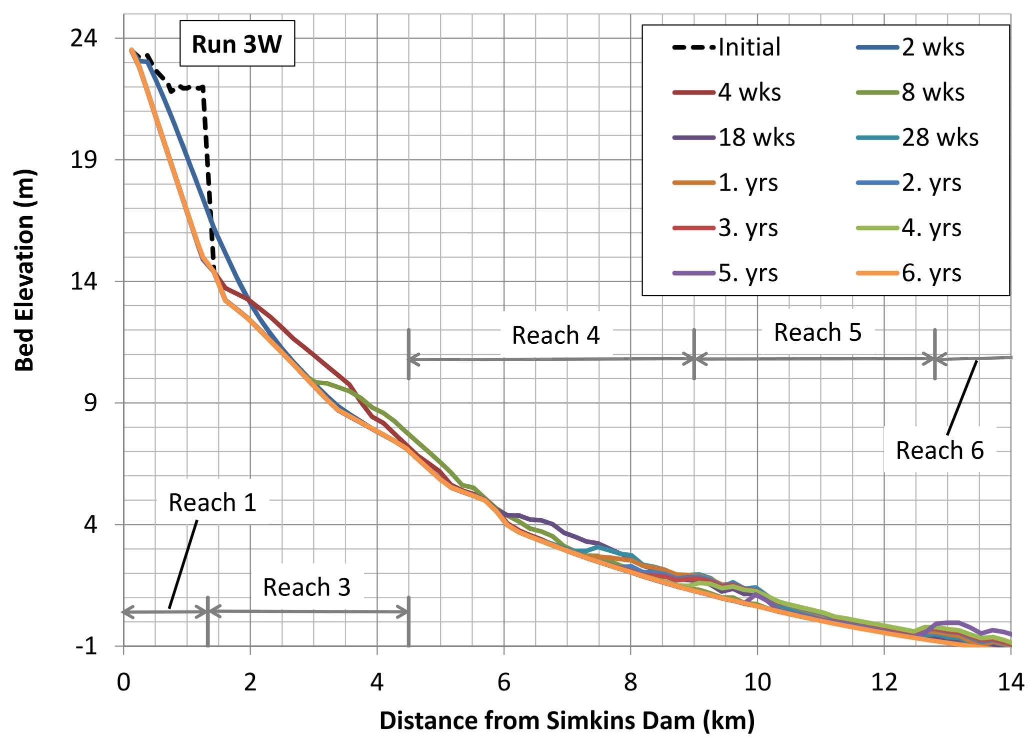

Figure 56. Simulated bed profile in the Patapsco River following Bloede Dam removal for **Run 3W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

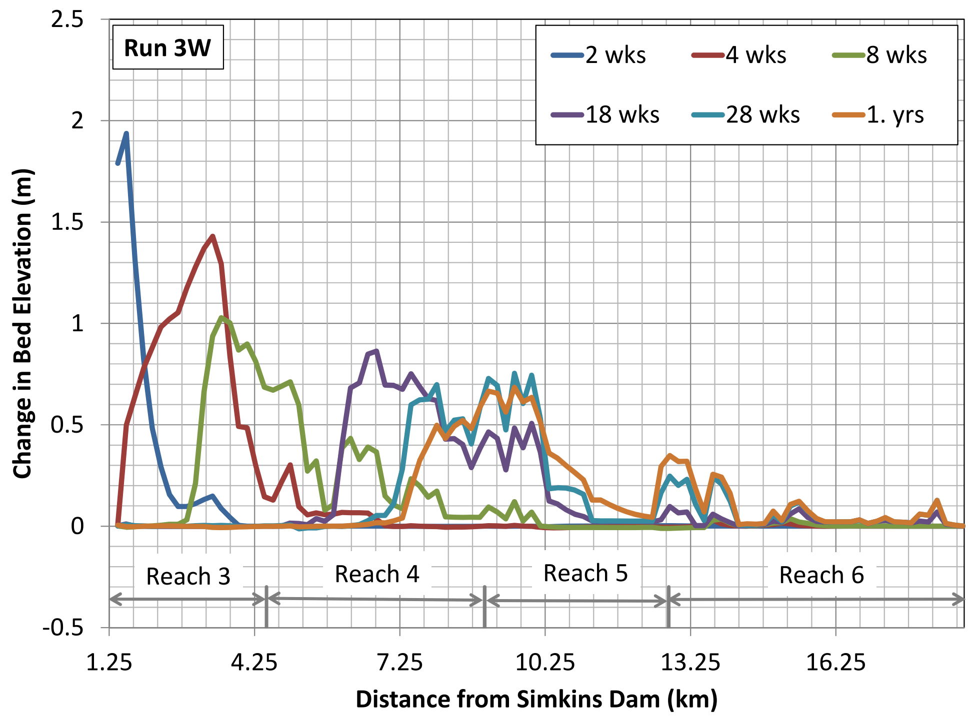

Figure 57. Simulated change in bed elevation downstream of Bloede Dam within the first year following dam removal for **Run 3W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

