SEDIMENT COLLECTOR CROSS VANE EVALUATION CUYAHOGA RIVER, CLEVELAND, OH

HYDRODYNAMIC & SEDIMENT MODELING

Prepared for:

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EXECUTIVE SUMMARY

A bedload sediment collector is installed in the Cuyahoga River, approximately 4 miles upstream of the Cuyahoga Ship Channel (CSC). The collector rests on the streambed and collects sediment through a grate in the top of the unit. Sediment is pumped to shore by an onshore hydraulic unit.

The purpose of this study was to evaluate whether the efficiency of the existing bedload collector could be improved substantially by adding some training structures, i.e., “vanes”, to channel sediment toward the collector. A secondary purpose was to evaluate whether a similar bedload collector (potentially including vanes, if appropriate) closer to the CSC could substantially reduce the quantity of sediment that is regularly dredged from the CSC.

The concept of these vanes is analogous to the “cross-vanes” outlined by Rosgen [1], however, the functional purpose of these vanes is opposite of Rosgen’s vanes. Rosgen’s vanes are designed to stabilize stream banks by channeling sediment away from the stream center toward the banks. This study proposes vanes oriented to channel sediment toward the center of the river, where the sediment collector is located.

The relationship between river vanes and sediment transport is complex because vanes that channel bedload toward the channel center also reduce the cross-sectional flow area of the river, increasing velocities over the collector. The increased velocities can lead to suspension of the bedload sediments, which then are not trapped by the collector.

While the primary purpose of this study was to evaluate the effectiveness of vanes at the current bedload collector site, this location is outside of Moffatt & Nichol’s existing calibrated sediment model for the Cuyahoga River. In order to complete the modeling goals of this study most efficiently, the downstream site (near the CSC) was considered first, using the calibrated sediment conditions from previous studies. Subsequently, the model was modified to provide a best-estimate of the upstream collector conditions using the available information.

Estimates were developed for collection rates at different flow rates and with different vane configurations. Using the suite of simulations performed, collection rating curves were developed and used to estimate hindcast collection quantities for previous years, which were benchmarked against the production data from the existing collector.

Based on these modeling studies, cross vanes would have a marginal, but potentially positive, impact on sediment collection rates. A wider angle vane (measured from the centerline) may provide greater benefit than narrower vanes. However, the modeling results were not conclusive of this benefit, particularly for the existing collector site.

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1.0 INTRODUCTION

This study provides a technical evaluation of cross vanes that are being considered as a possible way to increase the efficiency of a bedload sediment collector in the Cuyahoga River. Currently, a Streamside Systems® bedload collector (Figure 1-1) is installed in the Cuyahoga River approximately 4 miles upstream of the dredged shipping channel. The Port of Cleveland is considering the possibility of installing an additional collector in the area just upstream of the Cuyahoga Ship Channel (CSC) (Figure 1-2).

The Streamside® collector currently installed is a pilot project and produces sediment that is sold by Kurtz Brothers for a profit. The purpose of a new sediment collector near the CSC would be to reduce dredging and disposal costs by intercepting coarse sediments before they reach the shipping channel. Previous studies by Moffatt & Nichol (M&N) (e.g., [2] and [3]) have evaluated the potential effect of a sediment trap on reducing dredging requirements for the ship channel. Concepts evaluated in the previous studies considered both bedload and suspended sediments. Though a suspended sediment trap may be considered at a later date, the present study relates only to a bedload collector.

The Streamside® collector is approximately 30 feet wide (across the river). It sits on top of the river bed and collects sediment through a grate in the top of the collector. The collector is flushed by a hydraulic system, and the sediment is pumped to shore, where it is dewatered and stored. The landside components of the Kurtz Brothers installation are shown in Figure 1-3. Kurtz Brothers has provided a record of their sediment sales (summarized in Table 1-1) for reference in this study.

The collector is expected to intercept the bedload transiting that portion of the channel cross section where it is installed. At the current Kurtz Brothers location, the river is approximately 80 ft wide. At the downstream location considered for installation, the Cuyahoga River is approximately 150 ft wide. Rather than installing multiple collectors to span the width of the river, Port of Cleveland is considering whether training structures “vanes” can be installed along the channel bed upstream of the collector to direct bedload sediments toward a single collector in the channel.

The concept of these vanes is analogous to the “cross-vanes” outlined by Rosgen [1], however, the functional purpose of these vanes is opposite of Rosgen’s vanes. Rosgen’s vanes are designed to stabilize stream banks by channeling sediment away from the stream center toward the banks. This study proposes vanes oriented to channel sediment toward the center of the river, where the sediment collector is located.

While the primary purpose of this study was to evaluate the effectiveness of vanes at the current bedload collector site, this location is outside of Moffatt & Nichol’s existing calibrated sediment model for the Cuyahoga River. In order to complete the modeling goals of this study most efficiently, the downstream site (near the CSC) was considered first, using the calibrated sediment conditions from previous studies. Subsequently, the model was modified to provide a best-estimate of the upstream collector conditions using the available information.

Figure 1-1: Bedload Sediment Collector

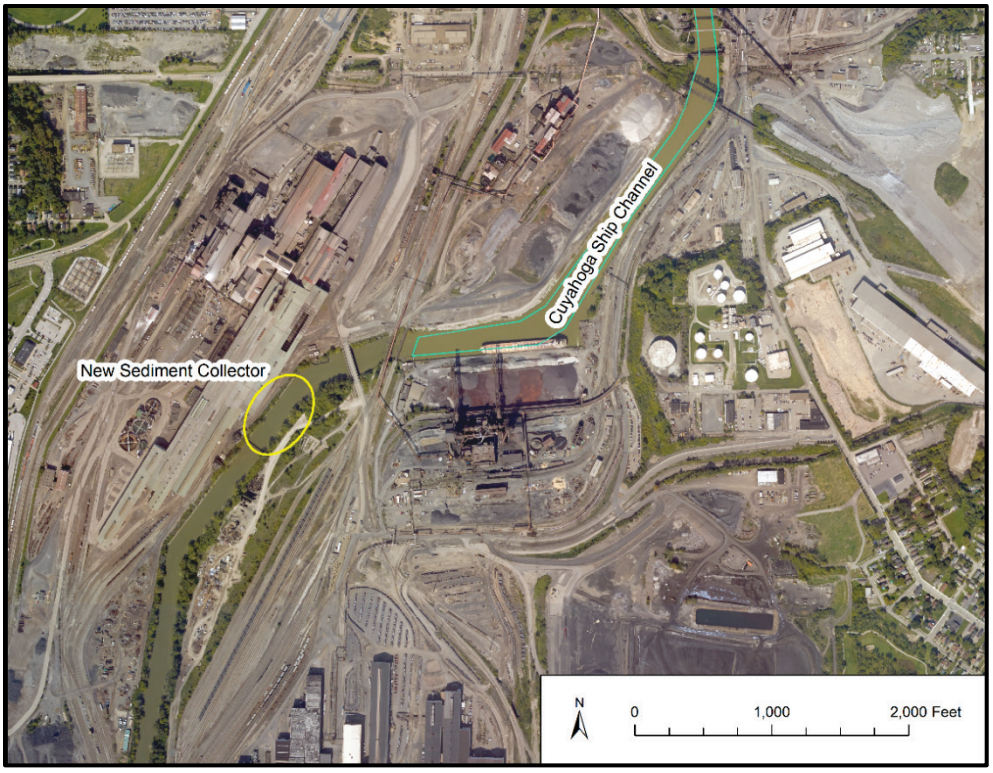

Figure 1-2: Potential Collector Location – Cuyahoga River (Above Ship Channel)

Figure 1-3: Land-side Components of Bedload Collector

Table 1-1: Sediment Sales Volumes from Kurtz Brothers

Date of Sale	Volume of Sale [yd^3]
7/23/2015	18
10/6/2015	44
10/7/2015	58
10/8/2015	399
3/17/2016	66
4/5/2016	110
6/29/2016	34
6/30/2016	46
7/5/2016	9
7/11/2016	25
7/12/2016	69
7/13/2016	14
12/13/2016	60
4/20/2017	88
5/9/2017	110
Current Inventory	264
Grand Total	1412

2.0 VANE CONCEPT DEVELOPMENT

When conceptualizing potential vane configurations, it is important also to consider that the optimal vane angle may not be the same between the two collector locations considered for this analysis. The vane configurations developed here will be evaluated both at the current collector location and at a potential downstream site. The following factors were identified that could influence the effectiveness of a vane configuration:

- **The location of the collector in the channel**: While it may seem natural to place the collector in the center of the channel, it is not the only possibility. Reasons to place the collector off the centerline might include asymmetry in the channel cross-section, asymmetry in the current field, or asymmetric vane configuration. For this study, it was assumed that the collector will be installed in the center of the channel. This is reasonable considering the relative symmetry in the river cross-section. Also, vane configurations that push sediment to a collector at the side of the river would likely be less efficient because the sediment would have to travel farther to get to the collector.

- **Shape and height of the vanes**: the potential construction costs were a factor in determining the best shape and height. Curved vanes were not considered because of the potentially higher construction costs. The vanes were assumed to be 2.5 feet high, which is a reasonable height above the river bottom that would direct bedload to the collector without overtopping the vane, in addition to being low enough to not significantly affect the river flow, i.e., not cause backup and upstream flooding. This size is also common for a precast concrete pile and a reasonable size for boulders, providing more than one straightforward way of placing the vanes.

- **Number of vanes**: With the collector in the center of the channel, it is reasonable to include at least one vane on either side of the collector at some point at or upstream of the collector. Since the primary purpose of the vanes is to channel bedload and there is no reason to expect a significant amount of settling of suspended sediment, it was determined that a single row of vanes (one on each side of the channel) would be sufficient. A second row would likely provide very minimal improvement.

- **Position of vanes along the river**: Should the vanes be located a distance upstream, or right at the collector? With the vanes channeling bedload toward the center of the channel, it seems reasonable to place the collector directly between the vane tips. Keeping the collector between the vanes forces the bedload to pass over the collector. If the vanes were placed further upstream the bedload may have opportunity to disperse within the channel (particularly if small eddies developed off the vane tips). While the precise location of the vanes could be adjusted for better efficiency in further studies, the vane tips were aligned with the collector for this study (Figure 2-1).

- **Vane orientation**: The primary variable for this analysis was the orientation of the vanes, the angle between the vane and the channel centerline. This angle induces a change in near-bottom velocity direction (and momentum) from along the river to along the vane. The angle of the vanes affects the at-bed velocity near the collector, which controls which sediment size fractions are mobilized as bedload, which fractions are suspended, and which fractions remain stationary on the bed. This effect was evaluated numerically using the models discussed in Section 3.0.

- **Vane length**: the last vane parameter to be defined was the vane length. Shorter vanes may provide a similar effect to longer vanes, but shorter vanes would include more complex effects around the exposed vane tips upstream. In order to isolate the effect of vane angle, this study considered that all vanes extent from the collector to the edge of the channel. When installed, the vanes may not extend all the way to the shoreline to avoid having them stick out of the water.

Three vane configurations were identified to be evaluated with hydrodynamic and sediment transport simulation (Figure 2-1).

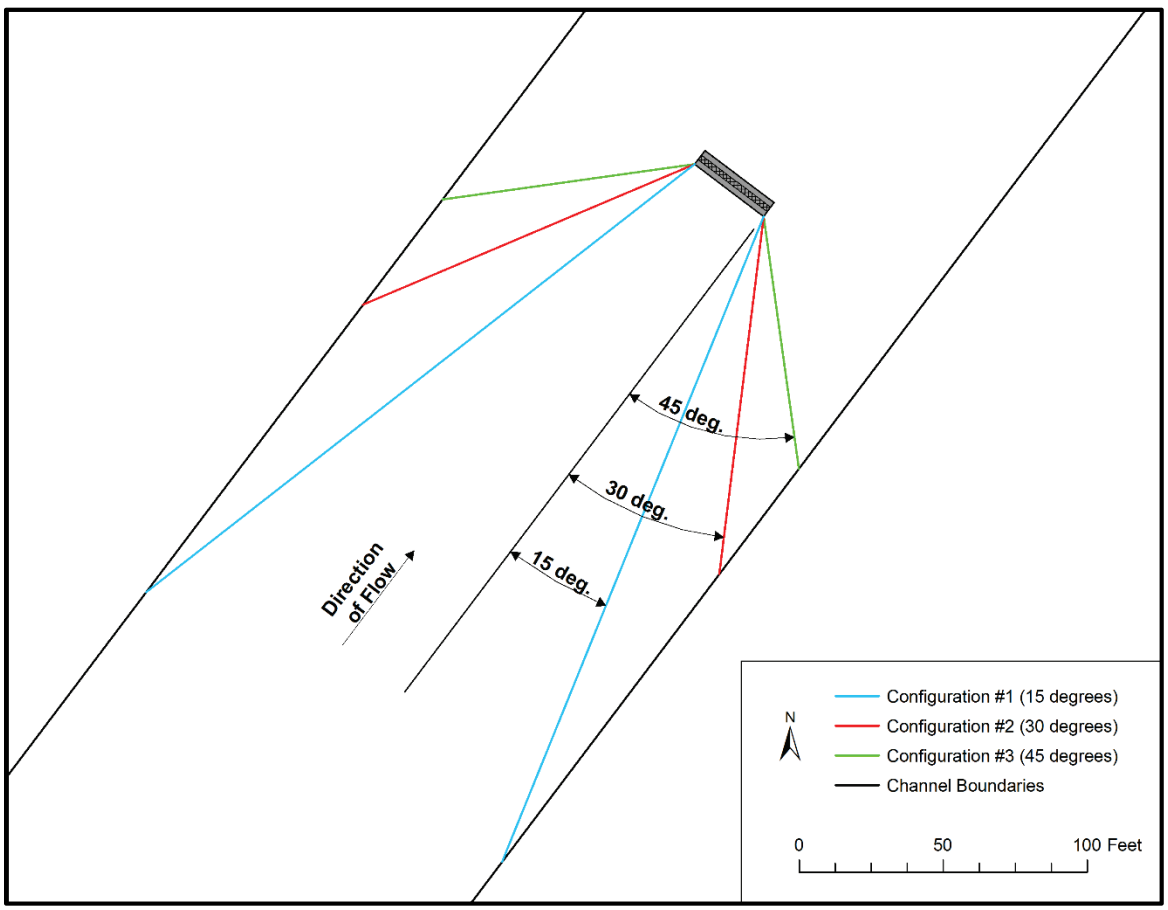

Figure 2-1: Vane Configurations

3.0 CONCEPT EVALUATION

A numerical hydrodynamic and sediment transport model was developed to further evaluate the concepts identified above. The primary purpose of the study was to consider whether vanes could improve the collection efficiency at the current collector location. However, calibrated sediment conditions from previous M&N studies were available for the downstream location. Consequently, it was determined better to evaluate the downstream site first and then modify that model for application at the existing site.

The reach of the Cuyahoga River for the potential downstream collector is relatively straight near the collector (Figure 1-1), a setting that would generally lend itself nicely to a depth averaged hydrodynamic model. However, the introduction of vanes on a riverbed adds a layer of complexity that would make a three-dimensional model more appropriate.

A three dimensional Delft3D-FLOW model was developed for this analysis based on the existing M&N model of the Cuyahoga River. The model was used to evaluate the hydrodynamics and shear stresses along the vanes and river bed near the collector. After evaluating the hydrodynamics, sediment transport was evaluated and some preliminary conclusions were drawn regarding the relative sediment collection efficiencies of the different configurations. The hydrodynamic model is discussed in Section 3.1. The sediment transport evaluation is discussed in Section 3.2.

3.1 Hydrodynamic Model development

Because the model was initially developed for evaluating the downstream collector site, the model discussion focuses on that site. The upstream site was modeled using modified versions of the same models as noted throughout the discussion of model development.

The hydrodynamic model was developed based on an understanding of the river reach from the existing M&N model. The bathymetry data available for this area is a single cross section (Location 2 in Figure 3-1). This cross section indicates a relatively flat bottom, which is consistent with the equilibrium bed profile determined by the previous morphology modeling effort. In order to focus this study on the effects of vane orientation, this study assumes a trapezoidal cross-section for the river channel. Using a trapezoidal channel is reasonable considering the bathymetry available.

The channel bottom depth and width were assumed to be 10 ft and 100 ft, respectively (based on the previous model) with 2.5:1 side slopes. The channel segment simulated extended approximately 500 ft upstream of the collector and 250 ft downstream of the collector. The model for the upstream collector considered a simple flat bottom channel with a depth of approximately 9 ft[1].

[1] Depth for the upstream model varies substantially with the flow rate because it is far enough upstream that the tailwater condition is not controlled by the lake level. No bathymetry data was available for the upstream site, so a more detailed characterization of the stream in this location was not possible.

3.1.1 Model Grids

Delft3D, like many similar models, does a much better job at characterizing obstacles in the flow field if the obstacles are aligned with grid cell boundaries (or if the grid cell boundaries are aligned to the obstacles). Because the grid cells needed to align with the vanes, and each of the vane configurations required its own computational grid. The model grids developed for this analysis are shown in Figure 3-2, Figure 3-3, and Figure 3-4 for Configurations #1, #2, & #3, respectively. The grids here are illustrated for the wider, downstream channel. The same computational grids were used for the upstream site, with cells along the boundaries removed from the domain to reduce the channel width to 80 ft.

In each model, 10 vertical layers were prescribed using the σ-layers capabilities of Delft3D. This means that each layer is a prescribed as a percentage of the water depth, and the physical thickness of each layer changes between deeper and shallower areas (or with changes in water level). As recommended by the manual, a gradual variation in layer thickness was assigned. From bottom to the surface, the thicknesses assigned were 2, 3, 4, 6, 8, 10, 12, 15, 20, and 20 (as percent of depth).

In addition to the model grids illustrated in Figure 3-2, Figure 3-3, and Figure 3-4, a simple grid with rectangular cells was considered as a benchmark for hydrodynamics and sediment transport to provide an understanding for the effect of grid cell orientation on the model results. The rectangular grid was used to simulate only scenarios without vanes.

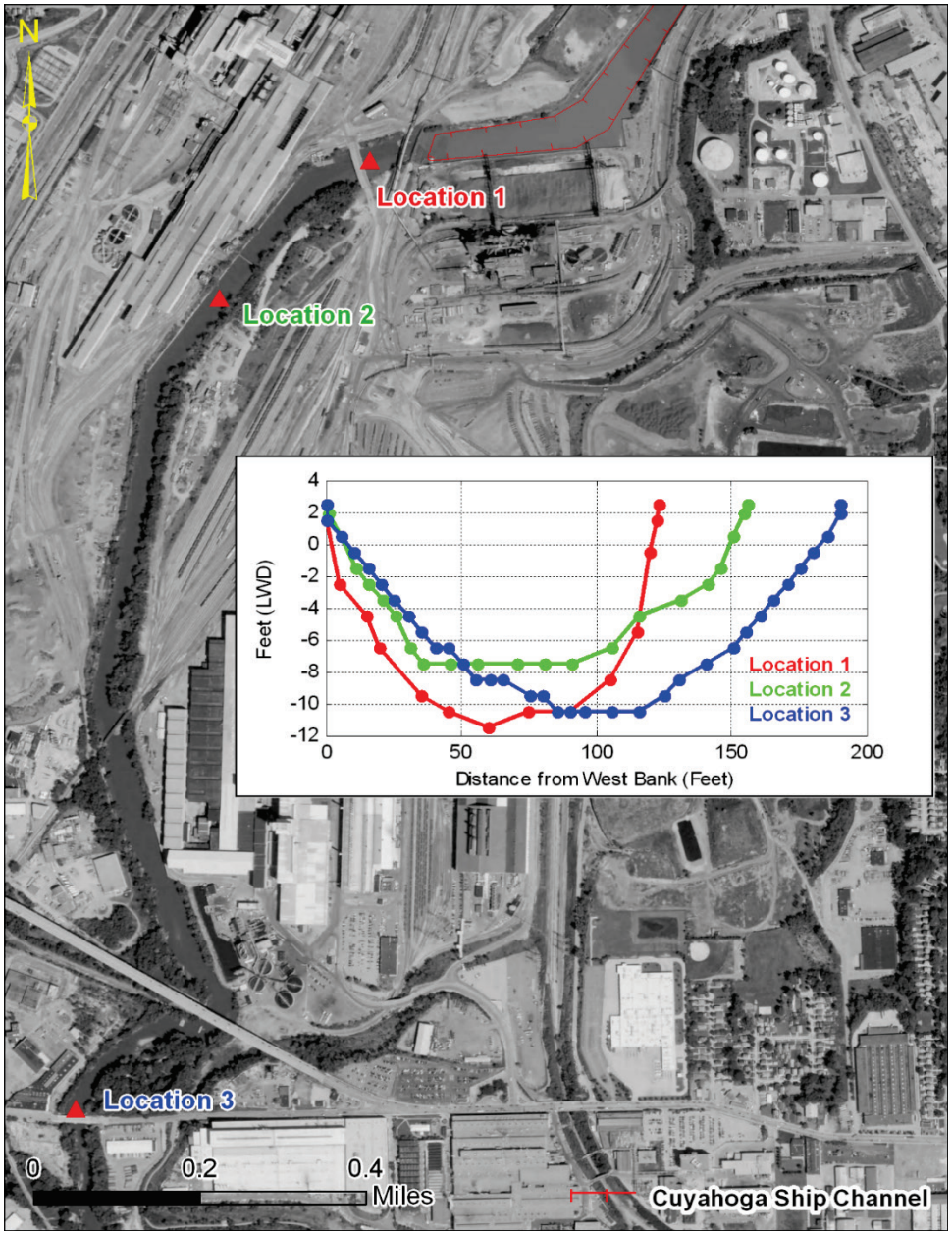

Figure 3-1: June 28th, 2012 Bathymetric Survey Results[2]

[2] Figure reproduced from the previous Moffatt & Nichol modeling effort [1].