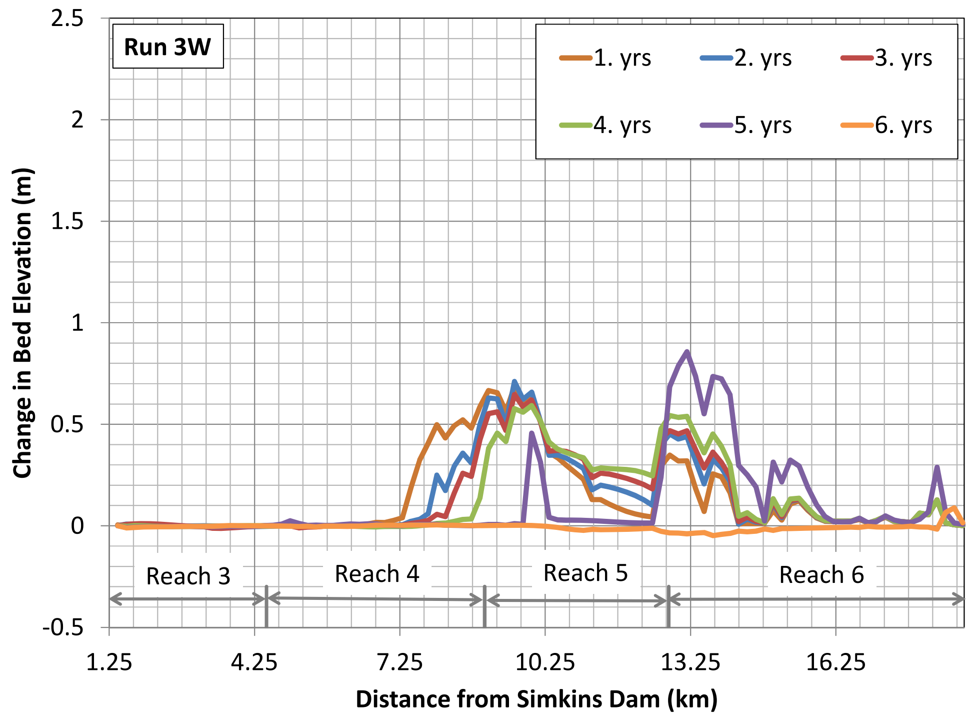

Figure 58. Simulated change in bed elevation downstream of Bloede Dam within six years following dam removal for **Run 3W**. Bloede Dam is located 1.25 km downstream of Simkins Dam.

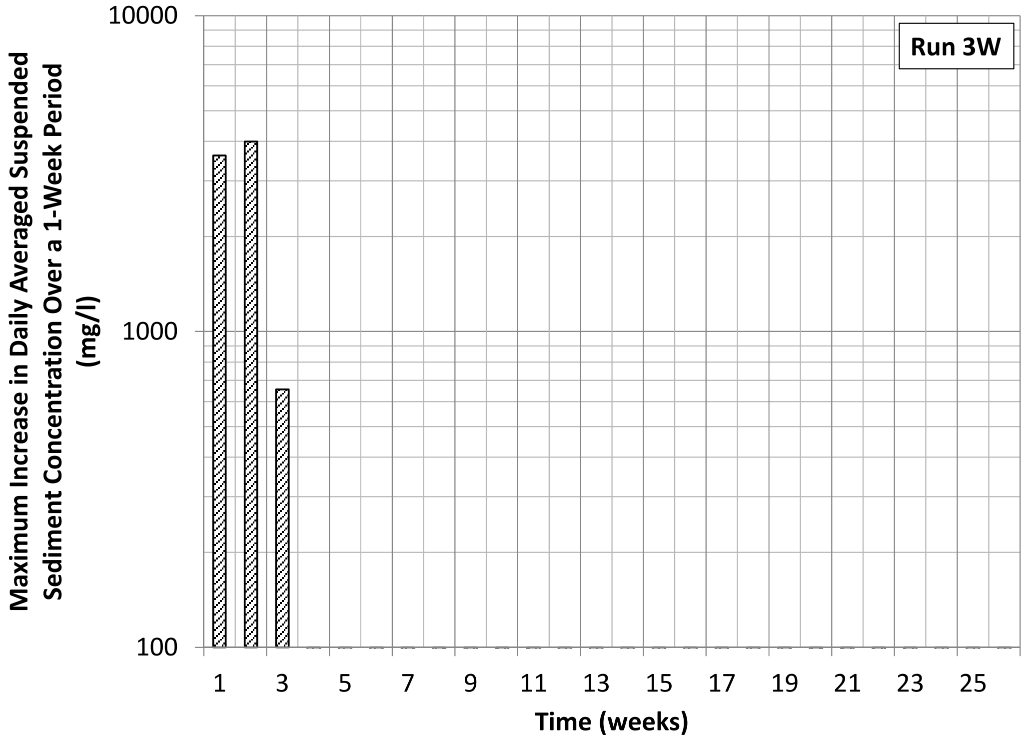

Figure 59. Simulated increase in suspended sediment concentration just downstream of Bloede Dam following dam removal for **Run 3W**.