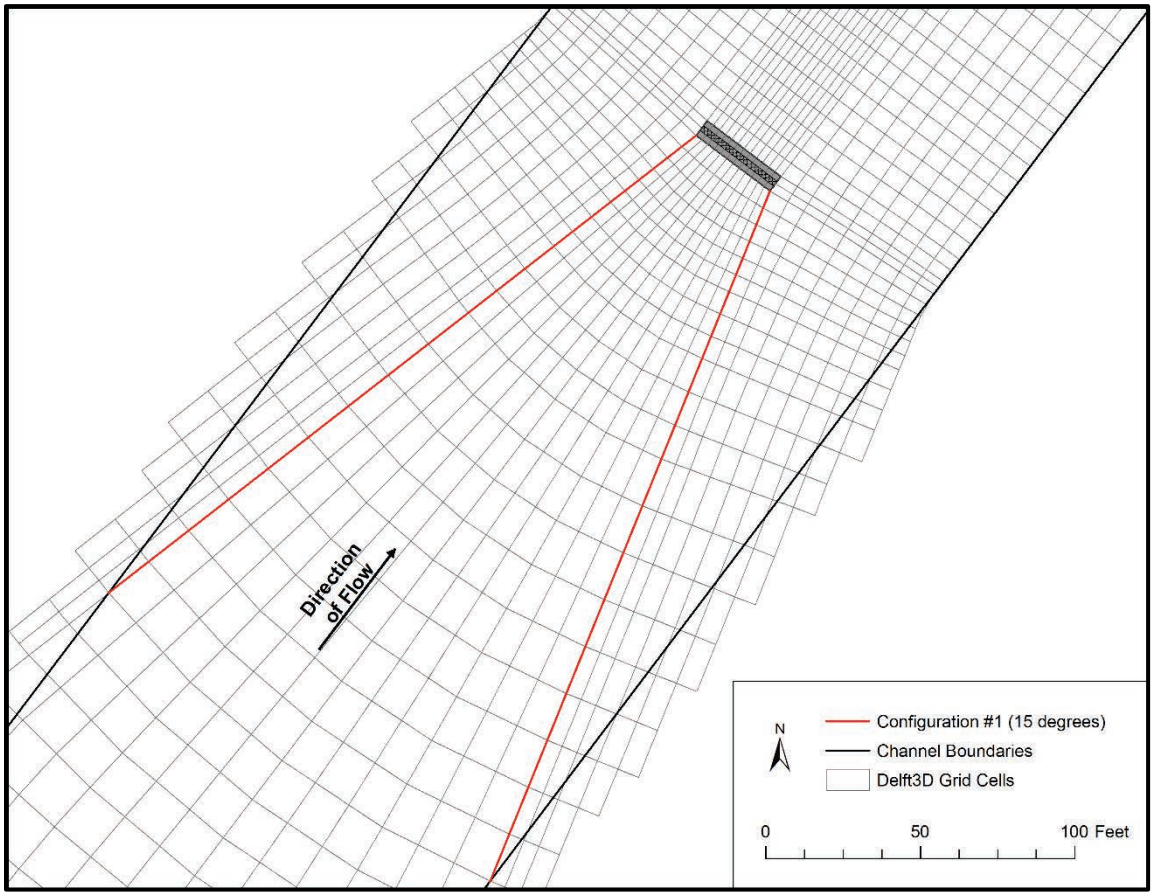

Figure 3-2: Delft3D Grid for Vane Configuration #1 (15°)

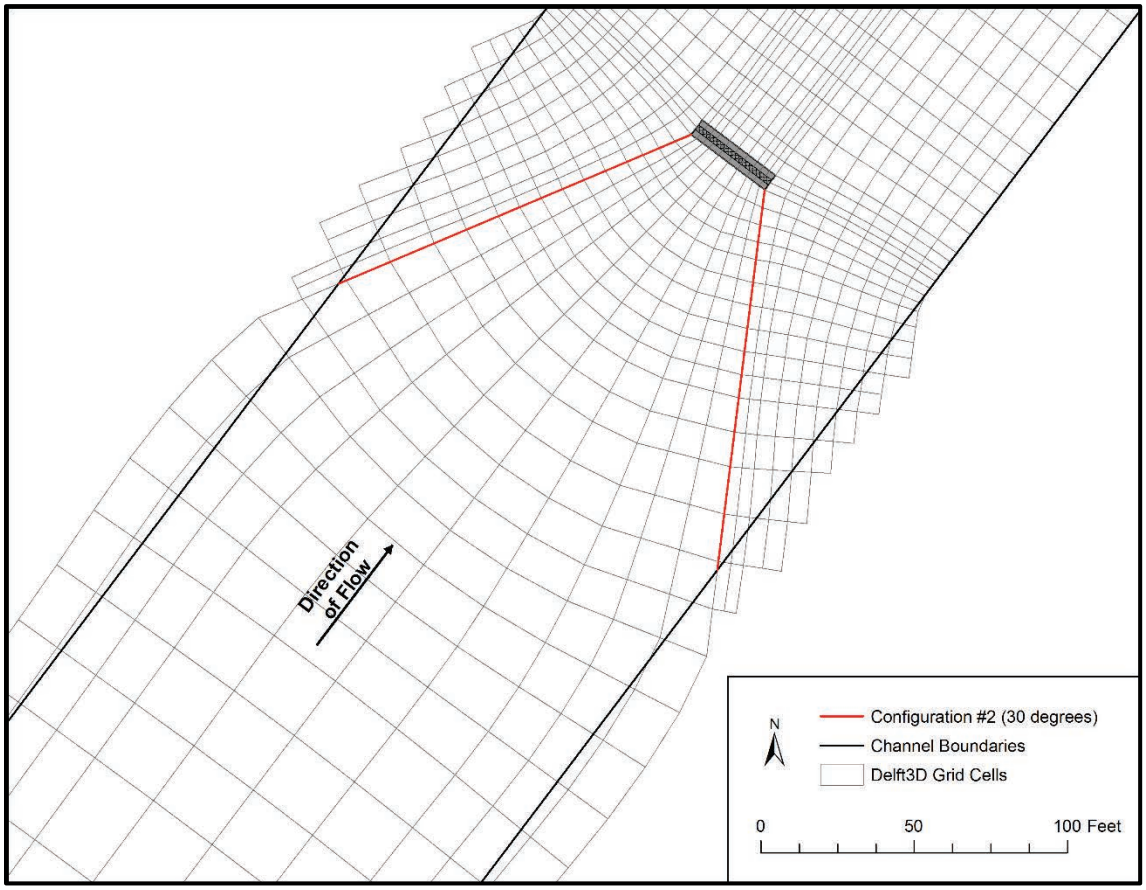

Figure 3-3: Delft3D Grid for Vane Configuration #2 (30°)

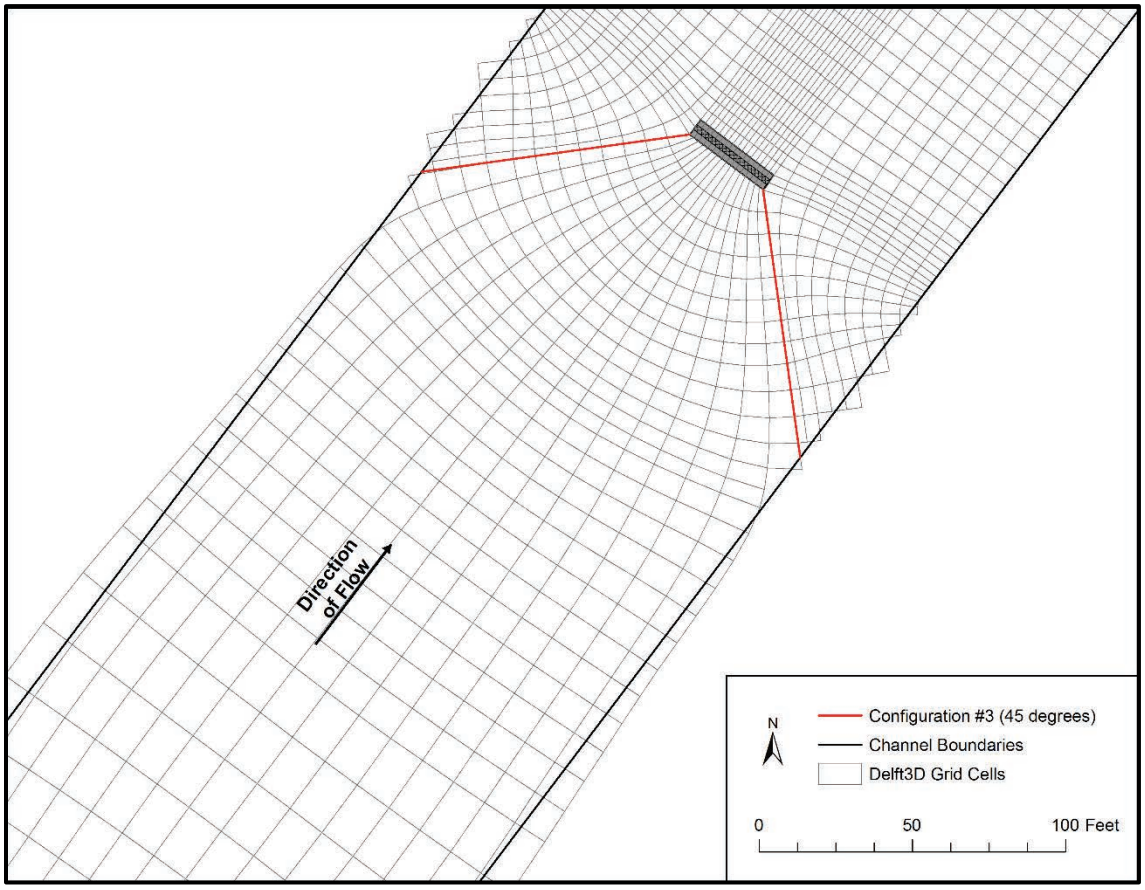

Figure 3-4: Delft3D Grid for Vane Configuration #3 (45°)

3.1.2 Boundary Conditions

The boundary conditions for the downstream model were a discharge boundary condition at the upstream end of the model and a water level boundary condition at the downstream end of the model. A constant value of 0.55m (1.8ft) Low Water Datum (LWD) was used as the downstream boundary condition for all simulations. This is a reasonable boundary condition based on the previous M&N modeling effort, which showed minimal head loss along the Cuyahoga River shipping channel at a range of discharge rates. For reference, the mean water level for the period of record is 0.64m (2.1ft) LWD. However, the level of 1.8ft LWD used in this analysis is a reasonably typical level and was used to be consistent with the previous analysis.

For the upstream model domain, the upstream boundary condition was a flow rate condition, and the downstream boundary condition was assigned as a water level based on a rating curve estimated for the stream location (Table 3-1). The rating curve was established using a river slope estimate of 0.0012 (based on gradients from the most recent FEMA map), and applying Manning's equation with a roughness coefficient of 0.025. This

rating curve is very approximate and introduces a considerable amount of uncertainty into the modeling.

Table 3-1: Stage Discharge Rating Curve Estimate for Existing Collector Site

Flow Rate [cfs]	Tailwater Depth [ft]
100	8.7
250	9.3
500	10.0
1000	11.0
2500	13.4
5000	16.4
8000	19.4

3.1.3 Initial Conditions

The model was started at rest (zero velocity, constant water level) with a one hour time for the boundary conditions to spin up. Given the small size and depth of the domain, a shallow water wave would take less than 1 minute to travel the length of the domain, which means that 1 hour should allow a relatively slow spin up.

3.1.4 Representation of the Vanes

The vanes were included in the Delft3D model using the current deflecting wall feature [4]. Current deflecting walls block flow between cells in three dimensional models. The top and bottom of each feature can be prescribed with a z coordinate (partial layer blocking is accounted for). For this model, the “wall” features were assigned as extending from the bottom of the channel up to a height of 2.5 ft, consistent with the vane height conceptualized in Section 2.0.

3.1.5 Simulation Matrix

The performance of each vane configuration was evaluated using a range of flow conditions. The flow conditions were evaluated in a quasi-steady state manner, meaning that that inflow to the model was applied at a constant rate until a steady equilibrium was reached.

For each flow rate, each model was run with and without vanes. The reason for this is that the particular size, shape, and orientation of the individual grid cells has some minor effect on the simulation results. Often these effects are insignificant. However, evaluating each grid both with and without vanes isolates the effect of the vanes. Isolating the effects of the

vanes is particularly important for the sediment transport analysis (Section 3.2) because a very minor difference in flow field can lead to substantial changes in morphology.

Table 3-2: Simulation Matrix

Configuration #1 Grid			**Configuration #2 Grid**			**Configuration #3 Grid**		
Run ID	Flow Rate [cfs]	Vanes	Run ID	Flow Rate [cfs]	Vanes	Run ID	Flow Rate [cfs]	Vanes
1	100	No	**1**	100	No	**1**	100	No
2	250	No	**2**	250	No	**2**	250	No
3	500	No	**3**	500	No	**3**	500	No
4	1,000	No	**4**	1,000	No	**4**	1,000	No
5	2,500	No	**5**	2,500	No	**5**	2,500	No
6	5,000	No	**6**	5,000	No	**6**	5,000	No
7	8,000	No	**7**	8,000	No	**7**	8,000	No
8	100	Yes	**8**	100	Yes	**8**	100	Yes
9	250	Yes	**9**	250	Yes	**9**	250	Yes
10	500	Yes	**10**	500	Yes	**10**	500	Yes
11	1,000	Yes	**11**	1,000	Yes	**11**	1,000	Yes
12	2,500	Yes	**12**	2,500	Yes	**12**	2,500	Yes
13	5,000	Yes	**13**	5,000	Yes	**13**	5,000	Yes
14	8,000	Yes	**14**	8,000	Yes	**14**	8,000	Yes

In addition to the simulations outlined in Table 3-2, several simulations were performed with the rectangular grid described in Section 3.1.1. The rectangular grid simulations were performed as a benchmark for the sediment collector without vanes, and also to consider a case with a “wide” sediment collector that extends all the way across the channel. This would simulate a case where multiple collectors were installed side-by-side instead of using vanes.

The simulations outlined in Table 3-2 were performed for both the upstream (existing) and downstream (potential) collector sites.

3.2 Sediment Transport Considerations

Sediment transport was included in the model in the same manner as the existing M&N model. The sediment transport characteristics are summarized as follows:

- Five sediment size classes were included in the analysis: four non-cohesive classes, and one cohesive class (mud). The cohesive sediment is not expected to be captured by the collector, but was included for consistency with the previous analysis and to

maintain a realistic sediment size distribution. The transport formulations and calibration parameters for these sediment classes were taken from the existing M&N model. The size classes used for this analysis are as follows with approximate bed composition fractions:

- Sediment 1: 100 μm (1%)
- Sediment 2: 200 μm (2%)
- Sediment 3: 500 μm (3%)
- Sediment 4: 2000 μm (94%)
- Sediment 5: mud (0%).

- An equilibrium upstream boundary condition was applied for both suspended and bedload fractions of the non-cohesive sediment. For this approach, the sediment concentrations are estimated by the model based on the flow characteristics at the inflow boundary. This is the same approach as used in the previous analysis.

- The bedload collector was included in the model using the "dredging" feature. The zone associated with the collector grating was set to continuously "dredge" any sediment that accumulated. This simulated the hydraulic pumping of sediment from the collector to allow for continuous collection of sediment. Grid cells associated with the collector were raise approximately 1 ft above the bed level to simulate the vertical protrusion of the collector above the bed. The precise height of the collector above the bed would be determined by how it is installed on the bed.

3.3 Model Results: Downstream Collector

Results are reported for each simulation after a quasi-equilibrium condition developed at approximately 8 hours of simulated time. The results of the hydrodynamic model are illustrated first (Section 3.3.1) followed by a discussion of the sediment trap efficiencies observed (Section 3.3.2). Results are reported first for the downstream collector site in relative detail before discussing the upstream collector site. The upstream site model is discussed in less detail because there is greater uncertainty associated with those results.[3]

3.3.1 Hydrodynamics

Figures summarizing the hydrodynamic model results were produced for each simulation and vane configuration. Two example figures are included here as Figure 3-5 and Figure 3-6 for a flow rate of 8,000 cfs with and without 15° vanes. Figure 3-7 provides a difference

[3] As discussed above, there was minimal information available for this study for the upstream location. Without good bathymetry, sediment, and water level records for model validation, the results are only used in a qualitative, comparative manner.

plot, illustrating the effect of the vanes. Table 3-3 shows the effect of vanes on the at-bed velocities and shear stresses at the collector. The shear stresses at the collector will control which sediment grain sizes are mobilized as bedload and suspended load under which flow rates. From these data, it is clear that the wider angle vanes create a higher shear stress at the collector, which would mobilize larger sediment fractions.

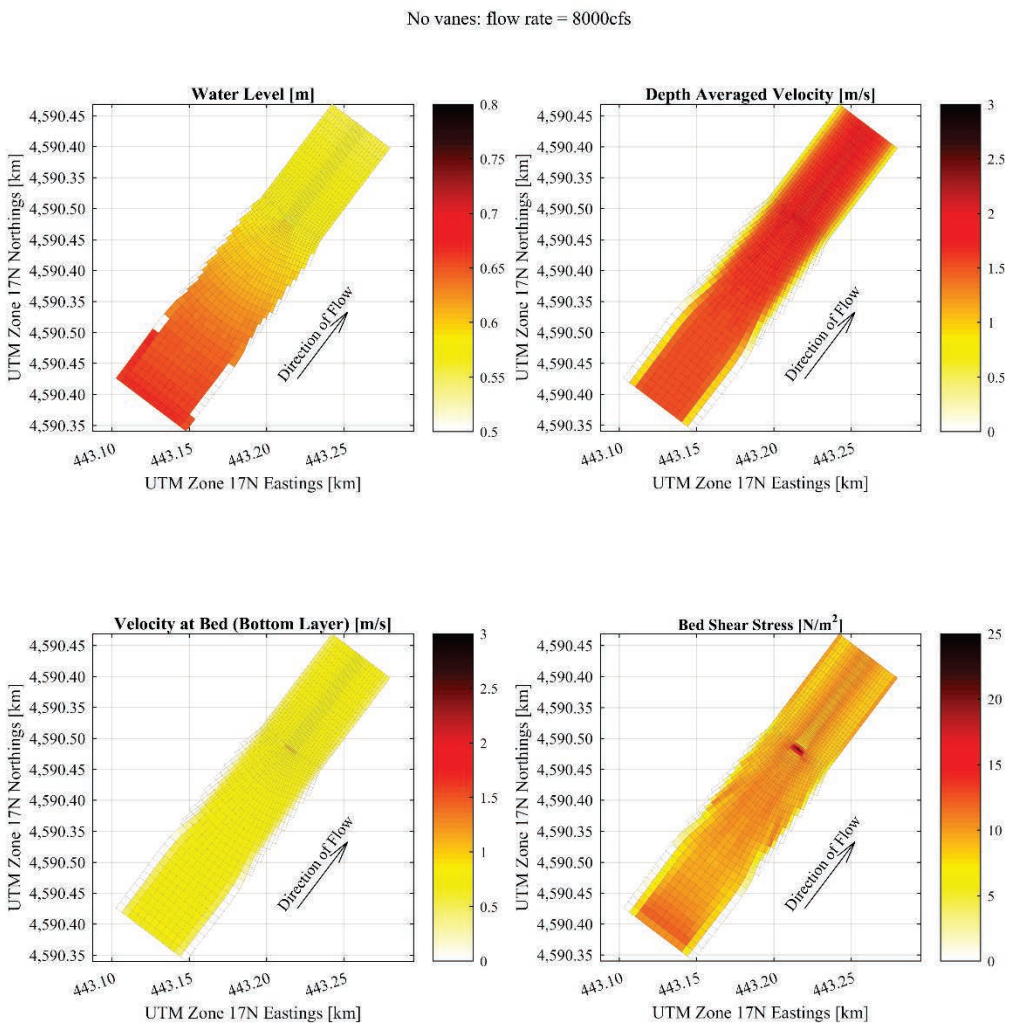

Figure 3-5: Hydrodynamic Results for 15° Grid: No Vanes

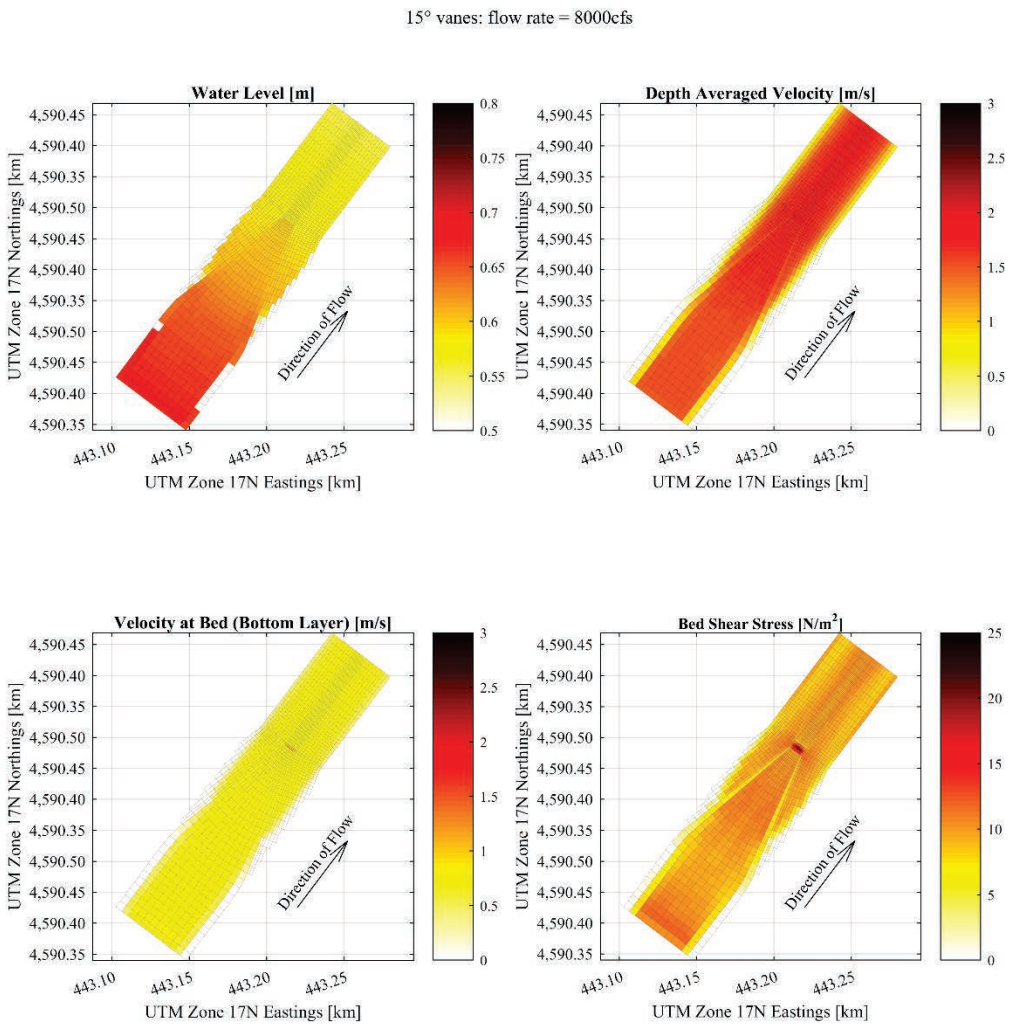

Figure 3-6: Hydrodynamic Results for 15° Grid: With Vanes

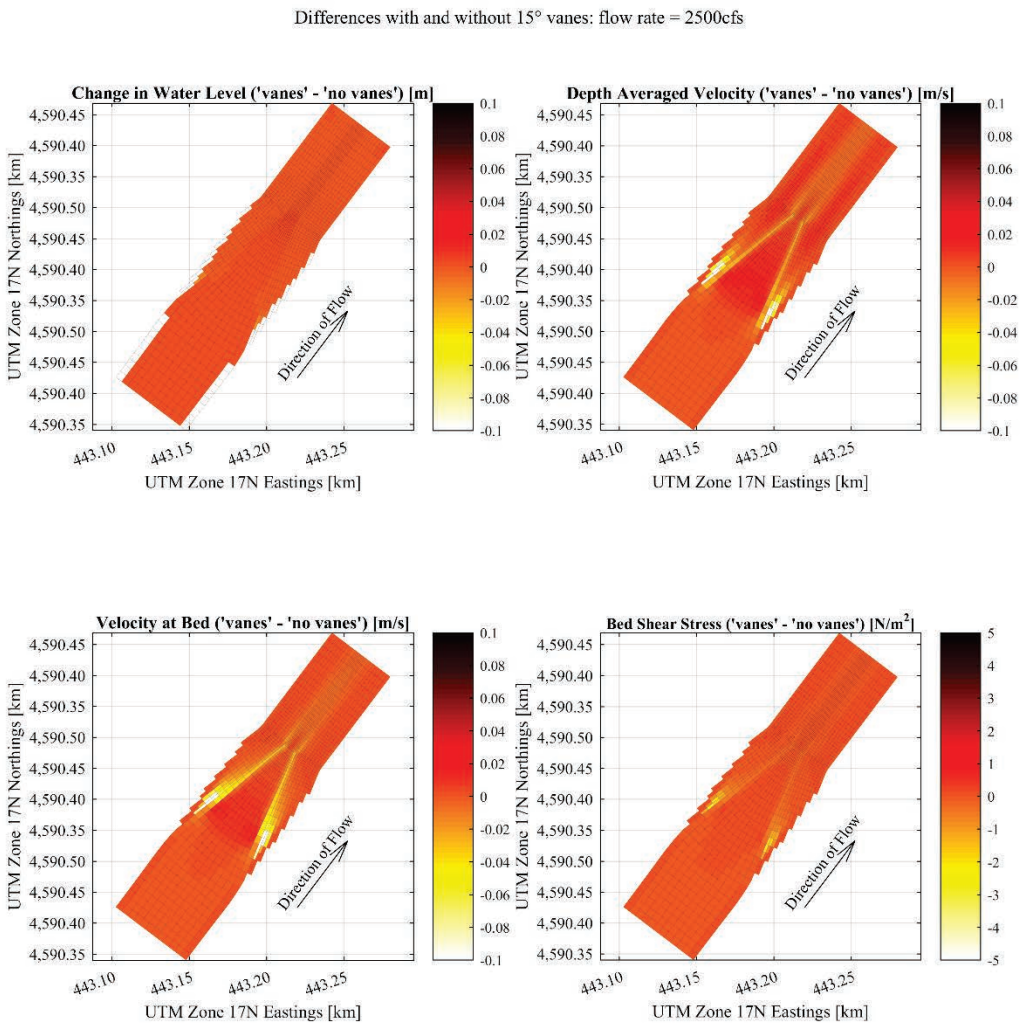

Figure 3-7: Difference Plot of Results for 15° Grid: With & Without Vanes

Table 3-3: Effect of Vanes on At-Bed Velocity and Shear Stress

Flow Rate [cfs]	Change in Near-Bed Velocity at Collector (with vanes – no vanes) [%]			Change in Bed Shear Stress at Collector (with vanes – no vanes) [%]		
	15° vanes	30° vanes	45° vanes	15° vanes	30° vanes	45° vanes
100	5	8	13	9	18	28
250	2	6	12	5	13	26
500	0	5	10	1	9	22
1000	-1	4	9	-2	8	19
2500	-1	4	9	-1	8	18
5000	0	6	15	0	13	31
8000	1	12	29	1	25	67

3.3.2 Sediment Transport

The sediment transport model is coupled with the hydrodynamic model and computes the bedload and suspended sediment transport for each flow rate and vane configuration. Bedload transport rates are shown in Figure 3-8 and Figure 3-9 for the non-cohesive sediment fractions with 8,000 cfs flow rates with and without 15° vanes.

The relative efficiency of the sediment trap with and without each vane configuration is shown in Table 3-4 through Table 3-8 for each flow rate and sediment size. Table 3-8 shows overall performance of the collector as a percent improvement in the total volume of sand and gravel (non-cohesive sediment) captured. From these comparisons, there is a visible trend that indicates an advantage for wider angle vanes. Of the three configurations, the 45° vanes produced the greatest sediment yield.

The result that wider vanes provide an increased sediment yield may seem counterintuitive. However, the higher shear stresses at the collector for the 45 degree vanes (Table 3-3) correlate with a higher bedload at the collector. These higher velocities correlate with the abrupt contraction of flow with the 45 degree vanes (rather than the more gradual 15 degree vanes).

While the primary purpose of the sediment modeling was to evaluate the relative effectiveness of the vane configurations, an order of magnitude estimate of sediment trapping quantities can also be made. Table 3-9 shows estimates of annual collection volumes based on historic daily mean stream flow data. The quantities were estimated based on a polynomial relationship between the logarithm of discharge and the logarithm of the sediment trap collection rate (using the model results, Figure 3-10). This method is very approximate, but it provides a comparison between the vane configurations and also allows for benchmarking against collection records from the existing collector that is installed upstream.

The upstream collector produced approximately 900 cubic yards of sediment between July 2015 and July 2016 (Table 1-1). This is comparable to the yields estimated for this analysis (bottom row of Table 3-9). Also, this study shows that minimal sediment is collected under typical conditions. Almost all the sediment is collected under high-flow conditions. This characteristic is confirmed by the operators of the upstream collector who have noted that the sediment arrives during rain events when the river runs higher. The alignment of the results of this analysis with the experience gained from the upstream collector provides a semi-quantitative validation of this sediment model, and provides confidence that the model incorporates the appropriate sediment transport, which is necessary for comparing vane configurations.

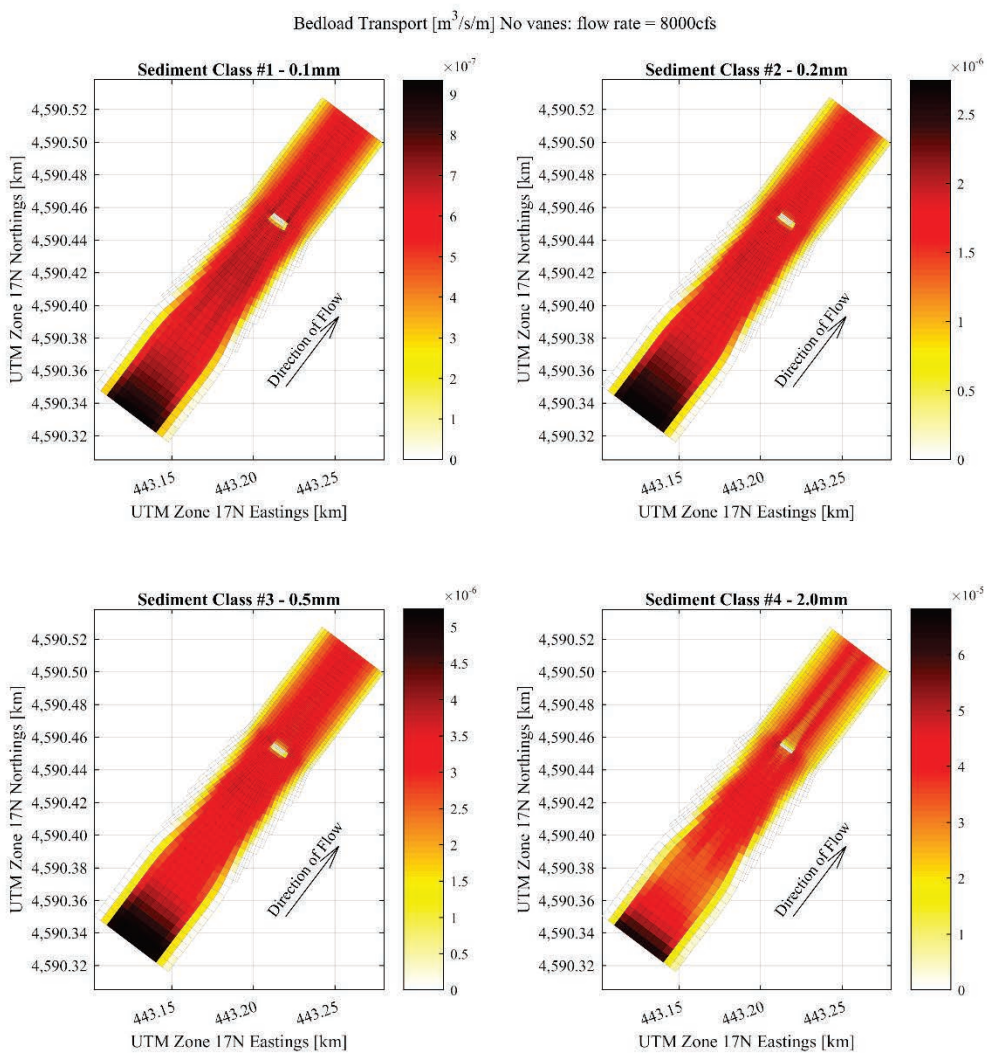

Figure 3-8: Bed Load Transport By Size Fraction: 8,000 cfs – No Vanes

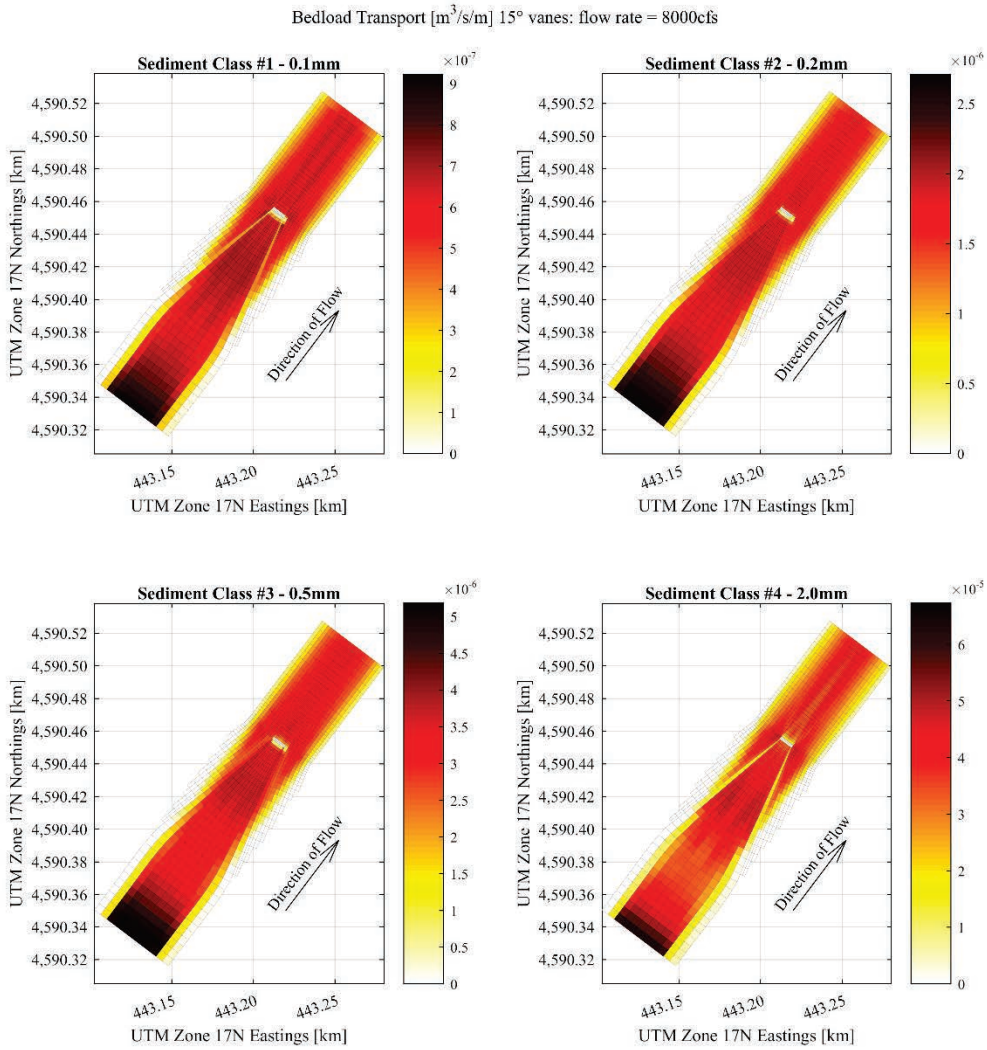

Figure 3-9: Bed Load Transport By Size Fraction: 8,000 cfs – 15° Vanes

Table 3-4: Effect of Vanes on Trap Efficiency: Sediment Size Class 1 (100µm)

Flow Rate [cfs]	Rate of Sediment Influx to Model Domain [yd^3/day]	Collection Rate [% Capture of Sediment Flux]				
		No Vanes	15 deg (Set14)	30 deg (Set15)	45 deg (Set16)	Wide Collector
100	n/a	n/a	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a
2500	1.4	4.33%	4.33%	4.72%	3.94%	16.33%
5000	72.9	0.15%	0.22%	0.19%	0.14%	0.70%
8000	430.9	0.37%	0.39%	0.12%	0.04%	1.17%

Note: "n/a" indicates a *de minimis* bedload (i.e., ≤0.001 yd^3/day), for which no percent change was computed.

Table 3-5: Effect of Vanes on Trap Efficiency: Sediment Size Class 2 (200µm)

Flow Rate [cfs]	Rate of Sediment Influx to Model Domain [yd^3/day]	Collection Rate [% Capture of Sediment Flux]				
		No Vanes	15 deg (Set14)	30 deg (Set15)	45 deg (Set16)	Wide Collector
100	n/a	n/a	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a
2500	1.3	10.10%	12.17%	11.19%	10.82%	31.63%
5000	73.9	0.61%	1.19%	0.94%	0.55%	2.37%
8000	512.9	1.31%	1.62%	0.72%	0.16%	4.87%

Note: "n/a" indicates a *de minimis* bedload (i.e., ≤0.001 yd^3/day), for which no percent change was computed.

Table 3-6: Effect of Vanes on Trap Efficiency: Sediment Size Class 3 (500µm)

Flow Rate [cfs]	Rate of Sediment Influx to Model Domain [yd^3/day]	Collection Rate [% Capture of Sediment Flux]				
		No Vanes	15 deg (Set14)	30 deg (Set15)	45 deg (Set16)	Wide Collector
100	n/a	n/a	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a
2500	0.7	47.50%	48.77%	53.10%	56.66%	n/a
5000	27.1	4.72%	8.09%	8.70%	7.46%	18.39%
8000	252.2	2.48%	5.96%	2.73%	0.63%	9.14%

Note: "n/a" indicates a *de minimis* bedload (i.e., ≤0.001 yd^3/day), for which no percent change was computed.

Table 3-7: Effect of Vanes on Trap Efficiency: Sediment Size Class 4 (2000µm)

Flow Rate [cfs]	Rate of Sediment Influx to Model Domain [yd^3/day]	Collection Rate [% Capture of Sediment Flux]				
		No Vanes	15 deg (Set14)	30 deg (Set15)	45 deg (Set16)	Wide Collector
100	n/a	n/a	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a
5000	77.1	32.44%	30.81%	50.68%	53.93%	~100%
8000	585.3	21.21%	24.70%	33.59%	38.27%	81.19%

Note: "n/a" indicates a *de minimis* bedload (i.e., ≤0.001 yd^3/day), for which no percent change was computed.

Table 3-8: Effect of Vanes on Trap Efficiency: Sum of All Non-Cohesive

Flow Rate [cfs]	Rate of Sediment Influx to Model Domain [yd^3/day]	Collection Rate [% Capture of Sediment Flux]				
		No Vanes	15 deg (Set14)	30 deg (Set15)	45 deg (Set16)	Wide Collector
100	n/a	n/a	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a
2500	3.2	14.80%	15.77%	16.47%	16.70%	52.43%
5000	206.3	10.17%	10.16%	15.98%	17.80%	35.83%
8000	2360.8	4.92%	5.91%	7.23%	8.45%	18.63%

Note: "n/a" indicates a *de minimis* bedload (i.e., ≤0.001 yd^3/day), for which no percent change was computed.

Table 3-9: Approximate Hindcast of Potential Sediment Yield

Approximate Potential Sediment Yield By Year					
Year	**Baseline (no vanes)**	**15° vanes**	**30° vanes**	**45° vanes**	**Wide Collector**
2002	167	185	231	241	611
2003	1,110	1,393	1,558	1,858	4,213
2004	1,081	1,411	1,507	1,879	4,135
2005	1,456	1,781	2,057	2,381	5,503
2006	710	903	993	1,202	2,701
2007	763	913	1,071	1,214	2,861
2008	1,064	1,303	1,495	1,736	4,014
2009	632	780	892	1,043	2,393
2010	78	83	106	107	282
2011	2,764	3,521	3,882	4,705	10,533
2012	861	1,117	1,208	1,494	3,297
Average	**971**	**1,217**	**1,364**	**1,624**	**3,686**

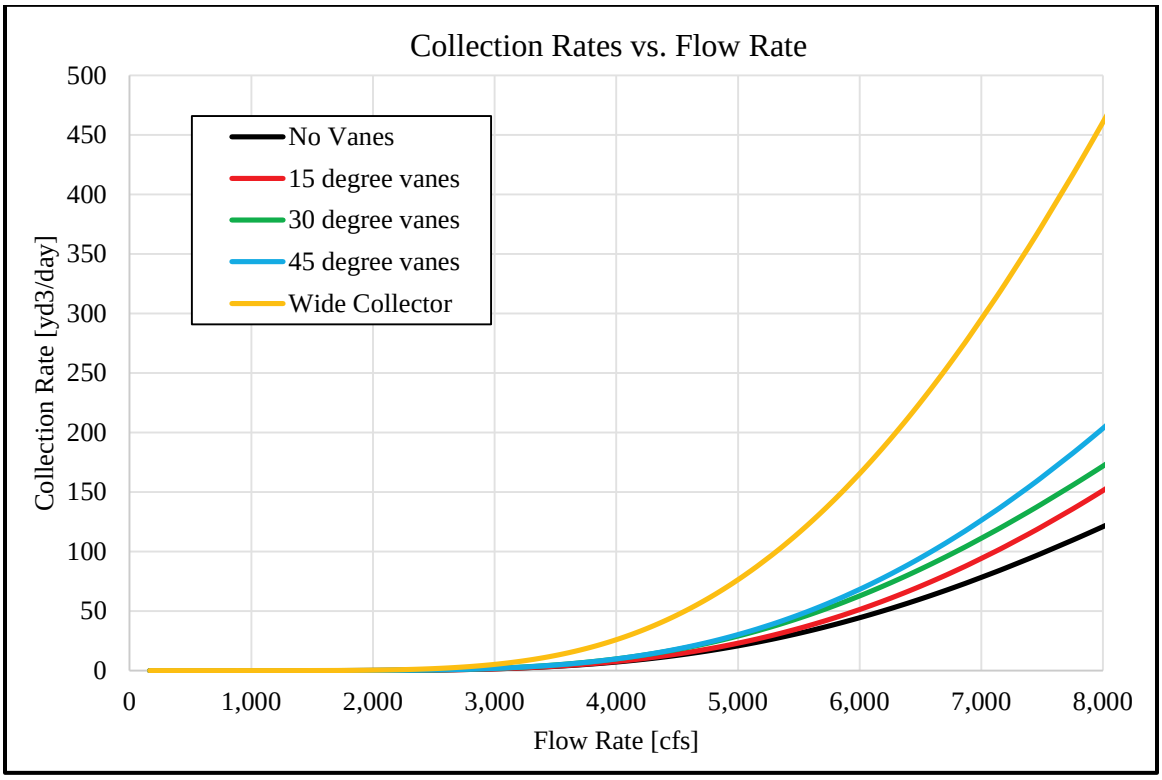

Figure 3-10: Collection Rates vs. Discharge – Downstream Collector

3.3.3 Uncertainty in Sediment Modeling Results

After presenting the sediment modeling results of Section 3.3.2, it is important to evaluate the uncertainty associated with the models. An estimate of modeling uncertainty can be obtained by comparing the results of RunIDs 1 through 7 for each of the grid configurations (Table 3-2). Each of these grids characterizes essentially the same hydrodynamic and sediment transport scenario. Differences of +/- 15-20% (Table 3-10) in results show that the model is affected by the orientation and size of the grid cells within the model.

Table 3-10: Differences of Sediment Collection Rates for Baseline Models

Flow Rate [cfs]	Configuration #1 Grid Collection Rate [yd^3/day]	Configuration #2 Grid Collection Rate [yd^3/day]	Configuration #3 Grid Collection Rate [yd^3/day]	Rectangular Grid Collection Rate [yd^3/day]
100	<0.01	<0.01	<0.01	<0.01
250	<0.01	<0.01	<0.01	<0.01
500	<0.01	<0.01	<0.01	<0.01
1000	<0.01	<0.01	<0.01	<0.01
2500	0.57	0.47	0.45	0.42
5000	22.00	18.82	22.80	20.31
8000	121.21	98.79	123.69	121.19

Another source of uncertainty in the analysis comes from the way Delft3D assigns the upstream sediment transport boundary condition. The bedload and suspended load fractions are computed based on an equilibrium condition, where the model estimates appropriate concentrations based on the flow regime. This boundary condition was validated for this modeling domain when used in the previous modeling study [2]. While it is clear that this boundary condition provides a reasonable estimate of influx sediment, the sediment concentrations are based on the flow regime, which changes slightly when vanes are introduced into the model. This creates a discrepancy in the sediment influx between the simulations with vanes and the simulations without vanes. In order to correct for this effect, the results presented in Section 3.3.2 were processed carefully to remove as much of this affect as possible.

Results were presented as a ratio of collection rate to sediment influx at the upstream boundary (e.g., Table 3-4 through Table 3-8). While each model may not have been in a full morphological equilibrium condition by the end of the simulation (i.e., there are some areas still eroding or accreting), benchmarking the collection rate against the upstream sediment influx removes the trickle-down effect that the vanes have on the velocity field, which changes the influx.

The collection rate ratios were used to estimate collection rates under uniform upstream influx assumptions. The average influx rate for each flow condition without vanes was used

as the baseline sediment influx. This value was used with the collection ratios to estimate collection rates without the bias from the upstream boundary condition. This approach also removes the effect of differences between the model grids (Table 3-10), because a single average sediment flux is used for each flow condition to estimate the unbiased collection rates.

Another significant source of uncertainty is long-term morphological changes that could impact the vane efficiency. Based on the work of Rosgen [1], it seems likely to expect some build-up of sediment on the upstream side of the vanes. However, the volume of sediment retained by the vanes may be limited by the discharge of sediment over the collector. It is also possible that a scour hole could develop downstream of the vanes. However, the courser sediments on the bed would likely prevent scour holes from growing excessively large or deep.

3.4 Model Results: Upstream Collector

The results for the vanes at the downstream collector site indicate the wider angle vanes may provide a marginal benefit for collection rates. This section evaluates the performance of the three vane configurations for the upstream collector location. The relative collection efficiencies of the collectors with vanes (compared to without vanes) are shown in Table 3-11. It is difficult to draw quantitative conclusions from these data because of the uncertainty in some of the modeling inputs. However, it does appear from the data that the wider angle vanes (45 degrees) would provide an improved collection rate as compared to the narrower vanes (or no vanes).

These data were used to develop a discharge vs. collection yield relationship (Figure 3-11) for the existing collector similar to Figure 3-10 (which relates to the potential downstream collector). These collection rates were used to produce hindcast estimates over a period of several years (Table 3-12) as well as monthly estimates for the periods over which the collector has been in operation (Table 3-13).

Several observations can be made regarding these results:

- The model does not clearly show a benefit from adding cross vanes for any of the vane configurations. There is a slight benefit for the 45 degree vanes, but that difference is within the tolerances of the model.

- The estimated volumes of Table 3-13 can be compared with the sales records of Table 1-1. This comparison indicates that the model is capturing approximately 50 percent less sediment than the actual collector has been collecting. This is due to the uncertainty in the many modeling inputs.

- When evaluating the historic collection rates and considering potential future collection rates, it is important to consider whether the flow rates since installing the collector are representative of historic flows. By comparing Table 3-12 and Table 3-13, it can be seen that the overall average flow rate for the period of

collection is similar to a long-term average flow rate. However, this average is influenced significantly by the first several months of 2017. If these months are excluded from the average, the average annual flow rate for the period of record would drop to about 1040 cfs, which is lower than the long-term average. A time history plot showing daily, monthly, and annual mean discharges is included in Figure 3-12.

Table 3-11: Relative Efficiency of Collector With and Without Vanes (Compared to the Collector With No Vanes)

Flow Rate [cfs]	15° vanes	30° vanes	45° vanes	Wide Collector
100	n/a	n/a	n/a	n/a
250	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a
1000	-9%	-7%	-4%	210%
2500	-29%	-21%	7%	169%
5000	-28%	-17%	1%	154%
8000	4%	11%	8%	155%

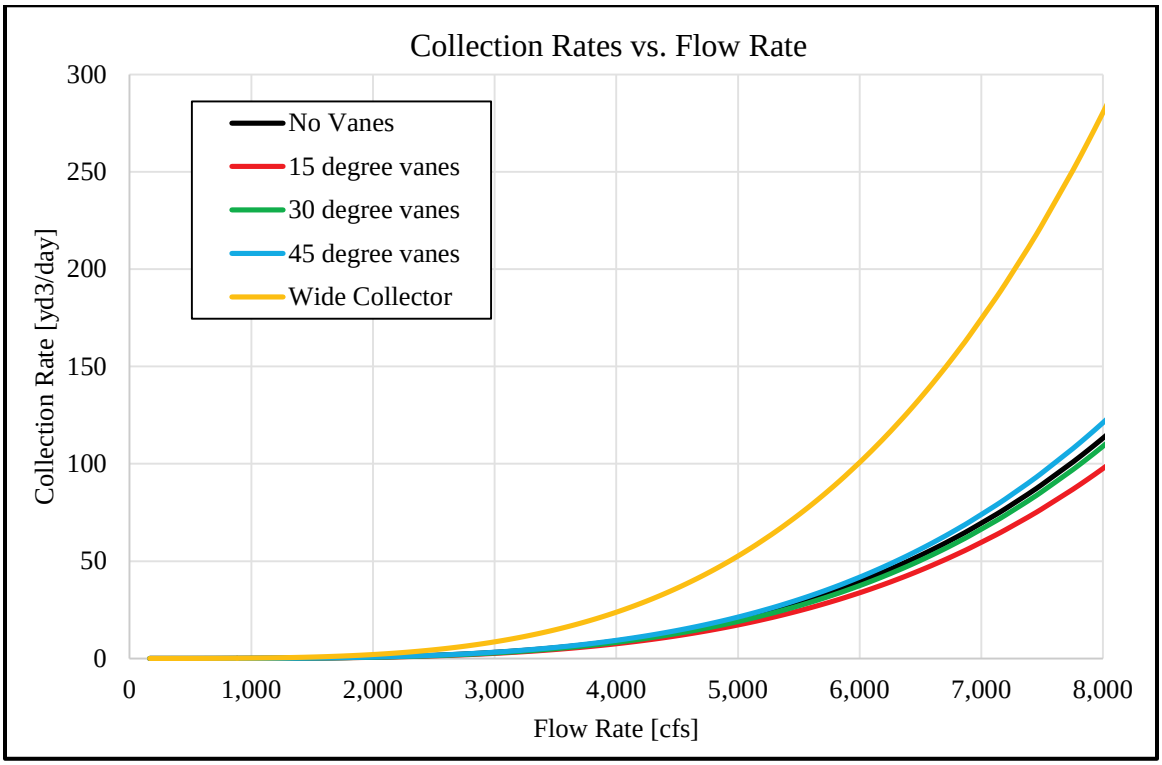

Figure 3-11: Collection Rate vs. Discharge – Upstream Collector

Table 3-12: Hindcast Sediment Yield for Upstream Collector

Year	Baseline (no vanes) [yd^3]	15° vanes [yd^3]	30° vanes [yd^3]	45° vanes [yd^3]	Wide Collector [yd^3]	Average Flow Rate [cfs]
2002	206	174	191	214	546	801
2003	1,299	1,116	1,244	1,384	3,251	1365
2004	1,486	1,283	1,436	1,594	3,668	1404
2005	1,461	1,253	1,395	1,553	3,674	1232
2006	906	779	869	966	2,266	1231
2007	823	702	779	869	2,102	1174
2008	1,168	1,001	1,113	1,240	2,945	1255
2009	658	565	629	700	1,652	891
2010	124	104	113	128	336	830
2011	3,267	2,820	3,153	3,501	8,080	1850
2012	1,068	922	1,031	1,144	2,640	1013
Average	**1,133**	**974**	**1,087**	**1,209**	**2,833**	**1186**

Table 3-13: Hindcast Collection Rates for Upstream Collector During Historic Collection

Year	Month	No vanes [yd^3]	15° vanes [yd^3]	30° vanes [yd^3]	45° vanes [yd^3]	Wide Collector [yd^3]	Average Flow Rate [cfs]
2015	July	32	27	29	33	87	1551
2015	August	0	0	0	0	1	559
2015	September	7	6	6	7	19	721
2015	October	1	1	1	1	3	550
2015	November	0	0	0	0	1	613
2015	December	75	63	70	78	192	1173
2016	January	2	1	1	2	5	860
2016	February	54	46	50	57	144	1717
2016	March	40	33	36	41	108	1911
2016	April	44	37	40	45	118	1828
2016	May	10	8	9	10	28	1131
2016	June	1	1	1	1	3	678
2016	July	1	1	1	1	2	614
2016	August	4	3	4	4	12	797
2016	September	6	5	5	6	15	767
2016	October	16	13	15	17	44	1086
2016	November	1	1	1	1	3	798
2016	December	16	13	14	16	44	1328
2017	January	20	17	18	20	55	1628
2017	February	8	6	7	8	23	1441
2017	March	61	51	56	63	163	2043
2017	April	133	112	123	139	349	2501
2017	May	138	117	128	144	362	2440
2017	June	0	0	0	0	0	292
Totals		**670**	**563**	**617**	**694**	**1,782**	**1209 (average)**

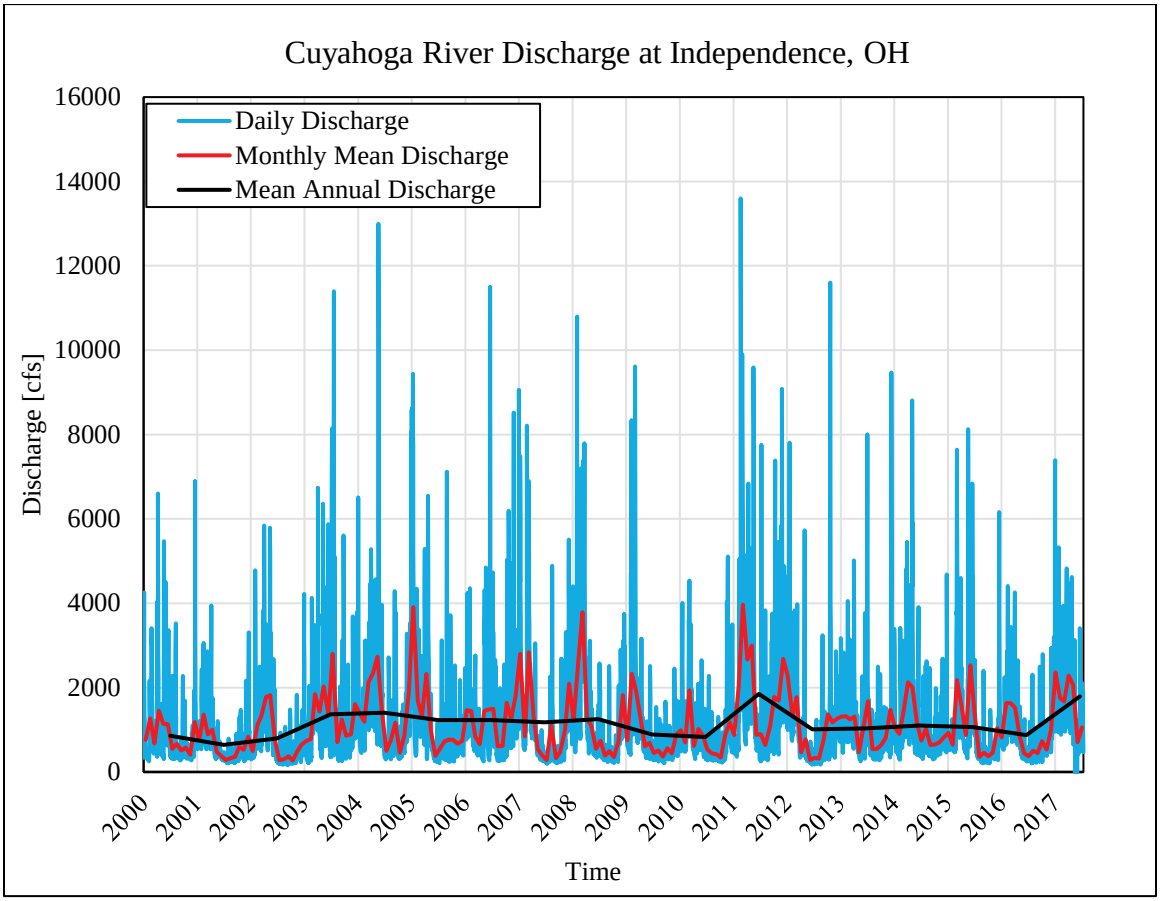

Figure 3-12: Cuyahoga River Discharge at Independence, OH

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study evaluated potential vane configurations for a bedload collector in the Cuyahoga River. Two collector locations were considered: 1) the location of the existing collector approximately 4 miles upstream of the Cuyahoga Ship Channel (CSC), and 2) a potential new location just upstream of the CSC. Three vane configurations were evaluated in detail using hydrodynamic and sediment transport models. Overall sediment transport rates were benchmarked against collection rates from the existing collector installed upstream.

The majority of sediment collection occurs at high-flow events when the larger sediment sizes are mobilized. The results of this study indicate that vanes at a wider angle to the channel centerline may do a better job at funneling sediment over the collector. However, this difference was not clear for the upstream collector location.

The concept for these vanes was taken from Rosgen [1], who employed cross-vanes to trap sediment along the banks of small streams. It seems reasonable to conclude from this study that the depth of flow (particularly in high-flow conditions) for the Cuyahoga River, does not produce a similar effect. The cross vane concept may be more applicable for relatively shallow streams.

It is important to note that the results of a sediment transport analysis are often best understood as qualitative in nature. Results are sensitive to many of the input parameters that are only supported by assumptions in this analysis. In particular, the local channel bathymetry would likely have a significant impact on bedload transport. A local bathymetry survey would be helpful to support a more refined analysis. Also, the models can be sensitive to sediment grain size. Sediment gradation was obtained from the previous M&N modeling study for the area.

Some key take-away points are summarized as follows:

- The bed load collector in its current location is working well and producing high quality material.
- This study does not indicate a substantial improvement of collection rates for the existing collector if cross vanes are installed.
- The existing unit could be allowed to operate as is and continue to provide quality material at a low operating cost.
- This study indicates that a bedload collector installed at the ArcelorMittal property, could produce material volumes of the same order of magnitude as the existing collector.
- Installing cross-vanes along with a collector at the ArcelorMittal site may provide a marginal improvement in sediment collection rates. However, it is not clear that

the cost of installing a bedload collector with (or without) cross vanes at the ArcelorMittal property would be economically justifiable.

- The success of using cross vanes to increase the yield of a collector appears to be heavily influenced by the shape of the river. If the river is too wide, the majority of the bedload will pass around the collector. In such cases, cross-vanes may (or may not) be of benefit, subject to site-specific studies. However, for deeper rivers, it appears the cross vanes would have a minimal impact on sediment collection rates.

- The overall concept of the bed load collector seems better suited for relatively narrow, shallow streams, where the collector itself can take-up a significant portion of the stream width. Placing the collectors in a shallow area of the Cuyahoga River could be an option, but it could impact canoeist and other waterway users.

- Potential use of bed load collectors and cross vanes in other locations would require careful analysis of siting conditions.

5.0 REFERENCES

[1] D. L. Rosgen, "The Cross-Vane, W-Weir and J-Hook Vane Structures... Their Description, Design and Application for Stream Stabilization and River Restoration," *Wetlands Engineering & River Restoration*, pp. 1-22, 2001.

[2] Moffatt & Nichol Engineers, "Sediment Characterization and Yield Sustainable Sediment Management," Project No. 7673-01, 2014.

[3] Moffatt & Nichol Engineers, "Dredging Projections and Alternative Analysis," Project No. 7673-01, 2014.

[4] Deltares, "Delft3D-FLOW, User Manual," Delft, 2014.